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Review Article

Evaluation of Maintenance Strategies Employed on the Critical Electromechanical Equipment in Sasol Synfuels Catalyst Preparation Unit

Pretty Maphosa[1], Patrick Nziu[2]

[1]*A Department of Mechanical Engineering, Mangosuthu University of Technology, 511 Griffiths Mxenge Hwy, Umlazi, Durban, South Africa.*
[2]*A Department of Mechanical Engineering, Walter Sisulu University, East London 5200, South Africa.*

[2]*Corresponding Author : pnziu@yahoo.com*

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Abstract *- Each industry and equipment is unique, as the product streams differ, as well as layouts and operation variables, to name a few. However, turnaround management is the most used strategy in the petrochemical industry. Equipment downtime remains the biggest challenge; thus, the purpose of the study was to evaluate the current maintenance practices used on the critical electromechanical equipment in the Sasol Synfuels Catalyst Preparation Unit. Data was collected from the SAP system database, from which the breakdown of work orders was obtained for the period from January 2016 to June 2021. The data was collected for each of the 13 electromechanical equipment identified in the catalyst preparation unit. A theoretical distribution was drawn after that to assess the effectiveness of the current maintenance strategy compared to the identified key performance indicators. The theoretical distribution analysis was used to determine the plant utilization, availability, and maintenance cost. The results concluded that the plant utilization is above the prescribed parameter of 90%. All 12 pieces of equipment had utilization results above 90% except for the arc furnace on the western unit, which resulted in 86.57%.*

Keywords *- Maintenance, Evaluation, SAP system database, Mean Time To Repair (MTTR), Availability, Maintenance cost, Mean Time Before Failure (MTBF).*

1. Introduction

The petrochemical industry is divided into three groups. The first is the Upstream Petrochemical industry. This is the baseline and supplier to the further production of the other petrochemical products, of which it aims to produce primary feedstock for the next group of products. Second is the intermediate petrochemical industry, which utilizes the products produced from the upstream to provide feedstock to the Downstream production, the last main group. The downstream petrochemical industry utilizes products from both the upstream and intermediate to produce the end products, such as synthetic plastic, rubber, etc. A study by MAJOZI (2015) explored how the petrochemical industry in South Africa accounts for about 55 percent of all chemicals produced, thus requiring high energy consumption. Sasol uses the Fischer-Tropsch process to produce liquids derived from coal, such as synthetic rubber, fertilizers, and secondary chemicals such as ethanol, butanol, ethyl acetate, acrylic acid, and butyl acrylate, including diesel fuel. Through continuous improvement and development, the Sasol Advanced process (SAS) was introduced, which introduced seven new SAS reactors in 1999. The whole process has a series of connections. This means that every unit depends on the other to provide the products needed; however small the unit might be, it is crucial to provide the output product. The catalyst is provided through U04/204, which is the catalyst preparation unit. It plays an important role in providing the catalyst needed for the SAS reactors. The catalyst is fed through process lines, which assist in creating hydrocarbons needed in downstream units.

Maintenance intends to retain or restore the equipment to a state in which it can perform the required function. In other words, maintenance is an action performed to prevent a device or component from failing due to either normal equipment degradation or breakdown. Several strategies are adopted to maintain process equipment and its complexities, considering the size of the Petrochemical plant. Every plant requires a unique maintenance structure, which is affected primarily by the size of the plant (FREDRIKSSON, 2012). Most industries' maintenance methodologies employ an integrated strategy where they incorporate both planned and unplanned activities. The speed at which the plant is brought back online often depends on the nature or complexity of the failure, the tools or machinery required, and availability. Other dependencies are parts availability, skills or expertise required, maintenance personnel availability, maintenance management system operational in the plant, technical support needed, etc. MINGANI (2013) reported three major maintenance objectives that incorporate both planned and unplanned maintenance. Equipment can be divided into two categories: statutory and rotary. What distinguishes one from the other is that one is stationary, and the other uses either electrical or hydraulic energy to operate. Each piece of equipment is unique in its design and operation. The maintenance strategy applied for a specific piece of equipment cannot be utilized on the other unless the design, environment, and operating conditions are the same. Even with that said, some limitations may cause the other to act differently due to unforeseen design limitations, such as human errors.

Pressure equipment, such as reactors, heat exchangers, and hoppers, is the major equipment utilized and maintained proficiently with the guidance of the Pressure Equipment Regulations, July 2009, Department of Labor, Occupational Health and Safety Act, 1993 Revision 2. These augments are crucial to the operation and the safety of people as they contain hazardous substances in large amounts under high pressure and temperature. Thus, Reliability-centered Maintenance is the most used maintenance policy, which governs the maintenance actions to be taken to mitigate and proactively maintain the equipment, thus preventing the risk of any unplanned damage.

Unlike most units, the catalyst preparation unit entails both statutory and rotary equipment. Electromechanical equipment refers to equipment that requires both mechanical and electrical components to function. Such equipment includes synchronous motors, electric valve actuators, pump sets, conveyors, and compressors. (SONDALINI, 2018). This equipment and machinery are subject to both electrical and mechanical wear, each of which has a different life span expectancy and failure rate. There are many data-analyzing software programs used to store and transpose data input to work orders. Many industries, such as Sasol, use the SAP data system as a single enterprise-class solution for data integration, data quality, data profiling, and text data processing.

2. Evaluation of Maintenance Strategies

MBOHWA's (2016) study investigates machinery breakdowns and their effects through the determination of plant utilization and availability, as well as the evaluation of sales lost due to downtime. With the aid of qualitative and quantitative approaches, a robust solution was obtained for an effective reliability-centred maintenance (RCM) decision diagram. Within the evaluation stage, MBOHWA (2016) used a key performance approach whereby a selection of maintenance key performance indicators (KPI) is chosen to measure the machines' performance based on them. Similarly, FREDIKSSON's (2012) study also explains how key performance indicators are to be utilized as indicators for obtaining critical assets. They are used to yield as an assessment and thus to indicate the subject's maintenance performance. Similarly, VISHNU's (2016) study states that the performance of an employed maintenance strategy can be analysed using different maintenance indicators such as Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), productivity, maintenance cost, and availability of assets, to name a few.

The importance of evaluating the current maintenance strategy employed is to determine the root cause of the continuous breakdowns. This will allow maintenance optimization to occur, which will minimize the cost of maintenance, minimize production loss, and maximize availability, including reliability. (HILBER, 2008). The calculation for each piece of equipment focuses on the failure rate, maintenance downtime in days, MTBF, MTTR, and the inherent availability of the equipment.

According to ONDIEKI (2008), availability is the likelihood that a stated percentage of equipment or missions will have no downtime above t in the mission time, T. This means that decreased reliability can be affected by good maintainability. The higher the plant availability, the more effective the maintenance strategy is, and vice versa. (MBOHWA, 2016).

Inherent availability is defined as the probability that a system or equipment, when operated under an ideal support environment, functions satisfactorily at any time as required. This, however, excludes preventive or scheduled maintenance actions, logistics delay time, and administrative delay time. This is expressed as in Eq. (1):

$$A_i = MTBF/(MTBF + MTTR) \quad (1)$$

The Mean Time To Repair (MTTR) simply considers the total time for the repair to be done. Many influences extend the repair time, such as access time, diagnosis time, and spare part procurement, as stated in the ONDIEKI (2008) study. Thus, each of the recovery activities will be obtained as in Eq. (2):

Ta/f; where T_a is the failure time over the number of failures f (2)

Apart from the MTTR, the failure rate λ will be determined in Eq. (3):

$\lambda = f/T$; where T is the total time of operation (3)

Mean Time Between Failures (MTBF) can be obtained using the inverse of failure rate as in Eq. (4) (INFRALET, 2016):

$$MTBF = \frac{TOTAL\ OPERATIVE\ TIME}{TOTAL\ NUMBER\ OF\ FAILURES}$$

$$MTBF = 1/\lambda \qquad (4)$$

The lower the maintenance cost due to downtime, the more effective the maintenance strategy is. According to ONDIEKI's (2008) study, the field is crucial to obtaining real conditions as it concerns failures and repair actions that have occurred online. As recording field incidents relies on people, it is subject to human errors, omissions, and misinterpretations.

3. Novelty of Study

The purpose of this study is to investigate the maintenance performance of the electromechanical equipment used in the Sasol catalyst preparation unit. This forms part of the case study, as several failures were experienced within the plant. Though maintenance strategies were already in place, the plant experienced high maintenance costs due to frequent equipment failures. To better understand system performance, it becomes essential to develop well-defined performance indicators for each equipment, which is the objective of this study.

4. Research Methodology

4.1. Case Study

The case study is mainly focused on electromechanical equipment utilized in the Sasol Synfuels catalyst preparation unit, which consists of:

1. Kiln
2. Conveyor belts
3. Arc Furnace
4. Casting Machine
5. Ball Mill

The Sasol Synfuels catalyst preparation unit consists of a Kiln (X04KN-101A and B), which uses the RMS (raw mill scale) fed by the conveyor belts (X04CV-101A and B) to burn the RMS and produce OMS (Oxidized Mill Scale). The OMS is then stored in the Bin. From the Bin using conveyor belts, the OMS is fed into the Arc furnace (X04AF-141A and B), which uses Electrodes to burn the product with promoters so that it melts the OMS into a molten catalyst.

The catalyst is fed into the crusher to crush the cooled catalyst into small quantities using jaws, using the casting machine (X04CM-141), with spraying water coolers. The catalyst is fed into the storage Hopper manually from the crusher, whereby conveyor belts are utilized to transport the catalyst into the rotating Ball mill (X04GM-141). The ball mill consists of steel balls to further reduce the size of the catalyst to a finer product according to the Sasol specification. Inside the ball mill is the classifier, better known as the vacuum pump, which extracts the unused catalyst and feeds it to the hopper to further crush the catalyst. The unreduced catalyst from the ball mill is fed into the Casting Bin using conveyor belts, where it will be stored until the demand for the reduced catalyst is needed. Eventually, the reduced catalyst is fed into the Reactors to create hydrocarbons.

4.2. Evaluation of the Current Maintenance Strategy within the Plant

The analysis contains both east and west units. The eastern unit consists of two arc furnaces, conveyor belts, and kilns, all running concurrently, making a total of 8 equipment. The western unit consists of 5 electromechanical equipment, thus making 13 pieces of equipment.

For this study, field information was gathered through the Sasol SAP system. Using the Sasol SAP system, the breakdown work orders were pulled from the system for each piece of equipment.

The following information is required as input in the SAP software to obtain the data, as shown in Figure 1.

1. Equipment Technical Identification
2. Specific work order code (AM05)
3. Work centre of the unit
4. Duration of data being collected.

Input data is crucial to obtain the correct data required. SAP will automatically pull the necessary information based on the inputs. The data can then be exported to either Excel or PDF form for use. The data collected had to be cleaned by analysing each work order together with assistance from the mechanical supervisor. The formulae were used in an Excel spreadsheet, and calculations were made for each specific piece of equipment.

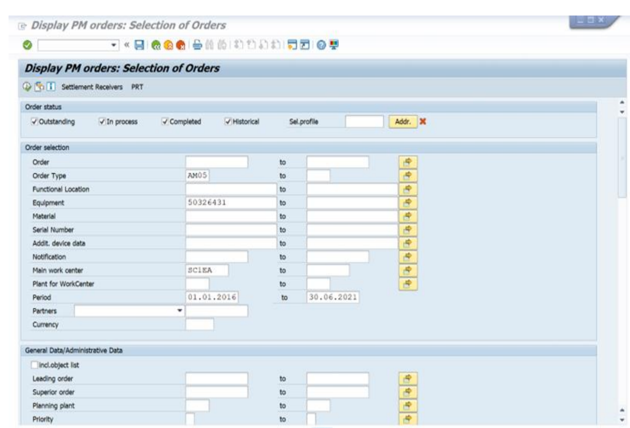

Fig. 1 SAP PM orders selection

The work orders were then classified correctly as breakdowns, and those identified as not breakdowns were then removed from the Excel list. Using the hypothesis test derived by the MBOHWA (2016) study, as in Appendix 2, the plant utilization and availability were obtained by comparing the electromechanical equipment in the Sasol catalyst preparation unit.

5. Results and Discussion of Results

5.1. Effectiveness of the Applied Maintenance Strategy

In this section, the effectiveness of the maintenance strategy applied to the electromechanical equipment was analysed. Mainly the western unit (004 unit) and the eastern unit (204 unit). As stipulated previously, the eastern unit consists of 2 arc furnaces, conveyor belts, and kilns, all running concurrently. On the western unit, there is only one piece of equipment.

This makes a total of thirteen pieces of equipment. The data input received from SAP for each piece of equipment was analysed and cleaned by obtaining each work order and notification attached to the work order to assess the breakdown notification. The graphs attached in Appendix 1 (Figures 2 to 53) illustrate the data results obtained from 13 different equipment dating from January 2016 to July 2021. Due to the rolling average of 12 months calculated for the MTBF, the data started in January 2017. The following results were obtained from the information received.

5.1.1. MTTR and Availability

MTTR is indirectly proportional to the availability, which is seen in Figures 2 and 3, to name a few. The arc furnace on the western unit from January 2017 to 2018 results reveal a low MTTR of 0.1 (1 hour) and high availability peaking at 91,36%. This, however, changes from January 2018 to 2021, and the MTTR gravitates to a higher outcome of 1,8 (1 day and 8 hours), and the availability drops to the lowest of 26.83 in September 2018. Similarly, the same trend is seen on arc furnace 141 A on the eastern side unit. The proportionality rate is also evident in all the other equipment, as when the availability increases, the MTTR reduces. From Equation 1 of inherent availability, the sum of MTTR and MTBF is directly proportional to the availability, thus the above observation.

5.1.2 MTBF and Number of Failures

Figures 4 and 7, to name a few, show the relationship between the number of failures and the MTBF. Though the MTBF is calculated using the 12-month rolling average, the graph is lagging compared to the failure rate. It is seen that they are directionally proportional to each other. The highest number of failures reaches two for the arc furnace, whilst the lowest is 0,5. The highest MTBF slowly declined between July 2018 and January 2019.

This trend is similar to that seen in Figure 4 for the casting machine; as the failure rate peaks soon after 12 months, the MTBF drops. Going back to the definition of MTBF according to ONDIEKI's (2008) study, MTBF is the mean value of the length of time between consecutive failures (computed as the ratio of the total cumulative observed time to the total number of failures) for a stated period in the life of an item. In simple terms, this is the inverse of the failure rate; thus, as the failure rate increases, the MTBF decreases.

5.1.3. Maintenance Cost and MTTR

From the obtained data, the maintenance cost was traced, but it is inconsistent. There is a relationship between the MTTR rate and maintenance costs, as seen in Figures 26 and 29 and Figures 30 and 33, to name a few. It is noted that when the MTTR is high, the maintenance cost increases. However, this is different from the arc furnace, which has a higher maintenance cost than all the equipment. The peak is seen from May 2018, which decreased after the period. ONDIEKI's (2008) study suggests that maintainability features, such as Mean Time To Repair (MTTR), influence maintenance costs, such as required manpower. This simply means that as the MTTR increases, the maintenance cost increases directly.

5.2. Overall Performance of the Plant

Using the equipment data extracted and analyzed, the key performance indicators were identified. Using the hypothesis test derived by MBOHWA's (2016) study, as in Appendix 2, Tables 1 and 2 were developed. Similarly, according to MBOHWA (2016), the four key performance indicators are used. With that said, the data extracted is from a period of a 4-year; thus, the average of each factor was concluded in the following tables.

Table 1. Theoretical distribution results for Western Unit 004

Asset equipment	Plant utilization averages over 4 years	Plant availability average over 4 years %	MTTR (hourly) average over 4 years	Maintenance cost sum variation over 4 years %
AF-141	86.57	51.17	8	8.82 underbudget
CM-141	98.8	95,01	4	24.31 overbudget
CV-101	99.01	98.57	1	11.4 underbudget
KN-101-R1	97.53	73.81	24	31,31 overbudget
GM-141	96.37	90.87	3	3.69 underbudget

Table 2. Theoretical distribution results for Eastern Unit 204

Asset equipment	Plant utilization average over 4 years	Plant availability average over 4 years	MTTR (hourly) average over 4 years	Maintenance cost sum variation over 4 years %
AF-141A	92.32	56.28	9	16.07 underbudget
AF-141B	94.72	69.02	9	10.52 underbudget
CM-141	97.17	72.83	24	17.23 overbudget
CV-101	97.81	86.51	9	3.27 overbudget
CV-201	98.41	95.38	2	1.72 underbudget
KN-101A	96.97	77.35	9	18.38 overbudget
KN-101B	97.77	88.08	5	7.65 overbudget
GM-141	95.35	81.72	4	8.08 overbudget

The obtained calculations clearly showed that much of the plant utilization per equipment is effectively utilized. However, the arc furnace on the western unit is underutilized. The plant utilization on the western arc furnace is significantly low, reaching an average of 86.57%, which is lower than 90%. Thus, in relation to the hypothesis test for proportion developed, the researchers concluded that the maintenance strategy employed on the arc furnace displayed that the maintenance strategy employed is not effective.

Further analysis of the output availability showed the ineffective availability of the arc furnace and the Kiln on the western side. Likewise, low availability percentage results are obtained on the eastern side, including the arc furnace, casting machine, kiln, ball mill, and conveyor belt 101, indicating a low availability utilization pattern. What is seen from the results is that the western unit has more equipment available than the eastern unit, which has more similar equipment.

The MTTR average is more than one hour/breakdown in the observed period for each machine. Almost all the equipment, except for the conveyor belt on the western unit, took an average of 1 hour to repair. The highest MTTR ratio is the Kiln on the western side and the casting machine on the eastern side, as they both have an average of 24 hours MTTR in the 4-year interval. The maintenance cost average has also been calculated, and the western unit has two pieces of equipment that are over budget: the casting machine and the kiln. On the other hand, equipment in the eastern unit that is over the planned budget is the casting machine, the conveyor belt 101, Kiln A and B, and the Ball mill.

6. Conclusion of Results

Based on the hypothesis test performed to obtain the overall performance of the plant. The plant utilization is above the prescribed parameter of 90%. All 12 pieces of equipment had utilization results above 90% except for the arc furnace on the western unit, which resulted in 86.57%. This is due to plant operations, which allow equipment to be serviced without interruptions to production, as a spare catalyst is stored. However, the availability percentage shows a significant effect, as 9 out of 13 pieces of equipment have a low availability percentage compared to the 90% effectiveness parameter. It is also seen that the mean time to repair for 12 pieces of equipment is more than the 1-hour repair time ratio. This concludes that though the plant is utilized effectively, the availability and MTTR ratio of the equipment are ineffective within the unit.

Availability of Data and Materials

The data used to support the findings of this study are included in the article.

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Appendix 1

004AF-141 (Arc furnace)

Fig. 2 004AF-141 Arc Furnace MTTR graph

Fig. 3 004AF-141 availability graph

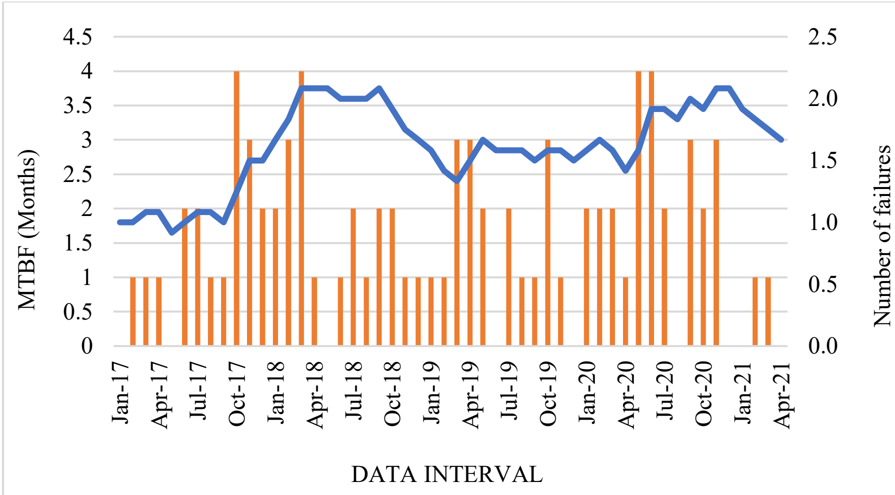

Fig. 4 004AF-141 Arc Furnace MTBF graph

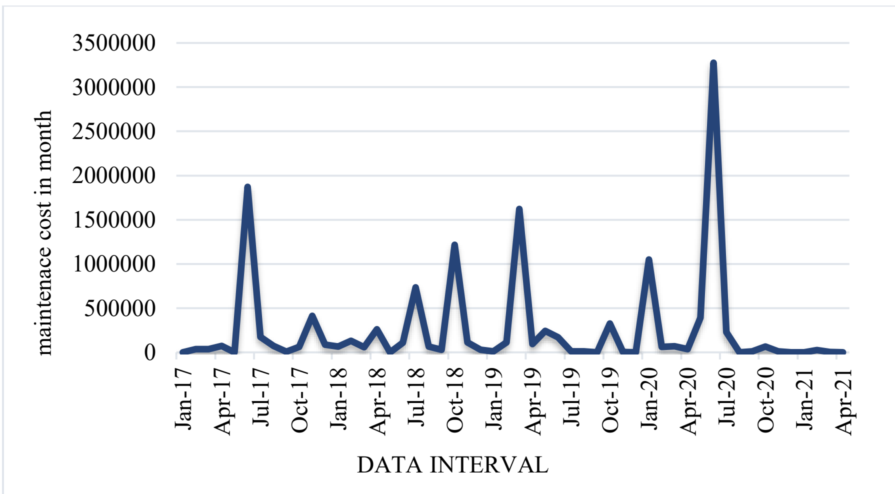

Fig. 5 004AF-141 Arc furnace cost graph

004CM-141 (Casting Machine)

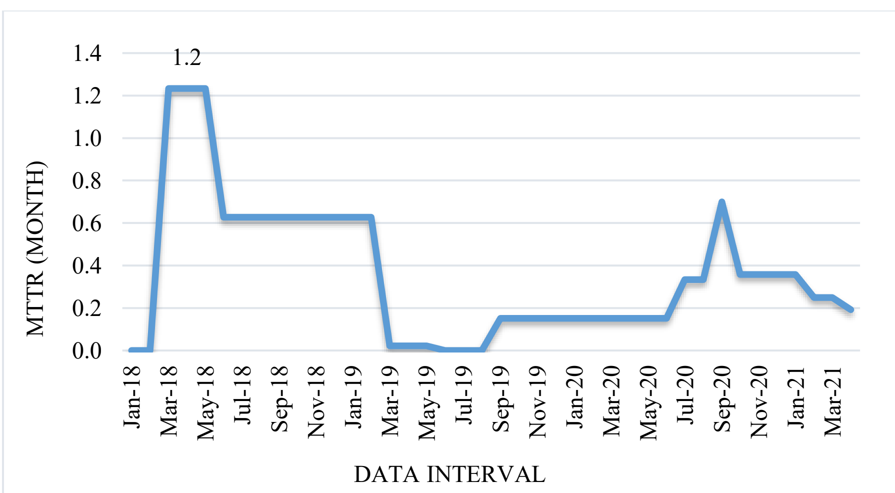

Fig. 6 004CM-141 casting machine MTTR graph

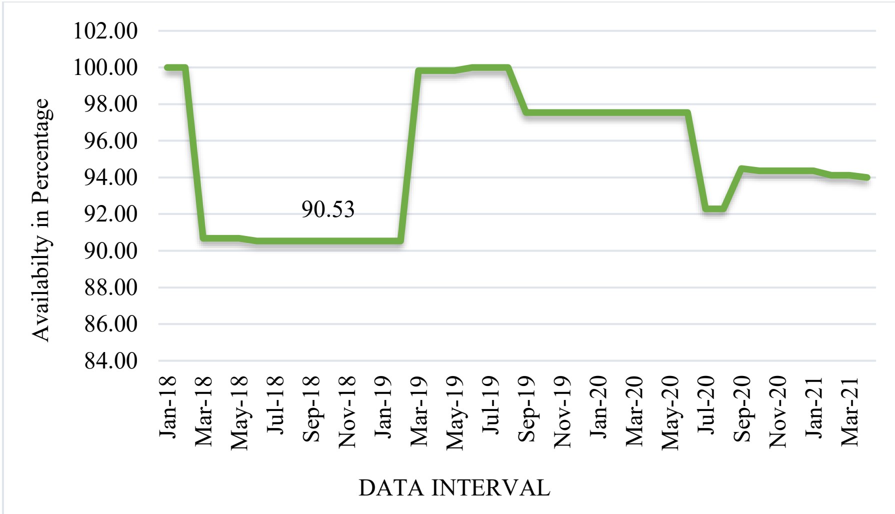

Fig. 7 004CM-141 casting machine availability graph

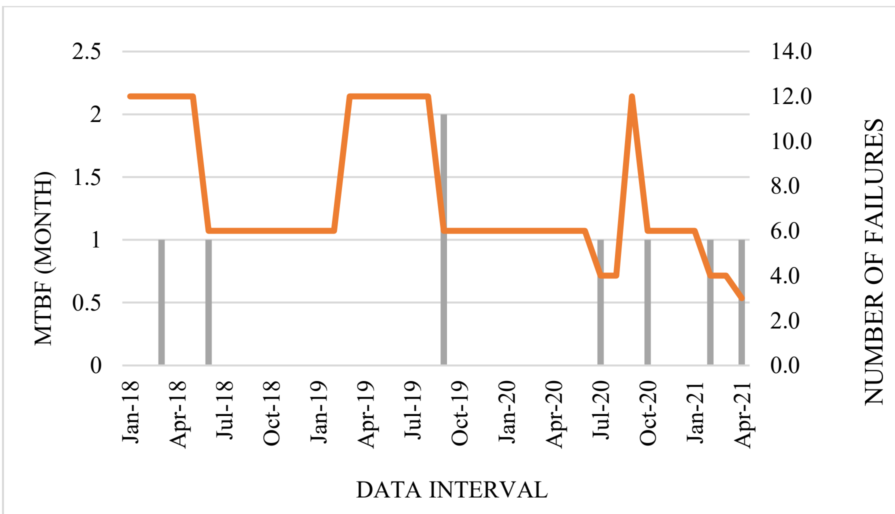

Fig. 8 004CM-141 casting machine MTBF graph

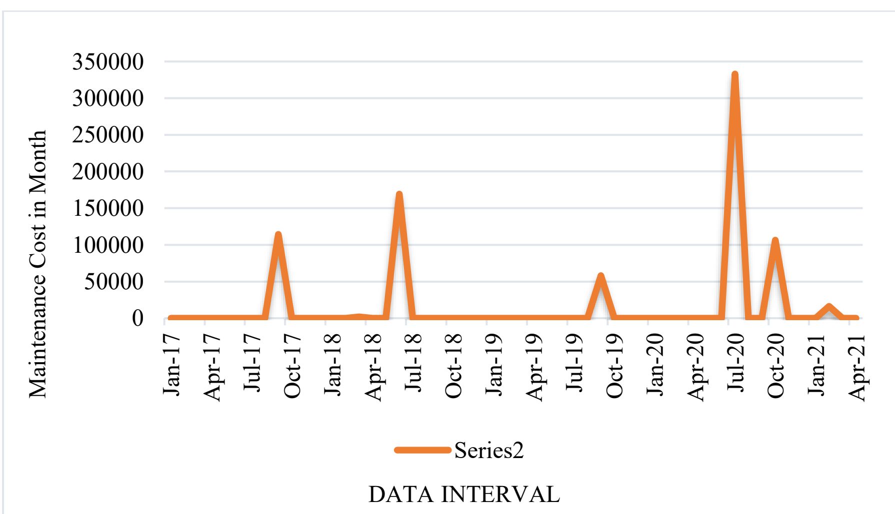

Fig. 9 004CM-141 casting machine cost graph

004CV-101 (Conveyor Belt)

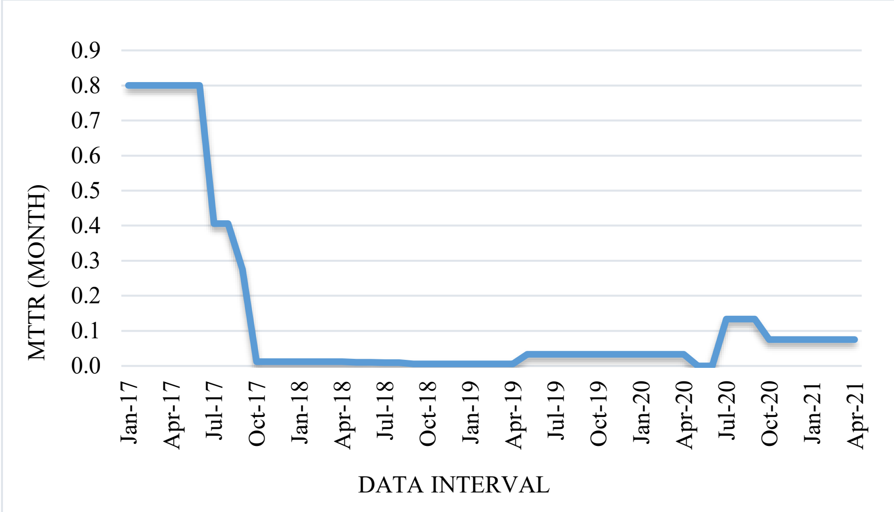

Fig. 10 004CV-101 conveyer belt MTTR graph

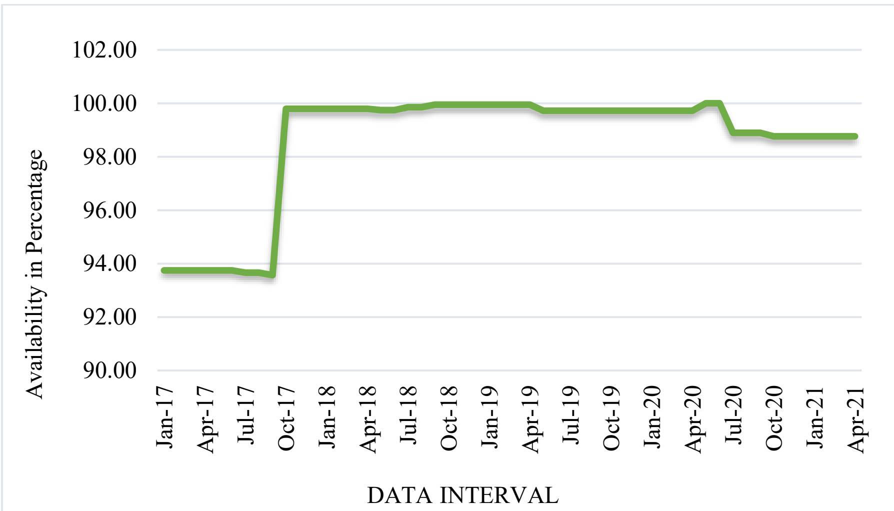

Fig. 11 004CV-101 conveyor belt availability graph

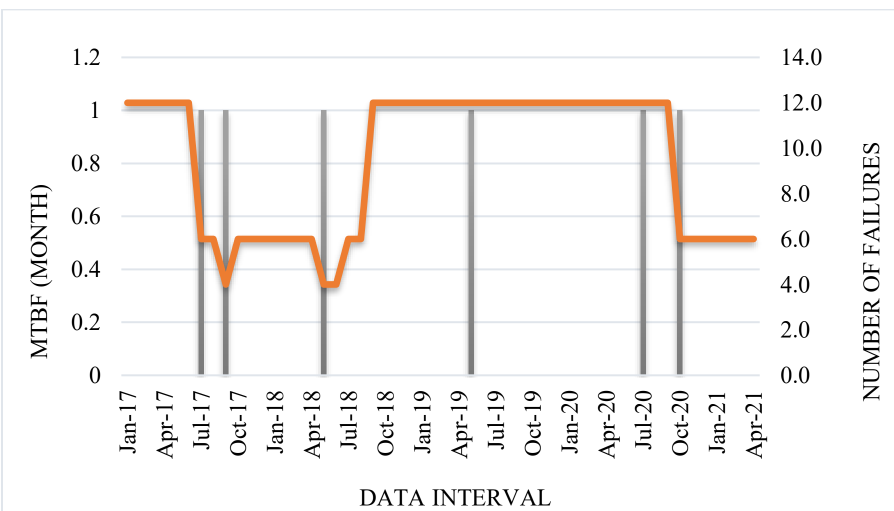

Fig. 12 004CV-101 conveyer belt MTBF graph

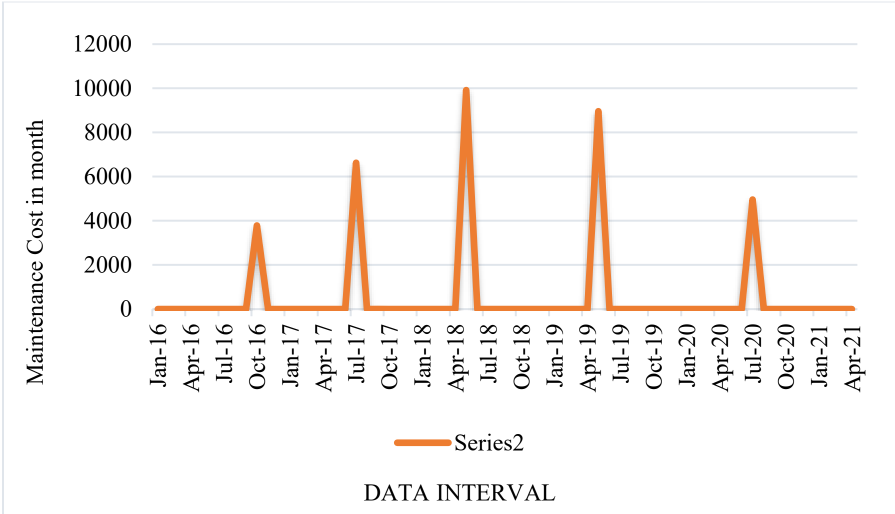

Fig. 13 004CV-101 conveyor belt cost graph

004GM-141 (Ball Mill)

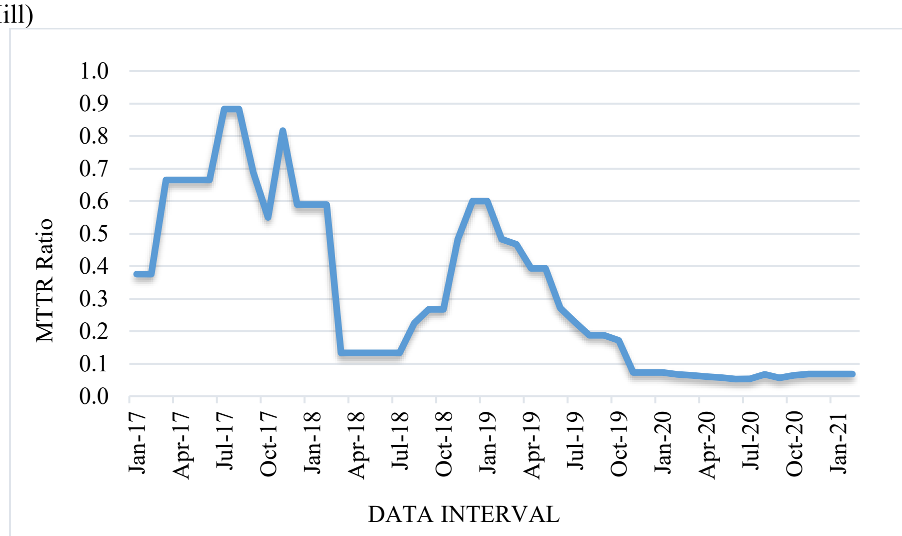

Fig. 14 004GM-141 ball mill MTTR graph

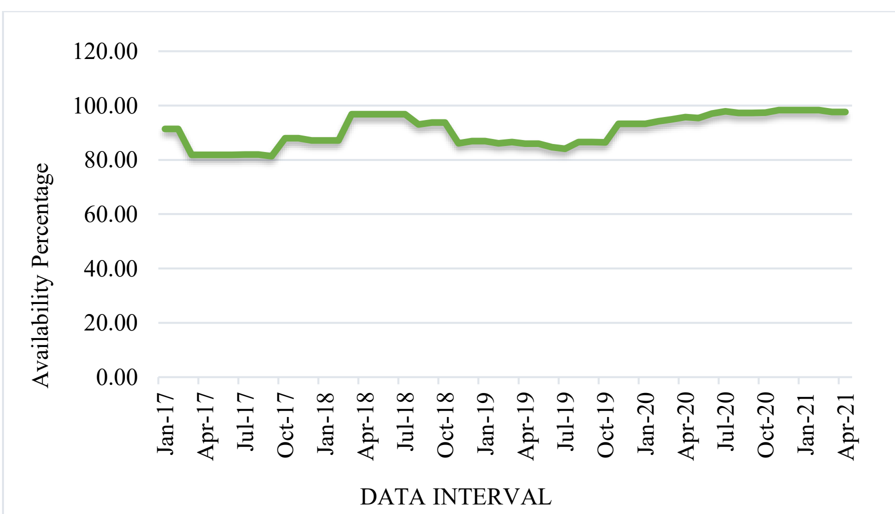

Fig. 15 004GM-141 ball mill availability graph

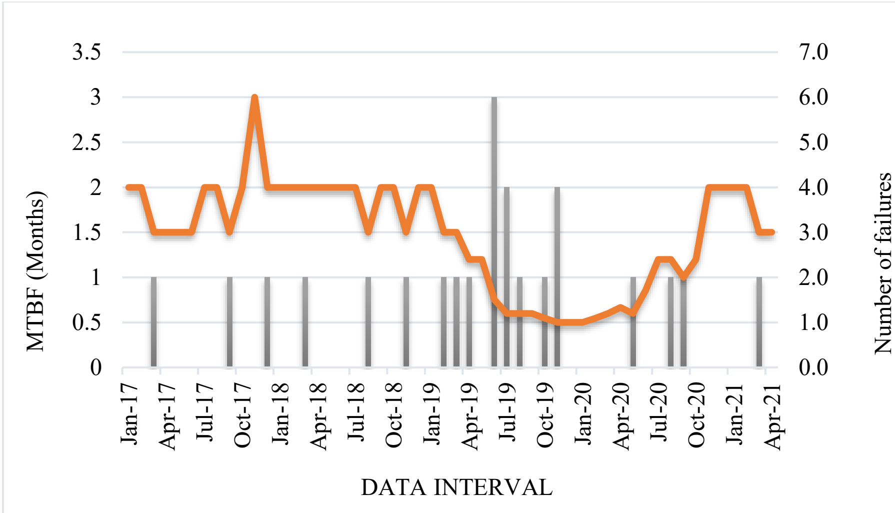

Fig. 16 004GM-141 ball mill MTBF graph

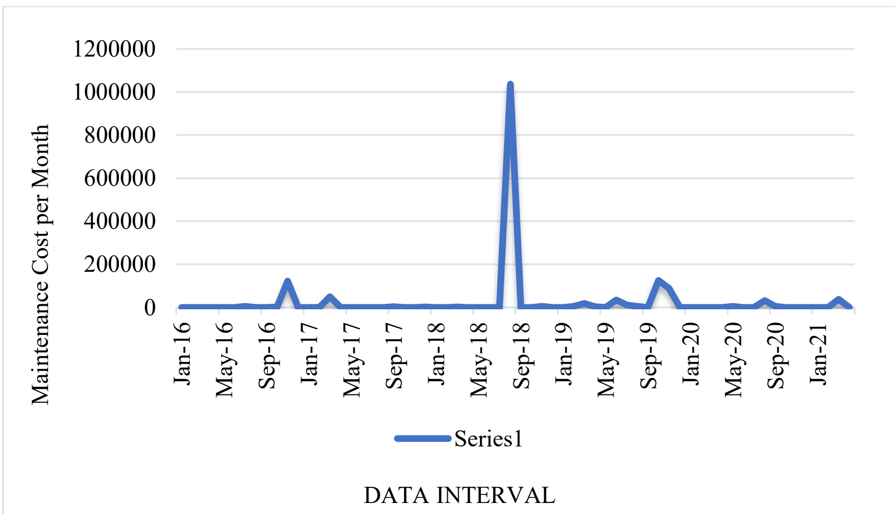

Fig. 17 004GM-141 ball mill cost graph

004KN-101-R1 (Kiln)

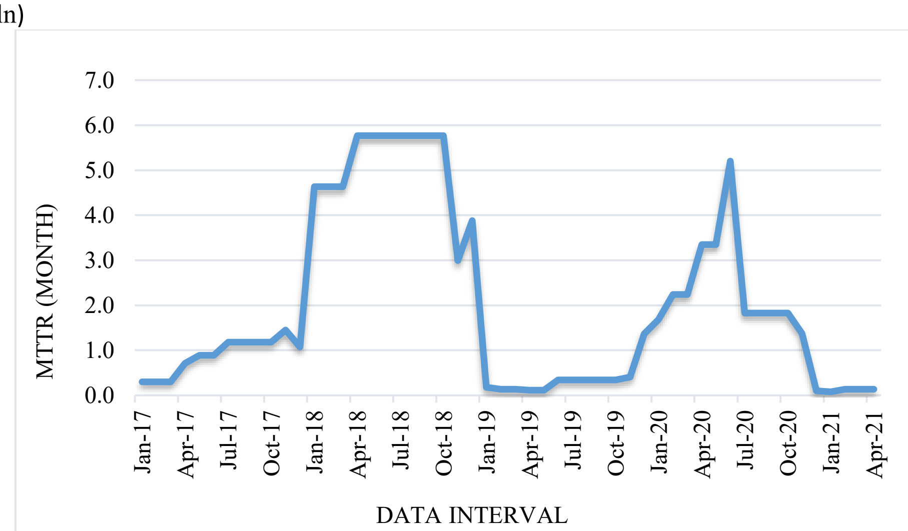

Fig. 18 004KN-101-R1 Kiln-R1 MTTR graph

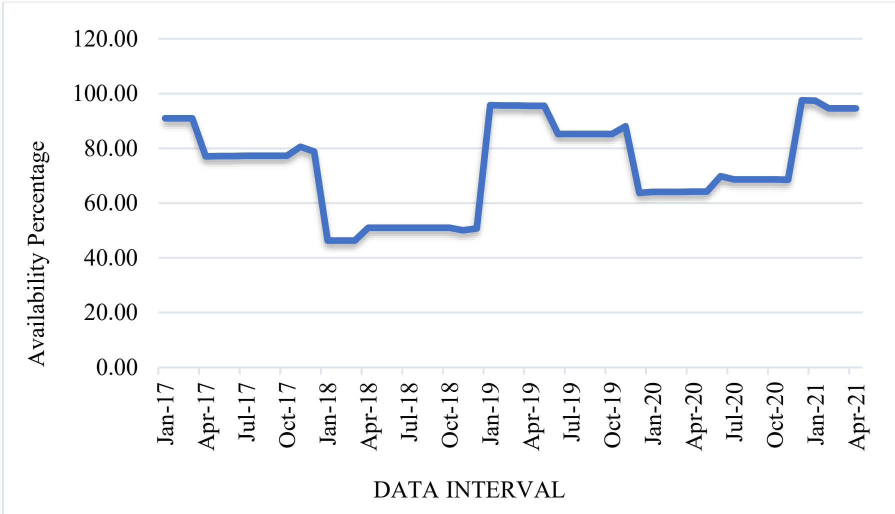

Fig. 19 004KN-101-R1 Kiln-R1 availability graph

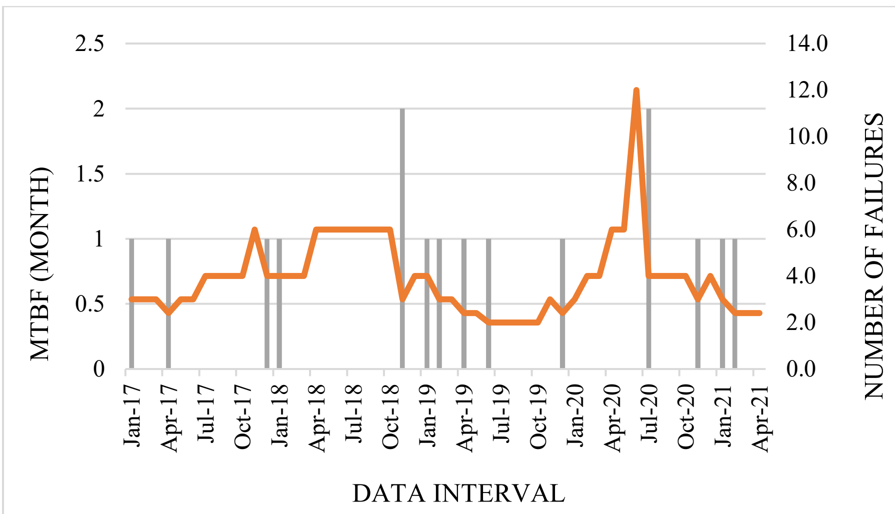

Fig. 20 004KN-101-R1 Kiln-R1 MTBF graph

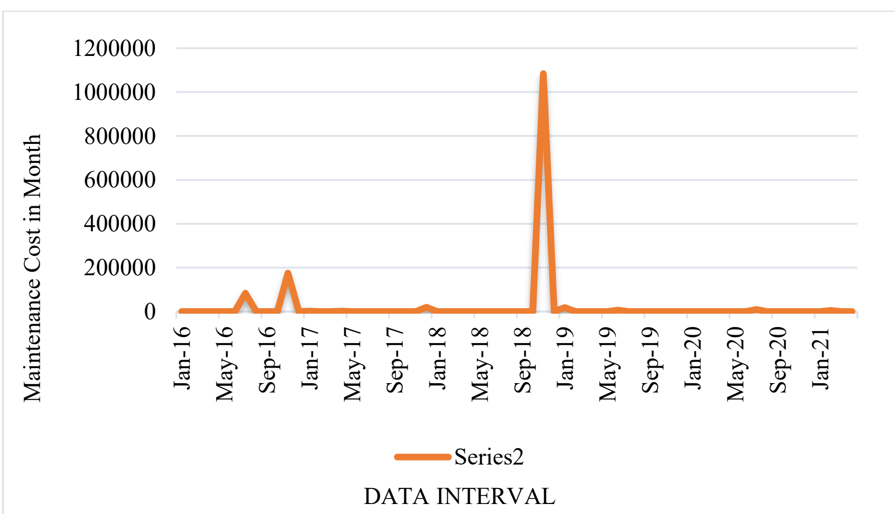

Fig. 21 004KN-101-R1 Kiln-R1 cost graph

Eastern Unit (U204)

204AF-141A (Arc Furnace)

Fig. 22 204AF-141A Arc furnace-A MTTR graph

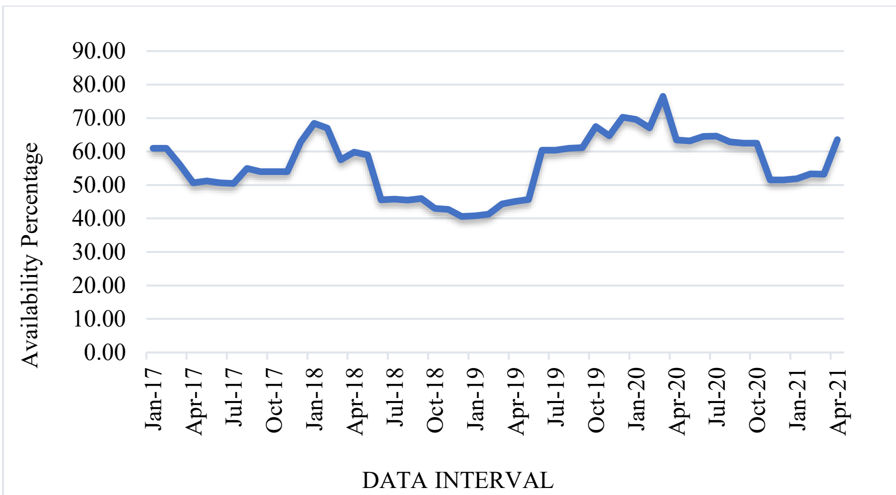

Fig. 23 204AF-141A Arc furnace-A availability graph

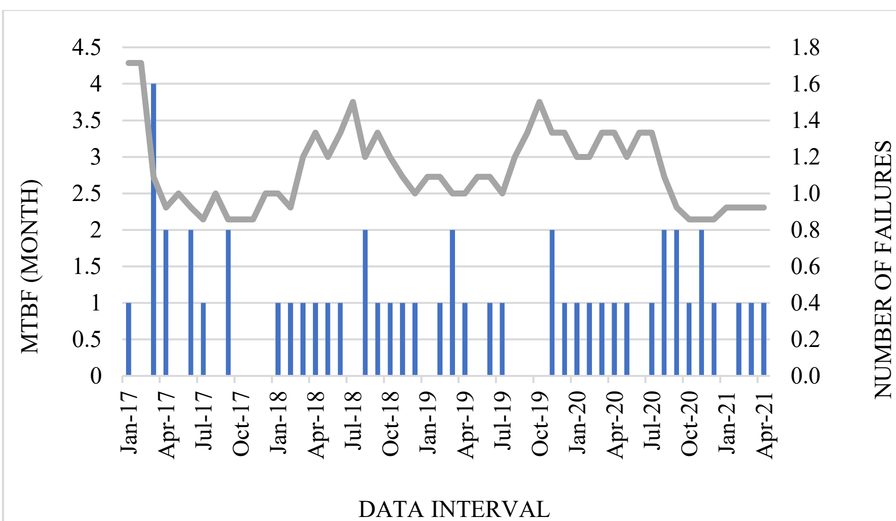

Fig. 24 204AF-141A Arc furnace-A MTBF graph

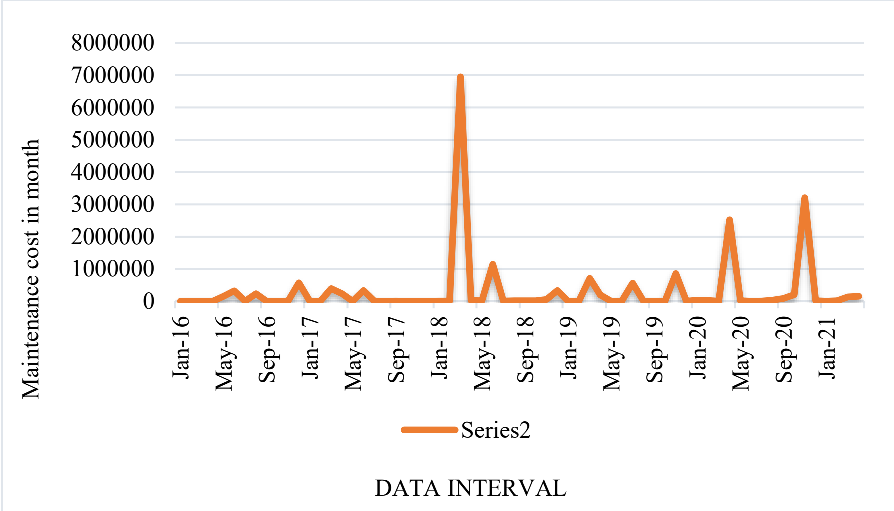

Fig. 25 204AF-141A Arc furnace-A cost graph

204AF-141B (Arc Furnace)

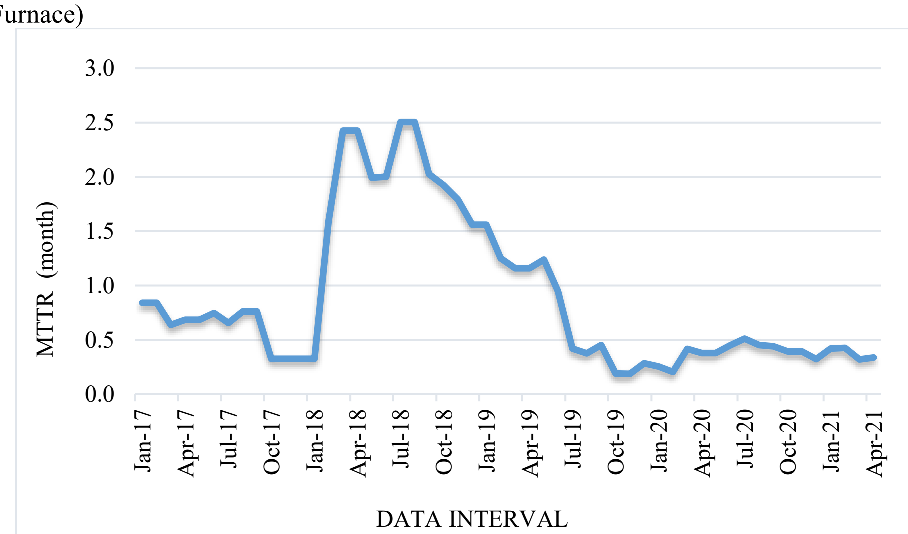

Fig. 26 204AF-141B Arc furnace-B MTTR graph

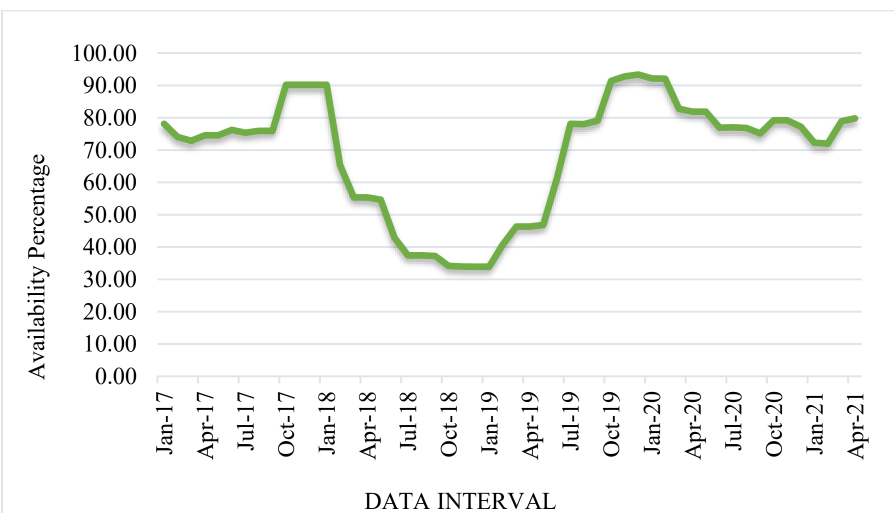

Fig. 27 204AF-141B Arc furnace-B availability graph

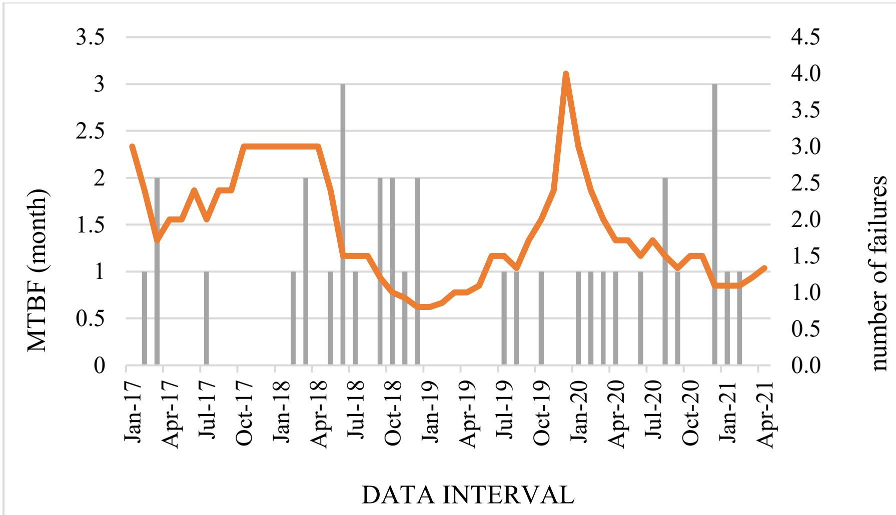

Fig. 28 204AF-141B Arc furnace-B MTBF graph

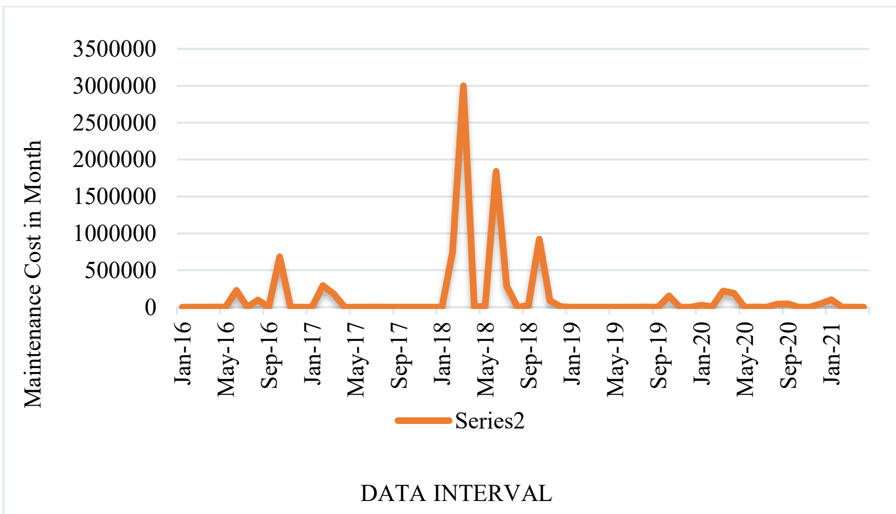

Fig. 29 204AF-141B Arc furnace-B cost graph

204CM-141 (Casting Machine)

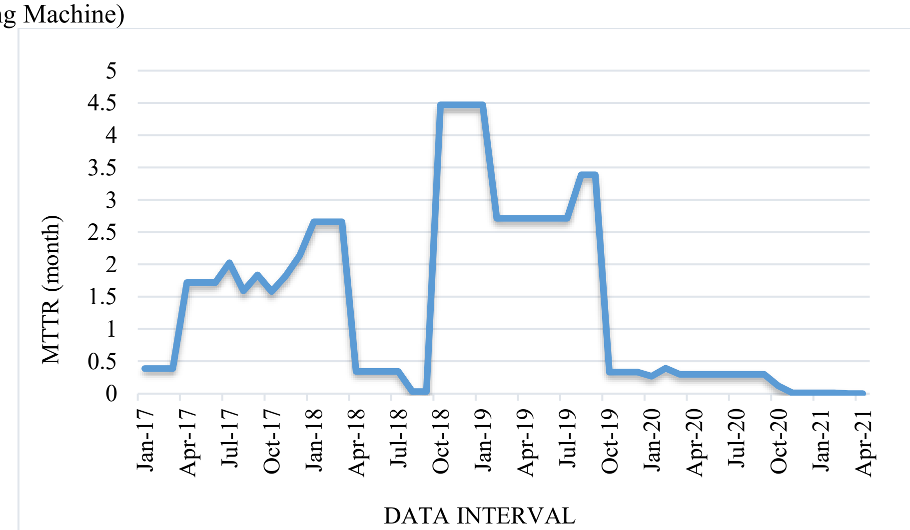

Fig. 30 204CM-141 casting machine MTTR graph

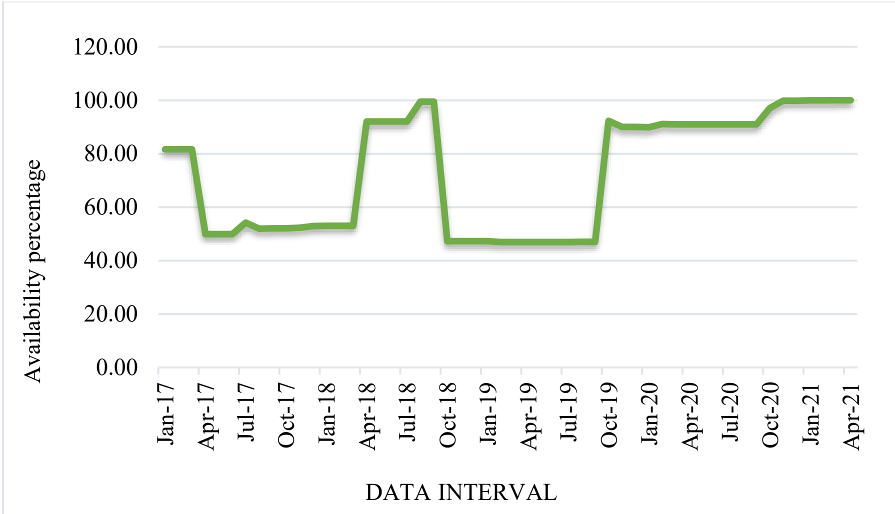

Fig. 31 204CM-141 casting machine availability graph

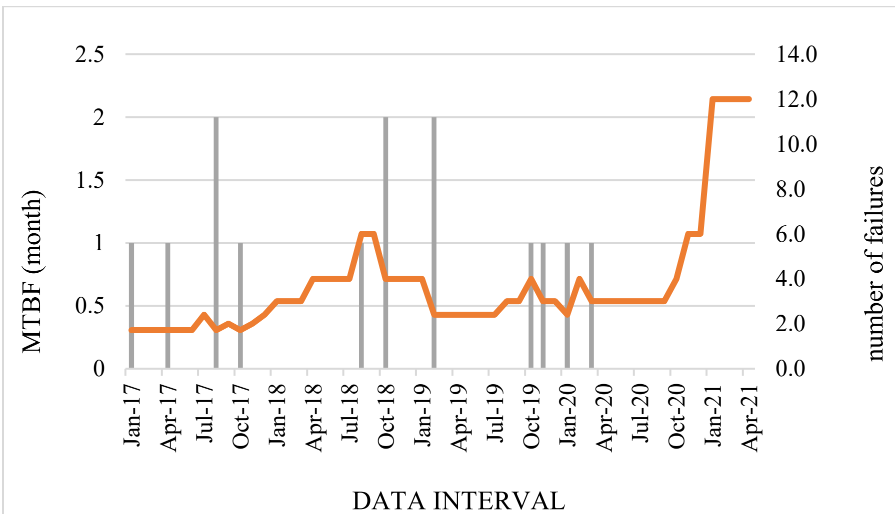

Fig. 32 204CM-141 casting machine MTBF graph

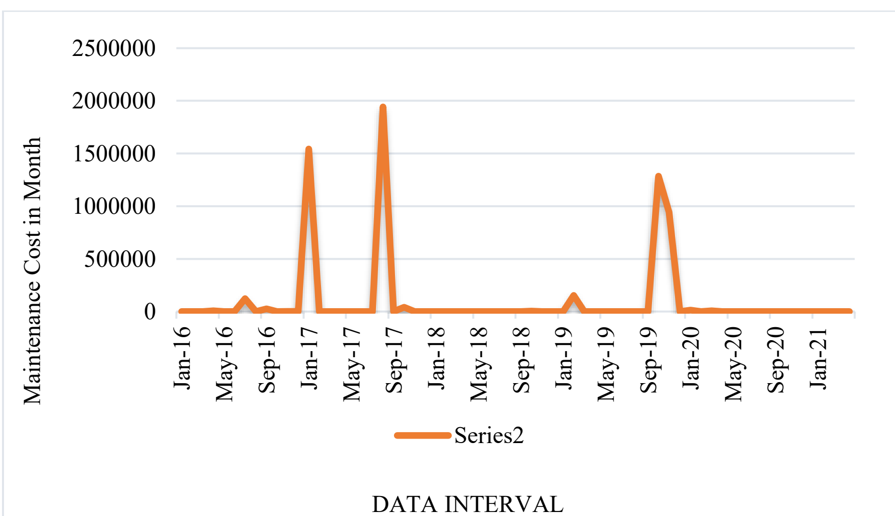

Fig. 33 204CM-141 casting machine cost graph

204CV-101 (Conveyor Belt)

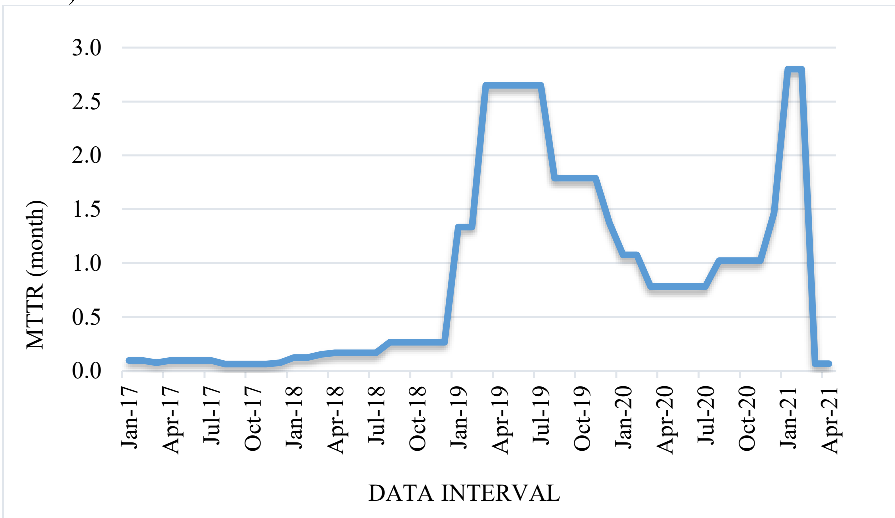

Fig. 34 204CV-101 conveyer belt MTTR graph

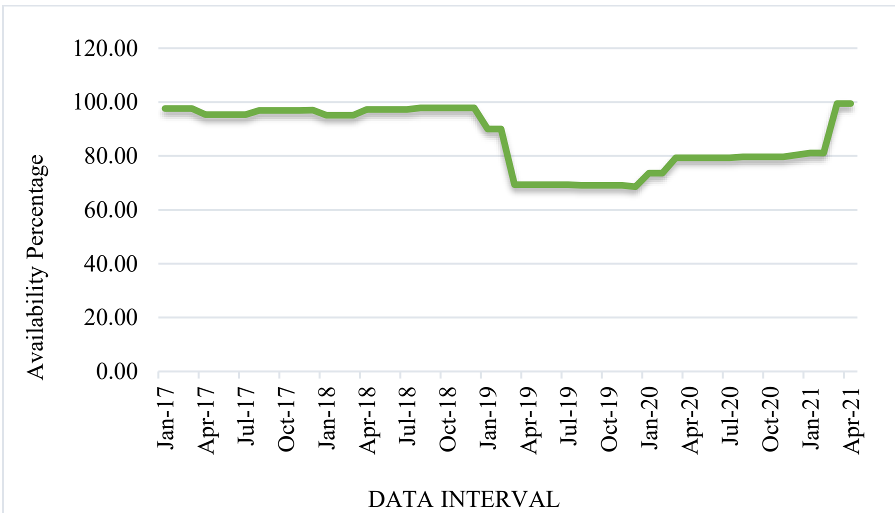

Fig. 35 204CV-101 conveyor belt availability graph

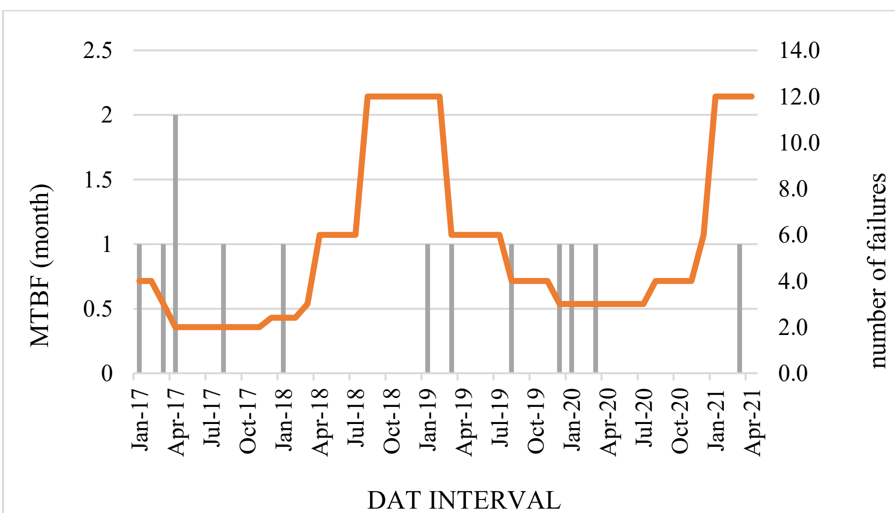

Fig. 36 204CV-101 conveyer belt MTBF graph

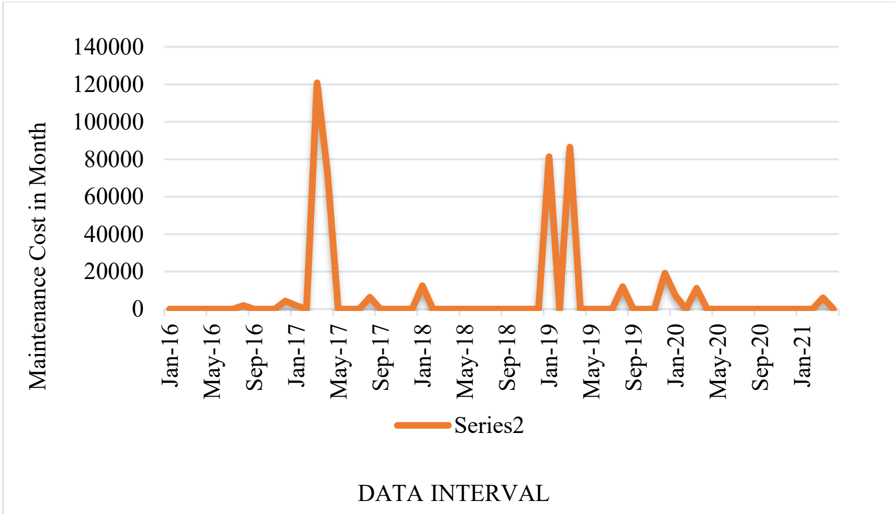

Fig. 37 204CV-101 conveyer Belt cost graph

204CV-201 (Conveyer Belt)

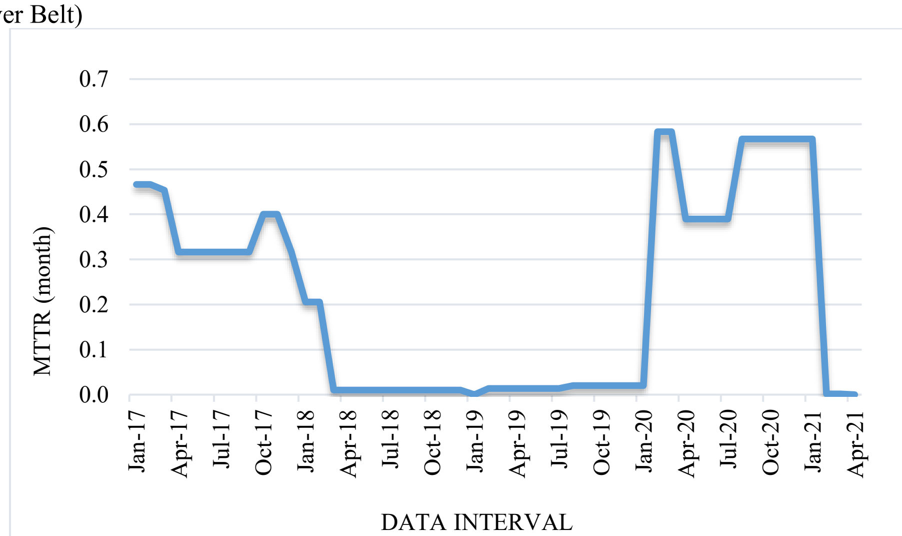

Fig. 38 204CV-201 conveyer belt MTTR graph

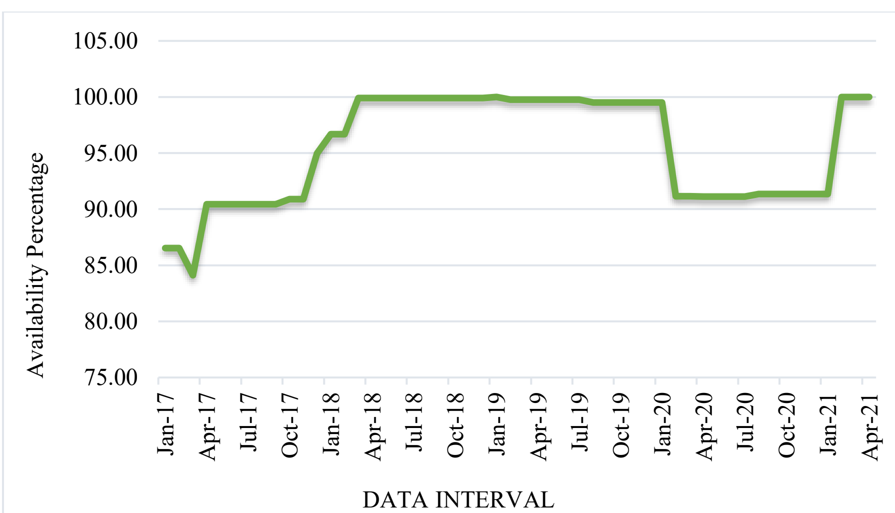

Fig. 39 204CV-201 conveyer belt availability graph

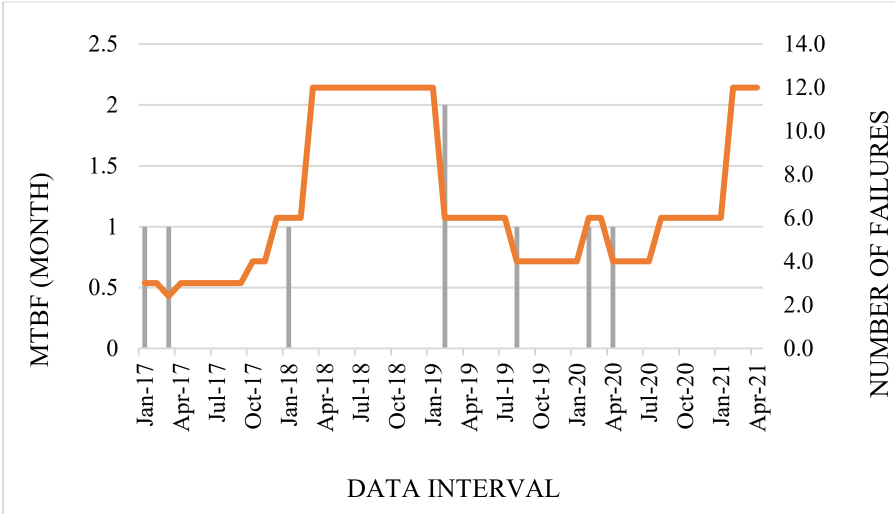

Fig. 40 204CV-201 conveyer belt MTBF graph

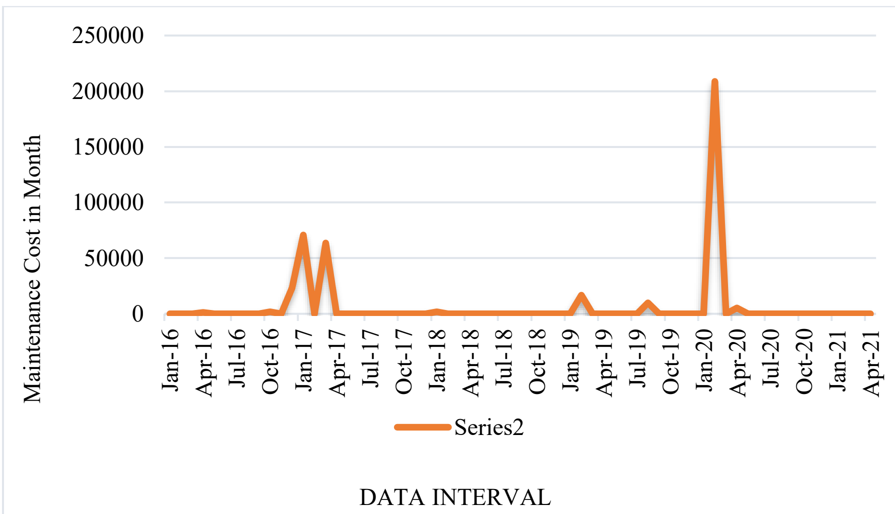

Fig. 41 204CV-201 conveyer belt cost graph

204GM-141 (Ball Mill)

Fig. 42 204GM-141 ball mill MTTR graph

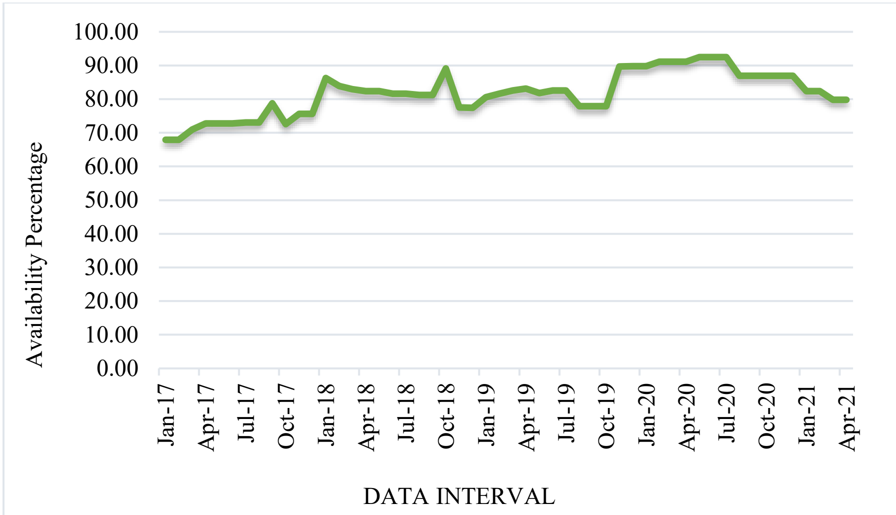

Fig. 43 204GM-141 ball mill availability graph

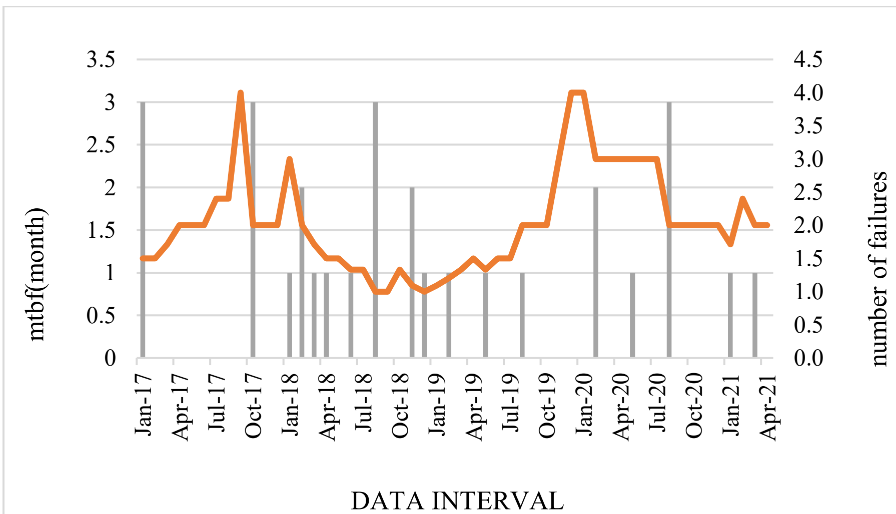

Fig. 44 204GM-141 ball mill MTBF graph

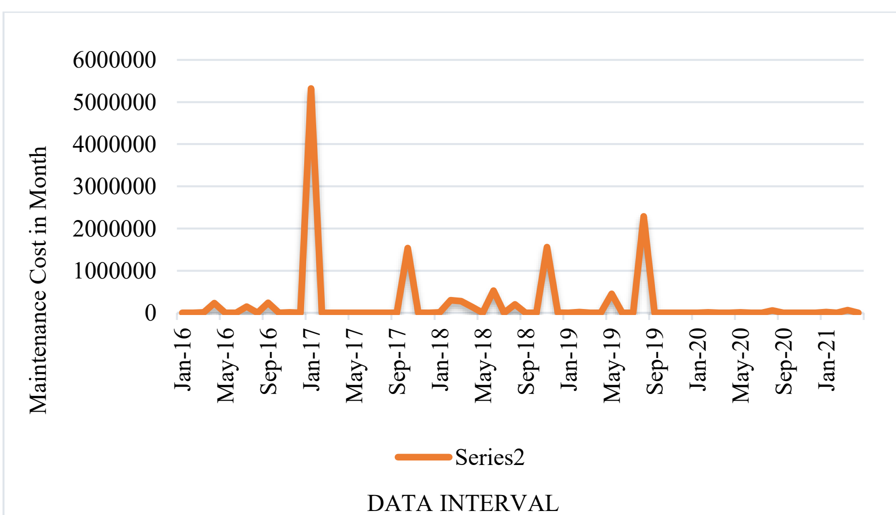

Fig. 45 204GM-141 ball mill Cost graph

204KN-101A (Kiln A)

Fig. 46 204KN-101A Kiln-A MTTR graph

Fig. 47 204KN-101A Kiln-A Availability graph

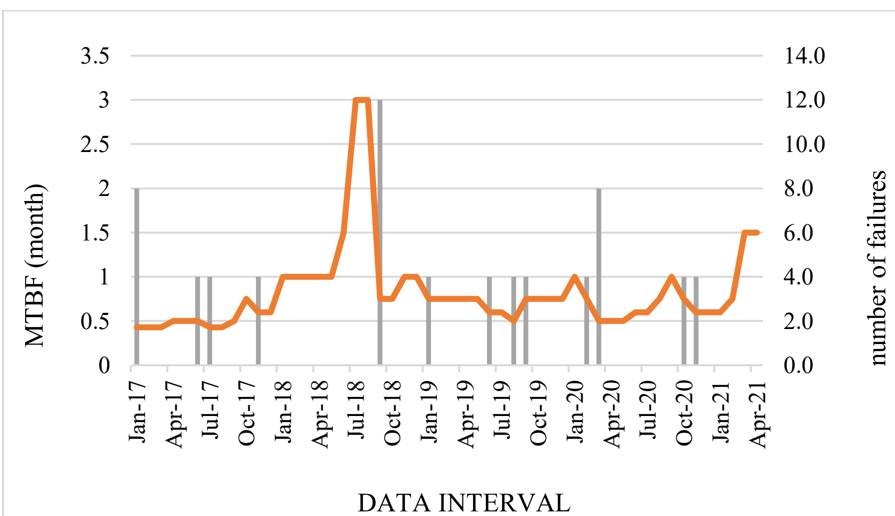

Fig. 48 204KN-101A Kiln-A MTBF graph

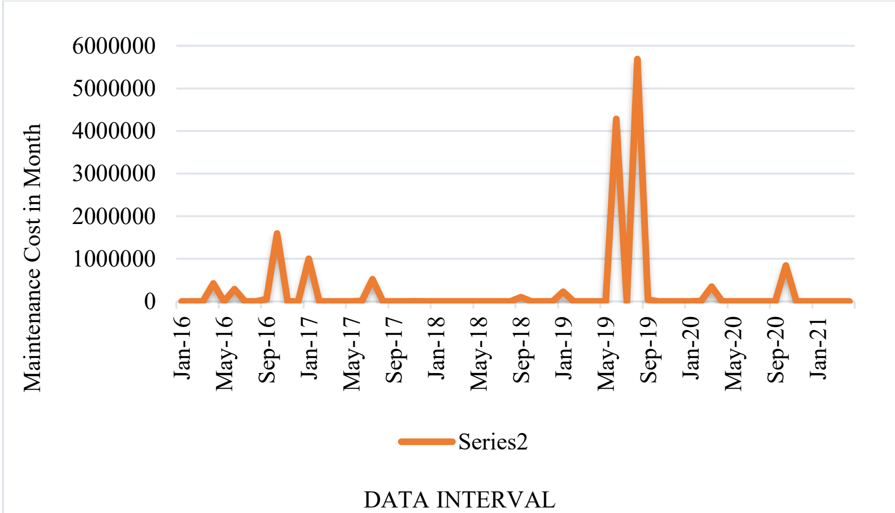

Fig. 49 204KN-101A Kiln-A Cost graph

204KN-101B (Kiln B)

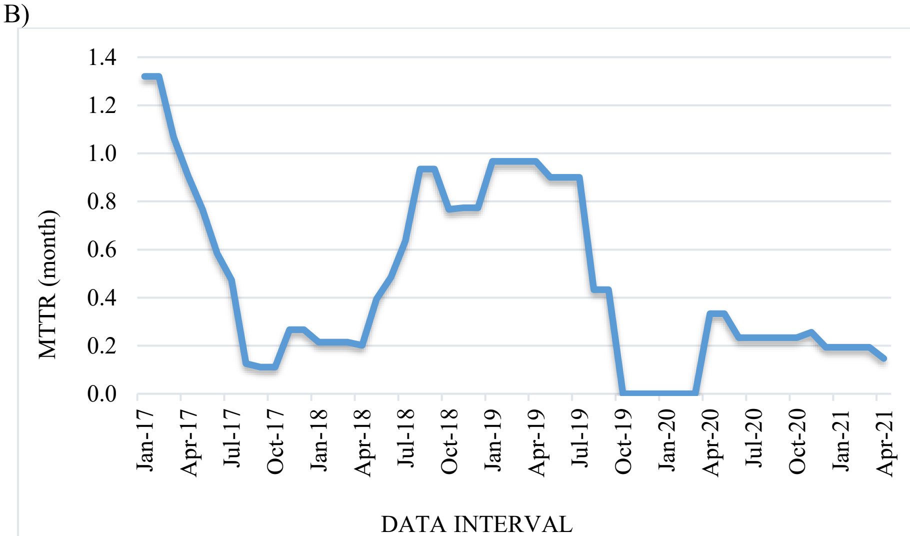

Fig. 50 204KN-101B Kiln-B MTTR graph

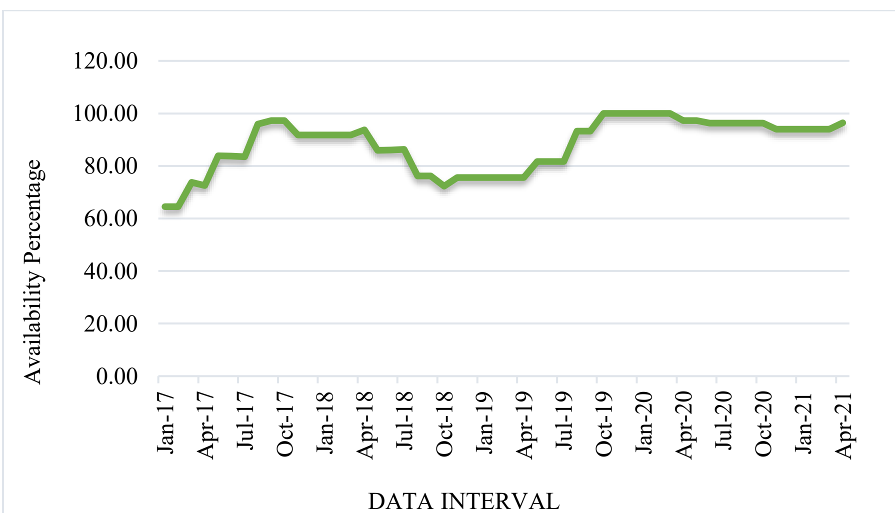

Fig. 51 204KN-101B Kiln-B availability graph

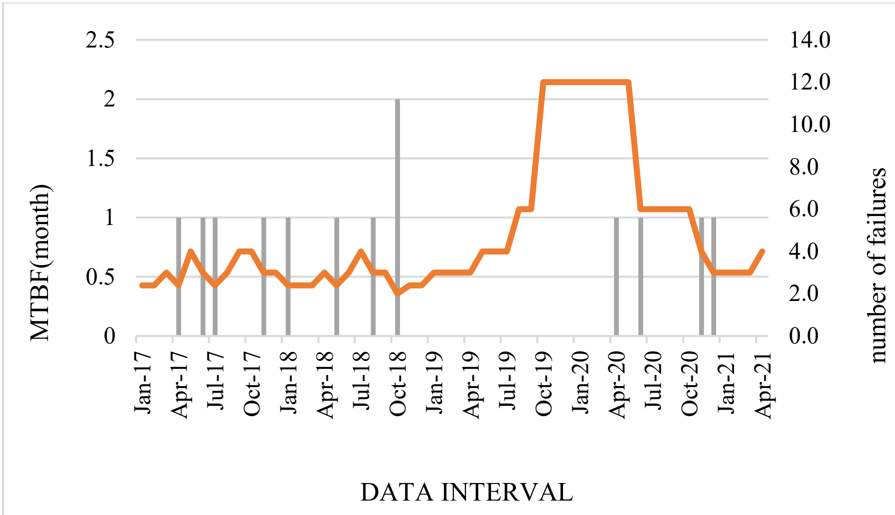

Fig. 52 204KN-101B Kiln-B MTBF graph

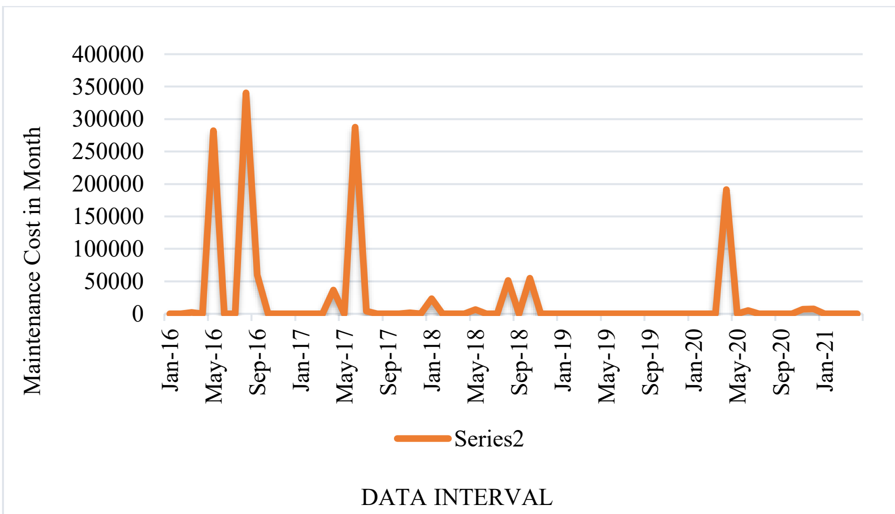

Fig. 53 204KN-101B Kiln-B Cost graph

Appendix 2

Hypothesis Development (MBOHWA, 2016)

The researchers developed the following hypothesis tests to explain and interpret the relationship between maintenance effectiveness evaluation factors and the effectiveness of the maintenance strategies on overall equipment utilization.

Plant Utilization Equipment-Wise

H_0: Not more than 90% is plant utilization equipment-wise in the observed period.
H_a: More than 90% is plant utilization equipment-wise in the observed period.
H_0: $P \leq 0.90$ not effective
H_a: $P \geq 0.90$ effective
If the p-value is less than α=0.05, reject the Null hypothesis.

Plant Availability, Equipment-Wise

H_0: Not more than 90% is plant availability equipment-wise for production in the period.
H_a: More than 90% is plant availability, equipment-wise, for production in the period.
H_0: $P \leq 0.90$ not effective
H_a: $P \geq 0.90$ effective
If the p-value is less than α=0.05, reject the Null hypothesis.

Maintenance Cost/Lost Sales due to Downtime

H_0: The maintenance cost is more than 10% of the budgeted total revenue in the period.

H_a: Maintenance cost is less than 10% of the total budgeted revenue in the period.

H_0: $P \geq 0.10$ not effective

H_a: $P \leq 0.10$ effective

If the p-value is less than α=0.05, reject the Null hypothesis.

Mean Time To Repair (MTTR)

H_0: MTTR is more than one hour/breakdown in the observed period for each machine.

H_a: MTTR is less than one hour/breakdown in the observed period for each machine.

H_0: $\mu \geq 1$ hour not effective

H_a: $\mu \leq 1$ hour effective

If the p-value is less than α=0.05, reject the Null hypothesis.

In this research paper, the plant utilization for the company was set at the level of 90% or above, plant availability was set at the level of 90% or above, and the cost of maintenance/lost sales due to downtime was set at 10% or less.