Improvement of Overall Equipment Effectiveness Using Total Productive Maintenance and Failure Mode Effect Analysis in Blast Furnace of Iron & Steel Industry

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Abstract— This paper aims for conducting Total Preventive Management significantly using Failure Mode Effect Analysis in Blast Furnace to improve productivity quality and reliability of Iron and Steel Industries. Many organisation experience a halt in operations as a result of damaged production machines; as a result, customer demand is not met, and productivity suffers. This study is conducted at Jaiswal Nico private limited, Raipur. Blast furnace where general equipments are very delicate and need to be replaced frequently. It results in slow down of operation. Calculation of overall equipment effectiveness is affected due to low efficiency and lack of continuous analysis. TPM-FMEA technique was much required for blast furnace to eradicate the general failure. In this paper first the general problem where identified for various equipment in blast furnace, the TPM is done and OEE is calculated. Again FMEA is applied to the same process and OEE is calculated again. Results are compared for values of OEE before FMEA (Financial Year 2018-19) and after FMEA (Financial Year 2019-20). Results are being validated using SPSS Software. Value of Overall Equipment Effectiveness is more in financial year 2019-20. After FMEA four components where identified which have high failure rate. Six big losses are also calculated to identify the time losses more minutely. TPM-FMEA is more comprehensive then alone TPM or alone FMEA. It gives more detail on failure root cause and potential failure also. During maintenance TPM-FMEA can be applied quarterly or six monthly so as to reduce the utilization losses and speed losses from time to time.

Keywords: FMEA, TPM, Quality, Reliability, Productivity, OEE, RPN, SPSS

I. Introduction

Total Productive Maintenance (TPM) is a unique Japanese philosophy, which has been developed based on the productive maintenance concepts and methodologies. This concept was first introduced by M/s Nippon Denso Co. Ltd. of Japan, a supplier of M/s Toyota Motor Company, Japan in the year 1971. Total productive maintenance is an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns and promotes autonomous maintenance by operators through day-to-day activities involving total workforce.

Nakajima (1989), a major contributor of TPM, has defined TPM as an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns, and promotes autonomous maintenance by operators through day-to-day activities involving the total workforce. In this stage eight activities are carried which are called eight pillars in the development of TPM activity. Of these four activities are for establishing the system for production efficiency, one for initial control system of new products and equipment, one for improving the efficiency of administration and are for control of safety, sanitation as working environment.

A. *Eight Pillars of TPM*

1) 5S: TPM starts with 5S. Problems cannot be clearly seen when the work place is unorganized. Cleaning and organizing the workplace helps the team to uncover problems. Making problems visible is the first step of improvement. The meaning of 5S is SEIRI- Sort out, SEITON – Organize, SEISO - Shine the workplace, SEIKETSU – Standardization, SHITSUKE - Self-discipline.
2) Autonomous Maintenance : This pillar is geared towards developing operators to be able to take care of small maintenance tasks, thus freeing up the skilled maintenance people to spend time on more value added activity and technical repairs. The operators are responsible for upkeep of their equipment to prevent it from deteriorating.
3) Continuous Improvement (KAIZEN): Kai" means change, and "Zen" means good (for the better). Basically kaizen is for small improvements, but carried out on a continual basis and involve all people in the organization. Kaizen is opposite to big spectacular innovations. Kaizen requires no or little investment. The principle behind is that "a very large number of small improvements are more effective in an organizational environment than a few improvements of large value. This pillar is aimed at reducing losses in the workplace that affect our efficiencies. By using a detailed and thorough procedure we eliminate losses in a systematic method using various Kaizen tools. These activities are not limited to production areas and can be implemented in administrative areas as well.
4) Planned Maintenance: It is aimed to have trouble free machines and equipments producing defect free products for total customer satisfaction. This breaks maintenance down into 4 "families" or groups such as Preventive Maintenance, Breakdown Maintenance, Corrective Maintenance, Maintenance Prevention
5) Quality Maintenance: It is aimed towards customer delight through highest quality through defect free manufacturing. Focus is on eliminating non-conformances in a systematic manner, much like Focused Improvement. We gain understanding of what parts of the equipment affect product quality and begin to eliminate current quality concerns, then move to potential quality concerns.

6) Education & Training: It is aimed to have multi-skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently. Education is given to operators to upgrade their skill.
7) Office TPM: Office TPM should be started after activating four other pillars of TPM. Office TPM must be followed to improve productivity, efficiency in the administrative functions and identify and eliminate losses. This includes analyzing processes and procedures towards increased office automation. Office TPM addresses twelve major losses. They are Processing losses.
8) Safety, Hygiene and Environment Control: In this area focus is on to create a safe workplace and a surrounding area that is not damaged by our process or procedures. This pillar will play an active role in each of the other pillars on a regular basis. A committee is constituted for this pillar which comprises representative of officers as well as workers. The committee is headed by Senior vice President (Technical). Utmost importance to Safety is given in the plant. Manager (Safety) is looking after functions related to safety.

To create awareness among employees various competitions like safety slogans, Quiz, Drama, Posters, etc. related to safety can be organized at regular intervals.

TPM evolved from TQM, which evolved as a direct result of Dr. W. Edwards Deming's influence on Japanese industry. Dr. Deming began his work in Japan shortly after World War II. As a statistician, Dr. Deming initially began to show the Japanese how to use statistical analysis in manufacturing and how to use the resulting data to control quality during manufacturing. The initial statistical procedures and the resulting quality control concepts fueled by the Japanese work ethic soon became a way of life for Japanese industry.

A well-conceived TPM implementation program not only improves the equipment efficiency and effectiveness but also brings appreciable improvements in other areas of the manufacturing enterprise. TPM is based on three interrelated concepts:

1) Maximizing equipment effectiveness;
2) Autonomous maintenance by operators; and
3) Small group activities.

Objectives of TPM

The objectives of TPM are:

1) Achieve Zero Defects, Zero Breakdown and Zero accidents in all functional areas of the organization.
2) Involve people in all levels of the organization.
3) Build different teams to reduce defects and Self-Maintenance.

Measurement of the success of TPM in evaluating and measuring the extent to which the successful implementation of TPM, the primary measurement tool used is the Overall Equipment Effectiveness (OEE). Mathematically, OEE formula is as follows:

OEE = Availability x Performance Rate x Quality

Overall Equipment Effectiveness (OEE) is a calculation carried out to determine the extent of the effectiveness of an existing machine or equipment. OEE is used as an indicator of the performance of a machine or equipment. The purpose of OEE is as a measure of the performance of a maintenance system, by using this method it can be seen the availability of machines or equipment (availability), production efficiency (performance), and the quality of the output of the machine/ equipment (quality).

Failure Mode and Effect Analysis (FMEA) were first developed as a formal design methodology in the 1960s by the aerospace industry with their obvious reliability and safety requirements. Later, its use spread to other industries, such as the automotive, oil and natural gas. FMEA aims to identify and prioritize possible imperfections in products and processes. FMEA analyses

1) Potential failure modes of product or machine,
2) Potential effects of failure,
3) Potential causes for failure (like Material defects, Design deficiencies,
4) Processing and manufacturing deficiencies, and Service condition etc.)
5) Assesses current process controls, and
6) Determines a risk priority factor.

FMEA is an essential function in design, from concept through development. Quality and reliability of products and manufacturing processes are critical to the performance of the final products. They are also important indices for meeting customer satisfaction. In order to fulfill customer requirement for quality and reliability, some actions for assuring the quality and reliability of products or processes should be taken by all engineers involved. One of the most powerful methods available for measuring the reliability of products or process is FMEA. Customers are placing increased demands on companies for high quality, reliable products. The increasing capabilities and functionality of many products are making it more difficult for manufacturers to maintain the quality and reliability. Traditionally, reliability has been achieved through extensive testing and use of techniques such as probabilistic reliability modeling. These are techniques done in the late stages of development. The challenge is to design in quality and reliability early in the development cycle. The cause and effect diagram is used to explore all the potential or real causes (or inputs) that result in a single effect (or output). Causes are arranged according to their level of importance, resulting in a depiction of relationships and hierarchy of events. This can help you search for root causes, identify areas where there may be problems, and compare the relative importance of different causes. There are several types of FMEA's; some are used much more often than others. FMEA's should always be done whenever failures would mean potential harm or injury to the user of the end item being designed. FMEA is a reliability procedure which documents all possible failures in a system design within specified ground rules. It determines, by failure mode analysis, the effect of each failure on system operation and identifies single failure points, which are critical to mission success or crew safety.

In general FMEA is a systemized group of activities designed to:

1) recognize and evaluate the potential failure of a product/process and its effects,
2) identify actions , which could eliminate or reduce the chance of potential failure occurring,
3) document process.

The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones. It may be used to evaluate risk management priorities for mitigating known threat-vulnerabilities. In FMEA, failures are prioritized according to three dimensions:

1) How serious their consequences are,
2) How frequently they occur,
3) How easily they can be detected.

Good FMEA methodology allows for the identification and documentation of potential failures of a system and their resulting effects. It also allows for the assessment of the potential failure to determine actions that would reduce severity, reduce occurrence, and increase detection.

The composite risk score for each unit operation step is the product of its three individual component ratings: Severity (S), Occurrence(O) and Detection (D). This composite risk is called a risk priority number (RPN). This number is then used to rank order the various concerns and failure modes associated with a given design as previously identified in the FMEA.

$$RPN = (S) \times (O) \times (D).$$

The RPN is a measure of design risk. The RPN is also used to rank order the concerns in processes (e.g., in Pareto fashion). The RPN will be between "1" and "1,000." For higher RPNs the team must undertake efforts to reduce this calculated risk through corrective action(s).

II. LITERATURE REVIEW

A. *TPM*

In today's highly dynamic and rapidly changing environment, the global competition among organizations has lead to higher demands on the manufacturing organizations (Miyake and Enkawa, 1999).

Moubray (as quoted by Eti et al, 2000) states that developing and executing a maintenance strategy consists of three steps;

1) Formulate a plan of what needs to be done for each component (i.e. work identification).
2) Acquire the resources (skilled personnel, spares and tools) needed to execute the proposed procedure effectively.
3) Implement the strategy (i.e. acquire and deploy the systems needed to manage the resources effectively).

The global marketplace has witnessed an increased pressure from customers and competitors in manufacturing as well as service sector (Basu, 2001; George, 2002

All the main ideas constituting the fourteen principles presented in the book "The Toyota Way" (Liker, et al., 2004) where developed by Sakichi Toyoda, his son Kiichiro Toyoda and his nephew Eiji Toyoda supported all the way long by Taiichi Ohno.. This model is actually representing the vision of which steps need to be accomplished, in order to become a state-of-the-art industry.

In today's fast-changing marketplace, slow, steady improvements in manufacturing operations do not guarantee sustained profitability or survival of an organization (Oke, 2005)

This has provided the impetus to the leading organizations worldwide to adopt effective and efficient maintenance strategies such as Condition Based Maintenance (CBM), Reliability Centered Maintenance (RCM) and Total Productive Maintenance (TPM), over the traditional firefighting reactive maintenance approaches (Sharma et al., 2005).

A coherent, unifying and integrative pattern of decisions in different maintenance strategy elements in congruence with manufacturing, corporate and business level strategies; determines and reveals the organizational purpose; defines the nature of economic and noneconomic contributions it intends to make to the organization as a whole (Pinjala et al, 2006)

The manufacturing industry has experienced an unprecedented degree of change in the last three decades, involving drastic changes in management approaches, product and process technologies, customer expectations, supplier attitudes as well as competitive behaviour (Ahuja et al., 2006).

There are few researches being conducted to investigate the relationship between maintenance and technical complexity. Technical complexity has many definitions. In production process, it can be defined as the extent to which human effort is replaced by machines (J. G. Arca, 2008)

(A. Salonen, 2011) Through proper and suitable maintenance programmes, major losses due to breakdowns and defects can be avoided. Even though these maintenance program will cost money, but the lack of maintenance will cost even more.

TPM is being implemented in industry as a group activity that reduces equipment maintenance, enhances productivity and improves profit by implementing various kaizen projects (Dogra et al. 2011)

OEE is akey performance indicator which has a positive impact in increasing the efficiency of a system (Zammori, Braglia, and Frosolini 2011)

The goal of the any TPM program is to improve productivity and quality along with increased employee morale and job satisfaction (R. S. Singh, 2012)

Focused TPM implementation over a reasonable time period can strategically contribute towards realisation of significant manufacturing performance enhancements (Wakjira and Singh 2012)

O'Malley, 2014 et.al. The Losses to machine or equipment effectiveness fall into the following loss categories utilization availability (planned and unplanned) performance.quality.

TPM captures day to- day fluctuations with an aim to reduce equipment downtime and improving plant maintenance tasks (Zammori 2014).

OEE is a powerful tool for identifying and eliminating losses, thereby developing efficient production system for achieving world-class manufacturing (Gupta, Vardhan, and Al Haque 2015).

Bhattacharjee, 2018 et. Al. Overall equipment effectiveness (OEE) is a framework to measure the efficiency and effectiveness of the manufacturing process. It is a measurement tool used to indicate how effectively machines are running. It measures if machines are utilized, how much of the time machines are operating the speed at which output is manufactured, and the percentage of the output that is of the right quality

B. Lean Approach and FMEA

J. P. Womack, 1990 et.al. The approach of lean manufacturing which focuses on waste reduction and performance enhancement has been gaining importance recently

A. J. R. Smith, 2008 et.al. The pursuit of optimizing manufacturing process has increased the efforts of manufacturing organizations in improving their internal and external performances in order to achieve competitive advantages

In the study of Namdari, in 2010 entitled, "Using FMEA method to optimize fuel consumption in Tillage by Moldboard Plow" it aimed to minimize the consumption of fuel in mouldboard plowing in tillage through the utilization of FMEA, tillage belongs to the greatest energy consumer when it comes to agricultural industry. Implementation of FMEA uncovered the factors which seriously affect the tillage fuel consumption; plowing speed with 640 RPN, soil moisture content with 480 RPN and plowing depth having 420 RPN. Effectiveness of FMEA is proven after countermeasures were executed, fuel consumption dropped by 16.40%.

A. Gurumurthy, 2011. Lean manufacturing has been the buzzword in manufacturing area.

Prajapati, conducted a study in 2012 entitled, "Application of FMEA in Automobile Industries: A Case Study". This study gave emphasis on two products, the air inlet manifold and the fuel injection pump. Researcher studied and analyzed the plant's manufacturing practice through the utilization of Failure Mode and Effect Analysis considering the severity value, occurrence number, detection and risk priority number. Causes and effects of several potential failures were discussed together with the preventions to be imposed. The recommended suggestions for each particular product significantly minimized the loss of the plant concerning money and time. It greatly improved the automobile industry, making the manufacturing process more efficient and productive.

A. Karim, 2013 et. al. The process of globalization encourages manufacturers to optimize their manufacturing process that enable them to deliver high quality products in a short period of time

R.V.B. De Souza,2014, et.al. Competitive pressures have been driving companies toward reduction of cost and improvement of operation for providing high quality products to the demanding market.

Dimaano (2014), entitled "Productivity Enhancement through Minimizing Machine Downtime at Wirebond Process of NXP Semiconductors Cabuyao Inc.", they used the concept of FMEA as the reference of identifying the root cause of existing problem and generating feasible improvements. The study is all about seeking out improvement on the productivity since this has been always the goal in any semiconductor industries. As the result, FMEA had been an effective solution to find the main causes of unscheduled machine errors in the production. With this the proponent have implemented the corrective measures in the production.

Macaraig (2015) et.al. This study entitled "Productivity Enhancement through Man: Machine Ratio Analysis of SOT404 Diebond Wirebond at NXP Semiconductors Cabuyao Philippines Inc." was focused on the allotment of manpower at SOT404-Frontline area. Their goal is to make the productivity better through man: machine ratio analysis by increasing the output, lessen delays and so as to minimize defective units.

Engr. Joel R. Cornejo, 2019 et.al. There are three stages in Process FMEA to ensure the success of the analysis. The first stage is to determine the potential failure modes. The second stage is to find the data for occurrence, detection, and severity rankings. Rankings of data will be based on suggested DFMEA criteria. The third stage is the modification of the current process design and the development of the control process based on the PFMEA report.

Total Productive Maintenance (TPM) and Failure Mode And Effect Analysis (FMEA)

Wakjira, 2012 et al., the engine is an input in the production process that requires energy to carry out the activities of the production process, the energy in question is energy in the form of fuel, lubricating oil, electric power, water for factories, etc.

Lazim H M, 2013 et. al Many things cause the cessation of a machine when doing production either due to damage by the device itself or because of something else. Therefore we need a way or method to maintain the function of the machine itself, keeping it able to operate to produce a lot of quality products.

Patidar L, 2015 et. al If a machine cannot function normally, the company will suffer a lot of losses resulting in a decline in the productivity of the company itself. In dealing with this, the company usually carries out certain types of maintenance so that all of its machines can operate normally

Thakore, 2015 et.al RPN is a mathematical product of the seriousness of the effects (Severity), the possibility of the cause will cause failure related to effects (Occurrence), and the ability to detect faults before they occur in the customer (Detection).

Mayangsari , 2015 et.al There are six equipment losses that cause low performance of machines and equipment. the six losses are known as six big losses which are divided into 3 categories of losses: downtime losses (breakdown, set up and adjustment) speed losses (idling and minor stoppages losses, reduce speed), and quality losses (rework and quality defects, start up reject)

Charles, 2016 et al. support is a primary function in a company that can be defined as an activity to take care of facilities so that the equipment is in a condition that is ready to use as needed.

Anggraini, 2017 et.al In the world of engine maintenance, there are six type of losses that must be avoided by every company that can reduce the level of effectiveness of a machine, known as the Six Big Losses.

Hqbek P, 2017 et.al In a sugar mills, there are several workstations in the production process, including the preparation station, grinding station, purification station, evaporation station, cooking station, Lutheran station, and finishing station. In the production process activities, all stations must have their own constraints, but at the grinding station, there are more obstacles due to broken machines or other things. Therefore in this study, measurement of engine performance will be carried out at the grinding station, whether the performance or productivity of the machine within six months of operation is said to be useful.

Reyes, 2018 et.al, maintenance means improving pre-existing capabilities, whereas repairs are defined as making things better and operating optimally

Ihueze, 2018 et.al In general, the problem that occurs on the production floor is the damage to the opinion machine. A common problem that is often found on the production floor is that production equipment does not operate properly so that it affects the next process.

Eissa, 2019 et.al Total Productive Maintenance (TPM) is one of the maintenance process methods developed to improve productivity in the work area by making the process more reliable and less wasteful [8]. This method is part of lean manufacturing.

Sayuti M, 2019 et.al After the effectiveness of the engine was known, the calculation of the magnitude of the ratio of the six components of the six big losses was equipment failure, set up and adjustments, idling and minor stoppages, reduced speed, scrap and rework and startup losses to find out what categories of losses are causing low OEE value of the machine.

Prabowo, 2020 et.al FTA is a technique used to identify risks that contribute to failure. This method is carried out with a top-down approach, which begins with the assumption of failure or loss from a top event and then details the causes of a top event to a root cause.

C. Correlation and Regression

Correlation test is as statistical methods to test the strength of relation of two variables interval or ratio scales. The relation between two variables was usually denoted r, or called r Pearson.

Lind, 2019 et. al. The coefficient correlation has a range values between -1.0 to 1.0. Two variables have perfect correlation when the values of coefficient correlation of -1.0 or 1.0. Positive and negative symbols represent the relation between two variables has tested. And regression test as statistical method that aims to reveal the linear relation between dependent variable and independent variables. From the regression test obtained coefficient regression then can be formed into linear equation. The regression equation function is to estimate change of dependent variable value in the future to affect on the independent variables. The general form of multiple regression equation is

$$Y = a + b_1X_1 + b_2X_2 + ... + b_kX_k$$

Where: "a" is the intersection of Y value or Y value when all X values equal to zero. And "b" is the slope of line or average change of Y value for one unit change of X values. This regression test can be done using SPSS software.

III. PROBLEM IDENTIFICATION

A. Gaps identification

This activity is carried out to identify things that will be the beginning of problems that occur in the field or company and the formulation of problems in research are things that are considered to be resolved from some of the problems that have been identified at the time of the survey so that what is the purpose of the research this can be achieved. Following gaps were identified during study:-

1) Total Preventive Maintenance were done only for various industries but not for a specific department in an organization
2) Continuous analysis of OEE was not done for Blast Furnace in Steel Industries
3) OEE calculation for blast furnace was very difficult to calculate
4) Various problems such as delay and breakdown was not analyzed in any paper
5) Blast furnace efficiency was not being priorities in any paper
6) Blast furnace efficiency was found to be very low
7) No measures were taken to improve the efficiency of Blast furnace
8) TPM and FMEA concepts was not combined for analysis on Blast Furnace
9) No validation tool were applied to validate the calculated OEE in various department

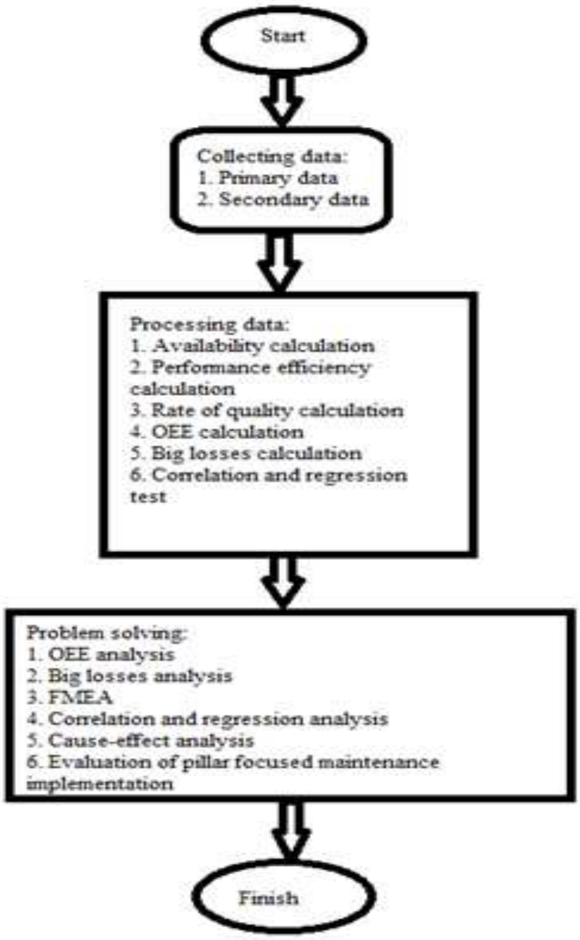
Research objectives of project

1) To Study various problem in Blast furnace
2) To calculate OEE in Blast furnace
3) To analyse various method to improve OEE IN Blast furnace
4) To formulate a new model for calculation of OEE
5) To apply FMEA in Blast furnace to improve OEE
6) To apply Regression Test in SPSS Software to validate the result

IV. RESEARCH METHODOLOGY

Primarily we have to collect various data associated with blast furnace such as equipment list, equipment runtime, maintenance record flow diagram, etc. From these various data, we have to calculate Overall Equipment Effectiveness and various efficiency associated with this, then calculation of six big losses. With the help of these 6 Big Losses, and to validate this correlation and regression test is done.

After this FMEA is applied to find out the major loss and rectify these losses. In FMEA we calculate RPN number for various equipment in blast furnace. On the basis of RPN number the major losses are identified. For highest RPN number of any equipment we will find out remedy for failure which is occurring frequently or before fixed period of time. The flowchart is given above for this research study



After that again OEE calculation is done which is the sure improved one for various equipment then average OEE is calculated for whole process. Again correlation and regression test is performed in SPSS after implementation of FMEA. Then Comparison of Various dat, graphs is being done before FMEA and after FMEA to prepare a result.

The formula to compute the availability is

$$Availability\ (\%) = \frac{Loading\ Time - Downtime}{Loading\ time} x\ 100$$

The formula to compute the performance efficiency is

$$Performance\ efficiency\ (\%) = \frac{Processed\ amount\ x\ Ideal\ cycle\ time}{Operating\ time} x\ 100$$

The formula to compute the rate of quality is

$$Rate\ of\ quality\ (\%) = \frac{Net\ Production}{Rollused} x\ 100$$

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A. FMEA Implementation

Failure mode effect analysis is executed by a multidisciplinary team of experts in blast furnace operation with the help of process flow chart the analysis team identifies the components in process. Criteria of ranking of severity, occurrence and detection are selected suitably by analyzing the past failure records of the furnace. Using values of severity, occurrence and detection number risk priority number is calculated.

S	Effect	Criteria: Severity of Effect	
1	None	Process parameter variability within specific limits. Adjustment or other process controls can be done during normal maintenance	Low maintenance costs/delivery impact
2	Very Minor	Process parameter variability within specific limits. Adjustment or other process controls can be done during production. No downtime.	
3	Minor	Downtime up to 10 minutes.	
4	Very Low	Downtime of between 10 to 30 minutes.	Medium maintenance costs/delivery impact
5	Low	Downtime of between 30 minutes and 1 hour.	
6	Moderate	Downtime of between 1 hour and 2 hours.	
7	High	Downtime of between 2 hours and 4 hours.	
8	Very High	Downtime of more than 4 hours	High maintenance costs/delivery impact
9	Hazardous - with warning	High severity ranking - Affect operator, plant or maintenance personnel, safety and/or affects non compliance and government regulation with warning.	
10	Hazardous - without warning	Very high severity ranking - Affect operator, plant or maintenance personnel, safety and/or affects non compliance and government	

Table I: Severety Criteria Ranking

Ranking	Criteria: Possible number of failures within hours of operation.	OR	Criteria: Possible number of failures within cycles of operation.	OR	Criteria: The reliability based on users required time.
1	1in 25000		1 in 900000 cycles		R(t)=98%MTBF is 50 times greater than User's required time.
2	1in 10000		1 in 900000		R(t)=95%MTBF is 20 times greater than User's required time.
3	1in 5000		1 in 540000		R(t)=90%MTBF is 10 times greater than User's required time.
4	1in 2500		1 in 360000		R(t)=85%MTBF is 6 times greater than User's required time.
5	1in 1000		1 in 270000		R(t)=78%MTBF is 4 times greater than User's required time.
6	1in 350		1 in 180000		R(t)=60%MTBF is 2 times greater than User's required time.
7	1in 80		1 in 90000		R(t)=37%MTBF is equal to User's required time.
8	1in 24		1 in 36000		R(t)=20%MTBF is about 60%of User's required time.
9	1in 8		1 in 900		R(t)=5%MTBF is about 30%of User's required time.
10	1in 1		1 in 90		R(t)<1%MTBF is about 10%of User's required time.

Table II: Occurrence Criteria Ranking

S	Effect	Criteria: Severity of Effect	
1	None	Process parameter variability within specific limits. Adjustment or other process controls can be done during normal maintenance	Low maintenance costs
2	Very Minor	Process parameter variability within specific limits. Adjustment or other process controls can be done during production. No downtime.	
3	Minor	Downtime up to 10 minutes.	
4	Very Low	Downtime of between 10 to 30 minutes.	Medium maintenance costs
5	Low	Downtime of between 30 minutes and 1 hour.	
6	Moderate	Downtime of between 1 hour and 4 hours.	
7	High	Downtime of between 4 hours and 8 hours.	
8	Very High	Downtime of more than 8 hours	High maintenance costs
9	Hazardous - with warning	High severity ranking - Affect operator, plant or maintenance personnel, safety and/or affects non compliance and government regulation with warning.	
10	Hazardous - without warning	Very high severity ranking - Affect operator, plant or maintenance personnel, safety and/or affects non compliance and government regulation without warning.	

Table III: Detection Criteria Ranking

V. CALCULATION & GRAPH

Calculation of Six Big Losses

Calculation of RPN

Component/ process	S	O	D	RPN
Bleeder valves	10	2	3	60
Conveyor feed belt	8	2	2	32
Skip car rope for charging	3	4	1	12
Cold blast Blower	8	1	2	16
Hot blast blower	9	1	2	18
Blast furnace gas injection	10	2	2	40
Oxygen injection	10	2	2	40
Cooling water supply pump	10	4	2	80
Tapping hose	8	4	4	128
Hot metal lifting by crane	9	3	2	54
Gas cleaning filter bags	4	3	3	36
Lancing hose	5	4	4	80
Water spraying Nozzle	7	3	1	21
Butterfly valve to regulate flow	9	3	2	54
Steam injection	7	2	3	42

Calculation of OEE

MONTH	OEE	
	2019-20	2018-19
APR	63.20	39.38
MAY	60.89	40.39
JUN	47.76	31.36
JUL	50.67	60.19
AUG	59.88	62.37
SEP	45.74	46.20
OCT	59.24	64.47
NOV	63.36	36.63
DEC	44.59	35.55
JAN	55.44	21.34
FEB	53.46	27.67
MAR	55.68	30.40

VI. RESULTS & DISCUSSION

Results

Causes for poor disturbances are as follows:-

1) Wearing and Burning of Tuyere
2) Low heat loss spell-accretion in lower part
3) High moisture load
4) Low prepared burden

After applying *FMEA following problems aand its remedies are given below:*

S no.	Component/ process	Additional control
1	Bleeder valves	Periodic maintenance
2	Conveyor feed belt	Lubricate the rotating parts regularly
3	Skip car rope for charging	Calibrate load cells
4	Cold blast Blower	Interlock system
5	Hot blast blower	Periodic maintenance
6	Blast furnace gas injection	Provide detectors with alarm system
7	Oxygen injection	Provide detectors with alarm system
8	Cooling water supply pump	Check the fuel level of diesel generator
9	Tapping hose	Change hose periodically
10	Hot metal lifting by crane	Interlocks with alarm
11	Gas cleaning filter bags	Regular inspection
12	Lancing hose	Check defects before use
13	Water spraying Nozzle	Check the water level for every 5 minutes
14	Butterfly valve to regulate flow	Periodic maintenance
15	Steam injection	Display Cautionary notice

Group Losses	Six Big Losses	Time Losses (hour)		Time Losses (%)		Cumulative	
		2019-20	2018-19	2019-20	2018-19	2019-20	2018-19
Downtime Losses	Equipment Failure	2112.58	1620.76	17.71	22.55	18	23
	Set Up & Adjustment	560.71	660.05	4.76	8.84	22	31
Speed Losses	Idle & Minor Stoppages	2673.29	2280.81	22.47	31.39	45	63
	Reduce Speed	6491	3049	54.09	36.47	99	99
Quality Losses	Scrap & Rework	59.28	25.16	0	0	100	100
	Startup Losses	0	0	0	0	100	100

Comparison between data of OEE in financial year 2019-20 and 2018-19 is being done and the following results were obtained:

- OEE in financial year 2019-20 is more as compared to 2018-19
- There are four main components which have high failure rate
- During Calculation of Six Big Losses there is comparative reduction from in financial year 2019-20. There was more losses in 2018-19
- During Linear Regression Analysis, Value of R^2 is good in both financial year 2019-20 as well as 2018-19

A. Discussions

The driving concept behind an OEE program is that it should be created to expose areas for improvement. It should not be used as a tool to compare one operation to a different operation or one plant to another plant. An OEE score for a plant is characteristic of its unique operating conditions. It is individual to that operation and cannot accurately be compared to a different operation. Plan to reduce the losses are as follows:-

1) Plan to reduce the utilization loss

- Prioritization of LD gas supply to BF >5000 NM3/hr.
- To ensure availability of belt for process critical belts as a standby
- Strengthening the daily management practices to eliminate foreign material in the supply circuit.
- Shoot inspection to be incorporated as daily management practice.
- Increase frequency for thickness measurement of the belt.

2) Plan to reduce the speed loss

- Low O/C ratio at the wall and improve design of tuyeres
- ASAM test, Softening-melting test, HOSIM test are to be regularized to understand better burden condition.
- To improve the efficiency of CDS and in-house initiatives to reduce moisture load by 20%.
- Compensate through coke rate to avoid Poor Wind Acceptance.

VII. Conclusion & Future Scope

A. Conclusion

Following conclusion made from this study is as follows:-

- TPM-FMEA is more comprehensive than alone TPM for blast furnace
- TPM-FMEA provide more details on the root cause and potential failure in blast furnace
- Rectification of potential failure can be eradicated by calculation of Risk Priority Number
- FMEA can be used from time to time to obtain potential failure which can be used for further improvement later on
- This study provide useful information for prioritization of correction actions to be implemented based on methodology adopted

B. Future Scope

- Pareto chart analysis, Fish bone diagram are the others methods to improve Overall Equipment Effectiveness of a blast furnace.
- Environmental related factors can also be added to find out and improve Overall Equipment Effectiveness of blast furnace
- FMEA can be merged with various industrial engineering fields to improve the error in the system of any industry.
- Apart from Total Preventive maintenance, seven pillars of maintenance can be considered for doing research and analysis
- 5S in maintenance can be updated from time to time to improve the quality of product and plant structure
- Cost of Total Preventive Maintenance can be decreased by improving various factors involved in it or reducing the steps involved in process of maintenance, can be considered as a research project
- Multiple Regression can also being done for better results

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