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# Reliability and Maintainability Analysis of a Robotic System for Industrial Applications: A Case Study

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**Abstract:** The reliability and maintainability analysis of an automated robotic system was carried out. Descriptive statistics of failure and repair data, and the best fit of them were carried out. Furthermore, the reliability, maintainability, failure rate, and repair rate models of the robotic system were calculated. The models could prove to be a useful tool both to assess the current conditions and to predict the reliability for upgrading the operations management policies of the robotic system. It was pointed out that (a) the operating time of the robotic system was 88.22% and the remaining 11.78% of the total operating time was under repair, and (b) the failure times follow the lognormal distribution whereas the repair times comply with the loglogistic distribution. The analysis could prove to be a useful tool for manufactures of robotic systems that could improve the design and operation of the systems that they manufacture and operate.

***Keywords:*** *Reliability, maintainability, applied statistics, robotic system, failure and repair data.*

## 1. Introduction

Robots are widely used in industries to perform simple repetitive tasks.A robotic system can be defined as a programmable, self-controlled machine that consists of mechanical, electronic, electrical, hydraulic, and pneumatic components. A failure on a robotic system can have enormous financial and legal consequences. A repeated failure leads to discomfort and customer dissatisfaction, with devastating effects on the market position of the responsible company. Therefore, the system should have a high level of reliability. Therefore, since failure intensity increases with age of the equipment, the equipment requires repair and monitoring. The analysis of the failure data that arise from the operation of the system provides valuable information for improving the efficiency, performance and quality of it [1].

The literature on robotics research is vast, but there has been only limited effort on robot system reliability [2]. Carlson and Murphy [3] proposed a new approach and studied the reliability analysis of mobile robots. The previous approach was extended by Carlson *et al.*[4] using statistical analysis they showed that the mean time between failure (MTBF), mean time to repair (MTTR) and downtime varies widely. Musto [5] presented a novel computational algorithm for solving the reliability-based inverse kinematics problem. Shen Cheng and Dhillon [6] studied reliability, availability, and mean time to failure of a repairable robot-safety system composed of $n$ robots, $m$ safety units, and a perfect switch. Sakai and Amasaka [7] demonstrated the theory and effectiveness of reliability-improvement countermeasures for industrial robots of automotive production line.

Hoshino *et al.* [8] proposed an optimal maintenance strategy on the basis of reliability engineering in fault-tolerant multi-robot systems. Bererton and Khosla [9] quantified the gain in productivity of a team of repairable robots compared to a team without repair

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capabilities based on reliability theory. In another study, Dhillon and Zhijian [10] presented reliability and availability analyses of a mathematical model representing a robot-safety system having n-redundant robots and one built-in safety unit with common-cause failures. Carreras *et al.* [11] and Carreras and Walker [12] used interval method to chalk out the reliability analysis of robot. Khodabandehloo [13] presented the use of systematic techniques such as fault tree analysis (FTA) and event tree analysis (ETA) to examine the safety and reliability of a given robotic system .Yamada and Takata [14] proposed a novel method for improving reliability of manufacturing facilities by optimizing operating conditions. The method is applied to an industrial robot. Sharma *et al.* [15] analyzed the reliability of multi-robotic system and computed various reliability parameters using the fuzzy approach.

The methodology available which can be followed for the reliability analysis of pasta robotic system comprises of ([16]-[19]): (a) understanding and identification of the system and coding the faults; (b) collecting, sorting and classifying failure and repair data for system and fault; (c) data analysis for verification of the identically and independently distributed (*i.i.d.*) assumption; (d) failure data fitting for system and faults with a theoretical probability distribution; (f) reliability and maintainability parameters estimation of the entire system with a best-fit distribution; and (g) identification of critical faults together with formulation of an adequate maintenance strategy with a goal to improve reliability.

In this study, the application of statistical approaches of failure and repair data for analysing the reliability and maintainability (R&M) of a robotic system are presented. The analysis includes the computation of the most important characteristics of the failure data, and the computation of the parameters of the theoretical distributions that best fit the failure data. The reliability and hazard rate models of the system that can be a useful tool for engineers to assess the current conditions, and to predict reliability for upgrading the operation management (*i.e.*, maintenance policy) of the system were calculated.

## 2. Pasta Packing Station

The packaging of the pasta production line contains packaging machines, a robotic system, conveyor belts, packing machines and a palletizer. The pasta that comes from the line through a load belt conveyor feeds the three-vertical electronic wrapping machines (see Figure 1).

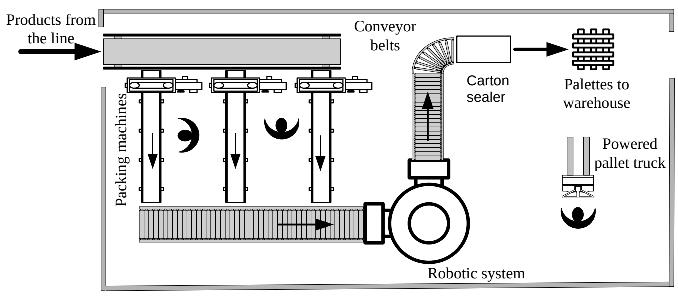


**Figure 1:** Schematic Presentations of the Pasta Packaging Line

The production and best before date with the lot number are printed together on the packaging film. The final products that exit from the pasta production line are loaded onto a conveyor. From there, they go onto the robotic system and are automatically-picked and put in cartons. Then, the cartons are directed to the carton sealer. The filled cartons are placed on a different conveyor that takes them to a worker who stacks them on palettes and transfers them to the finished-goods warehouse.

The robotic system is a complex system that consists of four basic subsystems: i) mechanical subsystem (*i.e.,* conveyor belt, gear box, *etc.*), ii) electrical subsystem (*i.e.*, servo motors, switches, sensors, *etc.*), iii) pneumatic subsystem (*i.e.,* air pistons and valves, *etc.*), and iv) electronic subsystem (*i.e.,* inverters, plc, *etc*.).The robotic system has two hands as grippers and is used to take the final products and put them into the cartons. Moreover, sensors are used to enable the robot to adjust variations in the position of products that are picked up, and to monitor the proper operation of it. When a failure occurs in a subsystem (or component) then the entire robotic system stops operating until the repair process have been completed properly.

## 3. Field Failure Data Construction for the Robotic System

Failure and repair data of the robotic system were collected from the files of the technical department by the end of each shift. They had been recorded in print by the technicians in charge (mechanical and electrical). A total of 166 failures were recorded (see Table 6 in Appendix).These records covered a time period of 55 working days, *i.e.*, 3 months. The pasta production line operates continuously in one eight-hour shift during each workday. From this eight-hour shift the packaging of the pasta production line operates five hours, the rest of the time the line is cleaned and prepared for the next working day. The records included the failures occurring per shift, the action taken to repair the failure, the down time, and the exact time of failure. Therefore, there is the exact time both for the robotic system failure and the repair of this failure. This means that the precision in computing the *time-between-failures* (TBF) of a failure and the *time-to-repair* (TTR) a failure were both recorded in minutes.

Over this working period, the robotic system operated a total of 16440minutes out of which 14503 minutes the line operated without failures and for the remaining 1937minutes the robotic system was under repair. Therefore88.22% $\left( {}^{14503}\!/\!{}_{16440} \times 100 \right)$ of the total operating time the line is function properly, whereas the rest 11.78% $\left( {}^{1937}\!/\!{}_{16440} \times 100 \right)$ of the total operating time the system was under repair.

The currently applied maintenance policy of the robotic system is both corrective and preventive; the preventive maintenance is scheduled and is performed periodically. On the other hand, corrective maintenance comprises of actions taken to restore a failed component or machine to the operational state. The actions involve repair or replacement of all failed components necessary for successful operation of the system. This maintenance policy may include any or all of the following steps: recognition, localization and diagnosis, correction (disassemble, remove, replace, reassemble, and adjust), and operation checkout.

## 4. Statistical Analysis of Field Failure Data

In order to obtain qualitative and quantitative analysis of the failure data for the robotic system, the descriptive statistics of the basic features of the failure and repair data for TBF, and TTR are presented in Table 1. Thus, it is possible to extract the minimum and the maximum value of the sample, mean, standard deviation (SD), coefficient of variation (CV), skewness and kurtosis of the failure data.

From Table 1 the following observations can be made: (a) in the robotic system for every 87.37 minutes there is a failure whose TTR ranges between 4 and 320 minutes. The

CV at machine level is less than one, thereby indicating that the TBF has low variability. (b) The mean TTR for robotic system is 11.67 minutes that ranges between 1 to 60 minutes, with high variability because the CV of the TTR is more than one.(e) Both TBF and TTR has positive skew value, meaning that they presented borderline mode < median < mean.

**Table 1:** Descriptive Statistics of the Robotic System

| Variable | N | Mean | SD | CV | Minimum | Maximum | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|
| TBF | 166 | 87.37 | 73.71 | 0.8437 | 4.00 | 320.00 | 1.28 | 1.01 |
| TTR | 166 | 11.67 | 14.89 | 1.2757 | 1.00 | 60.00 | 1.85 | 2.72 |

The reliability analysis of the failure data is usually based on the assumption that TBF and TTR data are independent and identically distributed in the time domain. For this reason, the trend tests and serial correlation tests of the system for the failure and repair data were carried out.

After collection, sorting and classification of the data, the validation of the assumption for independent and identically distributed (iid) nature of the TBF and TTR data of robotic system must be identified. Thus, the null hypothesis $H_0$: *No-trend in data* (homogeneous Poisson process), and the alternative hypothesis $H_1$: *Trend in data* (non-homogeneous Poisson process) is considered. Moreover, the test statistic $X^2$ is chi-square distributed with $2(n-1)$ degrees of freedom-*df* [20]. The $X^2$ statistic is calculated from the experimental failure data whereas the $x^2_{a,df}$ can be determined from the chi-square distribution given the degrees of freedom. If the statistic $X^2 > x^2_{a,df}$ then the null hypothesis is plausible, otherwise the null hypothesis is rejected and the alternative hypothesis $H_1$ is accepted. The validation of the trend for the TBF and TTR for the robotic system are displayed in Table 2, and at $a$ = 5% level of significance in the $H_0$ is not rejected for both TBF and TTR.

**Table 2:**Calculation of the Test Statistic $X^2$ for TBF and TTR of the Robotic System

| Variable | *df* | $X^2$ statistic | $x^2_{a,df}$ | Decision for $H_0$ |
|---|---|---|---|---|
| TBF | 330 | 383.51 | 288.91 | Not reject |
| TTR | 330 | 427.43 | 288.91 | Not reject |

In addition, the correlation of the failure data should be identified. Figure 2 shows the serial correlation diagrams of the TBF and TTR for the robotic system where the correlation coefficients are calculated for lags that range from 1 to 10 ($k$ = 1,2,3,…,10). The outcome is that there is a lack of correlations for the TBFs and TTRs.

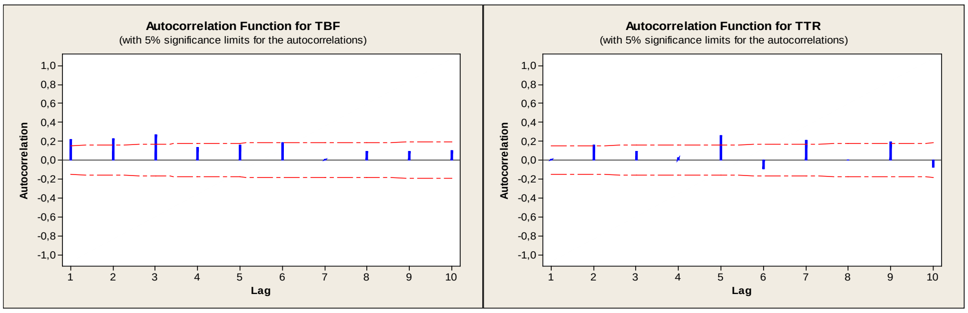


**Figure 2:** Correlation Diagrams of Time between Failure (TBF) and Time to Repair (TTR) for the Robotic System

Therefore, from the trend test and the serial correlation test it is obvious that the failure data for both TBF and TTR of the robotic system are free from the presence of trends and serial correlations.

## 5. Reliability Analysis

Reliability is the probability that a system will perform a required function, under stated conditions, for a stated period of time [21]. To identify the distributions of the trend-free failure data between several theoretical distributions (*i.e.,* Weibull, lognormal, exponential, loglogistic, normal and logistic distribution), the maximum likelihood estimation method was used per candidate distribution and assessed its parameters by applying a goodness-of-fit test - Anderson-Darling. The Anderson-Darling statistics of several theoretical distributions for TBF based on failure data of the machine level are summarized in Table 3. A smaller statistic value indicates that the distribution fits the data better, *i.e.,* for TBF the lowest value is 1.083 which belongs to the lognormal distribution. On the other hand, the TTR has the lowest value of 3.534 and is loglogistic distributed.

**Table 3:** The Anderson-Darling Statistic for TBF and TTR of the Robotic System

| Distributions | TBF | TTR |
|---|---|---|
| Weibull | 2.114 | 5.051 |
| Lognormal | 1.083* | 3.557 |
| Exponential | 3.528 | 9.969 |
| Loglogistic | 1.434 | 3.534* |
| SmallestExtremeValue | 12.634 | 21.853 |
| Normal | 8.261 | 17.972 |
| Logistic | 6.866 | 15.354 |

*(*) indicates the smallest value*

It is assuming $T$ as the continuous random variable representing the time between failures of the system, then it will be lognormally distributed if $Q$ = ln ($T$) is normally distributed. If $\mu$ and $s^2$are the mean and variance of $Q$ respectively, then the corresponding probability density function is:

$$f(t) = \frac{1}{st\sqrt{2\pi}} \exp\left[-\frac{(\ln t - \mu)^2}{2s^2}\right], \qquad t \geq 0$$

The reliability of the robotic system line is:

$$R_{Robot}(t) = \Pr\{T > t\} = \Pr\{\ln T > \ln t\} = \Pr\left\{\frac{\ln T - \mu}{s} > \frac{\ln t - \mu}{s}\right\} = \Phi\left(\frac{\mu - \ln t}{s}\right)$$

where $\Phi$ (.) is the distribution function of the standard normal distribution.

The mean TBF, variance, and mode of the line are found

$$\text{mean}\, TBF = \exp\left(\mu + s^2/2\right), \qquad \sigma^2 = \exp\left(2\mu + s^2\right)\left[\exp\left(s^2\right) - 1\right], \qquad t_{\text{mode}} = \exp\left(\mu - s^2\right)$$

The hazard rate function of the production line is given by

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{\frac{1}{st\sqrt{2\pi}} \exp\left[-\frac{(\ln t - \mu)^2}{2s^2}\right]}{\Phi\left(\frac{\mu - \ln t}{s}\right)}, \qquad t \geq 0$$

where $\mu$ and $s$ for TBF are 4.11098 and 0.8863, respectively (see Fig. 3).

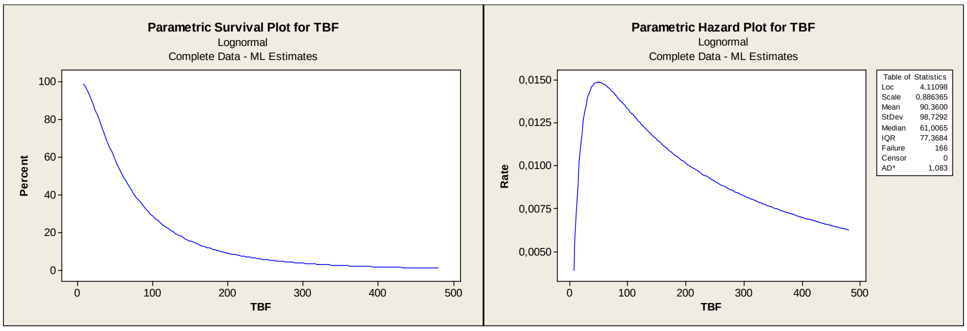


**Figure 3:** Reliability, Hazard Function and the Parameters for TBF of the Robotic System

In Figure 3, the reliability, hazard function and the evaluation of parameters for TBF of the robotic system are displayed. The following observations are made: (a) the reliability of the line, in 5 minutes of operation is 99.76%, in an hour (60 minutes) of operation is 50.75%, and in 5 hrs or 300 minutes (a working day) of operation is 4%. (b)A failure may occur in the first hour (increase failure rate) of system operation, after that the probability for a failure to occur in the following hours is diminished (decrease failure rate) with time.

The following conclusions can be derived for production line TBF based on Table 4 (see Appendix): (a) the time within which, 25% of the failures ($Q_1$, first quartile) are expected to occur, is 33.55 of operating minutes, whereas the time within which, half (50%) of the failures are anticipated to happen, is 61 of operating minutes, and (b) from the percentiles with 95% confidence interval, it is evident that the time within which, 5% of the failures are expected to happen, is 14.19 operating minutes.

## 6. Maintainability Analysis

Maintainability is the probability that a failed system will be restored to operational effectiveness within a given period of time *t* when the repair action is performed in accordance with the prescribed procedures [22]. Maintainability is the probability of completing the repair at a given time. Maintainability analysis is used to identify any weaknesses in maintenance operation on the production line. As mentioned above the TTR follows the loglogistic distribution. If $T_r$ has a loglogistic distribution with shape (or location) parameter $\mu$ and scale parameter $\sigma$, then $Y=log(T_r)$ is logistically distributed with parameters $\mu$and$\sigma$.Thus,

$$M(t)=\Phi_{logistic}[\frac{\log(t)-\mu}{\sigma}], \qquad \lambda_r(t)=r(t)/(1-M(t))=\frac{\frac{1}{\sigma t}\phi_{logistic}[\frac{\log(t)-\mu}{\sigma}]}{1-\Phi_{logistic}[\frac{\log(t)-\mu}{\sigma}]}$$

where $\Phi_{logistic}(z)=\exp(z)/[1+\exp(z)]$ and $\phi_{logistic}=\exp(z)/[1+\exp(z)]^2$ are the cumulative density function and the probability density function for a standardized logistic distribution with parameters $\mu$=0 and $\sigma$=1.

The scale and shape parameters for TTR are 1.6753and 0.7322, respectively (see Fig. 4). Moreover, the median for TTR can be estimated from $t_{median}=\exp(\mu)$ which is 5.34056.

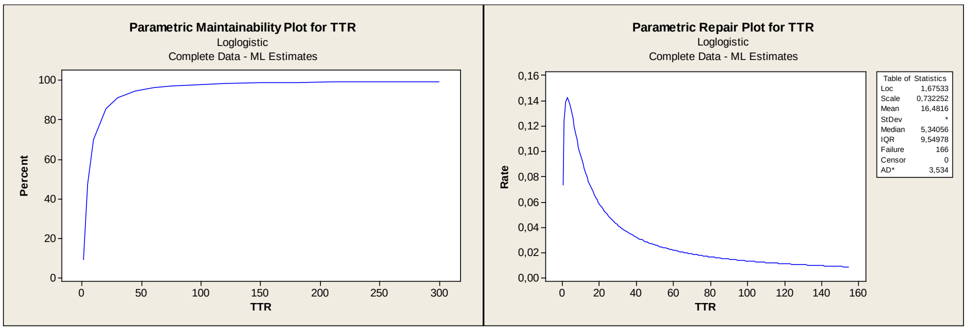


**Figure 4:** Maintainability, Repair Rate and the Parameters for TTR of the Robotic System

In Figure 4, the maintainability, repair rate and the evaluations of parameters for TTR of the robotic system are shown, and the following observations can be made: (a) for $Maint_{Robot}(45)=0.9483$, which means that there is a 94.83% probability that any failure in the system will be repaired within 45 minutes, (b) there is a 100% probability that any failure in the system will be repaired within $t$ > 210 minutes, (c) the TTR has an increasing repair rate up to 5 min and then an decreasing repair rate, meaning that if a repair process has not been completed in the first 5 min and is going on for rather a long time, then this indicates serious problems on the robotic system, *i.e.*, inadequate skill level of maintenance staff, no spare parts are available on the warehouse, insufficient management, *etc*.

In Table 5 (see Appendix) the distribution analysis of TTR for the robotic systemwas presented, and the following conclusions can be derived: (a) 25% of the failures (first quartile, $Q_1$) will be repaired within the first 2.38 minutes, 75% of the failures (third quartile, $Q_3$) will be repaired in 11.93 minutes, whereas half of the failures (interquartile range: IQR= $Q_3$ - $Q_1$) will be repaired in 9.54 minutes, and (b) from the percentiles with 95% confidence interval, one can perceive that 70% of the failures will be repaired within 10minutes.

## 7. Conclusions

The main research findings can be summarized as follows: a) the operating time of the robotic system was 88.22% and the remaining 11.78% of the total operating time the line is under repair because of the system's failures.The mean TBF is 87.37 minutes, whereas the mean TTR is about 12minutes, b) thefailure times follow the lognormal distribution, whereas the repair times comply with the loglogistic distribution, c) the reliability, hazard rate, maintainability, and repair rate models for a robotic system were determined, therefore line operation forecasting at least in short term is feasible, d) a failure may occur in the first hour (increase failure rate) of system operation, after that the probability for a failure to occur in the following hours is diminished (decrease failure rate) with time.

The reliability analysis is very useful for deciding maintenance intervals, and for planning and organizing maintenance. The current maintenance policy of the robotic system could be updated for improving the availability and the operation management of the system.

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## Appendix

**Table 4:** Distribution Analysis of TBF for the Robotic System

Censoring Information Count
Uncensored value: 166
Estimation Method: Maximum Likelihood
Distribution: Lognormal

*Parameter Estimates* (Standard 95.0% Normal CI)

| Parameter | Estimate | Error | Lower | Upper |
|---|---|---|---|---|
| Location | 4.11098 | 0.0687953 | 3.97614 | 4.24582 |
| Scale | 0.886365 | 0.0486456 | 0.795971 | 0.987026 |

*Goodness-of-Fit*
Anderson-Darling (adjusted) = 1.083

*Characteristics of Distribution* (Standard 95.0% Normal CI)

| | Estimate | Error | Lower | Upper |
|---|---|---|---|---|
| Mean(MTTF) | 90.3600 | 7.33640 | 77.0667 | 105.946 |
| Standard Deviation | 98.7292 | 13.8584 | 74.9832 | 129.995 |
| Median | 61.0065 | 4.19696 | 53.3111 | 69.8127 |
| First Quartile(Q1) | 33.5533 | 2.55740 | 28.8973 | 38.9595 |
| Third Quartile(Q3) | 110.922 | 8.45435 | 95.5298 | 128.794 |
| Interquartile Range(IQR) | 77.3684 | 7.12748 | 64.5873 | 92.6786 |

*Table of Percentiles* (Standard 95.0% Normal CI)

| Percent | Percentile | Error | Lower | Upper |
|---|---|---|---|---|
| 1 | 7.76003 | 1.02771 | 5.98595 | 10.0599 |
| 5 | 14.1971 | 1.49813 | 11.5446 | 17.4591 |
| 10 | 19.5907 | 1.81881 | 16.3315 | 23.5005 |
| 20 | 28.9334 | 2.31629 | 24.7318 | 33.8488 |
| 30 | 38.3276 | 2.81219 | 33.1938 | 44.2554 |
| 40 | 48.7362 | 3.40620 | 42.4972 | 55.8911 |
| 50 | 61.0065 | 4.19696 | 53.3111 | 69.8127 |
| 60 | 76.3661 | 5.33726 | 66.5901 | 87.5772 |
| 70 | 97.1048 | 7.12483 | 84.0980 | 112.123 |
| 80 | 128.633 | 10.2979 | 109.953 | 150.486 |
| 90 | 189.977 | 17.6375 | 158.371 | 227.891 |
| 99 | 479.610 | 63.5180 | 369.963 | 621.755 |

**Table 5** Distribution Analysis of TTR for the Robotic System

Censoring Information Count
Uncensored value: 166
Estimation Method: Maximum Likelihood
Distribution: Loglogistic

*Parameter Estimates* (Standard 95.0% Normal CI)

| Parameter | Estimate | Error | Lower | Upper |
|---|---|---|---|---|
| Location | 1.67533 | 0.100628 | 1.47810 | 1.87256 |
| Scale | 0.732252 | 0.0465599 | 0.646453 | 0.829438 |

*Goodness-of-Fit*
Anderson-Darling (adjusted) = 3.534

*Characteristics of Distribution* (Standard 95.0% Normal CI)

| | Estimate | Error | Lower | Upper |
|---|---|---|---|---|
| Mean(MTTF) | 16.4816 | 3.66596 | 10.6578 | 25.4877 |
| Standard Deviation | * | * | * | |
| Median | 5.34056 | 0.537408 | 4.38462 | 6.50491 |
| First Quartile(Q1) | 2.38899 | 0.265295 | 1.92171 | 2.96988 |
| Third Quartile(Q3) | 11.9388 | 1.36921 | 9.53539 | 14.9479 |
| Interquartile Range(IQR) | 9.54978 | 1.23157 | 7.41686 | 12.2961 |

*Table of Percentiles* (Standard 95.0% Normal CI)

| Percent | Percentile | Error | Lower | Upper |
|---|---|---|---|---|
| 1 | 0.18462 | 0.04297 | 0.11698 | 0.29135 |
| 5 | 0.61832 | 0.10313 | 0.44590 | 0.85741 |
| 10 | 1.06866 | 0.15026 | 0.81125 | 1.40775 |
| 20 | 1.93521 | 0.22712 | 1.53754 | 2.43572 |
| 30 | 2.87167 | 0.30614 | 2.33017 | 3.53901 |
| 40 | 3.96866 | 0.40337 | 3.25182 | 4.84351 |
| 50 | 5.34056 | 0.53740 | 4.38462 | 6.50491 |
| 60 | 7.18670 | 0.74109 | 5.87156 | 8.79642 |
| 70 | 9.93204 | 1.08795 | 8.01306 | 12.3106 |
| 80 | 14.7383 | 1.79360 | 11.6107 | 18.7083 |
| 90 | 26.6890 | 3.90543 | 20.0344 | 35.5541 |
| 99 | 154.488 | 37.0825 | 96.5108 | 247.293 |

**Table 6:** Presentation of Time Between Successive Failures (TBF) and Time to Repair (TTR) with their Cumulative (CumTBF/TTR) for the Pasta Robotic System Selected for Study that Cover a Period of 3-Months

| No | TBF | CumTBF | TTR | Cum TTR | No | TBF | Cum TBF | TTR | Cum TTR | No | TBF | Cum TBF | TTR | Cum TTR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 174 | 174 | 5 | 5 | 56 | 15 | 3149 | 2 | 540 | 111 | 314 | 9715 | 15 | 1305 |
| 2 | 31 | 205 | 5 | 10 | 57 | 26 | 3175 | 4 | 544 | 112 | 130 | 9845 | 10 | 1315 |
| 3 | 35 | 240 | 1 | 11 | 58 | 48 | 3223 | 8 | 552 | 113 | 31 | 9876 | 5 | 1320 |
| 4 | 26 | 266 | 2 | 13 | 59 | 38 | 3261 | 1 | 553 | 114 | 95 | 9971 | 15 | 1335 |
| 5 | 26 | 292 | 4 | 17 | 60 | 29 | 3290 | 1 | 554 | 115 | 225 | 10196 | 35 | 1370 |
| 6 | 12 | 304 | 3 | 20 | 61 | 157 | 3447 | 3 | 557 | 116 | 26 | 10222 | 4 | 1374 |
| 7 | 38 | 342 | 1 | 21 | 62 | 30 | 3477 | 2 | 559 | 117 | 120 | 10342 | 25 | 1399 |
| 8 | 29 | 371 | 1 | 22 | 63 | 48 | 3525 | 5 | 564 | 118 | 45 | 10387 | 5 | 1404 |
| 9 | 250 | 621 | 3 | 25 | 64 | 75 | 3600 | 2 | 566 | 119 | 35 | 10422 | 8 | 1412 |
| 10 | 30 | 651 | 2 | 27 | 65 | 88 | 3688 | 5 | 571 | 120 | 250 | 10672 | 3 | 1415 |
| 11 | 48 | 699 | 5 | 32 | 66 | 109 | 3797 | 10 | 581 | 121 | 30 | 10702 | 5 | 1420 |
| 12 | 75 | 774 | 2 | 34 | 67 | 125 | 3922 | 2 | 583 | 122 | 48 | 10750 | 5 | 1425 |
| 13 | 88 | 862 | 1 | 35 | 68 | 125 | 4047 | 2 | 585 | 123 | 75 | 10825 | 2 | 1427 |
| 14 | 109 | 971 | 15 | 50 | 69 | 90 | 4137 | 20 | 605 | 124 | 88 | 10913 | 1 | 1428 |
| 15 | 125 | 1096 | 2 | 52 | 70 | 34 | 4171 | 5 | 610 | 125 | 90 | 11003 | 15 | 1443 |
| 16 | 15 | 1111 | 22 | 74 | 71 | 180 | 4351 | 25 | 635 | 126 | 125 | 11128 | 2 | 1445 |
| 17 | 25 | 1136 | 1 | 75 | 72 | 47 | 4398 | 1 | 636 | 127 | 15 | 11143 | 30 | 1475 |
| 18 | 34 | 1170 | 5 | 80 | 73 | 320 | 4718 | 15 | 651 | 128 | 25 | 11168 | 1 | 1476 |
| 19 | 72 | 1242 | 1 | 81 | 74 | 130 | 4848 | 10 | 661 | 129 | 95 | 11263 | 5 | 1481 |
| 20 | 47 | 1289 | 1 | 82 | 75 | 52 | 4900 | 5 | 666 | 130 | 72 | 11335 | 10 | 1491 |
| 21 | 72 | 1361 | 15 | 97 | 76 | 275 | 5175 | 5 | 671 | 131 | 47 | 11382 | 1 | 1492 |
| 22 | 13 | 1374 | 1 | 98 | 77 | 225 | 5400 | 8 | 679 | 132 | 72 | 11454 | 15 | 1507 |
| 23 | 52 | 1426 | 50 | 148 | 78 | 120 | 5520 | 5 | 684 | 133 | 110 | 11564 | 15 | 1522 |
| 24 | 36 | 1462 | 1 | 149 | 79 | 310 | 5830 | 12 | 696 | 134 | 52 | 11616 | 50 | 1572 |
| 25 | 225 | 1687 | 8 | 157 | 80 | 58 | 5888 | 3 | 699 | 135 | 36 | 11652 | 5 | 1577 |
| 26 | 120 | 1807 | 5 | 162 | 81 | 128 | 6016 | 30 | 729 | 136 | 225 | 11877 | 8 | 1585 |
| 27 | 30 | 1837 | 1 | 163 | 82 | 220 | 6236 | 22 | 751 | 137 | 120 | 11997 | 5 | 1590 |
| 28 | 58 | 1895 | 35 | 198 | 83 | 70 | 6306 | 5 | 756 | 138 | 30 | 12027 | 1 | 1591 |
| 29 | 38 | 1933 | 3 | 201 | 84 | 153 | 6459 | 24 | 780 | 139 | 155 | 12182 | 35 | 1626 |
| 30 | 42 | 1975 | 3 | 204 | 85 | 195 | 6654 | 17 | 797 | 140 | 38 | 12220 | 3 | 1629 |
| 31 | 55 | 2030 | 2 | 206 | 86 | 87 | 6741 | 5 | 802 | 141 | 245 | 12465 | 20 | 1649 |
| 32 | 153 | 2183 | 24 | 230 | 87 | 45 | 6786 | 1 | 803 | 142 | 55 | 12520 | 2 | 1651 |
| 33 | 16 | 2199 | 1 | 231 | 88 | 55 | 6841 | 5 | 808 | 143 | 153 | 12673 | 30 | 1681 |
| 34 | 87 | 2286 | 5 | 236 | 89 | 140 | 6981 | 22 | 830 | 144 | 20 | 12693 | 2 | 1683 |
| 35 | 45 | 2331 | 1 | 237 | 90 | 30 | 7011 | 5 | 835 | 145 | 87 | 12780 | 5 | 1688 |
| 36 | 55 | 2386 | 5 | 242 | 91 | 18 | 7029 | 4 | 839 | 146 | 45 | 12825 | 1 | 1689 |
| 37 | 28 | 2414 | 60 | 302 | 92 | 31 | 7060 | 1 | 840 | 147 | 55 | 12880 | 5 | 1694 |
| 38 | 17 | 2431 | 2 | 304 | 93 | 15 | 7075 | 2 | 842 | 148 | 28 | 12908 | 60 | 1754 |
| 39 | 18 | 2449 | 4 | 308 | 94 | 19 | 7094 | 5 | 847 | 149 | 95 | 13003 | 10 | 1764 |
| 40 | 31 | 2480 | 30 | 338 | 95 | 35 | 7129 | 2 | 849 | 150 | 18 | 13021 | 5 | 1769 |
| 41 | 4 | 2484 | 1 | 339 | 96 | 38 | 7167 | 6 | 855 | 151 | 70 | 13091 | 5 | 1774 |
| 42 | 19 | 2503 | 5 | 344 | 97 | 44 | 7211 | 1 | 856 | 152 | 153 | 13244 | 24 | 1798 |
| 43 | 35 | 2538 | 2 | 346 | 98 | 220 | 7431 | 35 | 891 | 153 | 195 | 13439 | 17 | 1815 |
| 44 | 38 | 2576 | 55 | 401 | 99 | 155 | 7586 | 25 | 916 | 154 | 87 | 13526 | 5 | 1820 |
| 45 | 44 | 2620 | 1 | 402 | 100 | 315 | 7901 | 32 | 948 | 155 | 45 | 13571 | 1 | 1821 |
| 46 | 4 | 2624 | 3 | 405 | 101 | 158 | 8059 | 50 | 998 | 156 | 145 | 13716 | 5 | 1826 |
| 47 | 20 | 2644 | 1 | 406 | 102 | 90 | 8149 | 30 | 1028 | 157 | 140 | 13856 | 22 | 1848 |
| 48 | 15 | 2659 | 1 | 407 | 103 | 158 | 8307 | 60 | 1088 | 158 | 30 | 13886 | 5 | 1853 |
| 49 | 30 | 2689 | 50 | 457 | 104 | 109 | 8416 | 10 | 1098 | 159 | 50 | 13936 | 5 | 1858 |
| 50 | 20 | 2709 | 5 | 462 | 105 | 125 | 8541 | 35 | 1133 | 160 | 120 | 14056 | 25 | 1883 |
| 51 | 15 | 2724 | 1 | 463 | 106 | 100 | 8641 | 2 | 1135 | 161 | 15 | 14071 | 2 | 1885 |
| 52 | 220 | 2944 | 60 | 523 | 107 | 125 | 8766 | 20 | 1155 | 162 | 48 | 14119 | 5 | 1890 |
| 53 | 120 | 3064 | 5 | 528 | 108 | 220 | 8986 | 50 | 1205 | 163 | 35 | 14154 | 2 | 1892 |
| 54 | 45 | 3109 | 5 | 533 | 109 | 180 | 9166 | 25 | 1230 | 164 | 60 | 14214 | 5 | 1897 |
| 55 | 25 | 3134 | 5 | 538 | 110 | 235 | 9401 | 60 | 1290 | 165 | 75 | 14289 | 5 | 1902 |
| | | | | | | | | | | 166 | 214 | 14503 | 35 | 1937 |