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Terje Aven Availability Model Application to the N-1 System with One Unit of Backup Towing Motor Components for Kiln Machine Preventive Maintenance

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Abstract

The kiln machine is one of the pieces of machinery used to produce granite tiles. One of its many crucial components is the towing motor. The production process requires a high-performance and easily accessible kiln unit because it lasts for 24 hours. As a result, there will be less downtime since the extra towing motor can replace the damaged one. The Terje Aven availability model calculates the number of towing motor reserves. The availability of kiln equipment has not yet achieved its full potential because the company currently has six backup towing motors.

***Keywords**:* Availability, Downtime, Components Reserve

INTRODUCTION

One of the machinery used in the manufacture of granite tiles is the kiln machine. This machine is used as a firing machine to increase its power. This machine has several key components. One of them is the towing engine. Kiln machines run continuously, necessitating preventative maintenance to avoid machine damage. However, preventive maintenance might diminish kiln machine availability to the point that towing motor reserves are required to replace a failing towing motor.

The Terje Aven availability model is used to compute the number of towing motor reserves. Availability is the likelihood that a machine will be able to run for a certain period of time. The Terje Aven availability model on N-1 identical machine systems, which is supported by a 1 unit machine reserve, can be used to keep inefficient machines at bay. There are numerous towing motor reserves that may be costly.

Terje Aven created an availability model based on an N-1 identical machine system with a 1 unit machine reserve, where identical machines are defined as having the same performance..

The kiln machine is one of the machines used in the production of granite tiles. This machine is utilized as a firing machine to strengthen it. This machine contains several critical components. The towing motor is one of them. Kiln machines work 24 hours a day, which necessitates preventive maintenance to avoid machine damage. However, preventive maintenance might reduce kiln machine availability to the point where the presence of towing motor reserves is required to replace a failing towing motor.

LITERATURE REVIEW

Maintenance

Definition of Maintenance

Machine maintenance is an intricate matter as it relates to many other aspects of modern industrial practices (Huang et al., 2019). The maintenance policy aims to improve system reliability, prevent the occurrence of system failures, and reduce maintenance costs (H. Wang, 2002). Regarding the structure of the system of interest, the maintenance policies can be categorized into single-unit policies and multi-unit policies. The single-unit policies are designated for those standalone systems, and they have been extensively investigated by Wang (H.Wang, 2002). Therefore, single-unit maintenance could often be modeled as a stochastic process in which optimal PM decision variables can be obtained by minimizing the maintenance cost rate or maximizing machine availability in some circumstances. The maximum machine availability for the serial production line does not guarantee an optimal maintenance cost. The buffer states, for which we typically cannot compute the probability distribution (Li et al., 2009), determine the system production loss brought on by a maintenance action (Zou et al., 2017).

The elements of the multi-unit system differ from the single-unit system in that they are structurally or functionally dependent on one another. Based on the unique structures of the systems, such as serial systems (Ebrahimipour et al., 2013), parallel systems (Barros et al., 2007), and k-out-of-n systems (de Smidt-Destombes, van der Heijden, & van Harten, 2009), maintenance policies have been developed. The majority of the current maintenance practices for closely networked serial systems are based on "group maintenance" and "opportunistic maintenance." In contrast to The group maintenance policy (Xia et al., 2015), the opportunistic maintenance policy (Nicolai & Dekker, 2008; Shafiee & Finkelstein, 2015), determines the time window during which the inserted PM will not suffer additional production losses. They were motivated by the

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discovery that while one machine is undergoing repair, the others can do so concurrently without experiencing an additional loss of production. However, it does not apply to a normal serial production line, as the buffers between the machines could prevent the machine 4 stoppages from spreading to the adjacent machines (Liu et al., 2012; Zou et al., 2018).

Maintenance Form

Carvalho (2019) states three different maintenance management methods are frequently used in industrial and process plants.

First is run-to-failure (RTF) or reactive maintenance, in which maintenance interventions are conducted only after failures occur. This strategy is commonly used when equipment failure does not significantly impact operations or production.

Second, planned preventive maintenance (PvM), or time-based or scheduled maintenance, entails taking the necessary precautions and following the proper protocols to lessen the likelihood of equipment failure and prevent accidents or failures before they happen. It is frequently done to avoid an unplanned breakdown while the machinery is still operating. Therefore, this maintenance plan uses Run-to-failure and predictive maintenance to balance complexity.

Finally, predictive maintenance (PdM), which uses condition monitoring technology to analyze equipment performance via IoT systems that connect electronic devices to mechanical and digital machines and collect large amounts of data, is the third option. Data is collected over time to monitor the condition of equipment and build models that can aid in preventing problems.

Terje Aven Availability Study

Terje Aven's availability model is based on an N-1 unit identical and independent machine system where it has to have the same performance and doesn’t cause damage to other components. The Terje Aven availability model is supported only by one component or machine reserve that can replace damaged components. First, the time average proportion from the reserves system, which only has one inoperable component, must be calculated to obtain the availability system score.

Reliability Concept

Reliability is the ability of the machinery or equipment to function consistently without suffering damage. Time is a crucial factor in dependability since it is connected to failure rates and can provide more information about how reliable a system is. Reliability phenomena can be defined using a probability that fits a specific distribution. T random variables (failure times), which represent the failure process, have the following characteristics:

1. f(t), the density probability function
2. F(t), the cumulative distribution function
3. R(t), the reliability function
4. λ (t), the hazard rate function

Mean Time To Failure

According to Charles Ebeling (1996), the average value of each failure time interval is the mean time to failure (MTTF). The following mathematical calculation is used to calculate the MTTF score:

$$MTTF = \theta \Gamma \left(1 + \frac{1}{\beta}\right)$$

With :

θ : scale parameter

Γ(x) : a score from gamma table

β : shape parameter

Three Lambdha Scenario

The failure rate of machinery in a system is revealed by lambda (λ). In truth, failure rates do not always have a constant distribution, so an average lambda score is required to produce a lambda score that is near to reality. The average lambdha score is an approximation of a machine's failure rate prior to preventive maintenance times (T_{pm}). The following equation will be used to determine $\lambda_1, \bar{\lambda}$:

1. $\bar{\lambda} = \frac{1}{T_{Pm}} \int_0^{T_{Pm}} \frac{f(t)}{1-F(t)} dt$

2. $\lambda_1 = \frac{1}{\alpha}$

The following calculation is used to determine the value of λ_2 (ω)

3. $E_{Tpm} = \int_0^{Tpm} e^{-\omega x} dx$

The equation then states that to calculate the λ_2 (ω), the equation is as follows:

4. $1 - \omega E_{Tpm} = e^{-\omega T_{pm}}$

To get the λ_2 (ω), we must iterate until the difference between the right and left sides is close to 0.

Economic Order Quantity

One strategy for optimizing raw material ordering is the economic order quantity (EOQ) method. The Hadley-Within technique is used to calculate the Q and r values as follows:

1. Using the Wilson model to calculate Q value
2. Using the Q value from Step 1, calculate the probability of a lack of inventory.
3. Using the Poisson Table, manually calculate the reorder point (r) value.
4. Estimating the value of inventory shortages.
5. In addition, start the second iteration by adding the value for the shortage inventory assumption.
6. Following steps 1, 2, 3, 4, and 5 again. The iteration can generate Q and r optimal values if the outcome is the same as the first one.
7. Calculating the overall cost of the inventory.

METHODS

In this scenario, the data used are historical kiln machine data, motor towing component data, lead time, ordering cost, holding cost, and stockout cost.

Current Preventive Maintenance

High-performance, high-availability kiln equipment is required to support the production process because it lasts 24 hours. To avoid production process delays that could be costly to the organization, towing motor reserves must be available to replace damaged towing motors.

Troubleshooting

The Terje Aven availability model is used to determine the number of towing motor reserves. To avoid inefficiency and the number of towing motor reserves that could result in large investment costs, the Terje Aven availability model on the N-1 identical machine system, which is supported by a 1-unit machine reserve, can be employed.

DISCUSSION

The calculations for the Terje Aven availability model are included in this section.

Critical Components of Motor Towing

This section describes how to utilize a Pareto diagram to pinpoint important elements. In accordance with the 80%/20% concept, a towing motor component failure can account for up to 80% of the total damage; in this scenario, the component is regarded as vital for the towing motor.

Time Validation of Each Failure Component

The initial step in determining key component age replacement is to time validate each component's failure by performing a two-parameter Weibull distribution calibration. The steps for validating the failure time with the two-parameter Weibull distribution are as follows:

1. Determining the H0 and H1 hypotheses.
2. Calculating the S-Mann Test to see if the failure time is a Weibull distribution.
3. Using the F distribution table to calculate the Ftable value.
4. If the M value from the S-Mann test is less than the Ftable value, the component failure time is distributed according to the Weibull distribution.

Table 1 Time Validation of Planet Disc Components

i	t_i	Ln_{ti}	Z_i	M_i	$Ln_{ti+1}-Ln_{ti}$	$(Ln_{ti+1}-Ln_{ti})/M_i$	
1	44	3.784	-3.044	1.149	0.022	0.020	5.312
2	45	3.807	-1.895	0.566	0.065	0.114	
3	48	3.871	-1.329	0.398	1.216	3.060	
4	162	5.088	-0.932	0.320	0.320	0.999	
5	223	5.407	-0.612	0.279	0.009	0.032	
6	225	5.416	-0.333	0.258	0.281	1.087	
7	298	5.697	-0.075	0.254	0.120	0.473	0.757
8	336	5.817	0.179	0.268	0.061	0.226	
9	357	5.878	0.447	0.319	0.014	0.044	
10	362	5.892	0.766	0.558	0.008	0.015	
11	365	5.900	1.325				

Weibull Distribution Parameter Estimation

The Weibull distribution parameters are estimated to determine the scale parameter value (α) and the shape parameter value (β). The scale parameter specifies the component age, which can have an effect on the average value or data spread of the failure distribution. Aside from that, the shape parameter reflects the pattern of failure distribution. The scale and shape parameter values will be used in the Mean Time To Failure (MTTF) computation. The formulas for calculating scale and shape parameter values are as follows.

1. $b = \frac{N\sum_{i=1}^{r} Xi.Yi - \sum_{i=1}^{r} Xi.\sum_{i=1}^{r} Yi}{N\sum_{i=1}^{r} Xi^2 - \left(\sum_{i=1}^{r} Xi\right)^2}$ (1)

2. $a = \frac{\sum_{i=1}^{r} Yi}{N} - b\frac{\sum_{i=1}^{r} Xi}{N}$ (2)

3. $\beta = \frac{1}{b}$ (3)

4. $\alpha = \exp(a)$ (4)

Table 2 Weibull Distribution's Parameter Estimation for Planet Disc Components

i	ti (hari)	F(ti)	Yi	1/(1-F(ti))	Ln(1/(1-F(ti)))	Xi	Xi.Yi	Xi2	b	a	β	α
1	44	0,067	3,784	1,072	0,070	-2,664	-10,080	7,096	0,744	5,457	1,345	234,377
2	45	0,163	3,807	1,195	0,178	-1,723	-6,560	2,970				
3	48	0,260	3,871	1,351	0,301	-1,202	-4,653	1,445				
4	162	0,356	5,088	1,552	0,440	-0,822	-4,180	0,675				
5	223	0,452	5,407	1,825	0,601	-0,509	-2,750	0,259				
6	225	0,548	5,416	2,213	0,794	-0,230	-1,248	0,053				
7	298	0,644	5,697	2,811	1,033	0,033	0,188	0,001				
8	336	0,740	5,817	3,852	1,349	0,299	1,740	0,089				
9	362	0,837	5,892	6,118	1,811	0,594	3,500	0,353				
10	365	0,933	5,900	14,857	2,698	0,993	5,857	0,985				
Total			50,679			-5,231	-18,188	13,926				

Critical Components Age Replacement

The critical component age replacement calculation is taken by using Mean Time To Failure (MTTF) because MTTF values represent each failure time interval, with the result that the age replacement of the components can be known. The formula to figure out the mean time to failure (MTTF) is as follows:

$$MTTF = \theta\Gamma\left(1 + \frac{1}{\beta}\right) \quad (5)$$

The following is an example calculation for Planet Disc components:

$$MTTF = \theta\Gamma\left(1 + \frac{1}{\beta}\right)$$

$$= 250.507\,\Gamma\left(1 + \frac{1}{1.379}\right)$$

$$= 250.507\,\Gamma\,(1.73)$$

= 230 days

Three Lambdha Scenario

This section describes the 3-lambda scenario computation, which includes lambda 1, average lambda, and lambda 2.

1. Lambdha 1 is an optimal lower limit for cumulative distribution function with the age average expectation ETpm as follows.

$$\bar{F}(t) \leq \begin{cases} e^{-t/E_{Tpm}} & t < E_{Tpm} \\ 0 & t \geq E_{Tpm} \end{cases} \quad (6)$$

$$\lambda_1 = \frac{1}{\alpha} \quad (7)$$

$$\lambda_1 = \frac{1}{52.059}$$

$$\lambda_1 = 0.019$$

2. Average Lambdha is the average rate failure estimation in machines before the preventive maintenance time. The average rate failure estimation equation is based on K.C. Kapur and L.C. Lamberson's theories.

$$\bar{\lambda} = \frac{1}{T_{Pm}} \int_0^{T_{Pm}} \frac{f(t)}{1-F(t)} dt \quad (8)$$

The calculated value of $\bar{\lambda}$ is 0.014.

3. For t > ETpm dan F is Increasing Failure Rate (IFR) with machine lifetime expectation ETpm then ω i (λ2) value can be calculated by this formula.

Table 3 The Calculation of Lambdha 2

$\omega(\lambda_2)$	$1 - \mu_{Tpm}\omega$	$e^{-\omega T_{pm}}$	Difference
0,001791	0,9145	0,9143	0,0002
0,001801	0,9140	0,9139	0,0001
0,001811	0,9136	0,9134	0,0002
0,001821	0,9131	0,9130	0,0001
0,001831	0,9126	0,9125	0,0001
0,001841	0,9121	0,9121	0,0000
0,001941	0,9074	0,9075	-0,0001
0,001951	0,9069	0,9071	-0,0002
0,001961	0,9064	0,9066	-0,0002
0,001981	0,9054	0,9057	-0,0003
0,002011	0,9040	0,9043	-0,0003

Terje Aven Availability Model Calculation

Terje Aven's availability calculation is tallied from N = 2 to N = 9, with one towing motor operating and 1 unit of towing motor reserve. The process is continued until N = 9. Because the corporation has six towing motor reserves and 48 units of towing motors in operation, the computation is repeated until N = 9. The recommended number of towing motor reserves is 9 units based on Terje Aven availability for $T = T_{pm}$, $T < T_{pm}$, and $T > T_{pm}$ situations.

CONCLUSIONS

The results of the computations and observations are as follows:

1. The planet disc, ball ring, friction bearing planet disc, adjustable annulus race, adjustable sun race, fixed sun race, and dan bearing are key components of a towing motor, according to the Pareto Diagram.
2. The longest-lasting towing motor components are friction-bearing planet disc components (320 days) and bearings (50 days).
3. For $T = T_{pm}$, $T< T_{pm}$ and $T> T_{pm}$ condition is 9 unit of towing motor.

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