Reliability Analysis on Water Pumps in Water Supply System in Johor

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Abstract. The utilization of water pumps in supplying water facilities to consumer should be given priority in terms of operating performance and availability. In light of that, reliability assessments on water pumps were carried out through Mean Time Between Failure (MTBF), Mean Time to Repair (MTTR) and availability. Then, the water pumps’ brands were compared using Mean Cumulative Function (MCF) plot and suggestion strategies through Failure Modes, Effects and Criticality Analysis (FMECA) approach were conducted. There were two types of old and new water pumps which are raw water pump (RWP) and treated water pump (TWP). The name of the brand of old and new RWP and TWP are Brand A, Brand C, and Brand B. Throughout the study, the finding shows that old RWP and new TWP are the most reliable water pumps based on the computation. Besides, Brand A and Brand C were the best brands among others water pumps’ brand by comparing the performance using the MCF plot. Lastly, the suitable strategies suggested to be focused on predictive maintenance, preventive maintenance and corrective maintenance in handling the maintenance.

1. Introduction

Clean water is essential for life, yet the vast majority in the created world does not ponder the water they utilized for drinking, nourishment readiness and sanitation [1]. For the most part, crude water is taken from the earth and provided to a water treatment facility through water pumping for consequent treatment or decontamination. Furthermore, the way towards providing water treatment and treated water are conveyed by utilizing the water pumps. Besides, the utilization of water pumping can likewise result in the disappointment of water pump. To guarantee that physical resources keep on working to the limit with regards to which they were planned, a study [2] expressed that performing maintenance is required. In the exploration study [3], the explanation of having maintenance decision making such aging and deterioration are a result of the high extent of water spillage.

[4] stated that reliability is characterized by heuristic rules as guaranteeing two elective ways to every buyer hub from in any event one source or having all pipe measurements more prominent than a base endorsed esteem. Reliability is the likelihood of an item that will perform and work without disappointment for a given time frame under indicated conditions [5]. Similarly, of discernment characterized by [6] reliability is the likelihood of residual thing in a working state to be work in the time given where the framework began work at a consistent time.

Different techniques have been created by specialists to break down the water pump execution in the water supply framework. The research made by [6] proposed the technique for modified frequency
and duration analysis (FD). This strategy is utilized to break down the dependability of pumping system to make the reliability turns out to be increasingly practical and complete. The pump frameworks that are included to be examined in processing the reliability parameters for the approach are a mechanical disappointment and pressure-driven disappointment.

A study from [7] built up a model to assess the dependability of providing a realized interest design in a given water supply framework in which deficits were brought about by irregular disappointments of the pumping equipment. Be that as it may, there is no enhancement performed in their model and just pump disappointments are considered. [8] displayed an approach for reliability and availability appraisal of a water distribution network dependent on an adaptive pump operation. Because of a pipe break, pump operation was adjusted utilizing different sizes of pump blends. In their strategy, they assess hydraulic reliability as far as accessible water to satisfy the wanted interest.

Water supply framework are among the most basic foundation for the sustenance of social orders. Pumps are exposed to outer and interior consumption additional time, which can influence their mechanical quality, hydraulic execution and reliability of supply water. Low reliability of pump execution will result in the most noticeably awful conditions which may influence the way toward providing water to the client. Therefore, this study aims of three objective; (1) to analyze the reliability of water pumps through non-parametric reliability analysis, (2) to compare the reliability of several water pumps brands on their performance and efficiency using Mean Cumulative Function (MCF) plot, and (3) to suggest suitable strategies in handling water pumps maintenance using FMECA approach.

2. Methods
In this research, a primary data set has been taken from water operator in Johor. This data is recorded from 2014 to 2016 for old water pumps and 2017 to 2018 for new water pumps. The data consists of two categories of water pumps which are raw water pump (RWP) and treated water pump (TWP) with different status of water pumps.

2.1. Assessment of reliability
As stated by [4], reliability is characterized by heuristic rules as guaranteeing two elective ways to every buyer hub from in any event one source or having all pipe measurements more prominent than a base endorsed esteem [4]. Reliability is the likelihood of an item that will perform and work without disappointment for a given time frame under indicated conditions [9]. In addition, reliability is characterized as the likelihood that the circulation framework will work at some base characterized pressures while fulfilling the requests (water powered accessibility) given the conceivable disappointment of various segments [10].
The mean time between failure (MTBF) is a significant metric where the failure rate of assets should be overseen. It is the average time lapse between breakdowns of a system that excludes the time spent for repair, being repaired, being re-qualified and so on. The calculation of MTBF is as follow:

\[
MTBF = \frac{X}{Y}, \text{ where } X \text{ is total uptime, } Y \text{ is number of failures}
\]  
(1)

The total uptime is total hours of functioning without failure. Mean time to repair (MTTR) is the average time required to troubleshoot and repair failed equipment and return it to normal operating conditions. It is a fundamental technical measure of the maintainability of equipment and repairable parts. The calculation of MTTR is as follow:

\[
MTTR = \frac{Z}{Y}, \text{ where } Z \text{ is total downtime, } Y \text{ is number of failures}
\]  
(2)

The total downtime is total time of not functioning because of failure. Availability is the probability of being found or residing that the component or system in operating at time \( t \), given that it was operating at time zero. Availability can be defined as the proportion of time for which the equipment is able to perform its function. The calculation of availability is as in equation (3).
Availability = \frac{MTBF}{MTBF + MTTR} \tag{3}

2.2. Mean cumulative function
In a non-parametric analysis of recurrent event data, each population unit can be described by a cumulative history function for the cumulative number of recurrences [7]. The mean cumulative function plot shows the mean cumulative function versus time. The plot is a stage work with ventures at framework disappointments (fixes) or endpoints of interims. The plot is utilized to decide if the framework is improving, disintegrating, or staying steady.

2.3. Failure modes, effects and critical analysis
This procedure has been adapted in numerous various ways for different purposes. The steps that should be involved in Failure Modes, Effects and Criticality Analysis (FMECA) are as following [11]:

Step 1: Identification of system involve.
Step 2: Figure out the failure modes. All possible failure modes for each component were listed and identified.
Step 3: Acknowledge the failure effects if no action is taken in order to predict, prevent or detect the failure.
Step 4: Study the failure causes. The assessment for failure cause was carried out. It was based on the description by the data record.
Step 5: Risk Priority Number (RPN) ranking. This rating is rated by three assessments which are severity, occurrence and detection ratings. The failure with the highest RPN value was identified to be the critical equipment. The calculation of RPN is as follow:

\[ RPN = S \times O \times D, \]  \tag{4}

where \( S \) is severity, \( O \) is occurrence and \( D \) is detection

Step 6: Suggestion strategy or recommended action. For every equipment or component failure, the recommended task was planned as it will be used to suggest a better strategy to prevent or reduce the failure occurrence from repeating again in the future.

3. Results and discussion

3.1. Reliability assessment
The data then has been examined by referring to equation (1) to discover the MTBF of old and new RWP and TWP. From the estimation, the MTBF between the RWP and TWP proved that old RWP has longer MTBF compare to new RWP. Meanwhile, the MTBF for new TWP and old TWP showed that MTBF for new TWP is longer than old TWP. The longer the MTBF, the longer the water pump is likely to work before failing.

Besides, another appraisal of reliability for the failure data utilizing equation (2) to calculate the MTTR of both water pumps. Based on the outcome, it is plainly indicated that MTTR of old RWP had longer hours than new RWP. Other than that, it tends to be thought that old TWP indicates the MTTR recorded the shortest hours than new TWP. So, old RWP is more available to perform than new RWP as the consequence of availability computed the higher outcome. Conversely, the new TWP had higher availability than old TWP. So, the old RWP and new TWP are the most reliable water pump based from the computation. Table 1 shows the MTBF, MTTR and availability of RWP and TWP.
Table 1. MTBF, MTTR and availability

|                | RWP       | TWP       |
|----------------|-----------|-----------|
| Number of failure | 21        | 27        |
| Number of failure | 53        | 9         |
| MTBF (hours)    | 4988.3762 | 2599.4741 |
| MTTR (hours)    | 502.3527  | 321.4     |
| MTTR (hours)    | 1692.0808 | 693.2833  |
| MTTR (hours)    | 4642.5611 | 8562.89   |
| Availability (hours) | 0.9085 | 0.89  |
| Availability (hours) | 0.8562 | 0.8701  |

3.2. Comparison using MCF plot
The comparison between RWP and TWP were executed based on the performance operation of water pumps through their various brands. The first comparison was between old RWP and TWP which the brands involved were Brand A and Brand B. Besides, both categories of water pumps for the new pumps were compared by their same brand, Brand C to show which water pump had the most elevated number of failures. Lastly, there were likewise included in the comparison among new and old pumps of RWP and TWP.

From the comparison, it can be concluded that the best brand for RWP is Brand A by the old water pump and for TWP is Brand C by the new water pump. Table 2 here highlighted the best brand of both categories water pumps.
Table 2. Brands of RWP and TWP

| ID | Old Brand’s name | New ID | New Brand’s name |
|----|------------------|--------|------------------|
| 1  | RWP Brand A      | 1      | RWP Brand C      |
| 2  | None             | 2      | None             |
| 3  | RWP Brand A      | 3      | RWP Brand A      |
| 4  | RWP Brand B      | 4      | RWP Brand B      |

3.3. FMECA Approach
The group of water pumps involved for this research are categorized into RWP and TWP. The failure modes of pump are combined under their pump’s category. Throughout this research, even though the both group of pumps had the old and new water pumps, all of it were combined as it is easier to acknowledge the disappointment for both categories and can be prevented if the same failure modes repeatedly occur. The failure modes of both as shown in Table 3.

Table 3. Failure modes of RWP and TWP

| RWP | TWP |
|-----|-----|
| 1. Bearing Failure | 1. Bearing Failure |
| 2. Blockage | 2. Excessive Power Consumption |
| 3. Excessive Power Consumption | 3. Excessive Vibration |
| 4. Excessive Vibration | 4. Leakage |
| 5. Leakage | 5. Motor Failure |
| 6. Pump Failure | 6. Pump Failure |
| 7. Shaft Unbalance | 7. Pump Overheat |

The computation of Risk Priority Number (RPN) and Strategy rating of RWP and TWP as shown in Table 4 and 5.

Table 4. RPN and strategy of RWP

| Failure Modes | Severity | Occurrence | Detection | RPN | Strategy |
|---------------|----------|------------|-----------|-----|----------|
| Bearing failure | 3        | 2          | 1         | 27  | 2        |
| Blockage      | 3        | 2          | 1         | 20  | 1        |
| Excessive power consumption | 2        | 2          | 1         | 12  | 2        |
| Excessive vibration | 4        | 2          | 1         | 24  | 2        |
| Leakage       | 2        | 3          | 2         | 18  | 3        |
| Pump failure  | 2        | 1          | 4         | 8   | 3        |
| Shaft unbalance | 2        | 1          | 4         | 8   | 3        |
Table 5. RPN and strategy of TWP

| Failure Modes      | Severity | Occurrence | Detection | RPN | Strategy |
|--------------------|----------|------------|-----------|-----|----------|
| Bearing Failure    | 3        | 3          | 2         | 18  | 3        |
| Excessive Power    | 3        | 4          | 2         | 24  | 2        |
| Consumption        |          |            |           |     |          |
| Excessive Vibration| 2        | 3          | 2         | 12  | 3        |
| Leakage            | 4        | 4          | 1         | 16  | 3        |
| Motor Failure      | 2        | 3          | 3         | 18  | 3        |
| Pump Failure       | 4        | 4          | 2         | 32  | 1        |
| Pump Overheat      | 2        | 3          | 2         | 12  | 3        |

Several suggestion strategies were identified in correspondence to identify failure modes and effects. These suggestions were made by referring to all failure modes as in Table 6.

Table 6. Suggestion strategies

1. Have a routine check or periodic maintenance to know the pump’s condition.
2. Change the components by monthly to prevent the same disappointment occurs or preventive maintenance.
3. Adjusting the pump’s parameter of operation to avoid noise or vibration so that it would operate at BEP or corrective maintenance.
4. Pump discharge pressure. A gradual decrease in the developed head pressure of the pump may indicate that the impeller clearance has widened. An impeller clearance modification may be required to re-establish the pump to its planned structure execution. (Preventive maintenance).
5. Overall pump vibration. Fast approaching bearing failure can be preceded by an adjustment in bearing vibration. Excessive vibration can result from an adjustment in pump alignment or cavitation resonances between the pump, its foundation, or the valves located in the suction and/or discharge lines (Preventive maintenance).

4. Conclusion
As from the result of MTBF, MTTR and availability, it showed that the old RWP and new TWP are the most reliable water pump based from the computation. Throughout the comparison using MCF plot, the most appropriate brand among water pump could be chosen. From the first comparison of old RWP and TWP, it can be seen that Brand A had better performance than Brand B. Second, the comparison between new RWP and TWP using the same brand of water pumps that is Brand C demonstrated that the exhibition appeared by new TWP was far superior to new RWP. Furthermore, the brand of water pumps between old and new RWP resulted that Brand A brand would be wise to execution if compare to Brand C. Next, for the comparison of old and new TWP, the outcome discovered that Brand C was the best brand over Brand B and Brand A. Last but not least, the last method was Failure Modes, Effects and Critical Analysis (FMECA) which used to suggest suitable strategies in handling maintenance. After all, the procedures can be recommended to concentrate on the predictive maintenance, preventive maintenance and corrective maintenance as the disappointments of both categorize of water pumps are related to these suggestion strategies.
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