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**Categoría: STEM (Science, Technology, Engineering and Mathematics)**

**ORIGINAL**

# Increasing the Steam Boiler Maintainability Adopted Design Factors

## Aumento de la mantenibilidad de la caldera de vapor Factores de diseño adoptados

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**ABSTRACT**

Companies are increasingly compelled to evaluate all dimensions of product performance in order to maintain competitiveness in the face of global market challenges. Maintainability is a crucial aspect of product performance. Maintainability refers to a product's economical and efficient ability to undergo maintenance. Maintenance is necessary for the proper functioning and longevity of several durable items. Adopting maintainability design factors during the first stages of the design process can reduce maintenance expenses, minimize maintenance time, and enhance safety measures. In this paper, the steam boiler is studied and how to improve its maintainability through design factors to make it more maintainable. In order to reduce the time required to perform maintenance and thus reduce the system's downtime and make it available for a longer time, thus increasing production. The case study adopted in this paper is the steam boiler of the thermal power plant in south Baghdad. A study of the steam boiler was conducted, and maintainability was calculated according to the data obtained from the station. A part of the boiler was chosen to improve its maintainability, which is the air heater, as it is the most essential part due to its frequent malfunctions. A study was conducted on the air heater and its parts. The overhead crane was developed by suggestion into an improved design as a tool for accessibility, considered an important design factor for ease of access and handling and, at the same time, for the safety of maintenance workers. This improvement reduced from 24 to 48 hours of repair time for each fault, and the results after calculating the maintainability of the steam boiler after the improvement showed that it increased from 48,5 % to 53,5 %, i.e., an increase of 5 %.

**Keywords**: Maintainability; Design Factors; Improvement; Power Plant.

**RESUMEN**

Las empresas se ven cada vez más obligadas a evaluar todas las dimensiones del rendimiento de sus productos para mantener su competitividad frente a los retos del mercado mundial. La mantenibilidad es un aspecto crucial del rendimiento de los productos. La mantenibilidad se refiere a la capacidad económica y eficiente de un producto para someterse a mantenimiento. El mantenimiento es necesario para el buen funcionamiento y la longevidad de varios artículos duraderos. La adopción de factores de diseño de mantenibilidad durante las primeras etapas del proceso de diseño puede reducir los gastos de mantenimiento, minimizar el tiempo de mantenimiento y mejorar las medidas de seguridad. En este trabajo se estudia la caldera de vapor y cómo mejorar su mantenibilidad mediante factores de diseño para hacerla más mantenible. Con el fin de reducir el tiempo necesario para realizar el mantenimiento y reducir así el tiempo de inactividad del sistema y hacer que esté disponible durante más tiempo, aumentando así la producción. El caso de estudio adoptado en este trabajo es la caldera de vapor de la central térmica del sur de Bagdad. Se realizó un estudio de la caldera de vapor y se calculó su mantenibilidad según los datos obtenidos en la central.

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Se eligió una parte de la caldera para mejorar su mantenibilidad, que es el calentador de aire, ya que es la parte más esencial debido a sus frecuentes averías. Se realizó un estudio sobre el calentador de aire y sus piezas. El puente grúa se desarrolló por sugerencia en un diseño mejorado como herramienta de accesibilidad, considerado un factor de diseño importante para la facilidad de acceso y manipulación y, al mismo tiempo, para la seguridad de los trabajadores de mantenimiento. Esta mejora redujo de 24 a 48 horas el tiempo de reparación de cada avería, y los resultados tras calcular la mantenibilidad de la caldera de vapor después de la mejora mostraron que ésta aumentó del 48,5 % al 53,5 %, es decir, un incremento del 5 %.

**Palabras clave:** Mantenibilidad; Factores de Diseño; Mejora; Central Eléctrica.

## INTRODUCTION

Maintainability refers to the element of maintenance that takes into account the duration of downtime. It may be described as the likelihood that a malfunctioning item can be successfully restored to a satisfactory operational state within a certain timeframe.(1) The significance of maintainability is increasing due to the exorbitant running and support cost associated with equipment and systems. The concept of maintainability encompasses the many actions and considerations undertaken during the development, design, and installation phases of a manufactured product. These actions and considerations aim to minimize the need for maintenance, reduce the amount of time and effort necessary for maintenance tasks, decrease the reliance on specialized tools and equipment, lower logistical costs, mitigate the need for highly skilled personnel, and minimize the demands placed on facilities. This process aims to verify that the product satisfies the specified criteria for its intended use.(2) The consideration of maintainability is a crucial aspect in the design phase of engineering systems due to the growing reliance on the effective operation of many systems in everyday lives and routines.(3)

Many researchers have tried to study some systems or parts, especially mechanical parts, and how to improve their maintainability. A good results were obtained. For example, A. Coulibaly et al.(4) proposed a methodology to offer metrics for assessing maintainability and safety forecasts at the first phases of the design process. The evaluation technique use the Computer-Aided Design (CAD) three-dimensional model and a corresponding semantic matrix to collect data regarding the criticality and reliability of the components of the product. Based on the provided data, the researchers proceed to compute metrics pertaining to the maintainability and safety aspects of the product. The authors propose a methodology in a scholarly case study that exemplifies a system for transferring movement. The suggested methodology offers inherent measures of maintainability and safety that can aid designers in verifying design solutions against the specified performance level deemed acceptable by the given criteria. Moreover, these indications might be utilized for the purpose of comparing various alternatives. Ali Ebrahim(5) focused on identifying the specific dangers and failures within the operational processes that directly impact floating offshore structures' Reliability, Availability, Maintainability, and Safety (RAMS). The primary emphasis lies on the Dynamic Positioning (D.P.) system. To accomplish the objective, the individual has clearly defined the events and accidents that may arise from the identified dangers. Subsequently, they have sought to ascertain the potential outcomes resulting from the occurrence of these accidents. After thoroughly examining, the subsequent stage involved assessing and analyzing the detected hazard. The last component, the quantitative methodology, has been employed to assess the system's reliability, availability, and maintainability by utilizing mean time between failures (MTBF) and mean time to repair (MTTR) metrics for various system elements. The findings and computations indicate that enhancing the Mean Time Between Failures (MTBF) of these subsystems has the potential to enhance the overall reliability and maintainability of the system. This implies a significant decrease in the cost associated with the risk of failure throughout the operational phase of the vessel. Mallikarjuna et al.(6) studied the air heater of a boiler in a power plant, its malfunctions, and applicate some improvements such as Leakage Reduction, Soft Touch Seal, Double Sealing, and Diaphragm Plate Protection Sheets to increase boiler efficiency. Xiaogang Jian et al.(7) centers on the significance of doing a maintainability evaluation for a product. Drawing on the product life cycle theory principles, the research examines the case of the loader's transmission. It establishes an index system and calculation model for evaluating the product's maintainability. The fuzzy analytic hierarchy process (FAHP) can determine the weight coefficient for each indication. Subsequently, professionals provide numerical values to each indication based on maintenance initiatives. The transmission's maintainability is determined to be 0,778, indicating a classification at a high level. After implementing some enhancements, such as adjusting the oil addition process from a high to low position, the measure of maintainability has increased to 0,860. Simultaneously, the analysis findings indicate that transmission maintenance has become more convenient regarding regular maintenance time and efficiency compared to previous practices. Ahmad Al-Douri et al.(8) implemented a methodical strategy for resolving failure by utilizing an economic framework in the first phase of conceptual design. The applicability and utility of the suggested technique were demonstrated through a case study conducted on an ethylene plant. The process starts by employing fault tree analysis to discover the origins of failure. The process of Bayesian updating involves incorporating plant-specific data into the analysis of generic failure rate data, resulting in the estimation of suitable distributions for the relevant failure scenario(s). Simultaneously, Monte Carlo methods are employed to approximate the probability distributions of repair scenarios. Process simulation is employed to incorporate the occurrence of reliability failures. The utilization of Markov analysis is employed to ascertain the availability of a given system. Various design improvements are proposed to improve the accessibility of the specific part. The potential designs undergo evaluation to build an economic framework that facilitates the trade-off between failure and profitability. Marcantonio Catelani et al.(9) evaluate several Maintainability Allocation (M.A.) strategies to determine the optimal procedure for an electronic controller in a railway signaling system. The study suggests using the time characteristics-based maintainability evaluation technique as the most suitable approach due to its ability to evaluate the impact of each component on the system parameters. During the initial phase of the study, the purpose was to determine the value of $MTTR$ SYS within the range of 1 to 8 hours. The result gained from this investigation was $MTTR$ SYS equal to 4 hours. Subsequently, there has been a notable augmentation in the Mean Time to Repair (MTTR), resulting in a duration of 6 hours. A comparative analysis of the two scenarios reveals that there is a positive correlation between the rise in the objective Mean Time to Repair (MTTR) and the corresponding increase in the maintainability indices assigned to the items. Luo et al.(10) examined a flight control subsystem of an aircraft in design and its maintainability. The paper defines a set of comprehensive indicators. Nine maintainability design attributes are analyzed and classified according to their influences on maintenance. On this basis, maintainability design attributes are evaluated hierarchically, and maintainability comprehensive indicators are calculated. Assembly /disassembly is identified as the weaknesses attribute in the subsystem maintainability design, followed by simplicity and accessibility. These results show that the proposed maintainability evaluation method effectively assesses mechanical products in cases with limited historical data for the design stage's maintainability assessment. Nevertheless, this method cannot improve the maintainability weaknesses, so the designers should do this work. Ashrith Jain et al.(11) studied the Cessna Skymaster 337F aircraft as a case study to understand the retrofitting process and propose solutions for the battery storage system in terms of maintainability. The aircraft is being converted into a hybrid electric aircraft by replacing the rear engine with an electric motor powered by batteries. Before the design, the requirements are based on the battery selection, weight distribution, and space exploration. During the design, maintainability guidelines and safety features are included. To achieve an optimal solution, trade-offs must be made between these factors. Possible locations for the battery storage system were identified at the back of the fuselage, close to the electric motor. Important maintainability attributes that influence the maintenance operators are accessibility, assembly / disassembly, ergonomics, and maintenance safety. However, a detailed design of the solution and structural and thermal analysis by simulations and application of the maintenance operations in a virtual environment are still required to support the proposed design solutions. Dongqiao Bai et al.(12) focused on the Fuzzy-TOPSIS-based update of process plant control systems using RAM (reliability, availability, and maintainability). They provide an answer to the problem of process plant upgrades going extinct due to parts' obsolescence. Upgrading provides solutions that are easy to maintain, very dependable, and readily available (typically, all parts are replaced with updated and compatible technology) for the duration of the process plant's service life. A case study for modernizing the stacker and reclaimer at a cement mill is used to examine the idea's application and assessment. The comparison of pre- and post-upgradation scenarios validates the study's implementation and anticipated outcomes. The process plant update resulted in a cost-effective solution, with 17 % more automation, 80 % more plant maintainability, and 17 % less downtime. Jie Geng et al.(13) suggested an innovative proactive approach to maintainability design. A mapping connection between maintainability and functionality/ structurability (F/S) spaces is constructed in a "many to many" fashion based on the product's F/S elements and maintainability. Two parts of this mapping relationship are the quantitative assessment and the graphical depiction. Separately, the quantitative evaluation offers a clear and objective relationship confirmation result. Two similar goods with distinct design concepts may be chosen for comparison using the visualization representation's complete and user-friendly features: the virtual prototype approach and the suggested methodology.

Through a review of the literature, it was found that many methods of studying and analyzing the required component are used to select the most important part that negatively affects the efficiency of the component. Different methods have been used to calculate maintainability and make some improvements. In this work, relying on historical information with the opinion of experts and maintenance engineers is considered to choose the most important part that requires improvement in a power station. Through maintenability design factors and avoiding the difficulties that faces maintenance, an improvement is proposed and applied. This study focuses on studying steam boilers and how the design factors for maintainability can be improved to make them more maintainable.

**Research Roadmap for Mantainability Nomination**

The concept of maintainability pertains to the capacity of a system to undergo repair and be restored to operational status through the efforts of employees possessing specialized skill sets, according to prescribed procedures, and employing designated resources.[14] The primary goal of maintainability engineering is to provide a system or product that is designed in a manner that facilitates ease of maintenance, ensuring its ongoing and cost-effective utilization, as well as maximizing client accessibility. Establishing maintainability design objectives is crucial at the early stages of product development.[3] The purpose of this research, which studying the steam boiler and improvement of the design factors to increase its maintainability is achieved through a five-stage, as seen in figure 1. The present study utilized the South Baghdad Thermal Power Station Steam boiler as the chosen case study.

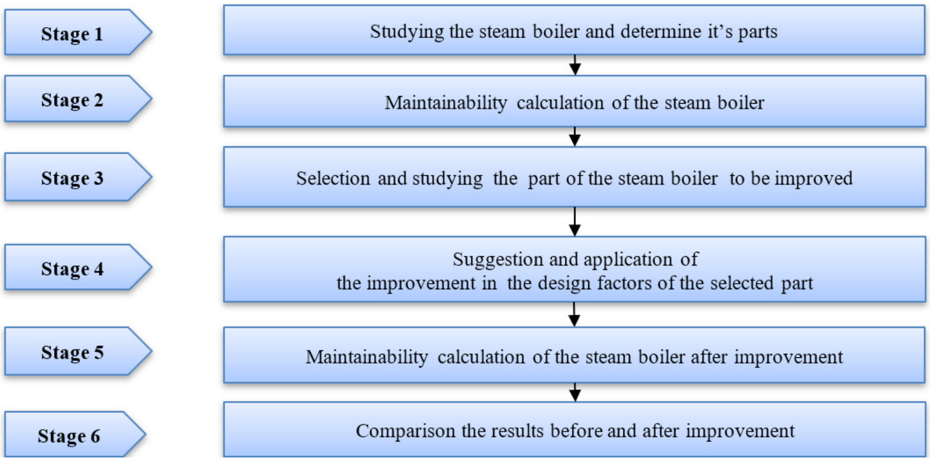


**Figure 1.** The roadmap of Research

**Applying Stage 1**

This stage consists of Studying the steam boiler and determining it's parts:

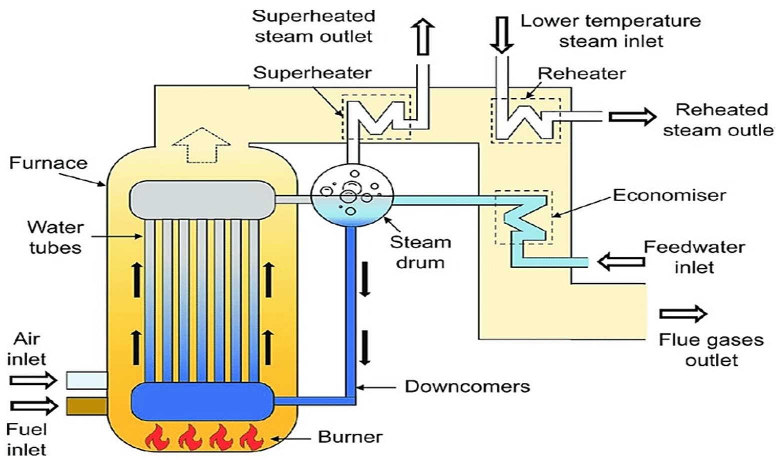


**Figure 2.** The steam boiler[15]

The boiler is a crucial component of the station. A steam boiler may be described as a container characterized by a restricted heating surface area and a finite water capacity. The use of thermal energy elevates the temperature of the water to its boiling point, resulting in the generation of a finite quantity of steam. The boiler comprises many key components observed at the work site and gathered from the available information. These fundamental parts are as follows and as shown in figure 2: Drum, Headers, Furnace, Super Heater, Economizer, Air Heater, Steam Coil, Induced Draft Fan, and Chimney. Also, the boiler consists of the necessary accessories such as Safety Valves, Soot Blower, Boiler operation control devices, and Measuring Instruments (disposal devices, pressure gauges, temperature measuring devices, gas analyzer, and automatic control devices).

## Applying Stage 2

This stage consists of the maintainability calculation of the steam boiler:

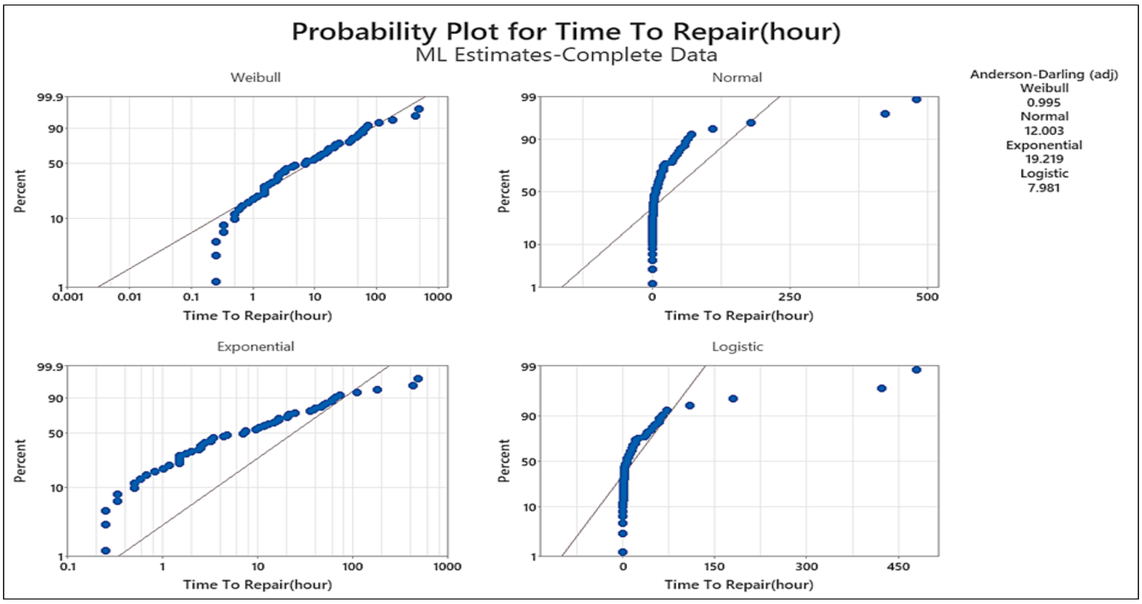


**Figure 3.** Probability plot for Time To Repair (TTR)

Calculate Time To Repair (TTR) as shown in table 1 and analyze the data to determine if this data is subjected to any distribution to calculate the mean time to repair, repair rate, and maintainability of the steam boiler. After calculating the time to repair, this data must be analyzed to find out which type of distribution applies to it to complete the rest of the calculations and find the maintainability of the steam boiler. The Minitab program is adopted for this purpose. The data obtained is subjected to the Weibull distribution, as shown in figure 3.

Mean Time To Repair (MTTR) for four years = $\sum_{1}^{58}$ TTR (hour)/58 =34,296 hour (1)

The repair rate (μ) are calculated by using the equation as follows:[16]

$$\mu = \frac{1}{\text{MTTR}} = \frac{1}{34.296} = 0.0292 \text{ per hour} \quad (2)$$

The maintainability are calculated by using the maintainability function for Weibull Distribution:[17]

$$Mw(t) = 1 - e^{-\left(\frac{t}{\alpha}\right)^{\theta}} \quad (3)$$

(α and θ) are considered, in which α is the distribution scale parameter, and θ is the distribution shape parameter, which can obtain by using the Minitab program, as shown in figure 4.

α =16,8802, θ =0,535065, and t is the variable repair time, as in table 1.

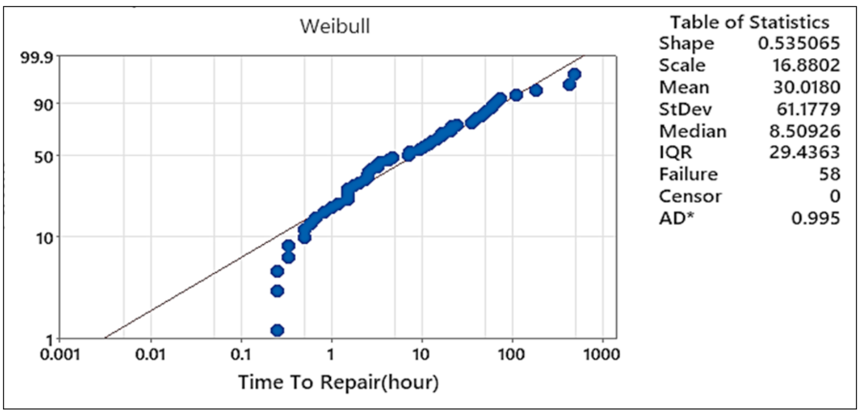


**Figure 4.** Distribution overview plot for Time To Repair (TTR)

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**Table 1.** Calculation of Time To Repair (TTR) and Maintainability

| No. | Date of the failure occurance | Time of the failure occurance | Date of the part return to work | Time of the part return to work | Time To Rapair TTR (hour & minute) | TTR (hour) =hours +(minutes/60) | Maintainability Mw(t) = 1- e^(-(t/α)ᵉ) |
|---|---|---|---|---|---|---|---|
| 1 | 8/2/2019 | 11:05 | 8/2/2019 | 18:30 | 7:25:00 | 7,42 | 0,475 |
| 2 | 13/03/2019 | 9:00 | 31/3/2019 | 0:00 | 423:00:00 | 423 | 0,996 |
| 3 | 18/05/2019 | 16:50 | 18/05/2019 | 20:15 | 3:25:00 | 3,42 | 0,347 |
| 4 | 18/05/2019 | 22:50 | 19/05/2019 | 13:30 | 14:40:00 | 14,67 | 0,605 |
| 5 | 20/05/2019 | 0:05 | 20/05/2019 | 16:30 | 16:35:00 | 16,58 | 0,629 |
| 6 | 20/05/2019 | 17:35 | 21/05/2019 | 14:20 | 20:45:00 | 20,75 | 0,673 |
| 7 | 20/07/2019 | 7:10 | 21/07/2019 | 21:20 | 38:10:00 | 38,17 | 0,787 |
| 8 | 28/08/2019 | 0:05 | 28/08/2019 | 11:30 | 11:25:00 | 11,42 | 0,556 |
| 9 | 1/10/2019 | 0:10 | 3/10/2019 | 12:20 | 60:10:00 | 60,17 | 0,861 |
| 10 | 3/10/2019 | 21:20 | 3/10/2019 | 23:50 | 2:30:00 | 2,5 | 0,302 |
| 11 | 4/10/2019 | 0:00 | 4/10/2019 | 15:35 | 15:35:00 | 15,58 | 0,616 |
| 12 | 10/11/2019 | 12:05 | 12/11/2019 | 16:25 | 52:20:00 | 52,33 | 0,84 |
| 13 | 7/1/2020 | 0:05 | 9/1/2020 | 17:55 | 65:50:00 | 65,83 | 0,874 |
| 14 | 17/02/2020 | 0:15 | 18/02/2020 | 0:50 | 24:35:00 | 24,58 | 0,706 |
| 15 | 26/02/2020 | 11:35 | 26/02/2020 | 14:10 | 2:35:00 | 2,58 | 0,307 |
| 16 | 2/5/2020 | 0:05 | 6/5/2020 | 14:07 | 110:02:00 | 110,03 | 0,935 |
| 17 | 7/5/2020 | 1:15 | 7/5/2020 | 14:15 | 13:00:00 | 13 | 0,581 |
| 18 | 7/5/2020 | 16:30 | 8/5/2020 | 13:50 | 21:20:00 | 21,33 | 0,678 |
| 19 | 11/5/2020 | 10:30 | 11/5/2020 | 17:30 | 7:00:00 | 7 | 0,464 |
| 20 | 29/07/2020 | 23:15 | 31/7/2020 | 0:00 | 48:45:00 | 48,75 | 0,829 |
| 21 | 9/8/2020 | 6:50 | 10/8/2020 | 18:30 | 35:40:00 | 35,67 | 0,775 |
| 22 | 10/8/2020 | 23:30 | 31/8/2020 | 9:30 | 481:00:00 | 481 | 0,998 |
| 23 | 6/12/2020 | 8:05 | 6/12/2020 | 11:20 | 3:15:00 | 3,25 | 0,339 |
| 24 | 14/12/2020 | 12:07 | 14/12/2020 | 15:20 | 3:13:00 | 3,22 | 0,338 |
| 25 | 19/12/2020 | 0:05 | 20/12/2020 | 22:10 | 46:05:00 | 46,08 | 0,819 |
| 26 | 16/1/2021 | 0:05 | 23/01/2021 | 12:14 | 180:09:00 | 180,15 | 0,971 |
| 27 | 24/03/2021 | 8:30 | 24/03/2021 | 13:15 | 4:45:00 | 4,75 | 0,398 |
| 28 | 11/4/2021 | 0:15 | 12/4/2021 | 16:30 | 40:15:00 | 40,25 | 0,796 |
| 29 | 14/05/2021 | 13:50 | 14/05/2021 | 13:45 | 0:40:00 | 0,67 | 0,163 |
| 30 | 15/06/2021 | 8:05 | 17/06/2021 | 19:00 | 59:00:00 | 59 | 0,858 |
| 31 | 25/7/2021 | 0:35 | 25/07/2021 | 21:00 | 20:25:00 | 20,42 | 0,669 |
| 32 | 14/08/2021 | 7:25 | 14/08/2021 | 10:10 | 2:45:00 | 2,75 | 0,315 |
| 33 | 14/08/2021 | 15:55 | 14/08/2021 | 16:30 | 0:35:00 | 0,58 | 0,152 |
| 34 | 15/08/2021 | 4:53 | 15/08/2021 | 6:38 | 1:45:00 | 1,75 | 0,257 |
| 35 | 17/08/2021 | 11:45 | 17/08/2021 | 13:15 | 1:30:00 | 1,5 | 0,239 |
| 36 | 18/08/2021 | 2:30 | 18/08/2021 | 3:00 | 0:30:00 | 0,5 | 0,141 |
| 37 | 18/08/2021 | 5:00 | 18/08/2021 | 17:00 | 12:00:00 | 12 | 0,565 |
| 38 | 28/8/2021 | 1:45 | 28/08/2021 | 2:35 | 0:50:00 | 0.83 | 0.181 |
| 39 | 1\09\2021 | 9:10 | 1\09\2021 | 11:10 | 2:00:00 | 2 | 0.273 |
| 40 | 7\09\2021 | 10:40 | 7\09\2021 | 11:40 | 1:00:00 | 1 | 0,1978 |
| 41 | 5/10/2021 | 17:35 | 5/10/2021 | 22:14 | 4:21:00 | 4,35 | 0,384 |
| 42 | 11/10/2021 | 5:15 | 11/10/2021 | 14:45 | 9:30:00 | 9,5 | 0,521 |
| 43 | 12/10/2021 | 18:50 | 12/10/2021 | 19:10 | 0:20:00 | 0,33 | 0,115 |
| 44 | 15/10/2021 | 10:10 | 15/10/2021 | 20:25 | 10:15:00 | 10,25 | 0,535 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 45 | 15/10/2021 | 21:25 | 15/10/2021 | 22:55 | 1:30:00 | 1,5 | 0,239 |
| 46 | 18/10/2021 | 17:35 | 21/10/2021 | 18:10 | 72:25:00 | 72,42 | 0,887 |
| 47 | 8/2/2022 | 9:20 | 8/2/2022 | 10:30 | 1:10:00 | 1,17 | 0,213 |
| 48 | 8/2/2022 | 22:00 | 8/2/2022 | 23:00 | 1:30:00 | 1,5 | 0,239 |
| 49 | 17/02/2022 | 7:45 | 17/02/2022 | 8:15 | 0:30 | 0,5 | 0,141 |
| 50 | 23/04/2022 | 11:45 | 23/04/2022 | 14:08:00 | 2:23:00 | 2,38 | 0,296 |
| 51 | 1/6/2022 | 4:10 | 1/6/2022 | 20:38:00 | 16:28:00 | 16,47 | 0,627 |
| 52 | 6/6/2022 | 7:00 | 6/6/2022 | 7:20 | 0:20:00 | 0,33 | 0,115 |
| 53 | 17/06/2022 | 13:20 | 7/06/2022 | 13:35:00 | 0:15:00 | 0,25 | 0,0997 |
| 54 | 17/6/2022 | 16:35 | 7/6/2022 | 23:50:00 | 7:15:00 | 7,25 | 0,471 |
| 55 | 22/08/2022 | 6:30 | 22/08/2022 | 6:45 | 0:15:00 | 0,25 | 0,0997 |
| 56 | 22/08/2022 | 20:20 | 22/08/2022 | 22:50 | 2:30:00 | 2,5 | 0,3023 |
| 57 | 25/0812022 | 1:00 | 26/08/2022 | 2:30 | 1:30:00 | 1,5 | 0,239 |
| 58 | 28/08/2022 | 5:40 | 28/08/2022 | 5:55 | 0:15:00 | 0,25 | 0,0997 |

Then the maintainability of the steam boiler, according to the data for the period from (1/1/ 2019) to (1/9/2022) is calculated as follows:

Boiler Maintainability before improv. = $\sum_{1}^{58} Mw(t)/58 = 0,485$ (4)
$= 48,5\ \%$

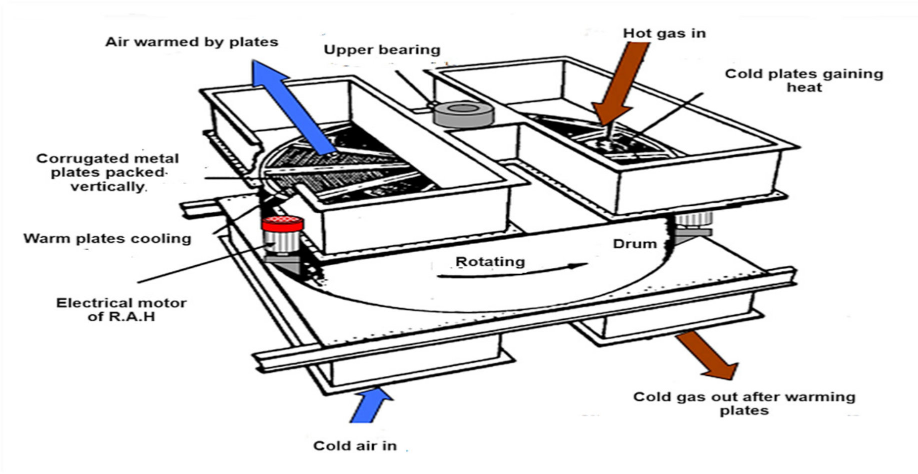


**Figure 5.** Regenerative Air Heater (R.A.H)[18]

**Applying Stage 3**

This stage consists of selecting and studying the part of the steam boiler to be improved: according to the data obtained from the station, it was found that the air heater has more faults compared to the rest of the parts, and it is maintainable and can be improved. The air heater is prone to several defects, including the fusion of its basket, since it cannot endure high temperatures. Additionally, blockages occur in the heater's apertures due to materials and gas deposition. The air heater necessitates the shutdown and subsequent re-operation of the boiler to undergo cleaning when a soot blower is employed. Vibrations in the air heater bearing arise due to either a delay in maintenance or the natural degradation of its lifespan. A regenerative-type air heater is a heat transfer surface that enables the elevation of air temperature by transferring heat from other sources, such as flue gas. Elevated-temperature air is crucial for expediting the combustion process within the boiler's furnace.[6] The air heater has several parts: Electrical motor, Basket, Upper bearing, Lower bearing, Axial shaft, and Drum, as shown in figure 5.

**Applying Stage 4**

This stage consists of suggestion and application of the improvement in design factors of the selection part: the maintenance engineers and workers face some difficulties during the breakdown of one of the parts of the steam boiler in general and the air heater in particular, which is how to handle these parts and take them down to be maintained and returned to their place. This station uses a bridge crane, as figure 6 (a) shows. However, its current state does not alone fulfill the required purpose because the crane runway rails are not long enough to take the part out of the building and lower it to be taken to the maintenance department for maintenance, as shown in figure 6 (b). Therefore, an external crane must be rented to compensate for the shortcomings in the station's crane.


(a) (b)

**Figure 6.** (a) Overhead Single Girder Crane in Power Plant. (b) Crane location in the steam boiler for the power plant

This crane is an overhead single girder crane equipped by a Russian company. Its maximum load is 10 tons, and the length of the wire rope is 50 m. The crane is installed on a horizontal rail called a grider or bridge of about 2 m in length, which is fixed on both sides by two runway rails of about 50 m each and made of high-tensile steel (S.T. 52) material. The crane moves in a linear motion utilizing an electric drive called a bridge drive above each rail and contains an electric hoist that controls the movement of the vertical pulley rope up and down, as illustrated in figure 7.

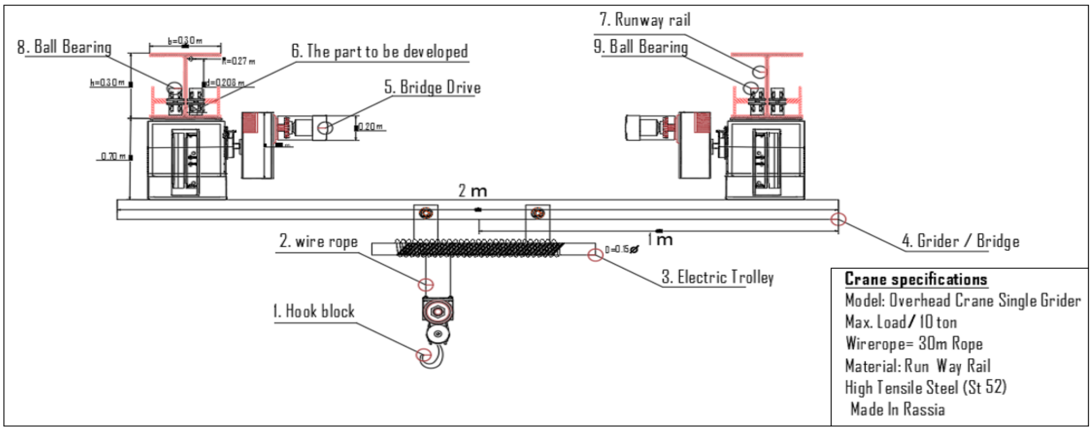


**Figure 7.** Structure of Overhead Crane

Here, it is possible to suggest a development in the crane used in the building, as shown in figure 8, which is to increase the length of the crane runway rails, which are of the I-beam type subjected to European standards that bear direct and tensile loads to lower the idle part to the ground without renting an external crane.

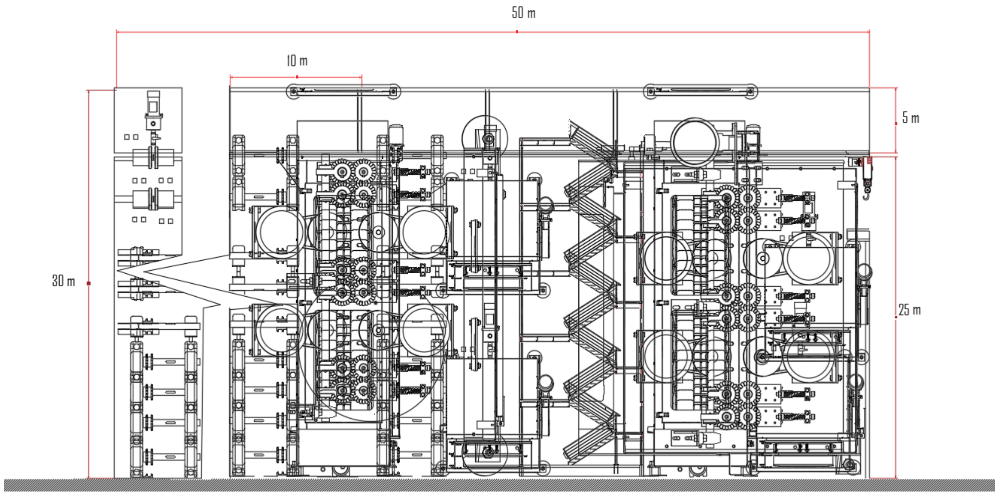


**Figure 8.** Overhead crane before development

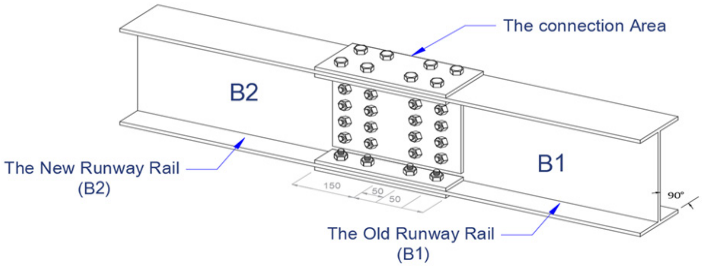


**Figure 9.** The I-beams connection region[19]

The increase in the length of the crane rails is achieved by attaching new rails to the old rails, each with a length of 5 meters. The rails are connected using a plate and screws, as a fastening method as shown in figure 9.

Each rail is fixed to support so that no breakage or warp occurs in the rail, thus damaging the part during its transportation. The supports are made of high-strength steel material (Steel 52), and its structure is of the type H-beam according to the European standard because it can bear direct and tensile loads. Also, the wide cross-section allows it to bear torsion loads, unlike the I-beam, which cannot bear twisting loads due to small cross-sections. Of course, detailed design calculations are to be done by designers.

The supports must be fixed in the ground using a solid foundation to avoid damage due to loads and torque. These two supports are connected with a U-channel truss according to the European standard made of high-strength steel material (Steel 52) for strengthening, supporting the crane rails that handle heavy loads, as shown in figure 10 and 11. Moreover, a distance of 5 meters is sufficient for entering the car or any transport vehicle to place the faulty piece or part inside it and transfer it to the maintenance department to repair it.

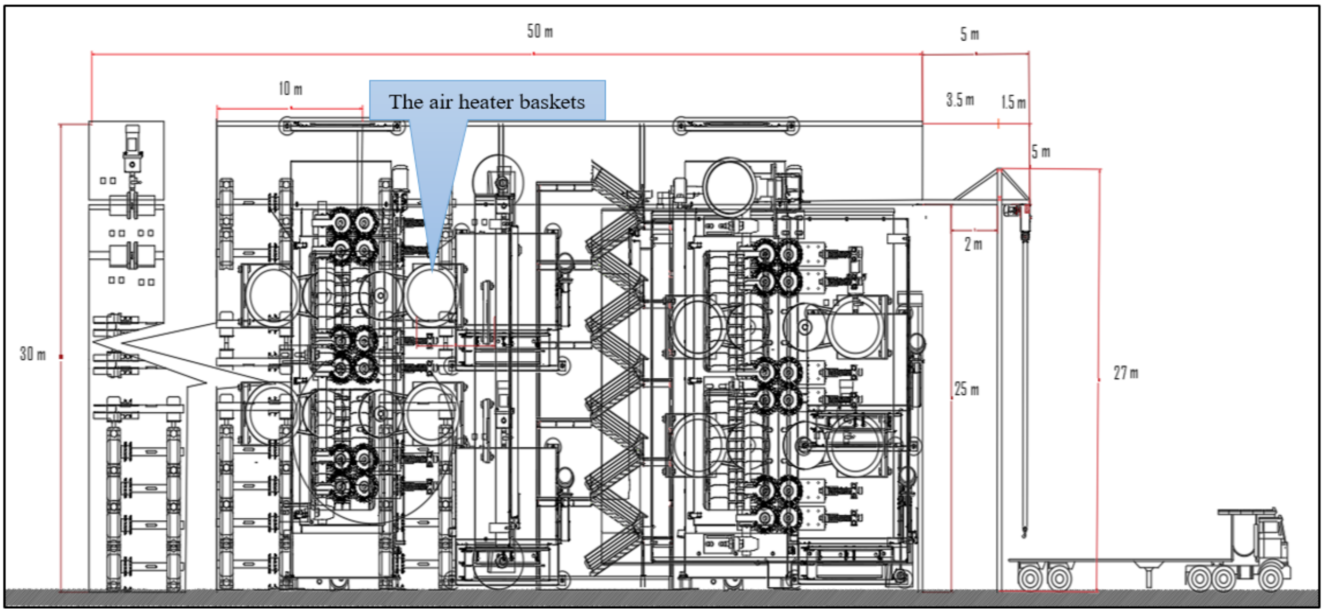


**Figure 10.** Overhead crane after development (side view)

This development will improve the ease of access to the location of the part in which the failure occurs and facilitate handling the parts to and from their original location. Furthermore, safety for the workers has been achieved during handling, reducing the waiting time until the arrival of the external crane and saving the cost of renting the crane and its drive. When an emergency failure occurs in the part, the crane is rented, and the arrival time of the rented crane is about 24-48 hours. Whereas, after the development of the existing crane, it is possible to save this time from all the repair time for the faults in the air heater. Moreover, the cost of renting the crane is 100 000 IQD per hour, including the cost of the crane driver, and the crane is needed for three days at least. So, the total required cost is 7 200 000 IQD, and it is possible to dispense with this recurring cost and make this development, whose cost does not exceed 4,000,000 IQD, and it will be for one time only. This improvement in the bridge crane design was accomplished from the point of view of an industrial engineer. However, a thorough study of the design in detail, structural and thermal analysis through simulations, and extensive calculations on static and dynamic stability by a specialized mechanical engineer is still necessary.

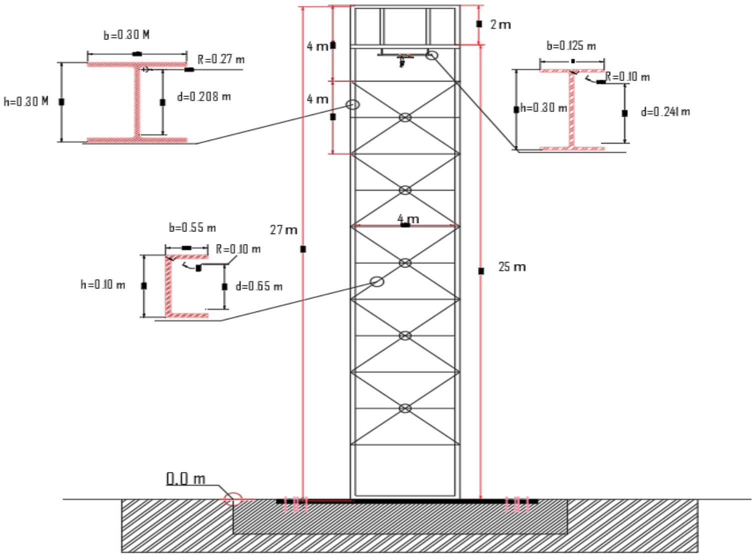


**Figure 11.** Overhead crane after development (Front view)

**Applying Stage 5**

This stage consists of the Maintainability calculation of the steam boiler after improvement:

The data for (TTR) is calculated and analyzed to calculate the steam boiler's maintainability after the improvement. The time for repairing each fault in the air heater of the steam boiler is reduced from 24 to 48 hours for each fault, as shown in table 2, according to the experts in the station, after improvement in the design factors for maintainability. This improvement was mentioned in detail in the fourth stage. After calculating the time to repair, this data is analyzed to find out which type of distribution applies to it to complete the rest of the calculations and find the maintainability of the steam boiler. The Minitab program was adopted for this purpose. It turns out that this data is subject to the Weibull distribution, as shown in figure 12.

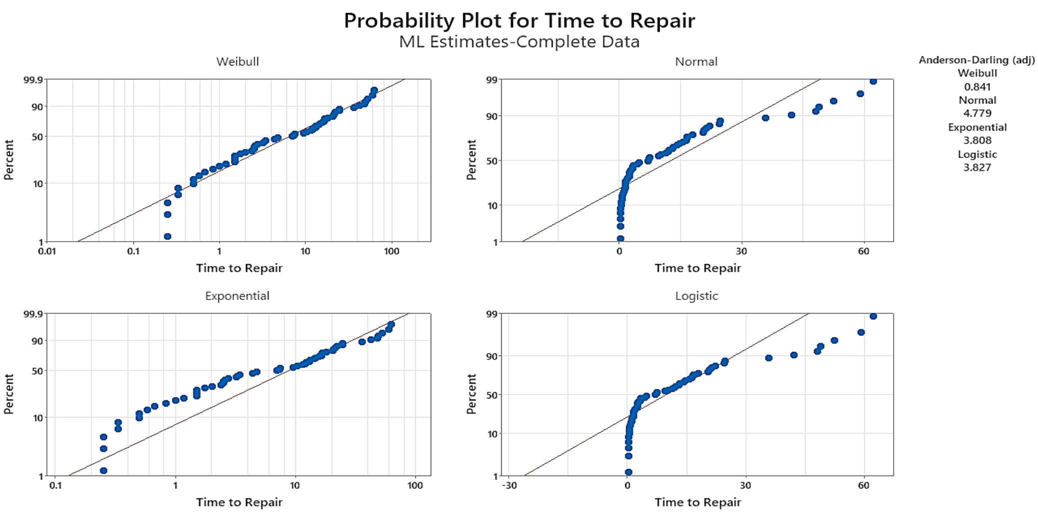


**Figure 12.** Probability plot for Time To Repair (TTR) after improvement

- Mean Time To Repair (MTTR) for four years after improvement by using the equation (1) equal28,917 hour
- Repair rate (μ) after improvement by using the equation (2) equal 0,0346 per hour
- The maintainability are calculated by using the equation (3), while the parameters (α and θ) can be obtained using the Minitab program, as illustrated in figure 13.

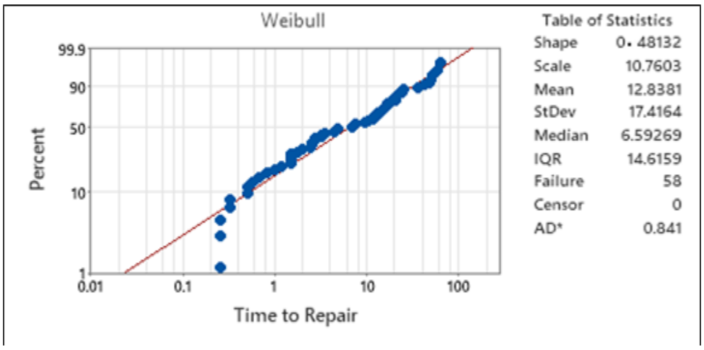


**Figure 13.** Distribution overview plot for Time To Repair (TTR) after improvement

α =10,7603, θ =0,48132, and t is the variable repair time, as in table 2.

Table 2. Calculation Time To Repair (TTR) and maintainability after improvement

| No. | Time To Repair | α | ɵ | n=-((t/α) ^ɵ) | e(n) | Mw(t)=1-e(n) |
|---|---|---|---|---|---|---|
| 1 | 7,42 | 10,7603 | 0,48132 | -0,836190246 | 0,433358371 | 0,566641629 |
| 2 | 423 | 10,7603 | 0,48132 | -5,854265779 | 0,00286764 | 0,99713236 |
| 3 | 3,42 | 10,7603 | 0,48132 | -0,57596983 | 0,562159405 | 0,437840595 |
| 4 | 14,67 | 10,7603 | 0,48132 | -1,160882948 | 0,313209511 | 0,686790489 |
| 5 | 16,58 | 10,7603 | 0,48132 | -1,231325047 | 0,291905533 | 0,708094467 |
| 6 | 20,75 | 10,7603 | 0,48132 | -1,371732543 | 0,253667089 | 0,746332911 |
| 7 | 14,17 | 10,7603 | 0,48132 | -1,141667468 | 0,319286178 | 0,680713822 |
| 8 | 11,42 | 10,7603 | 0,48132 | -1,029053937 | 0,357344871 | 0,642655129 |
| 9 | 12,17 | 10,7603 | 0,48132 | -1,061046338 | 0,34609349 | 0,65390651 |
| 10 | 2,5 | 10,7603 | 0,48132 | -0,495334725 | 0,609366903 | 0,390633097 |
| 11 | 15,58 | 10,7603 | 0,48132 | -1,195002616 | 0,302703162 | 0,697296838 |
| 12 | 52,33 | 10,7603 | 0,48132 | -2,141072597 | 0,117528714 | 0,882471286 |
| 13 | 17,83 | 10,7603 | 0,48132 | -1,275165206 | 0,279384808 | 0,720615192 |
| 14 | 24,58 | 10,7603 | 0,48132 | -1,488254346 | 0,225766422 | 0,774233578 |
| 15 | 2,58 | 10,7603 | 0,48132 | -0,50290168 | 0,604773253 | 0,395226747 |
| 16 | 62,03 | 10,7603 | 0,48132 | -2,323685665 | 0,097912049 | 0,902087951 |
| 17 | 13 | 10,7603 | 0,48132 | -1,095280874 | 0,334445657 | 0,665554343 |
| 18 | 21,33 | 10,7603 | 0,48132 | -1,390055588 | 0,249061459 | 0,750938541 |
| 19 | 7 | 10,7603 | 0,48132 | -0,813064273 | 0,443496986 | 0,556503014 |
| 20 | 48,75 | 10,7603 | 0,48132 | -2,069275109 | 0,126277286 | 0,873722714 |
| 21 | 35,67 | 10,7603 | 0,48132 | -1,78039687 | 0,168571233 | 0,831428767 |
| 22 | 481 | 10,7603 | 0,48132 | -6,227767026 | 0,001973855 | 0,998026145 |
| 23 | 3,25 | 10,7603 | 0,48132 | -0,562007342 | 0,570063602 | 0,429936398 |
| 24 | 3,22 | 10,7603 | 0,48132 | -0,559504363 | 0,571492246 | 0,428507754 |
| 25 | 22,08 | 10,7603 | 0,48132 | -1,413370171 | 0,243321863 | 0,756678137 |
| 26 | 132,15 | 10,7603 | 0,48132 | -3,344062137 | 0,0352933 | 0,9647067 |
| 27 | 4,75 | 10,7603 | 0,48132 | -0,674634362 | 0,509342622 | 0,490657378 |
| 28 | 16,25 | 10,7603 | 0,48132 | -1,219467503 | 0,295387418 | 0,704612582 |
| 29 | 0,67 | 10,7603 | 0,48132 | -0,262814071 | 0,768884842 | 0,231115158 |
| 30 | 59 | 10,7603 | 0,48132 | -2,268343283 | 0,103483481 | 0,896516519 |
| 31 | 20,42 | 10,7603 | 0,48132 | -1,361188644 | 0,25635588 | 0,74364412 |
| 32 | 2,75 | 10,7603 | 0,48132 | -0,51858733 | 0,595361003 | 0,404638997 |
| 33 | 0,58 | 10,7603 | 0,48132 | -0,245185877 | 0,782559065 | 0,217440935 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| 34 | 1,75 | 10,7603 | 0,48132 | -0,417197179 | 0,658890988 | 0,341109012 |
| 35 | 1,5 | 10,7603 | 0,48132 | -0,387363356 | 0,678844388 | 0,321155612 |
| 36 | 0,5 | 10,7603 | 0,48132 | -0,228281402 | 0,79590026 | 0,20409974 |
| 37 | 12 | 10,7603 | 0,48132 | -1,053886416 | 0,348580385 | 0,651419615 |
| 38 | 0,83 | 10,7603 | 0,48132 | -0,291348614 | 0,747255129 | 0,252744871 |
| 39 | 2 | 10,7603 | 0,48132 | -0,444891437 | 0,640893849 | 0,359106151 |
| 40 | 1 | 10,7603 | 0,48132 | -0,31868549 | 0,727104195 | 0,272895805 |
| 41 | 4,35 | 10,7603 | 0,48132 | -0,646665868 | 0,523789251 | 0,476210749 |
| 42 | 9,5 | 10,7603 | 0,48132 | -0,941803316 | 0,389924045 | 0,610075955 |
| 43 | 0,33 | 10,7603 | 0,48132 | -0,186901772 | 0,829525215 | 0,170474785 |
| 44 | 10,25 | 10,7603 | 0,48132 | -0,976886033 | 0,376481627 | 0,623518373 |
| 45 | 1,5 | 10,7603 | 0,48132 | -0,387363356 | 0,678844388 | 0,321155612 |
| 46 | 24,42 | 10,7603 | 0,48132 | -1,483583622 | 0,226823381 | 0,773176619 |
| 47 | 1,17 | 10,7603 | 0,48132 | -0,343701564 | 0,709140529 | 0,290859471 |
| 48 | 1,5 | 10,7603 | 0,48132 | -0,387363356 | 0,678844388 | 0,321155612 |
| 49 | 0,5 | 10,7603 | 0,48132 | -0,228281402 | 0,79590026 | 0,20409974 |
| 50 | 2,38 | 10,7603 | 0,48132 | -0,483744801 | 0,616470504 | 0,383529496 |
| 51 | 16,47 | 10,7603 | 0,48132 | -1,227386247 | 0,293057558 | 0,706942442 |
| 52 | 0,33 | 10,7603 | 0,48132 | -0,186901772 | 0,829525215 | 0,170474785 |
| 53 | 0,25 | 10,7603 | 0,48132 | -0,163522973 | 0,849146991 | 0,150853009 |
| 54 | 7,25 | 10,7603 | 0,48132 | -0,826913684 | 0,437397151 | 0,562602849 |
| 55 | 0,25 | 10,7603 | 0,48132 | -0,163522973 | 0,849146991 | 0,150853009 |
| 56 | 2,5 | 10,7603 | 0,48132 | -0,495334725 | 0,609366903 | 0,390633097 |
| 57 | 1,5 | 10,7603 | 0,48132 | -0,387363356 | 0,678844388 | 0,321155612 |
| 58 | 0,25 | 10,7603 | 0,48132 | -0,163522973 | 0,849146991 | 0,150853009 |

Then, the maintainability of the steam boiler after improvement, according to the data above, is calculated by using equation 4 equal 0,535, which means equal 53,5 %

**Applying Stage 6**

This stage consists of Comparison of the results before and after the improvement:

Based on the calculations made in table 1 and then according to the distribution to which the data is subject, the steam boiler maintainability was calculated before improvement and was 48,5 %.

After improving the design factors for maintainability, including handling, accessibility, and safety factors for equipment and personnel, which were manufactured on the overhead crane used to handle the idle parts of the steam boiler, particularly the air heater, the fault repair time was reduced from 24 to 48 hours for each fault. This means that sum of the repair times for air heater malfunctions (22 malfunctions) is reduced about (528 – 1056) hours.

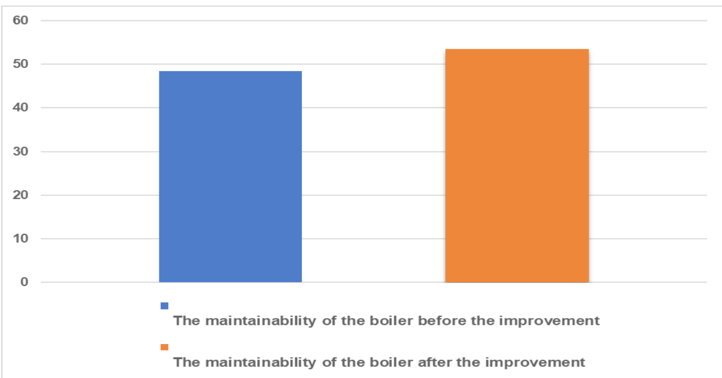


**Figure 14.** Comparison of the maintainability of the boiler before and after the improvement

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The calculations were made as in table 2. Then, according to the distribution to which the updated data is subjected, maintainability was calculated after improvement, which became 53,5 %, meaning it increased by 5 %. This percentage is suitable for the improvement that has been made, which concerns only one of the design factors for maintainability and for one part of the steam boiler parts that may be causing the boiler's failure. In addition, improving maintainability is not easy, especially for the complex mechanical components in huge service establishments. An analysis of the bar chart using the Excel program clarifies the values and the percentage of improvement, as illustrated in figure 14.

## CONCLUSIONS

Improving design for maintainability is a critical, complex, but significant issue. Maintainability design factors are considered when designing any system or product to reduce the time required for maintenance and reduce costs. Due to the current challenges in design and maintainability, this study focused on studying the steam boiler of the South Baghdad Thermal Station because it is a fundamental service institution for providing electrical energy to citizens. Next, determine the boiler's maintainability using the data obtained from the station. The air heater is selected as part of the boiler for design improvements and maintainability according to its frequent failures. Mainainibility improvement reduces its impact on the downtime of the power station and increases its efficiency.

According to engineering and technical experts and after studying the air heater, the maintainability design factors of the air heater can be addressed to improve its maintainability and facilitate its maintenance. By contacting this part and seeing most of the defects of the parts and difficulties related to maintenance, the improvement in the design factors for maintainability is the handling and ease of access to the part while taking into account the safety of the worker and the part. This improvement is related to the overhead crane, as maintenance engineers and workers face some difficulties when the air heater baskets fail due to their location being high above the ground, difficult to reach, and cannot be maintained on-site. It has to be handled by a gantry crane, and since the available crane is not sufficient for the purpose in its current state, a modification in the design of the crane rails has been proposed to increase the length of the crane rails by attaching new rails to the old rails to a length of 5m. This development saves time in repairing faults and reduces the costs incurred by the station before development and periodically when faults occur. When comparing maintainability results before and after the improvement in maintainability design factors, it was found that maintainability increased by 5 %, which is a good and helpful value for maintenance staff and, thus, for the station.

Studying green maintainability as it has the advantage of reducing negative environmental impact and reducing material/energy consumption as well as routine maintenance tasks of increasing performance, reducing risks, and reducing costs may be the point worth noting in the future.

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