Availability and reliability assessment of production systems using simulations

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Abstract. Reliability assessments in the industry is needed to support production planning, facility maintenance, and other related matters. The reliability of an equipment is usually assessed based on the operating period of its components. Likewise the reliability of the system can be assessed based on the reliability of the subsystem. Assessment of the reliability of production systems as a combination of a number of subsystems can be done using analytical models suitable for series and parallel arrangements. For complex production systems, valuation can use a combination of series and parallel models. But for a production system that consists of a lot of equipment in a series arrangement, evaluations using analytical models will provide low reliability that does not reflect real conditions. In the industry studied, the reliability of the system with 14 subsystems in a series arrangement is around 0.2%. Therefore, reliability assessment needs to be done by simulation. Using the proposed simulation model, the reliability of the system obtained is around 90.4%. This assessment shows that the assessment of the reliability of the production system is more appropriate using simulations, and the proposed simulation model can be used in reliability assessments.

Keywords: Reliability, Availability, Productivity, Production System

1. Introduction

A competitive world with increasing customer demand for reliable product shipments in recent years has made reliability engineering a more challenging task. The availability and effectiveness of production systems is also increasingly important in planning and optimization. In this case, reliability analysis is one of the main tools to ensure product quality and delivery deadlines that will maintain certainty in customer loyalty and company reputation. Therefore, evaluating equipment reliability is an important part of most production planning, product design and development, and maintenance program management. [1] This is increasingly challenging for systems consisting of various components, which have become global and essential in today’s society. [2,3]

System reliability is usually assessed using mathematical and statistical equations that are appropriate for system configuration. The reliability of a system or sub-system can be assessed using analytic models for serial and parallel configurations. [4,5,6] However, the results of this assessment do not always show a real situation because the assessment of the reliability of a production system consisting of many subsystems in a long series arrangement will give very low results. In dealing with this problem, equipment reliability assessment needs to be done with simulation applications, by developing and using the appropriate simulation models as needed. [7,8,9].
2. Reliability

2.1 Definition
The reliability of a machine or a system is its ability to consistently perform the intended function or mission in accordance with the request, without degradation or failure. In manufacturing, reliability is the probability of failure-free performance over the useful life of an item or machine within a certain period of time under specified environmental conditions and duty cycles [10]. The analytical method used to calculate the reliability of a system will depend on the configuration of components. The two basic models of system configuration are series configuration and parallel configuration. [5,6]

2.2 Series Configuration
In a series configuration, failure of any component will cause a failure for the entire system, so the reliability of the system is determined by the probability of success of all units in the system. All units must succeed for the system to succeed. The reliability of the system is then expressed by the equation:

\[
R_s = P(X_1 \cap X_2 \cap ... \cap X_n) = P(X_1)P(X_2|X_1)P(X_3|X_1X_2)\cdots P(X_n|X_1X_2\cdots X_{n-1})
\]

where:
- \( R_s \) is the reliability of the system
- \( X_i \) is the event of unit \( i \) being operational
- \( P(X_i) \) is probability that unit \( i \) is operational

In the event that failure of any component will affect the failure rate of the other components, the conditional probabilities in the above equation must be considered. In the case of the independent component, the above equation becomes:

\[
R_s = P(X_1)P(X_2)\cdots P(X_n)
\]

In a pure series system, the reliability of the system is the same as the product reliability of its constituent components, so the reliability of the series system is always lower than the reliability of the most unreliable components. The number of components determines the reliability of the system in a series arrangement. Increasing the number of components in series will reduce system reliability.

2.3 Parallel Configuration
In a system with \( n \) simple parallel units, at least one unit must be successful for the system to succeed. The units in a parallel arrangement are called redundant units, and redundancy is an important aspect in system design and reliability. Increased redundancy is one of several methods of increasing system reliability. The probability of failure for a system with statistically independent parallel components is the probability that 1 unit fails, 2 units fail, and so on until all units in the system fail. In this system, all \( n \) units must fail for the system to fail. The unreliable system is then provided by:

\[
Q_s = P(X_1 \cap X_2 \cap \cdots \cap X_n) = P(X_1)P(X_2|X_1)P(X_3|X_1X_2)\cdots P(X_n|X_1\cdots X_{n-1})
\]

where:
- \( Q_s \) is the unreliability of the system
- \( X_i \) is the event of failure of unit \( i \)
- \( P_i \) is the probability of failure of unit \( i \)

If the failure of one component affects the failure rate of the other components, then conditional probabilities in the above equation must be considered. In the case of the independent component, the above equation becomes:

\[
Q_s = P(X_1)P(X_2)\cdots P(X_n)
\]

\[
Q_s = \prod_{i=1}^{n} P(X_i) \quad Q_s = \prod_{i=1}^{n} Q_i
\]
2.4 Reliability and Availability
The effectiveness of the production system is used as a standard to measure manufacturing productivity. This identifies the percentage of production time that is truly productive. A high effectiveness score means that the manufacturing system is reliable and produces a high percentage of good products. In this context, reliability determines availability and productivity because damaged equipment is not available for use but must stop during repair.[1,4]

Equipment failure and material shortages will result in loss of availability including unplanned outages such as replacement time and repair time. The use of equipment also generally requires time for preparation in the form of installation time or setup time. Likewise changeover time is included in the analysis of the effectiveness, because this determines the time that can be used for manufacturing.[1]

3. Method
System reliability assessment is carried out in two stages of research.
1) In the first stage, field research was carried out to obtain equipment reliability, sub-system reliability and system reliability. This reliability assessment uses an analytic model.
2) The second stage is reliability assessment by using simulations to obtain predictions of subsystem and system reliability. For this assessment, a simulation model is designed, and the generation of imitation data is carried out using the TTF and TTR distribution patterns obtained from field research.

Discrete system simulations are run using imitation data in the operation of simulation models. The simulation is carried out in the number of iterations and replications that meet the validation. The simulation results are then verified and validated by comparing them with the results of the analysis of the availability and productivity of the actual system.

4. Result and Discussion
4.1 Field research
To facilitate this research, one plant was chosen as the target. A palm oil extraction plant was chosen which is available to provide production and maintenance data needed in the reliability analysis. This plant consists of two parts, palm oil processing plant and palm kernel processing plant. The reliability assessment study was conducted only at palm oil processing plants.

At the palm oil processing factory studied, there are 32 units of equipment used in processing. All of this equipment can be grouped into 14 subsystems in a series arrangement, consisting of 6 subsystems with one unit of equipment and 8 subsystems with several units of equipment in a parallel configuration. By using the reliability assessment equation, the reliability of each unit of equipment can be obtained.

Historical data on failure time (TTF) and time to repair (TTR) of each equipment in the one year period, 2018, were obtained from the archives of the maintenance department. Observation and data collection is also carried out for production operations and elements of activities that use the available time. Next, the reliability assessment of each equipment and the operating time analysis were carried out to determine the availability of the system.

By grouping equipment into 14 subsystems, an analysis of the availability and reliability of systems and sub-systems can be carried out. The reliability of subsystems with multiple equipment is assessed using a parallel reliability assessment model. The analysis results are presented in table 1.

The configurations of all equipment that are grouped in 14 subsystems are series configurations. The reliability of the system can be defined as average reliability by considering that failure of certain equipment will affect the operation of the equipment or subsystem itself without causing termination of the entire plant.

By using analytic models for configuration series of 14 subsystems, the reliability of the production system is a product of the reliability of all equipment as follows:

\[ R_s = 0.3845 \times 0.811 \times 0.2994 \times 0.6165 \times 0.6315 \times 0.4106 \times 0.4132 \times 0.7533 \times 0.5041 \times 0.9809 \times 0.9758 \times 0.9659 \times 0.9012 \times 0.9901 \]

\[ R_s = 0.00193 \text{ or } 0.193\% \]
Table 1. The configuration and reliability of 14 subsystems in factory of PT. XYZ

| Order | Subsystem                  | Units | Configuration | Reliability | Availability |
|-------|----------------------------|-------|---------------|-------------|--------------|
| 1     | Loading Ramp               | 1     | Single        | 0.3845      | 99.60        |
| 2     | Sterilizer                 | 2     | Paralel       | 0.8110      | 98.79        |
| 3     | Tippler                    | 1     | Single        | 0.2994      | 99.44        |
| 4     | Fruit Bunch Conveyor       | 1     | Single        | 0.6165      | 99.39        |
| 5     | Thresher                   | 2     | Paralel       | 0.6315      | 99.06        |
| 6     | Re-thresher                | 1     | Single        | 0.4106      | 99.11        |
| 7     | Main Fruit Conveyor        | 1     | Single        | 0.4132      | 99.24        |
| 8     | Fruit Elevator             | 2     | Paralel       | 0.7533      | 99.60        |
| 9     | Top Distribution Conveyor  | 1     | Single        | 0.5041      | 99.27        |
| 10    | Digester                   | 4     | Paralel       | 0.9809      | 98.98        |
| 11    | Screw Press                | 4     | Paralel       | 0.9758      | 98.63        |
| 12    | Vibrating Screen           | 3     | Paralel       | 0.9659      | 99.05        |
| 13    | Oil Purifier               | 3     | Paralel       | 0.9012      | 99.25        |
| 14    | Sludge Centrifuge          | 6     | Paralel       | 0.9901      | 99.16        |

The reliability of the system as average reliability can be calculated as Rs.

\[
Rs = \frac{R_1 + R_2 + \ldots + R_n}{n}
\]

\[
Rs = \frac{(0.3845+0.8110+0.2994+0.6165+0.6315+0.4106+0.4132+0.7533+0.5041+0.9809+0.9758+0.9659+0.9012+0.9901)}{14} = 0.6884
\]

Average availability is 0.9918 or 99.18%

The reliability of the production system using an analytical model is very low under 1 percent, which is very difficult to accept as a result of an assessment that reflects the real situation. While the average reliability is 0.6884 or 68.84% with an availability rate of 99.18%. Thus the analytic model is not suitable for use in assessing the reliability of production systems. Therefore, reliability assessment needs to be carried out using simulations, and for this reason it is necessary to develop a simulation model that is suitable for the production system being assessed.

4.2 Simulation Results

Research in the laboratory is conducted to assess the reliability of subsystems and systems using system simulations. The simulation is run by operating the simulation model using imitation data. Imitation data for the time interval between damage is generated using random numbers and the pattern of time interval distribution between damage (TTF) as a reference model obtained from observational data analysis. In this case, the MTTF and time interval distribution patterns between damage are obtained from the analysis of historical data of each equipment using reliability analysis software. Reliability analysis was carried out for 32 equipment from 14 subsystems. Distribution patterns obtained from the analysis are 4 equipment with Normal patterns, 17 equipment with Lognormal patterns and 5 equipment with Weibull patterns.

The development of simulation models begins with the preparation of a reliability assessment model in the form of an algorithm or flowchart for determining the length of time used for equipment repair. The algorithm model is then translated into a series of formulas in an Excel worksheet.

Using imitation data, the imitation operation is performed to get a prediction of the total repair time for all equipment in a period of 1 year. The simulation is run in 287 working days in a year starting from the first day. The time between failures on each equipment and subsystem is predicted using random numbers as probabilities in the distribution pattern model, while the repair time is predicted randomly using uniform patterns. In accordance with this prediction, the simulation is executed by carrying out imitation operations of each subsystem on the system. The procedure for implementing the simulation in the form of an algorithm is presented in Figure 1.
Figure 1. Simulation algorithm of system reliability assessment

The simulation is run for 365 calendar days in one year. The number of effective working days in one year is 287 working days after deducting 52 working days for Sunday as a free day every week, and 26 days for half a working day on Saturday. On Saturdays, the factory operates in half a day, between 8 and 12 hours. In this simulation, the time interval between damage (TTF) for each equipment is calculated in units of minutes with respect to the predicted repair time (TTR) based on field data obtained in units of minutes. From field information it is known that the factory operates an average of 18 hours per working day. Thus, the operating time in one year is 287 x 18 x 60 minutes = 309,960 minutes.

In accordance with company policy, equipment preparation must be carried out routinely every working day before production operations. The duration of preparation time, known as setup time, is determined by the factory manager. The length of setup time is not the same from day to day but varies depending on the situation at hand. The duration of this setup is not related to the length of time required to repair damaged equipment. From the field recording of the implementation of the setup in the past year, the total preparation time in one year is 48,852 minutes, so that the total time available for production operations in one year is 309,960 - 48,852 = 238,614 minutes.

By using the average time needed to repair damage to each unit of equipment, the simulation application provides a prediction of repair time for each equipment. These prediction results are obtained by taking into account the frequency of equipment damage in one year. The predicted total repair time for all equipment in one year is 25,350 minutes. Prediction of the total length of time to repair equipment, as shown in table 2, is the average value of the total time to repair equipment obtained from simulation applications with 10 replications, 10 iterations per each replication, and 30 cycles per iteration.

The effective time available in one year period is 309,960 - 25,350 - 48,852 = 235,758 minutes. From the simulation, the total number of repairs is 430 events per year or around 1.5 repairs per day. Within 1 year, there were 57 days without repairs, and the highest number of repairs was 5 repairs in one day. With a total available time of 235,758 minutes, the availability of the system is 235,758 / 309,960 = 0.7607 or 76.07%. While the ratio of total processed materials (252/413 tons) to installed capacity (327/180 tons based on 30 tons / hour) is 0.7714 or 77.14%. The difference between availability and production ratio is quite small around 1%, so the simulation model can be used to determine system reliability. Based on this availability, the reliability of the system is 0.904 or 90.40%, which is higher than the analytical reliability value of 67%.
Table 2. Results of system simulation

| Replication | Repairs | TTR (minutes) | Availability | Reliability |
|-------------|---------|---------------|--------------|-------------|
| 1           | 431     | 25525         | 0.7596       | 0.9053      |
| 2           | 433     | 25667         | 0.7604       | 0.9032      |
| 3           | 434     | 25040         | 0.7574       | 0.9055      |
| 4           | 429     | 25583         | 0.7602       | 0.9050      |
| 5           | 430     | 25677         | 0.7618       | 0.9029      |
| 6           | 426     | 25229         | 0.7614       | 0.9035      |
| 7           | 425     | 24942         | 0.7612       | 0.9042      |
| 8           | 432     | 25171         | 0.7633       | 0.9038      |
| 9           | 430     | 25304         | 0.7608       | 0.9029      |
| 10          | 426     | 25363         | 0.7613       | 0.9038      |

Average 430 25350 0.7607 0.9040

The average reliability of the production system as shown in table 1 is 99.18%, not so different from the simulation results which is 90.40%. Thus the assessment of system reliability, especially production systems that consist of many subsystems and equipment, is appropriate using simulations.

5. Conclusion

Discrete system simulation applications are suitable for evaluating the reliability of systems consisting of many equipments in long series settings. The results of the reliability assessment with the simulation application are more representative than the results of the assessment with the analytic model. Likewise in the case of availability assessment, the use of simulation provides more complete results including frequency and time to improve equipment in the system.

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