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Assessing Reliability in Manufacturing Systems by a New Arrangement of the Mean Time Between Failures (MTBF)

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Abstract

This work has studied the size of the mean time between failures (MTBF) because it has a vital role in assessing reliability in manufacturing systems. Previous studies have indicated that the reliability value depends on the size of MTBF, so they indicated only 11 types of time that reliability value depends on, and they used methods of DFR and RCM to enhance the reliability level. To assess and increase reliability value, this work referred to the four main times: mean time between failures (MTBF), mean time to diagnosis (MTTD), mean time to repair (MTTR), and mean time to failure (MTTF) in more detail. Also, it designed a new arrangement of failure notification time, failure diagnosis time, downtime, failure repair, testing time, and recovery periods for ongoing operations in manufacturing systems through a new redistribution of 19 times and time intervals in detail between the four main times, so it revealed and added 8 types of other times and time intervals more than previous studies because they have vital roles in increasing reliability value. Thus, the new arrangement contains two parallel pathways and 19 types of times and time intervals. The first pathway represents 5 positions and 11 types of start and end times; the second pathway represents 4 positions and 8 time intervals. Consequently, MTBF becomes longer because the new arrangement shortens the time distances between the start of failure and repair process end, between diagnosis end and test, and between inspection end and the system's return to normal operating conditions. The motivations are to raise the reliability value, quality level, and effective maintenance and save costs. This work used the data collection and analysis method. The results showed that there is a higher reliability for manufacturing systems when the time arrangement is better, MTBF is longer, MTTD is shorter, MTTR is smaller, MTTF is longer, and the error rate is lower.

Keywords: Reliability Value, MTBF, Quality Level, Repair Process, Manufacturing System.

Nomenclature:

R: value of reliability.
e: natural log base.
λ: failure rate (lambda).
t: time duration.
MTBF: mean time between failures.
MTTD: mean time to diagnose (or mean time to detect or discover).
MTTR: mean time to repair.
MTTF: mean time to failures.

1. Introduction

Reliability is the probability that a system of manufacturing will carry out its functions in a given time under normal operating conditions [1], and it is the probability that a system runs easily for an amount of time [2]. The reliability can be assessed and quantified in manufacturing systems [3], but the value of reliability is varying according to the kind of processes [4]. Reliability is a part of a quality system because its value is linked to ongoing performance and repair processes in manufacturing systems [5]; also, to improve manufacturing systems, continual reliability is required [6].

Moreover, reliability is regarded as a crucial indicator of manufacturing system improvement [7]. But any manufacturing system is not regarded as reliable when it fails to provide the same performance after doing the repair process [8]. Each component of manufacturing systems has an individual level of reliability; then, the overall reliability value of a manufacturing system R (t) can be computed [9, 10]:

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$$R(t) = R1(t)\ R2(t)\ \ldots\ Rn(t)$$

Where R1, R2, and Rn are the reliability of components.

It was recognized that a better degree of reliability leads manufacturing systems to be at a high quality level, and many benefits can be obtained, such as the systems can better detect errors, reduce failures, decrease expenses, and minimize the duration of repair processes [11]. Then, it was proven that better performance of manufacturing systems resulted from the effectiveness, reliability, availability, maintainability, and capability of the system [12]. Also, in most cases, it was confirmed that to increase reliability value, the failures in manufacturing systems should be collected, analyzed, and corrected [13]. The precise maintenance in manufacturing systems can enhance reliability and performance [14], and implementing a strategy for maintenance ensures continual operational state [15].

MTBF (mean time between failures) has a crucial role in continual different operations because the reliability value is connected with it, and MTBF includes other three times such as MTTD (mean time to diagnose), MTTR (mean time to repair), and MTTF (mean time to failures) [16].

They form the four main times inserted deeply into the manufacturing operations, and they are strongly linked to the reliability value [17]. Figure 1 shows the four main times with intervals, failures, and repairs [18].

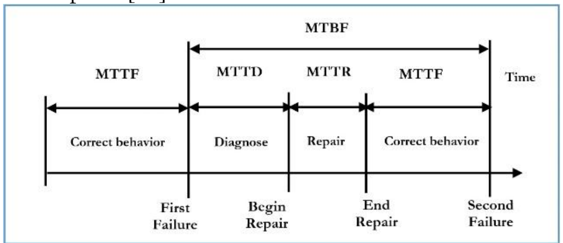

Figure 1: Four main times with failure intervals and repair processes [18].

Regarding previous studies, a study has identified the failures and failure rate in engineering systems [19]; it has presented the time by the equation (MTBF = MTTR + MTTF), and it has shown that high reliability comes from large (MTBF). It used two methods of reliability prediction and reliability estimation.

An investigation on MTBF to improve the reliability of a typical power transformer has been achieved by a study [20]. The aim is to get performance and value of reliability; therefore, it has applied a mathematical equation that links the MTBF, time, and failure together as follows:

$$MTBF = \int_0^\infty tf(t)dt$$

f(t) is the instantaneous product failure rate, t is time duration, and MTBF = 1/λ, where λ (failure rate or lambda) of products.

A study has shown that any lack of reliability will have consequences on repair processes, safety, and costs [21]. Therefore, it applied DfR (design of reliability) because it proved that DfR has led to reducing failure rates, time, and costs. To obtain precise results, it used a number of statistical quality tools, such as control charts, DOE (design of experiments), and the Taguchi method, to enhance reliability value.

A study [22] has developed a model of RCM (reliability-centered maintenance) with the aim of improving the MTBF value because the model extended the life of the equipment and improved the database in the maintenance department. Therefore, by applying this model, the MTBF value was improved, the reliability value increased, defective products were reduced by 75%, and the repair time was reduced by up to 95%.

The downtime in manufacturing systems has been conducted by a study [23]. The aim of the study was to improve the performance of equipment. The study used the TPM (total productive maintenance) method by calculating OEE (overall equipment effectiveness). It has investigated six types of losses that occur in equipment, so the study selected maintenance procedures to increase equipment performance and then calculated MTBF and MTTR to increase equipment reliability.

An interrelation between reliability level and different losses in manufacturing systems has been examined by a study [24], and it has proved that reliability is a significant measure of quality level. The study has proved that the losses will be minimized by the higher reliability. The study has used the method of CTQ (critical quality characteristics) to ensure the reliability and stability of manufacturing systems for a longer time.

Also, another study has investigated the interrelation between MTBF, reliability value, and maintenance procedures [25]. It has declared that MTBF is a crucial maintenance metric for measuring performance and equipment design in manufacturing systems. In addition, the study has examined that MTBF is one technique that can be used to reduce the impact of failures, reduce maintenance stoppage, save costs, and work faster.

As for the methodology, this work followed the data collection and analysis of the collected data as well to achieve the objectives. It collected data on each of the reliability, the four main times, failure rate, repair time, and recovery time, and then analyzed their levels. It also provided a reliability assessment for the new arrangement of (MTBF), which contains (MTTD, MTTR, and MTTF); in addition, the methodology includes the results, discussion, and conclusions.

The motivation for this work is that when the reliability value increases, the quality level increases, and the length of (MTBF) increases, so failures are discovered quickly, and the repair process is easy, and the performance will be high.

The importance of this work includes that the designed new arrangement reduces the efforts spent in failure diagnosis and repair processes and improves the maintenance process because the new arrangement contains ensures returning to the normal state.

The main objectives of this work are:

- To provide a clear assessment of reliability and show how reliability and MTBF affect each other in terms of increasing or decreasing their values.

- To present a new arrangement for (MTBF, MTTD, MTTR, and MTTF) and then to achieve reliability assessment in manufacturing systems based on the new arrangement of MTBF. Then to identify 19 times and time intervals and include them in the new arrangement.

2. Reliability and MTBF:

Data collection on reliability and MTBF indicates that reliability has interrelationships with failure rate and repair processes [26]. Also, reliability is connected to failure rate and time of stoppage in each stage of operations in manufacturing systems [27, 28]. The value of reliability depends on the number of failures and repair processes [29], and the measurement of reliability value is based on failure-free or few-failure conditions [30]. The value of reliability (R) is determined by the failure rate (λ) and the time duration by which the manufacturing system will restore its suitable level of operation after failure occurrence and repair process [31&32]:

$$R = e^{-\lambda t} \quad \text{............... (1)}$$

Where $\boldsymbol{e}$ is the natural log base and the failure rate ($\boldsymbol{\lambda}$) is the reciprocal of $\boldsymbol{MTBF}$, then the formula for the reliability value [33] will be equal to:

$$\lambda = \frac{1}{MTBF} \quad \text{.............. (2)}$$

$$R = e^{\frac{-t}{MTBF}} \quad \text{.............. (3)}$$

There are four main times (MTBF, MTTD, MTTR, and MTTF) that are strongly associated with the reliability value of manufacturing systems [34], but there is a group of times that are worked within MTBF and have high effects on the reliability of manufacturing systems; they include the time of testing, time of inspection, duration of stoppage of operations, time of initial recovery, time of initial operation, duration of repair process, and time of achieving maintenance of other connected parts [35, 36]. There are 4 main sources of failures: undiscovered defects, low safety, bad design, and higher loads on the system than normal [37]. Consequently, there are many tasks interrelated to reliability value, as briefly indicated in Figure 2.

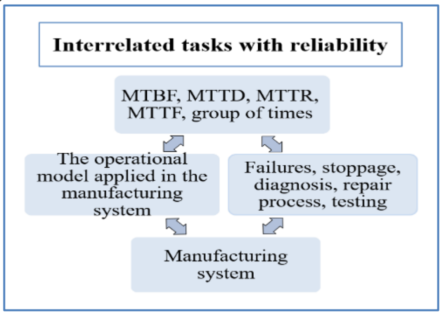

Figure 2: Tasks that are interrelated to reliability value in manufacturing systems.

The length between first and second failures in manufacturing systems is represented by MTBF [38]; also, MTBF is calculated as the total operating time divided by the total failures [39]. Furthermore, the size of MTBF is the sum of equipment uptime of all machines divided by the failures of all machines, and the size of MTTR is the sum of repair time of all machines divided by the failures of all machines [40 & 41].

In regards to reliability assessment, investigations have proved that the greater value of reliability is closely correlated with its longer MTBF, lower failure rate (λ), shorter MTTR, and high-quality maintenance [42]. Also, other investigations have proved that the longer MTBF can be obtained from fewer numbers of components, less labor, and fewer costs [43].

MTTD represents the mean time to diagnose or (the mean time to detect or discover); it refers to how long it takes for the manufacturing system to find and identify any failure that happens, but MTTR is the time that is required to repair a component or a full system; it is the duration of stoppage of the system; it is the time needed to replace a faulty part with a new one, and it is the period for restoring the manufacturing system to its satisfactory functional state [44]. MTTF is the duration time between the end of the repair process and the second failure; they have vital roles in limiting the value of reliability because it represents the long-term, suitable operation of the system [45 & 46].

3. Analysis of data:

When analyzing the previous studies, it was proven that high reliability comes from a large mean time between failures, and also that the value of reliability is limited by the rate of occurrence of errors in manufacturing systems, and at the same time, the occurrence of errors also depends on the mean time between failures.

Moreover, they proved that any decrease in the level of reliability may affect both costs, safety, and repair procedures. They showed that losses will be reduced through higher reliability, and it was confirmed that reliability is an important measure of the quality level of manufacturing systems. Therefore, the previous studies investigated the existence of a mutual relationship between 5 parameters, such as mean time between failures, failures, reliability value, maintenance procedures, and equipment performance, and emphasized the importance and necessity of implementing a maintenance strategy because maintenance enhances the performance of maintenance systems. Previous studies have shown that MTBF includes three other times, such as MTTD, MTTR, and MTTF, and that they constitute the four main times and that they are closely related to the reliability value. They declared that each component of the manufacturing systems has an individual level of reliability and mathematically proved that the total value of reliability is equal to the product of the reliability of the components. They also declared that there are 5 elements that contribute to improving the performance of the manufacturing system: (1) effectiveness; (2) reliability; (3) availability; (4) maintainability; and (5) system capabilities. They proved that (MTBF) and it was proven that the mean time between failures and the reliability level depend on each other, but that both depend on each of the four main times, the set of times, failure rates, the number of failures, the interruption of any step of the system operation, diagnosis, repair process, testing, inspection, and the type of business model applied in the manufacturing system. It was also noted that there are 4 main sources of failures, including (1) undetected defects, (2) reduced process safety, (3) poor component design, and (4) loads on the system that are higher than normal. For the four main times, it was noted that the mean time between failures is 3 times, the mean time between failures is 5 times, and the mean time between failures is 2 times in detail.

4. New arrangement of MTBF:

In order to increase the reliability value and operate manufacturing systems more efficiently, this work made a new arrangement of the four main times (MTBF, MTTD, MTTR, and MTTF) by rearranging their time contents related to each of them, by identifying 5 times of start and end and 4 interval times, and then these 9 times were inserted and distributed among the four main times. Therefore, the new arrangement is a new distribution process and a new form of how to deal with times and interval times.

Figure 3 shows the new layout of the nine times and interval times. The new arrangement used two parallel pathways as follows:

1. The first pathway includes A, B, C, D, and E, which represent 5 times of start and end.
2. The second pathway includes pathways 1, 2, 3, and 4, which represent 4 time intervals.
3. These nine types of the two pathways contain other times and time intervals in detail.

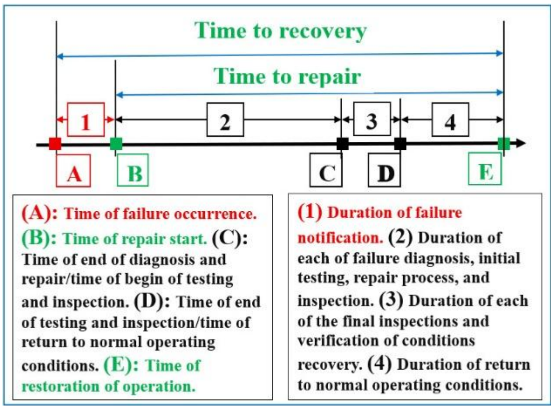

Figure 3: New layout of times and interval times in the new arrangement.

5. Results and discussion:

The results have shown that the reliability can be assessed and quantified, but its value is varying according to the kind of processes; also, a high degree of reliability ensures a high-quality level of manufacturing systems.

The results found that reliability value depends on 5 factors, such as (1) longer MBTF, (2) lower failure rate (λ), (3) shorter MTTR, (4) high-quality maintenance, and (5) control of the repair process, because these factors control times after suitable organizing procedures.

The results affirmed that failure occurrences lead to lowering reliability value and reducing the size of (MTBF). However, the results found that there are 4 sources of failure occurrence; they include undiscovered defects, bad safety in operations, bad design of equipment, and extra loads on systems' working. Also, the results affirmed the necessity of doing crucial maintenance because it proved an interrelation between maintenance, reliability value, and MTBF.

The results confirmed that reliability level and sizes of MTBF, MTTD, MTTR, and MTTF depend on 5 factors such as (1) number and size of failures, (2) speed of repair process, (3) design of components of manufacturing systems, (4) type of processes, and (5) shape of paths of times. The results have indicated 9 benefits resulting from high reliability value as indicated in Table 1.

Table 1. Benefits that result from high reliability value.

Reduced failures	decreased duration of repair process	reduced losses
lowered failure rate (λ)	increased performance ratio	shortened MTTR
discovering failures quickly	reduced maintenance stoppage	costs are saved

As a methodology, previous studies have used 5 methods such as DfR, RCM, Taguchi, TPM, and CTO, and they used tools of control charts and DOE to increase reliability value, but this work has designed a new arrangement of times to increase reliability value.

Previous studies have referred to the system's effectiveness to increase reliability, but this has concentrated on reorganizing distances between failures and repair processes and work movement within new arrangements to increase reliability value.

Previous studies have declared (7) times that are worked within MTBF that where include: (1) testing time, (2) inspection time, (3) stoppage duration of operations, (4) initial recovery time, (5) initial operation time, (6) repair process duration, (7) time of achieving maintenance of other connected parts. But this work made some progress by giving MTBF a stronger role and by presenting a new distribution of times and a new layout of 9 times and time intervals as presented in figure 3. Moreover, the new arrangement presented 19 times of start and end and time intervals that were organized in 2 pathways organized to ensure better reliability value and greater size of MTBF as indicated in table 2.

Therefore, this work has presented additional 8 times and time intervals in detail into manufacturing system working; therefore, they became better linked to operations and filled the gap remaining in reliability assessment, then more linked with raising and lowering reliability value.

Table 2: Two pathways of times for start and end situations and time intervals in the new arrangement.

Pathways	19 times and time intervals in detail
Pathway 1: A, B, C, D, and E	11 times of start and end: (1) Start of failure occurrence. (2) Start of work stoppage. (3) Start of failure repairs. (4) End of failure repairs. (5) Start doing any test. (6) End of test. (7) Start of operation inspection. (8) End of inspection. (9) Start of recovery. (10) Time of return to normal operating conditions. (11) Start of restore of operations.
Pathway 2: 1, 2, 3, and 4	8 time intervals: (1) Time interval of failure notification. (2) Time interval of failure diagnosis. (3) Time interval of stoppage. (4) Time interval of doing initial testing. (5) Time interval of doing inspection. (6) Time interval of doing repair, (7) Time interval of test operation of the component or system entirely. (8) Time interval of return to normal operating conditions.

Furthermore, with presenting a new arrangement, (MTBF) becomes longer because it shortens time intervals between the start of failures and repair, between diagnosis and start of test, and between end of inspection and return to normal operating conditions.

(MTTR) becomes smaller because the new arrangement now includes time to replace faulty parts with new ones and time to test with the repair process.

(MTTF) becomes longer because the new arrangement now controls the time intervals between successive faults.

Figure 4 shows the factors for achieving a high reliability value.

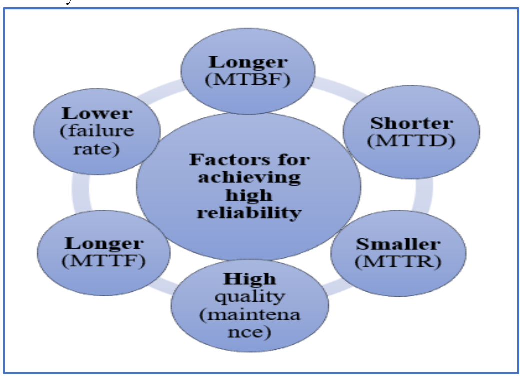

Figure 4: Shows factors for achieving high reliability as a result of applying the new arrangement.

6. Conclusions and recommendations:

Reliability plays a prominent role in manufacturing systems because it contributes to detecting failures effectively, and conducting a reliability assessment is necessary and useful to know the level of operation of the manufacturing system, and a high reliability value gives 9 benefits to manufacturing systems. The reliability value changes according to the change in the size of MTBF, failures, the repair process, and the maintenance level. In addition, the reliability value increases when failures are detected and addressed in a timely manner, and then performing timely maintenance ensures a continuous increase in the reliability value because it reduces the downtime of the system or its components, thus reducing operating expenses. The goal of reliability assessment is to know the reliability value of the manufacturing system to obtain distinctive performance. Data on reliability and the four main times (MTBF, MTTD, MTTR, and MTTF) were collected; the reliability value also depends on these four main times because they are deeply integrated into all stages of the operations of the manufacturing system. Previous studies have shown and announced (11) types of times, such as MTBF, MTTD, MTTR, and MTTF, and include (1) the time of testing, (2) time of inspection, (3) duration of stoppage of operations, (4) time of initial recovery, (5) time of initial operation, (6) duration of repair process, (7) time of achieving maintenance of other connected parts; they are sources of increasing and decreasing the reliability value. This work has analyzed the data; it was found that there is a gap in the number and type of these times, so this work designed a new arrangement and added 8 new times and time intervals, and it became 19 times and time intervals inserted in the new arrangement and became components of the four main times. The first pathway represents the start and end times; it contains 5 locations and 11 times of start and end in detail. The second pathway represents the time intervals; it contains 4 locations and 8 time intervals in detail. This work recommends implementing the new arrangement, so it gives a more accurate state of operations and increases reliability value; then, the new arrangement is characterized by enlargement of MTBF, which becomes longer because it shortens time intervals between the start of failures and repair, between diagnosis and test beginning, and between inspection with return to ordinary conditions. MTTR becomes smaller because the new arrangement now includes rapid time for replacing defect parts with new ones, and MTTF becomes longer because the new arrangement controls the time intervals between sequential failures.

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