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Predictive Modelling of a K-Unit Botttling Plants for Reliability Improvement

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Abstract

The study presents an innovative approach of investigating and predicting the reliability of a K- unit configuration system. This novel approach investigated the major systems on each production line, in order to predict their optimal reliability for their respective hour of operation. The series network framework consists of a rinser machine, filler machine, capping machine, labeling machine and coding machine. The reliability of each system was evaluated by assuming a failure rate, $\lambda = 0.04 per hour$ to each subsystem and the mean time to failure was equally evaluated. Based on the calculation using the predicted model, at a mission hour of 24,168,312 and 456 hours, the respective reliabilities were; 0.3829, 0.0012, 0.0000038 and 0.000000012. The result showed that the reliability of the system decreases drastically with increasing mission time. Based on this result, the productivity of the plants is expected to be very low, hence the need to improve the reliability. The result also showed that the predicted model is good and efficient in predicting and improving plant performance. Further to this result, the reliability of the bottling machines can be improved by applying the developed model.

Keywords: : Failure mode and Effect Analysis, Maintenance, Reliability, Production Technology, Bottling Machines.

1. **Introduction**

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It is a regular occurrence in practice that, engineering components' performance in operation is always low compared to the theoretical design strength irrespective of the environment and factors that they are subjected to while in service [1]. These factors include; poor material selection, casting defects, inadequate maintenance and design deficiencies [2]. This become expedient for failure analyst to properly look into the failure behavior of these engineering components, in order to avert, reduce and /or improve on the performance of the components and the entire system or machine [3]. For reliability improvements of processes and machines in additive manufacturing industries, Failure mode and effect analysis (FMEA) used with fault tree analysis (FTA) have proved effective and reliable in predicting the hazards rate of system failure as well as improving the system performance [4]. Also, [5, 6,7,8] showed that hybrid (Fuzzy FMEA) has effectively eliminate the inherent uncertainties associated with failures in liquefied hydrogen gas tankers as well as water gasification. In fact, Failure mode and effects analysis technique was employed in geothermal power plants to detect the potential hazards caused by failure mode in order to enhance power production [9].

Furthermore, Failure mode and effects analysis (FMEA) technique has proven effective in revealing the potential causes of failures in thin-film technology production [10]. Also, [11] showed that the result of the critical investigation of potential failures and its consequences in heating ventilation and air conditioner (HVAC) system using Failure mode and effects analysis (FMEA) had improved the convenience of the occupants as well as its operation and maintenance. On the same hand fuzzy based Failure mode and effects analysis (FMEA) technique was used to reduce the possibilities of accident occurrence in aircraft landing device. However, the reliability of the technique has not been found satisfactory based on the severity of failure of component [12]. Consequently, [13] noted that the reliability of photovoltaic equipment has been on the decrease due to the presence of several failure mode resulting from the presence of humidity on the equipment. More so, noise and vibration increases the wear rate of engineering component in service, thus reducing the reliability at large [14]. In addition, distortion of hardness and toughness eventually affect the fatigue properties of engineering component. Thus the possibility of a machine or component performing better becomes difficult [15, 16,17]. Certainly, Failure mode and effects analysis (FMEA) is a good technique for evaluation of system reliability. However, it has limitations in some applications where frequency of failure is high. Therefore, the aim of this research is to develop a predictive model for assessing the reliability of bottling plants using K-unit reliability evaluation technique. Also, to determine the respective reliability of the plants per week using the model in order to justify its importance over existing model.

Nomenclature

λ_R- failure rate of the rinser machine
λ_F -failure rate of the filler machine
λ_C -failure rate of the capper machine
λ_L -failure rate of the labeler machine
λ_S -total failure rate of the system

E -denote the successful operation of each unit
E_R- successful operation of the Rinser machine
E_F -successful operation of the filler machine
E_C -successful operation of the capper machine
E_L -successful operation of the labeler machine
R_S -series system reliability
$P(E_R)$ -probability of occurrence of event E_R
$P(E_F)$ -probability of occurrence of event E_F
$P(E_C)$ -probability of occurrence of event E_C
$P(E_L)$ -probability of occurrence of event E_L

$R_j(t)$ - Reliability of unit j at time t

$R_S(t)$ - system reliability at time t

$MTTF_S$ is the series system mean time to failure

R, F, C, L   Rinser, Filler, Capper and Labeller machines

FMEA: Failure mode and effect analysis

2. Materials and Method
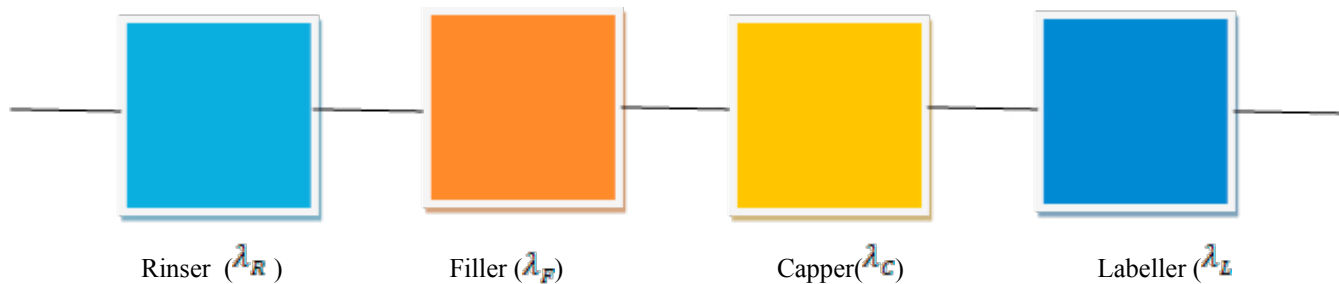
2. 1 .1Modelling of the system reliability

Fig.1. K-Unit Assembly of Bottling Plants.

Consider a K-unit configuration of the bottling plants shown in figure 1. Some assumptions were utilized for effective modelling practice. These assumptions are that the line is composed of four (4) identical systems in series, the failure rate is constant for each system and sub-system denoted by λ and all unit must function under a recommended operating speed for the successful operation of the bottling line. Since the failure rate for each machine is assumed to be λ, the total failure rate for a system in series is given by [18]:

$$\lambda_S = \lambda_R + \lambda_F + \lambda_C + \lambda_L \tag{1}$$

$R_S = P(E_R\, E_F\, E_C\, E_L)$ denote the occurrence probability of events E_R, E_F, E_C, E_L

If the above machines fail independently; equation (1) becomes

$$R_S = P(E_R)\, P(E_F)\, P(E_C)\, P(E_L) \tag{2}$$

Equation (2) becomes;

$$R_S = R_R \cdot R_F \cdot R_C \cdot R_L \tag{3}$$

For constant failure rate λ_j of each unit, from equation (1) i.e. $\lambda_j(t) = \lambda_j$

We have $R_j(t) = e^{-\lambda_j}(t)$ $\tag{4}$

Substituting equation (4) into equation (3)

$$R_S(t) = e^{-\lambda_R(t)} \cdot e^{-\lambda_F(t)} \cdot e^{-\lambda_C(t)} \cdot e^{-\lambda_L(t)}$$

$$R_S(t) = e^{-\sum_{j=1}^{k} \lambda_j(t)} \tag{5}$$

2. 1.2 Modelling of the system mean time to failure (MTTF)

From equation (5)

$$MTTF_S = \int_0^\infty e^{\sum_{j=1}^{k} \lambda_j t} \, dt \text{ [18]:} \tag{6}$$

Integrating equation (6) within the interval of 0-∞ gives:

$$MTTF_S = \frac{1}{\sum_{j=1}^{k} \lambda_j} \tag{7}$$

2.2 Determination of the Reliability and Mean Time to Failure of the bottling machines

The machines are identical, independent in configuration and in series. From experience, assuming that we have one (1) failure per day from any of the machines, then failure rate can be obtained as $\frac{1}{24}$ = 0.04 failure per hour, $\lambda = 0.04 per\ hour$. For different hours of operation, substituting the values into equation (5) gives the reliability of the machine. Substituting the failure rate into equation (7) gives the mean time to repair of the series system

This amounts to 6.25 hours.
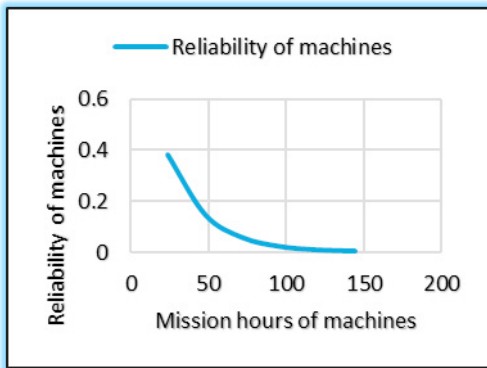
3. Results and Discussion

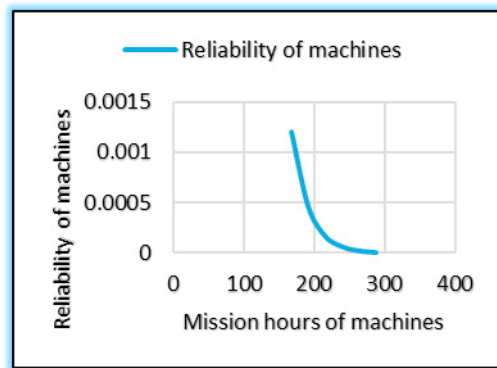Fig.2. Plot of Reliability against Mission hours of Machines for week1

Fig.3. Plot of Reliability against Mission hours of Machines for week 2
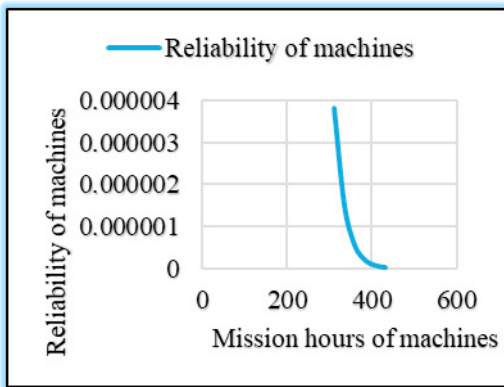

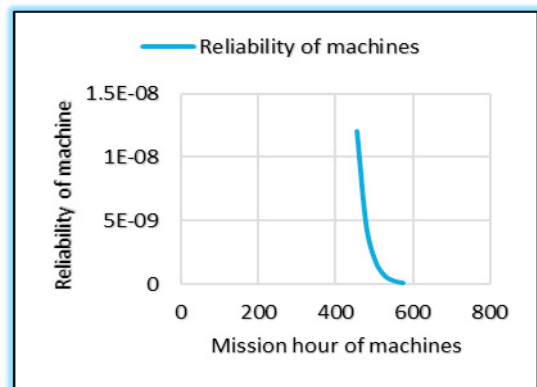Fig.4. Plot of Reliability against Mission hours of Machines for week3

Fig.5. Plot of Reliability against Mission hours of Machines for week 4

Figure 2, presents the plot of reliability versus mission hours of machine operation for week 1. It can be deduced from the plot that the reliability of the machine reduced with an increasing mission hours of machine operation. A typical inference that can be drawn from the plot, reliability of the machine at 24 hours of operation was found to be 0.3829 compared to when the mission hours of the machine was increased to 144hours having a drastic drop in reliability of 0.0032. This implies that the machines are not performing according to the required efficiency reasons could be downtime. More so, figure 3, also represent the variation of reliability with mission hours of machine operation for week 2. It was observed from the fig.3 that the same trend of geometric decrease in reliability showed forth as mission hours was increased. Further to these, reliability at 288 hours was found to be 0.0000099 indicating poor performance of the machines. However, figures 4-5, present the plot of reliability versus mission hours for weeks 4 and 5. From the two plot, it was observed that the fall in reliability was at a geometric progression. With machine reliability at 432hours being 0.000000031 for week 4 and reliability at 576hours being 0.000000000099.

Conclusion

A predictive model was developed using K-Unit approach for reliability evaluation. The model was applied to evaluate the reliability of bottling plants assembled in series with variations in hours of operation for four (4) weeks. The result revealed the geometric fall in reliability with increasing mission hours in each of the week, with week 4 having the lowest performance. Based on the result of the calculations using the model, it was possible to say that the machines' performance was not good compared with expected target. Running the machines for longer hours without adequate planned maintenance will eventually lead to increased equipment downtime. Adequate maintenance of the bottling machines would be needed to improve on the machine reliability. Therefore, predictive model was useful in evaluating the reliability of bottling plants.

Acknowledgement

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