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Using failure mode and analysis its effects technique to improve the overall equipment effectiveness (Case study in Al-Ittihad Sugar Refining Plant/Iraq)

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Abstract : Organizations have used the Failure Mode and its Effects Analysis (FMEA) technique, which is considered one of the most effective methods in the industry and is of outstanding importance for quality management to identify known and potential errors. This study aims to use the Failure Mode and its Effects Analysis technique in improving the overall equipment effectiveness (OEE), representing a community The study was the centrifugation station, one of the stations of the production department in the Al-Ittihad Sugar Refining Plant. The study sample was (16 batch centrifugal). The study used the Pearson correlation coefficient to prove that using the (FMEA) technique leads to improving (OEE) indicators. The study demonstrated the existence of an inverse correlation between the failure mode technique, analysis of its effects, and overall equipment effectiveness, and it came up with a set of recommendations, the most prominent of which is focusing on conducting periodic inspection of equipment at close intervals, as it contributes to early detection of potential failure modes and taking measures that prevent failure from occurring or reduce its effects on the equipment.

Keywords: failure mode and analysis of its effects technique, risk priority number, overall equipment effectiveness.

Introduction: In today's competitive global market, organizations are making great efforts to develop processes and products and provide distinguished products to customers with high quality and low cost. To achieve this, they have used the Failure Mode and Effects Analysis (FMEA) technique, which has been proven to be an effective technique in preventing potential failure in the long term, and which uses a priority number. Risks to reduce or eliminate risks. On the other hand, overall equipment effectiveness is the key to ensuring success in manufacturing. Using Overall Equipment Effectiveness (OEE) as an indicator depends on the availability, performance, and quality of machines. This indicator has been applied in industry to evaluate the effectiveness of equipment, which is a basic necessity for organizations. As it wants to succeed and survive in the global competitive market, equipment is an important element to support the production process.

The first topic: The scientific methodology of research

First: The problem of the study

Organizations seek to improve their productivity, raise the quality of their products, reduce production costs, and increase the effectiveness of production equipment. Through field visits by the researcher to the sugar refining factory to study and identify the problems facing the factory, the following problems were noted:

1 - The large number and length of operations in sugar manufacturing, which require continuity during the operating times of the stations, made it impossible for the factory to stop and continue its work for (8) hours for each work shift.

2 - The lack of availability of some spare parts for the batch centrifugal, which require waiting time until they arrive at the factory, which sometimes causes the machine to be out of service.

3 - The repeated occurrence of failure in some sorters and certain patterns of failure due to poor quality spare parts, which lead to the failure of this batch centrifugal.

In light of the above problems, this study attempts to understand and explain the role played by the failure mode technique and analysis its effects in improving the overall equipment effectiveness by formulating the following questions:

1 - Is it possible to determine the failure modes of the equipment in the Al-Ittihad Sugar Factory according to the failure mode technique and analysis its effects?

2 - What are the failure modes that can be considered critical failure modes in the factory at the study site?

3 - What is the nature of the relationship between failure mode and analysis of its effects technique, the overall effectiveness of the equipment?
4 - Can the overall equipment effectiveness be improved based on failure mode and analysis of its effects technique?
5- Is it possible to rely on the results of failure mode and analysis its effects technique in improving the effectiveness of factory equipment?

Second: The importance of the study

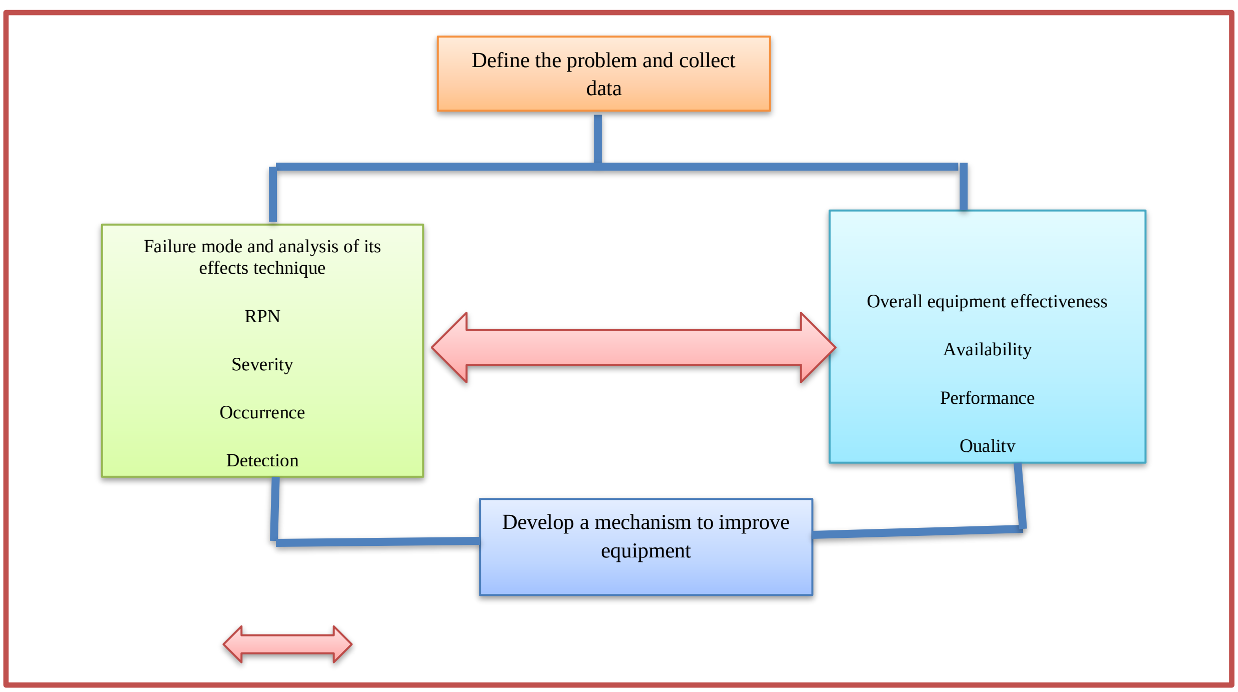
The importance of this study lies in achieving the following points:
1 - It contributes to reducing the number of failure modes by identifying and focusing on them in the Al-Ittihad Sugar Factory.
2 - The importance of this study is gained through its discussion of an effective and vital technique that helps the factory at the study site (the sugar factory) and provides results that contribute to improving the effectiveness of the overall equipment.
3 - The study variables are among the important variables that contribute effectively and mainly to improving the organization's productivity and product quality and its success in light of the challenges it faces in competitive environments.

Third: Objectives of the study

The main objective of this study is to prove the relationship between failure mode technique, analysis its effects, and overall equipment effectiveness, and provide a theoretical framework that explains this relationship. In light of the problem of the study and its importance, the objectives of the study can be limited to the following:
1 - Understand the causes and patterns of failure in the Al-Ittihad Sugar Factory, prioritize these patterns, and analysis their effects.
2- Improving maintenance plans by understanding the pattern that occurs repeatedly.
3 - Reducing unplanned downtime by analysis the failure mode technique and analysis its effects.
4 - Study the relationship between failure mode technique and analysis its effects and overall equipment effectiveness (OEE).
5 - Providing practical and applied recommendations that would improve the effectiveness of the overall equipment by applying the failure mode technique and analysis its effects.

Fourth: Hypothetical plan for the study

Figure (1) shows the relationship between the study variables:
A- Independent variable: failure mode and analysis of its effects technique.
B- Dependent variable: overall equipment effectiveness



centrifugal, and the study was adopted to analysis failure patterns for (12 months of the year 2023).

Seventh: Study methodology

The researcher adopted a case study, field experience, and direct observation of records and documents to determine the course and activities of the production process and identify the failure patterns suffered by the Al-Ittihad Sugar Refining Plant for the period from (20/9/2023 to 31/3/2024).

The second section: The theoretical framework of the study

First: Failure mode and analysis of its effects technique

1 - The origins and development of failure mode and its effects analysis (FMEA) technique

The US Army developed the Failure Mode and Effects Analysis (FMEA) technique in 1949 according to the Military Procedures Document (MIL-P-1629), which was revised in 1980 (Cabanes et al., 2021:4). This technique was first introduced in the aerospace manufacturing department in the United States in the 1950s and was initially used to solve quality and reliability problems for military products. It has been widely applied in many industries (Wu et al.,2021:1409). However, the first notable applications of FMEA technique are related to the amazing development of the aviation industry in the mid-1960s, and studies conducted by NASA for this technique in 1963 contributed to its use to improve safety in operations (Kharola & Singh, 2014: 211). In the 1970s, Ford Motor Company used FMEA technology in the automobile industry and it was developed and standardized by the Automotive Industry Action Group (AIAG) (Dobra & Josvai, 2021:56). In 1990, the International Organization for Standardization (ISO) recommended the use of (FMEA) technology to review the design in the (ISO 9000) series, and the first version of the Society of Automotive Engineers (SAE) standard (1739J-) was developed in 1994, which was developed in partnership with Chrysler, Ford, and General Motors. (Liu,2016:4). In recent years, FMEA technique has become highly desirable, as it is used during the design stage to avoid failure and control the process before and during operation (Sharma & Srivastava, 2018: 1-2).

2 - The concept of failure mode and its effects analysis (FMEA) technique

The FMEA technique seeks to determine how the system will behave in the event of failure, as it involves the integration of many expert tasks to determine the analysis components, determine failure modes, predict the effects of failure, and suggest corrective actions. (Peliez & Bowles, 1995:450) (Besterfield et al., 2012:275) noted (FMEA) is an analytical technique that combines technology and people's experience in identifying expected failure patterns for a product or process and planning to eliminate or reduce them. As for (Kharola & Singh, 2014:211), the Failure Mode and Effects Analysis (FMEA) technique is one of the well-known quality management techniques. Its purpose is to examine failure modes in products, designs, and processes. For his part (Li & Chen, 2019:137), he emphasized that the Failure Mode and Effects Analysis (FMEA) technique is valid for identifying and interpreting failures or errors to improve the reliability of systems, designs, and products. (Wang et al., 2021:2) described it as an engineering technique that is widely used to identify and eliminate or reduce known or potential failures, problems, and errors before they occur in the system, design, process, or product, and implement corrective measures before the product reaches the customer. (Ivancan & Lisjak, 2021:3-4) defined it as a technique for inductive analysis, which is a systematic and documented iterative process that is conducted to identify failures or basic errors at the system level and their effects on its performance. It helps to develop risk priorities and mitigation procedures and is an opportunity for continuous improvement of the system or process. It can be performed either using actual failure modes from historical field data or failure modes derived from design analysis, reliability prediction activities, and experience with how parts fail. As for (Liu et al., 2023:5246) he pointed out that (FMEA) is a reliability analysis technique that identifies all possible failure modes in the system and all the potential effects of the failure modes on the system, classifies each failure mode and suggests solutions and preventive measures.

Based on the above, the researcher believes that the **Failure Mode and Effects Analysis (FMEA) technique is a preventive or corrective technique that works to identify and analysis potential and known failure patterns in the system, design, process, or products, evaluate and arrange them according to the degree of their severity and effects, and take the necessary measures that can be applied to eliminate the failure. Or reduce its effects, which are important and valuable to achieve safety, quality and reliability.**

3 -Types of failure mode and its effects analysis (FMEA) technique.

(Sharma & Srivastava,2018:2) indicated that the types of FMEA technique are determined according to the nature of the application, and they classified them into three main types:

A - Concept FMEA

Concept analysis is used in the early stages at the system and subsystem level, and focuses on potential failure modes associated with particular functions to propose the concept. This type of FMEA technique involves the interaction of multiple systems and the interaction between system elements in the concept stages.

B - Design FMEA

This type of FMEA technique focuses on identifying and preventing failure modes in products, and related to their design, in order to validate the design criteria specified for a specific functional performance level at the level of the system and the subsystem or the most important element. The function of this type is to determine the identity of the first stages From developing the design, identifying failure modes in order to eliminate their effects.

C - Process FMEA

This type of FMEA technique focuses on potential failure modes caused by the process due to manufacturing or assembly defects. The process consists of two types:

• Manufacturing FMEA: In manufacturing, failure modes are generally dimensional or visible while they are present.

• Assembly FMEA: In assembly, these failure modes are generally relational, dimensions, missing parts, incorrectly assembled parts.

For his part (Stern,2019:86-87) added two other types:

D - Service FMEA: focuses on service functions.

E - Software: Focuses on software functions.

4 - Failure Mode and Effects Analysis technique Objectives (FMEA)

FMEA works to achieve the goals that aim to identify, prevent, and correct failures, as (Gusan et al.,2023:1170) explained these goals as follows:

A- Early identification of non-conformities, identifying their causes, and preventing their occurrence.

B- Discovering technical weaknesses in the system, design, and process and eliminating them before they occur.

C- Discovering the causes of malfunctions and taking corrective measures, focusing on eliminating the causes of defects.

D- Develop a plan to improve product quality and maintenance.

5 - Risk Priority Number (RPN)

The most obvious result of documenting the collective knowledge of cross-functional teams is the Risk Priority Number. The higher the RPN value) for the failure mode, the more dangerous it is, as the total values of (RPN) are within Values from (1 to 1000) (Zheng & Tang, 2020:1). (Soebandrija et al., 2022: 1246) defined the risk priority number (RPN) as an important tool for evaluating and analyzing failure modes and their effects. It works to arrange failure modes according to importance based on the degrees of the risk priority number (RPN) that can be obtained through the equation The following:

$$\mathbf{RPN = S \times O \times D} \quad \ldots\ldots\ldots\ldots \text{ Equation (1)}$$

These factors can be explained as follows:

A - Severity

Severity means the severity of the potential effects of failure, which requires evaluating the failure based on its effects. The severity of failure is classified on a scale from (1 to 10), where level (1) indicates the lowest level of risk (no risk and no effect), while level (10) indicates) to the highest level of risk (high risk and failure impact) (Priharanto et al., 2023:826)

B - Occurrence

Occurrence is the value of how often possible causes of failure occur (Liu &Tang,2022:3-4). (Yazdi et al., 2017:114) confirmed that the probability levels for failure are classified into (10) levels between (1 is the best case for failure to occur and 10 is the worst case for failure to occur). (Yazici et al.,2021:3)(Zheng&Tang,2020:6).

C - Detection

(Priharanto et al., 2023:825) defined detection as the possibility of detecting a fault before failure occurs. The degree of detection is evaluated against the ability to identify potential failure modes, as detection depends on the probability of failure occurring using a scale from (1 to 10). The level indicates (1) To almost certain detection of failure, and level (10) indicates that it is very unlikely to detect failure patterns in the system, process, or in the products before they reach the customer.

Second: The concept of overall equipment effectiveness (OEE)

Total Equipment Effectiveness (OEE) was introduced by Nakajima in 1988 in Japan when Total Productive Maintenance (TPM) was implemented, and it is one of the most widely used and well-known key performance indicators (KPI) for measuring production efficiency (Dobra & Josvai, 2021:55). Overall Equipment Effectiveness (OEE) is a calculation that is performed to determine the effectiveness of existing machines or equipment. (OEE) is used as a measure of the performance of machines or equipment, and three components or elements can be observed: the availability of machines or equipment (Availability), and performance efficiency. (Performance), and the quality of equipment outputs (Quality) (Muthalib et al., 2020:2). As for (Heng et al., 2019:630)) defined it as a quantitative tool necessary to measure productivity in manufacturing industries, and it is designed to identify and eliminate related losses to improve performance and reliability. With the development of industrial digitization, OEE measurement has automatically become the basic part of manufacturing execution systems (MES).), as the validity and usefulness of estimating overall equipment effectiveness (OEE) depends largely on the collection of data that must be available and accurate. According to (Lindegren et al., 2022:29), overall equipment effectiveness (OEE) is an important measure that shows the efficiency of the manufacturing process compared to its full potential, as the focus on (OEE) at present has become more due to the technologies associated with Industry (4.0) that allow To monitor, maintain and improve productivity, in addition, OEE can be used to identify areas of improvement. Many modifications have been made to the original formula of OEE, as it was developed by practitioners and academics to illustrate the importance of manufacturing organizations adapting and customizing the model to suit their own production. This is what (Sathler et al.,2023:376) indicated that OEE is a sufficiently versatile tool that can be adapted due to its simplicity and efficiency to support decisions and a culture of continuous improvement. It focuses on improving equipment productivity by reducing major operational losses in the system, which is Especially useful in improving technology.

1 - The importance of overall equipment effectiveness (OEE)

Overall equipment effectiveness has gained increasing attention as a leading measure for improving production, as (Hartman & Moussa,2023:18) indicate that OEE is essential for manufacturing organizations because of its importance as follows:

A- It is a basic measure that has achieved widespread use as an indicator of manufacturing efficiency and evaluating the effectiveness of equipment and production processes by raising the ratio of the actual output of the equipment to the maximum possible production under ideal production conditions.

B- It can be an important first step in identifying the root causes of equipment inefficiency and identifying strategies necessary to enhance operational processes and improve efficiency that enable organizations to use their resources effectively and maximize profits. It also helps manufacturing organizations identify areas of improvement and track progress towards them.

C- Total Equipment Effectiveness (OEE) is an effective means that enables manufacturers to identify areas of waste and inefficiency, such as machine downtime or production defects, and to identify potential bottlenecks in the production process.

D- Overall Equipment Effectiveness (OEE) helps organizations monitor the performance of individual pieces of equipment or entire production lines and compare the performance of different machines or tools by formulating appropriate strategies that can eliminate overall waste and inefficiency.

2 - Elements (indicators) of overall equipment effectiveness (OEE)

Manufacturers can evaluate production efficiency and identify processes that operate more effectively and processes that need improvement through components or measures of overall equipment effectiveness (AVAILABILITY, PERFORMANCE, AND QUALITY). Overall equipment effectiveness (OEE) must be at the highest level of performance, and an organization is classified as a world leader when it is The OEE ratio (85%) is the standard percentage of overall equipment effectiveness (OEE) applied internationally and determined by the Institute of Plant Maintenance (JIPM). The overall equipment effectiveness is calculated according to the following equation: (Saputra & Radyanto, 2023: 7156).

Overall Equipment Effectiveness (OEE) = Availability x Performance x Quality.

Equation (2)

A - Rate of availability

The availability rate means (machine availability), as the Japanese Institute for Factory Maintenance (JIPM) has set the standard that shows the standard availability rate (90%) (Djunaidi et al., 2022:163). The availability rate is calculated taking into account the planned operating time less the period during which the equipment is not available for operation, which is known as downtime (Sathler et al., 2023:377). The equation represents availability as follows.

$$\text{Availability} = \frac{\text{Planned uptime} - \text{Downtime}}{\text{Planned operating time}} \times 100\% \qquad \text{........ Equation (3)}$$

Availability can be calculated using another equation (Zubair et al., 2021:4))

$$\text{Availability} = \text{Uptime} / \text{Loading time} \times 100\% \qquad \text{.......... Equation (4)}$$

B- Rate Performance

(Amperajaya et al., 2022:323) indicated that the performance ratio is a ratio that shows the ability of the equipment to produce the product. The data used to measure the performance ratio is the actual output, the ideal cycle time, and the available production time. The global performance ratio is (95%), which was determined by the Japanese Institute for Factory Maintenance (JIPM) and is obtained through the following equation: (Singh et al. ,2020:35).

$$\text{Performance rate} = \frac{\text{actual output x ideal cycle time}}{\text{Available production time}} \times 100\% \qquad \text{........ Equation (5)}$$

For their part (Al-Samman and Al-Daoudi, 2007: 7) and (Haddad et al., 2021: 57), they indicated that the performance rate can be calculated in another way through the ratio of the amount of actual output produced by the machine to the amount of planned output according to the following equation:

Performance rate = actual outputs / planned outputs x 100% .... Equation (6)

C- Quality Rate

The quality rate shows the extent of success achieved by the machine in producing a defect-free product, and this means measuring the good parts produced against the total parts produced (Valero et al., 2023:1187). (Sathler et al.,2023:378)) confirmed that quality is related to the final product as a result of a process or operation of equipment, and the global percentage of quality rate is (99%). The quality rate can be obtained by applying the following equation:

$$\text{Quality rate} = \frac{\text{total parts produced - defective parts}}{\text{Total parts produced}} \times 100\% \qquad \text{...... Equation (7)}$$

The third section: the applied aspect of the study

First: Implementing the failure mode and analysis its effects technique

(FMEA) technique will be implemented in the sorting station because of the importance this station represents in the sugar production process, as well as because it is the station most susceptible to malfunctions, and stopping the equipment in this station affects a decrease in the factory's sugar productivity, as the Risk Priority Number (RPN) is being determined to identify failure patterns and defects. that occur in the miller, and to determine their effects, and to work to prevent the occurrence of these defects. Data was obtained based on the opinions of experts and engineers working in the mechanical maintenance department and the production department through personal interviews, and by referring to the miller records present in the factory, and it was determined (12) A mechanical failure pattern that occurs in the batch centrifugal, and the effects of the potential failure (severity S), the probability of failure occurring (occurrence, O), and the degree of failure detection (detection, D). The failure patterns were arranged according to the value of the risk priority number, as the smaller the value (RPN), the better. Failure is less dangerous and impactful, and the following table (1) shows the value (RPN) for failure modes in sugar batch centrifugal.

Table (1) Risk Priority Number (RPN) value for batch centrifugal failure modes

No	Fuilure mode	severity	occurrence	detection	RPN
1	The milling knife was damaged	9	8	3	216
2	Engine burners damaged	8	6	4	192
3	The milling brake is damaged	8	4	6	192
4	Damage to milling knife orchards	5	9	4	180
5	Devis center damaged	8	7	3	168
6	Damage to the Coplin milling drum	7	7	3	147
7	Cutting or loosening of the centrifugal screws	6	7	3	126
8	Damage to the separator charging sensor gate	6	4	5	120
9	Damage to the cheese (Air Seal)	5	8	3	120
10	The batch centrifugal distributor was damaged	7	7	4	112
11	The difference in distance between the knife and the screen	4	8	3	96
12	Damage to the caliper dampers (wheels)	5	6	3	90

Source: Prepared by the researcher based on the opinions of the engineers in the factory and the' batch centrifugal records

From Table (1), we notice that the highest value of (RPN) is (216), which represents the failure of damage to the separator screen, and the lowest value is (90), which represents the failure of damage to the separator dampers. In order to determine the degree of severity of the risk priority number, their severity was classified according to There are three levels: (Zidan& Al-Khatib, 2021: 10)

1 - The first level from (321 - 1000), which is a dangerous (large) level that is unacceptable.

2 - The second level is from (64 – 320), which is a moderate risk level.

3 - The third level of (1 - 63) is a simple (small) risk level.

We find that the highest value of the Risk Priority Number (RPN) is (216), which represents damage to the milling screen, as it is classified within the second level, which is considered a moderate risk, as well as for failure modes (damage to engine bearings 192, damage to milling brakes 192, damage to milling knife blades 180, damage to axle). Centering of the milling cutter 168, damaged milling machine cuplin screw 147, cutting or loosening of milling machine screws 126, damage to milling machine charging sensor gate 120, damage to milling machine cheese 120, damage to milling machine distributor 112, difference in distance between knife and screen 96, milling dampers damaged 90) It is also classified as The second level (moderate risk), and there are no failure modes classified within the third level of the risk matrix classifications (slight risk).

Second: Analysis of the overall equipment effectiveness

1 - Calculate the results of the overall equipment effectiveness indicators

This study used centrifugation equipment, which separate sugar grains from the syrup and produce sugar ready for consumption. The sugar refining plant includes (16) batch centrifugal. Twelve-month data was analysis, and planned downtime times were determined (2 hours per month). In order to extract the availability rate, performance rate, and quality rate of the sorters, the main (morning) work shift was approved, with a working time of (8) hours per day and for (30) working days per month, for the year 2023, and Table (3) shows the results of the overall equipment effectiveness.

Table (2) Results of overall equipment effectiveness for the year 2023

No	Month	1	2	3	4	5	6	7	8	9	10	11	12
1	Available time (minutes /month)	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400	14400
2	Planned downtime (minutes/month)	120	120	120	120	120	120	120	120	120	120	120	120
3	Load time (min/month)	14280	14280	14280	14280	14280	14280	14280	14280	14280	14280	14280	14280
4	Unplanned downtime (minutes/month)	960	1320	2100	2640	1320	960	1200	1500	1620	1800	1140	1080
5	Operating time	13320	12960	12180	11640	12960	13320	13080	12780	12660	12480	13140	13200
6	Availability = Uptime / Loading time	%93.2	%90.7	%85.2	%81.5	%90.7	%93.2	%91.5	%89.4	%88.6	%87.3	%92	%92.4
7	Actual output (tons/month)	38280	37310	36000	35000	37000	38300	37600	36800	36600	36700	37700	38000
8	Defective (tons/month)	395	420	450	330	430	380	385	410	425	432	440	455
9	Quality rate	%98.9	%98.8	%98.7	%99	%98.8	%99	%98.9	%98.8	%98.8	%98.8	%98.8	%98.8
10	Planned output (tons)	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000
11	Ideal cycle time = available time / planned output	0.360	0.360	0.360	0.360	0.360	0.360	0.360	0.360	0.360	0.360	0.360	0.360
12	Actual cycle time = available time / actual output	0.377	0.386	0.400	0.412	0.390	0.376	0.383	0.392	0.394	0.393	0.382	0.379
13	Rate of speed = ideal cycle time / actual cycle time	%95.4	%93.2	%90	%87.3	%92.3	%95.7	%94	%91.8	%92.3	%91.6	%94.2	%95
14	Performance rate	%95.7	%93.3	%90	%87.5	%92.5	%95.7	%91.7	%92	%91.5	%91.7	%94.2	%95

Source: Prepared by the researcher based on factory data.

Through the results of Table (4), the average for the overall equipment effectiveness indicators (availability, performance, and quality) is extracted. The following Table (5) shows the overall equipment effectiveness rates for the year 2023.

Table (3) Total equipment effectiveness rates for the year 2023

month	Availability rate%	Performance rate%	Quality rate%	OEE%
1	93.2	95.7	98.9	88.2
2	90.7	93.3	98.8	83.6
3	85.2	90	98.7	75.7
4	81.5	87.5	99	70.6
5	90.7	92.5	98.8	82.9
6	93.2	95.7	99	88.3
7	91.5	91.7	98.9	82.9
8	89.4	92	98.8	81.2
9	88.6	91.5	98.8	80
10	87.3	91.7	98.8	79
11	92	94.2	98.8	85.6
12	92.4	95	98.8	86.7
Average	**%89.6**	**%92.5**	**%98.8**	**%82**

Source: Prepared by the researcher based on factory data.

From the table (3), it becomes clear to us that the availability rate was 89%, which is lower than the global availability rate of 90% or more. Likewise, the performance rate was 92.5%, which is lower than the global average of 95% or more, and the quality rate was also 98.8%. This is lower than the global average of 99%. As for the total equipment effectiveness rate, it was 82%, which is lower than the global total equipment effectiveness rate of 85%.

Third: Testing the correlation hypotheses

The Pearson correlation score is calculated between the independent variables of the Failure Mode and Its Effects Analysis (FMEA) technique, which is represented by the risk priority number and risk factors (severity, occurrence, and detection) and the dependent variables, the effectiveness of the overall equipment and their indicators (availability, performance, and quality). Table (4) shows this relationship.

Table (4) Degree of correlation between the independent variables (FMEA) and the dependent variables (OEE)

Independent variable	Dependent variable	Degree of correlation
Severity	Availability	**0.1472**
Severity	Performance	**0.1996**
Severity	Quality	**-0.0966**
Severity	OEE	**0.1792**
Occurrence	Availability	**0.0870**
Occurrence	Performance	**0.0522**
Occurrence	Quality	**0.6121**
Occurrence	OEE	**0.0938**
Detection	Availability	**-0.0870**
Detection	Performance	**-0.5371**
Detection	Quality	**-0.4443**
Detection	OEE	**-0.5963**
RPN	Availability	**-0.2172**
RPN	Performance	**-0.1478**
RPN	Quality	**0.1713**
RPN	OEE	**-0.1787**

Table (4) indicates the following:

A - There is a correlation between the independent variable Severity (S) and the dependent variables. Each of the first dependent variables (availability) had a non-significant correlation of approximately (15%), and the second dependent variable (performance) also had a non-significant correlation of (20%). Approximately %), and with the third dependent variable (quality) there was a negative correlation of approximately (10%), and with the fourth dependent variable, overall equipment effectiveness (OEE), there was a non-significant correlation of approximately (18%).

B- There is a correlation between the independent variable occurrence (O) and the dependent variables. The first dependent variable (availability) had a non-significant correlation of approximately (9%), and the second dependent variable (performance) also had a non-significant correlation of (5). Approximately %), and with the third dependent variable (quality) there was a significant correlation of (61%), and with the fourth dependent variable, overall equipment effectiveness (OEE), there was a non-significant correlation of (about 9%).

C - There is a correlation between the independent variable detection (D) and the dependent variables. The first dependent variable (availability) had a strong negative (inverse) correlation of approximately (61%), and the second dependent variable (performance) had a negative (inverse) correlation.) also by approximately (54%), and with the third dependent variable (quality) there was also a negative correlation of (44%), and with the fourth dependent variable overall equipment effectiveness (OEE) there was a strong negative (inverse) correlation of (60%) almost.
D - There is a correlation between the independent variable Risk Priority Number (RPN) and the dependent variables. Each of the first dependent variables (availability) had a negative correlation of approximately (22%), and the second dependent variable (performance) also had a negative correlation of (15). Approximately %), and with the third dependent variable (quality) there was an insignificant correlation of (17%), and with the fourth dependent variable, overall equipment effectiveness (OEE), there was a negative correlation of (about 18%).
Section Four: Conclusions and recommendations

First: Conclusions

1- The failure mode and effects analysis technique provides the identification of all failure modes and their effects by analyzing and evaluating them and determining the causes of their occurrence, the chances of their occurrence, the chances of discovering them, and the severity of their effects, which allows focusing on high-risk and recurring patterns.
2- The risk priority number is an important tool for evaluating failure patterns and dealing with risk factors (risk, occurrence, and detection) to prioritize risks and obtain results that contribute to taking corrective measures to limit failure or reduce its effects.
3 - Total Equipment Effectiveness provides the ability to analysis the readiness of equipment, the efficiency of its performance, and the quality of its products by using three indicators (availability, performance, and quality) to measure the effectiveness of the total equipment.
4 - Equipment effectiveness: Total equipment is an efficient tool for measuring equipment productivity and maintaining its optimal level.
5- In light of the results reached in testing the hypotheses, which proved that there is an inverse statistically significant correlation between the failure mode technique and the analysis of its effects and the effectiveness of the overall equipment, as the lower the value of the risk priority number for the failure mode technique and the analysis of its effects technique, the higher the overall equipment effectiveness rates and vice versa.

Second: Recommendations

1- Focus on conducting periodic inspection of equipment at close intervals, as it contributes to early detection of potential failure patterns and taking measures that prevent failure from occurring or reduce its effects on the equipment.
2 - Conduct periodic maintenance of the equipment and facilitate procedures for implementing preventive maintenance that will preserve the equipment and help increase its productive life.
3- The factory at the study site must note the expected lifespan of each part of the equipment, provide alternative spare parts in anticipation of any emergency that occurs, and work to replace corroded and damaged parts before they cause the equipment to stop and lose its effectiveness.
4- Conducting continuous improvements, including training workers operating the equipment on how to operate the equipment ideally, perform maintenance, how to replace damaged parts, and provide appropriate operating conditions for the equipment, such as the appropriate temperature.
5- Providing high-quality spare parts for equipment from global platforms that are reliable for failure patterns that frequently occur.
6- The possibility of applying the subject of the study in different industrial fields.

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