Performance Analysis of Biscuit Manufacturing Plant in Steady State Using Fuzzy Availability

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ABSTRACT
This paper deals with the performance analysis of biscuit manufacturing plant consisting of six sub-systems using fuzzy availability in the steady state. These six sub-systems are arranged in series and parallel configurations. Mathematical formulation of the problem is carried out using Markov process and the governing differential equations are solved in steady state using normalizing condition. The effect of variations of fuzzy availability for different failure, repair rates and system coverage factor for each sub-system in steady state is also studied.

KEYWORDS
Manufacturing System, Modeling, Markov Process and Fuzzy Availability.
MATERIAL AND METHODS
The profust reliability theory is based on the following two assumptions:

1. Probability assumption: the system failure behavior is fully characterized in the context of probability measures.

2. Fuzzy states assumption: the system success and failure are characterized by fuzzy states. At any time the system can be viewed as being in one of the two fuzzy states to some extent. This means that system failure cannot be defined in a precise way, but in a fuzzy way.

For ease of reference, in the following we provide some essential concepts and results in profust reliability theory. For more details, refer to Cai (1996).

Suppose a system with \( n \) topological (non-fuzzy) states \( S_1, S_2, \ldots, S_n \).

Let \( U = \{ S_1, S_2, \ldots, S_n \} \) denote the universe of discourse. On this universe we define a fuzzy success state

\[
\tilde{S} = \left\{ (S_i, \mu_S(S_i)), i = 1, 2, \ldots, n \right\} 
\]

and a fuzzy failure state

\[
\tilde{F} = \left\{ (S_i, \mu_F(S_i)), i = 1, 2, \ldots, n \right\} 
\]

where \( \mu_S(S_i) \) and \( \mu_F(S_i) \) are the corresponding membership functions, respectively.

The system profust availability is defined as

\[
\tilde{A}(t) = \text{Prob} \{ \text{at time } t \text{ the system is in fuzzy success state } \tilde{S} \},
\]

\[
\tilde{A}(t) = \sum_{S_i} \mu_S(S_i) \cdot P_i(t) \quad \text{(for all success states)}
\]

INTRODUCTION
The reliability engineering is one of the important engineering tasks in designing and development of a technical system. Conventional reliability theory considers the assumptions of the probability theory and the binary states of a component/system as working or failed. It is well known that the binary state modeling for reliability of components as well as for the system is too simplistic and does not capture the reality for most systems which can have many levels of performance. Let us take an example of a system comprises two independent processing units which can perform their own tasks in parallel. Evidently we can take the system to be fully functioning when both processing units are functioning and the other one is failed, the system operates at degraded and demonstrates a significant attribute of performance degradation. At this point the system is neither fully functioning nor fully failed, but in intermediate state. This implies that the crisp definitions for system failure and success are no longer appropriate and thus the binary state assumption should be relaxed. Zadeh (1965) introduced fuzzy set theory. This theory can handle all the possible states between a fully working state and completely failed state. Thus the binary state assumption in conventional reliability is replaced by fuzzy state assumption. This approach to the reliability is known as profust reliability and developed by Cai (1996). An important problem in the profust reliability theory is how to plan maintenance policy in the presence of the fuzzy state assumption. Cai et al. (1991) described fuzzy reliability modeling of gracefully degradable computing systems and show that the fuzziness, coverage factor and maintenance have significant effects on the fuzzy reliability behavior of gracefully degradable computing systems. Cai et al. (1990) used fuzzy reliability for street-lighting lamps replacement and make a comparison between two replacement policies, viz. the block replacement policy in a non-fuzzy environment and the periodic replacement policy without repair at lamp failures in a fuzzy environment. Cai et al. (1991A) applied fuzzy reliability to discuss the survivability index for computer communication networks (CCNs) and also evaluated fuzzy availability to discuss the effect of maintenance. Cai et al. (1993 and 1995) used fuzzy states as a basis for a theory of fuzzy reliability and discuss all the forms of fuzzy reliability and typical systems including the series system, parallel system, markov model and mixture model. Verma et al. (2007) also discussed all the forms of fuzzy reliability. They evaluated fuzzy availability using two different approaches and fuzzy availability modeling of semi-markovian system. Verma et al. (2007) also found profust reliability of degraded diesel engine power plant and studied the effect of various parameters such as failure rates and system coverage factor on profust reliability. Chongshan (2009) calculated fuzzy availability of a repairable consecutive-2-out-of-3: F-system. Zuang (1995) presented a method of reliability analysis in the presence of fuzziness attached to operating time. Chowdhury and Misra (1992) presented a method to find an expression of fuzzy system reliability of a non-series parallel network taking into consideration the special requirements of fuzzy sets. Pandey and Tyagi (2007) calculated profust reliability of a power loom plant which is modeled as a two units gracefully
This paper proposed a method of failure rate parameter estimation using fuzzy numbers. Guan and Wu (2006) studied a repairable consecutive-k-out-of-n: F system with fuzzy states. Qiang et al. (2009) established an improved method of fuzzy reliability analysis on deep sliding plane in rock foundation under dam. Mohanta et al. (2005) presented a fuzzy markov model for determination of fuzzy state probabilities of generating units including the effect of maintenance scheduling. Chen (1996) presented a new method for fuzzy system reliability analysis based on fuzzy time series and the α-cuts arithmetic operations of fuzzy number, where the reliability of the components of a system at different time can have different membership functions. Aliev and Kara (2004) used time dependent fuzzy set for fuzzy system reliability analysis. Kumar et al. (2009) calculated fuzzy reliability and fuzzy availability of the serial process in butter-oil processing plant.

**MATHEMATICAL MODELING OF THE SYSTEM**

Mathematical modeling is carried out using simple probabilistic considerations and differential equations associated with the transition diagram (Figure 1) are developed on the basis of Markov birth-death process. These equations are further solved for determining the steady state fuzzy availability of the biscuit manufacturing plant. Various probability considerations give the following differential equations associated with the biscuit manufacturing plant.

\[
\frac{dP_1(t)}{dt} + \left( \sum_{i=1,3,6} \lambda_i c + \sum_{i=2,4,5} \lambda_i (1-c) \right) P_1(t) = \mu_1 P_2(t) + \mu_1 P_3(t) + \mu_1 P_4(t) + \mu_2 P_5(t) + \mu_4 P_6(t) + \mu_5 P_7(t)
\]

\[
\frac{dP_2(t)}{dt} + \left( \mu_6 + \sum_{i=1,4,6} \lambda_i c + \sum_{i=2,4,5,9} \lambda_i (1-c) \right) P_2(t) = \lambda_6 c P_1(t) + \mu_3 P_4(t) + \mu_2 P_5(t) + \mu_2 P_6(t) + \mu_3 P_7(t) + \mu_2 P_{12}(t)
\]

\[
\frac{dP_3(t)}{dt} + \left( \mu_1 + \sum_{i=1,3,6} \lambda_i c + \sum_{i=1,2,4,5,7} \lambda_i (1-c) \right) P_3(t) = \lambda_3 c P_5(t) + \mu_6 P_8(t) + \mu_6 P_9(t) + \mu_5 P_{10}(t) + \mu_5 P_{11}(t)
\]

\[
\frac{dP_4(t)}{dt} + \left( \mu_1 + \mu_3 + \lambda_4 c + \sum_{i=1,2,4,5,7,8} \lambda_i (1-c) \right) P_4(t) = \lambda_4 c P_1(t) + \mu_6 P_6(t) + \mu_6 P_7(t) + \mu_3 P_{16}(t) + \mu_5 P_{17}(t) + \mu_3 P_{18}(t)
\]

\[
\frac{dP_5(t)}{dt} + \left( \mu_3 + \sum_{i=1,3,6} \lambda_i c + \sum_{i=1,2,4,5,8} \lambda_i (1-c) \right) P_5(t) = \lambda_3 c P_1(t) + \mu_6 P_4(t) + \mu_6 P_5(t) + \mu_6 P_6(t) + \mu_6 P_7(t) + \mu_2 P_{23}(t) + \mu_2 P_{24}(t) + \mu_2 P_{25}(t)
\]

\[
\frac{dP_6(t)}{dt} + \left( \mu_1 + \mu_6 + \lambda_5 c + \sum_{i=1,2,4,5,8,9} \lambda_i (1-c) \right) P_6(t) = \lambda_5 c P_1(t) + \mu_6 P_4(t) + \mu_6 P_5(t) + \mu_6 P_7(t) + \mu_6 P_{26}(t) + \mu_2 P_{27}(t) + \mu_2 P_{28}(t)
\]

\[
\frac{dP_7(t)}{dt} + \left( \mu_1 + \mu_6 + \lambda_3 c + \sum_{i=1,2,4,5,7,9} \lambda_i (1-c) \right) P_7(t) = \lambda_3 c P_1(t) + \mu_6 P_4(t) + \mu_6 P_5(t) + \mu_6 P_{16}(t) + \mu_2 P_{23}(t) + \mu_2 P_{24}(t) + \mu_2 P_{25}(t)
\]

\[
\frac{dP_8(t)}{dt} + \left( \mu_1 + \mu_6 + \lambda_5 c + \sum_{i=1,2,4,5,8,9} \lambda_i (1-c) \right) P_8(t) = \lambda_5 c P_1(t) + \mu_6 P_4(t) + \mu_6 P_5(t) + \mu_6 P_{26}(t) + \mu_2 P_{27}(t) + \mu_2 P_{28}(t)
\]

\[
\frac{dP_9(t)}{dt} + \mu_6 P_9(t) = \lambda_6 (1-c) P_9(t) \quad i=9,10,11 \quad \text{and} \quad j=2,4,5 \quad \text{respectively.}
\]
\[
\frac{dP_i(t)}{dt} + \mu_j P_i(t) = \lambda_j (1-c) P_2(t) \quad i = 12, 13, 14, 15 \quad \text{and} \quad j = 2, 4, 5 \quad \text{and} \quad 9 \quad \text{respectively.} \tag{13}
\]

\[
\frac{dP_i(t)}{dt} + \mu_j P_i(t) = \lambda_j (1-c) P_3(t) \quad i = 16, 17, 18, 19 \quad \text{and} \quad j = 2, 4 \quad \text{and} \quad 5 \quad \text{respectively.} \tag{14}
\]

\[
\frac{dP_i(t)}{dt} + \mu_j P_i(t) = \lambda_j (1-c) P_4(t) \quad i = 20, 21, 22, 23, 24 \quad \text{and} \quad j = 7, 2, 8, 4 \quad \text{and} \quad 5 \quad \text{respectively.} \tag{15}
\]

\[
\frac{dP_i(t)}{dt} + \mu_j P_i(t) = \lambda_j (1-c) P_5(t) \quad i = 25, 26, 27, 28, 29 \quad \text{and} \quad j = 2, 8, 4 \quad \text{and} \quad 5 \quad \text{respectively.} \tag{16}
\]

\[
\frac{dP_i(t)}{dt} + \mu_j P_i(t) = \lambda_j (1-c) P_6(t) \quad i = 30, 31, 32, 33, 34 \quad \text{and} \quad j = 7, 2, 4, 5 \quad \text{and} \quad 9 \quad \text{respectively.} \tag{17}
\]

\[
\frac{dP_i(t)}{dt} + \mu_j P_i(t) = \lambda_j (1-c) P_7(t) \quad i = 35, 36, 37, 38, 39, 40 \quad \text{and} \quad j = 7, 2, 8, 4 \quad \text{and} \quad 5 \quad \text{respectively.} \tag{18}
\]
\[
\frac{dP_i(t)}{dt} + \mu_j P_i(t) = \lambda_j (1-c)P_s(t) \quad i = 41, 42, 43, 44 \quad \text{and} \quad j = 2, 8, 4 \quad \text{and} \quad 5 \quad \text{respectively.}
\]  

(19)

With initial conditions

\[
P_k(0) = \begin{cases} 
1, & \text{if } k = 1 \\
0, & \text{if } k \neq 1 
\end{cases}
\]

(20)

Generally the management is interested in fuzzy availability of the system, which is obtained by the condition

\[
\frac{d}{dt} \rightarrow 0 \quad \text{as} \quad t \rightarrow \infty
\]

i.e., by putting \( \frac{d}{dt} = 0 \) and taking probabilities independent of \( t \) in equations from (4) to (19) we get

\[
\left( \sum_{i=1,3,6} \lambda_i c + \sum_{i=2,4,5} \lambda_i (1-c) \right) P_1 = \mu_6 P_2 + \mu_1 P_3 + \mu_3 P_5 + \mu_2 P_9 + \mu_4 P_{10} + \mu_5 P_{11}
\]

(21)

\[
\left( \mu_6 + \sum_{i=1,6} \lambda_i c + \sum_{i=2} \lambda_i (1-c) \right) P_2 = \lambda_6 c P_1 + \mu_3 P_6 + \mu_2 P_{12} + \mu_4 P_{13} + \mu_5 P_{14} + \mu_9 P_{15} + \mu_1 P_{17}
\]

(22)

\[
\left( \mu_1 + \sum_{i=3,6} \lambda_i c + \sum_{i=2,4,5,7} \lambda_i (1-c) \right) P_3 = \lambda_4 c P_1 + \mu_3 P_5 + \mu_7 P_{16} + \mu_2 P_{17} + \mu_4 P_{18} + \mu_5 P_{19}
\]

(23)

\[
\left( \mu_1 + \mu_3 + \lambda_6 c + \sum_{i=2,4,5,7,8} \lambda_i (1-c) \right) P_4 = \lambda_3 c P_1 + \mu_4 P_8 + \mu_3 c P_9 + \mu_7 P_{20} + \mu_6 P_{21} + \mu_5 P_{22} + \mu_9 P_{23} + \mu_5 P_{24}
\]

(24)

\[
\left( \mu_3 + \sum_{i=3,6} \lambda_i c + \sum_{i=2,4,5,7} \lambda_i (1-c) \right) P_5 = \lambda_3 c P_1 + \mu_4 P_8 + \mu_6 P_9 + \mu_2 P_{41} + \mu_4 P_{42} + \mu_4 P_{43} + \mu_5 P_{44}
\]

(25)

\[
\left( \mu_3 + \mu_6 + \lambda_1 c + \sum_{i=2,4,5,6,7,8} \lambda_i (1-c) \right) P_6 = \lambda_5 c P_2 + \mu_6 P_8 + \lambda_6 c P_9 + \mu_2 P_{25} + \mu_8 P_{26} + \mu_4 P_{27} + \mu_3 P_{28} + \mu_9 P_{29}
\]

(26)

\[
\left( \mu_1 + \mu_6 + \lambda_3 c + \sum_{i=2,4,5,7,8} \lambda_i (1-c) \right) P_7 = \lambda_3 c P_2 + \mu_3 P_8 + \lambda_3 c P_9 + \mu_7 P_{30} + \mu_2 P_{31} + \mu_4 P_{32} + \mu_9 P_{33} + \mu_5 P_{34}
\]

(27)

\[
\left( \mu_3 + \mu_5 + \mu_6 + \sum_{i=2,4,5,7,8,9} \lambda_i (1-c) \right) P_8 = \lambda_5 c P_2 + \lambda_3 c P_3 + \mu_7 P_{35} + \lambda_4 c P_4 + \mu_6 P_{37} \\
+ \mu_2 P_{36} + \mu_4 P_{38} + \mu_5 P_{39} + \mu_3 P_{40}
\]

(28)

\[
\mu_j P_i = \lambda_j (1-c)P_1 \quad i = 9, 10, 11 \quad \text{and} \quad j = 2, 4 \quad \text{and} \quad 5 \quad \text{respectively.}
\]

(29)

\[
\mu_j P_i = \lambda_j (1-c)P_2 \quad i = 12, 13, 14, 15 \quad \text{and} \quad j = 2, 4, 5 \quad \text{and} \quad 9 \quad \text{respectively.}
\]

(30)
\[ \mu_j P_i = \lambda_j (1 - c) P_i \quad i = 16,17,18,19 \quad \text{and} \quad j = 7,2,4 \quad \text{and} \quad 5 \quad \text{respectively.} \]  
\[ \mu_j P_i = \lambda_j (1 - c) P_4 \quad i = 20,21,22,23,24 \quad \text{and} \quad j = 7,2,8,4 \quad \text{and} \quad 5 \quad \text{respectively.} \]  
\[ \mu_j P_i = \lambda_j (1 - c) P_6 \quad i = 25,26,27,28,29 \quad \text{and} \quad j = 2,8,4,5 \quad \text{and} \quad 9 \quad \text{respectively.} \]  
\[ \mu_j P_i = \lambda_j (1 - c) P_7 \quad i = 30,31,32,33,34 \quad \text{and} \quad j = 7,2,4,5 \quad \text{and} \quad 9 \quad \text{respectively.} \]  
\[ \mu_j P_i = \lambda_j (1 - c) P_8 \quad i = 35,36,37,38,39,40 \quad \text{and} \quad j = 7,2,8,4,5 \quad \text{and} \quad 9 \quad \text{respectively.} \]  
\[ \mu_j P_i = \lambda_j (1 - c) P_3 \quad i = 41,42,43,44 \quad \text{and} \quad j = 2,8,4 \quad \text{and} \quad 5 \quad \text{respectively.} \]

Solving these equations recursively, we get
\[ P_2 = K_1 P_1 \]  
\[ P_4 = K_3 P_1 \]  
\[ P_3 = K_4 P_1 \]  
\[ P_6 = K_5 P_1 \]  
\[ P_7 = K_6 P_1 \]  
\[ P_8 = K_7 P_1 \]  
\[ P_i = \delta_j P_i \quad i = 9,10,11 \quad \text{and} \quad j = 2,4 \quad \text{and} \quad 5 \quad \text{respectively.} \]  
\[ P_i = \delta_j P_2 \quad i = 12,13,14,15 \quad \text{and} \quad j = 2,4,5 \quad \text{and} \quad 9 \quad \text{respectively.} \]  
\[ P_i = \delta_j P_3 \quad i = 16,17,18,19 \quad \text{and} \quad j = 7,2,4 \quad \text{and} \quad 5 \quad \text{respectively.} \]  
\[ P_i = \delta_j P_4 \quad i = 20,21,22,23,24 \quad \text{and} \quad j = 7,2,8,4 \quad \text{and} \quad 5 \quad \text{respectively.} \]  
\[ P_i = \delta_j P_6 \quad i = 25,26,27,28,29 \quad \text{and} \quad j = 2,8,4 \quad \text{and} \quad 5 \quad \text{respectively.} \]  
\[ P_i = \delta_j P_7 \quad i = 30,31,32,33,34 \quad \text{and} \quad j = 7,2,4,5 \quad \text{and} \quad 9 \quad \text{respectively.} \]  
\[ P_i = \delta_j P_8 \quad i = 35,36,37,38,39,40 \quad \text{and} \quad j = 7,2,8,4,5 \quad \text{and} \quad 9 \quad \text{respectively.} \]  
\[ P_i = \delta_j P_5 \quad i = 41,42,43,44 \quad \text{and} \quad j = 2,8,4 \quad \text{and} \quad 5 \quad \text{respectively.} \]

Where
\[ K_1 = \frac{Q_o T_5 + Q_o T_6}{T_3 T_8}, \quad K_2 = \frac{T_6 + T_2 K_1}{T_5}, \quad K_3 = \frac{N_1 + N_2 K_1 + Q_1 K_2}{T_4}, \quad K_4 = \frac{\lambda_3 c + Z_3 K_1 + Z_6 K_2 + Z_7 K_3}{N_5}, \quad K_5 = \frac{K_1 Z_1 + K_2 Z_3 + K_3 Z_4 + \lambda_6 c K_4}{Q_6}, \quad K_6 = \frac{\lambda_1 c K_1 + \lambda_6 c K_2 + L_0 K_3 + M_2 K_5}{N_7}. \]
\[ K_7 = \frac{\lambda_4 c K_5 + \lambda_6 c K_3 + \lambda_3 c K_6}{L_8} \]

\[ T_2 = \frac{1}{Q_6} \left[ Z_2 - \frac{\mu_6}{\mu_3} + \frac{Z_4 N_2}{T_4} \right] \]

\[ T_4 = \frac{1}{Q_6} \left[ Q_4 Q_6 - Z_4 Z_{10} \right] \]

\[ T_6 = \frac{\lambda_4 c T_4 + Z_1 N_1 + M_3 T_3 T_4}{T_4} \]

\[ T_8 = \frac{1}{T_5} \left[ Q_7 T_3 - Q_9 T_7 \right] \]

\[ Q_4 = \frac{1}{N_7} \left[ N_4 N_7 - L_{13} L_3 \right] \]

\[ Q_7 = L_2 - \frac{\mu_3 Z_2}{Q_6} - \frac{\mu_3 \lambda_6 c Z_5}{N_5 Q_6} \frac{N_2}{T_4} \left[ \frac{\mu_3 Z_4}{Q_6} \right. \left. + \frac{\lambda_6 c Z_7}{N_5 Q_6} \right] \]

\[ Q_8 = \frac{\lambda_6 c + \lambda_6 \mu_4 c^2}{N_5 Q_6} + \frac{N_1}{T_4} \left[ \frac{\mu_3 Z_4}{Q_6} \right. \left. + \frac{\lambda_6 c Z_7}{N_5 Q_6} \right] \]

\[ Q_9 = \mu_4 \delta_3 + \frac{\mu_5 Z_3}{Q_6} + \frac{\lambda_5 c\mu_3 Z_6}{N_5 Q_6} + \frac{Q_3}{T_4} \left[ \frac{\mu_3 Z_4}{Q_6} \right. \left. + \frac{\mu_1 \lambda_6 c Z_7}{N_5 Q_6} \right] \]

\[ L_4 = \sum_{i=1,3,6} \lambda_i c \]

\[ L_2 = \mu_6 + \sum_{i=1,6} \lambda_i c \]

\[ L_3 = \mu_1 + \sum_{i=3,6} \lambda_i c \]

\[ L_4 = \mu_1 + \mu_3 + \lambda_6 c \]

\[ L_5 = \mu_3 + \sum_{i=1,6} \lambda_i c \]

\[ L_6 = \mu_3 + \mu_6 + \lambda_1 c \]

\[ L_7 = \mu_1 + \mu_6 + \lambda_3 c \]

\[ L_8 = \mu_1 + \mu_3 + \mu_6 \]

\[ L_9 = \frac{\mu_3 \lambda_6 c}{L_8} \]

\[ L_{10} = \frac{\mu_1 \lambda_6 c}{L_8} \]

\[ L_{11} = \frac{\mu_6 \lambda_3 c}{N_7} \]

\[ L_{12} = \frac{\mu_6 \lambda_1 c}{L_8} \]

\[ M_1 = \mu_5 \delta_5 + \mu_9 \delta_9 \]

\[ M_2 = M_1 + \frac{\mu_3 \lambda_3 c}{L_8} \]

\[ M_3 = \frac{\mu_6 M_2}{N_7} \]

\[ N_1 = \frac{\lambda_3 c L_3 + \lambda_6 c Z_{10} L_3}{Q_6 \mu_3} \]

\[ N_2 = \frac{Z_8}{\mu_3} \left[ Z_{10} - \frac{\mu_6}{\mu_3} \right] \]

\[ N_3 = L_3 - \frac{\lambda_6 \mu_6 c}{N_7} \]

\[ N_4 = \frac{L_4}{L_8} \]

\[ N_5 = \frac{L_5}{Q_6} \]

\[ N_6 = \frac{L_6 - \lambda_1 \mu_1 c}{L_8} \]
Now, using the normalizing condition \( \sum_{i=1}^{44} P_i = 1 \), we get

\[
P_i = \left[ \left( 1 + \sum_{i=1}^{4} \delta_i \right) + K_1 \left( 1 + \sum_{i=2,4,5} \delta_i \right) + K_2 \left( 1 + \sum_{i=2,4,5,7} \delta_i \right) + K_3 \left( 1 + \sum_{i=2,4,5,7,8} \delta_i \right) \right]^{-1}
\]

The fuzzy availability \( \tilde{A}(\infty) \) of the system

\[
\tilde{A}(\infty) = P_1 + \frac{1}{2} P_2 + \frac{1}{4} P_3 + \frac{1}{8} P_4 + \frac{1}{16} P_5 + \frac{1}{32} P_6 + \frac{1}{64} P_7 + \frac{1}{128} P_8
\]

\[
= \left[ 1 + \frac{3}{4} K_1 + \frac{3}{4} K_2 + \frac{1}{2} K_3 + \frac{3}{4} K_4 + \frac{1}{2} K_5 + \frac{1}{2} K_6 + \frac{1}{4} K_7 \right] P_1
\]

**RESULTS AND DISCUSSION**

We now consider the effect of various parameters on fuzzy availability of the system in this section. Here, the fuzzy availability of the system is computed by altering the failure and repair rates of the sub-systems.

(i) **Effect of failure rates and repair rates of Mixing on fuzzy availability of the system:** - The effect of failure and repair rates on fuzzy availability of the system is studied by varying the values of \( \lambda_1 \text{ and } \mu_1 \). The failure and repair rates of other sub-systems have been taken as: \( \lambda_2 = 0.0002, \lambda_3 = 0.004, \lambda_4 = 0.015, \lambda_5 = 0.0002, \lambda_6 = 0.0001 \). The fuzzy availability of the system is calculated using this data and the results are shown in Table 1 (given in appendix-A).

The table 1 shows that the fuzzy availability of the system decreases approximately by 0.00027875 to 0.001705193 with the increase in failure rate from 0.001 to 0.004 (with increment of 0.001) for different values of system coverage factor and repair rates. Also fuzzy availability of system increases approximately by 0.000014142 to 0.001127752 with the increase in failure rate from 0.001 to 0.004 (with increment of 0.001) for different values of system coverage factor and repair rates. Also fuzzy availability of system increases approximately by 0.000004419 to 0.000018297 with the increase in coverage factor from 0.0002 to 0.0005 (with increment of 0.0001) for different values of system coverage factor and repair rates.

(ii) **Effect of failure rates and repair rates of Forming on fuzzy availability of the System:** - Effect of failure and repair rates of sub-system, namely, forming on fuzzy availability of the system is studied by varying the values of \( \lambda_2 \text{ and } \mu_2 \). The failure and repair rates of other sub-systems have been taken as: \( \lambda_1 = 0.0005, \lambda_3 = 0.004, \lambda_4 = 0.0015, \lambda_5 = 0.0052, \lambda_6 = 0.0002, \lambda_7 = 0.0001, \lambda_8 = 0.008, \lambda_9 = 0.0047, \mu_2 = 0.02, \mu_3 = 0.46, \mu_4 = 0.1, \mu_5 = 0.08, \mu_6 = 0.06, \mu_7 = 0.002, \mu_8 = 0.31, \mu_9 = 0.9 \). The fuzzy availability of the system is calculated using this data and the results are shown in Table 2 (given in appendix-A).

The table 2 shows that the fuzzy availability of the system decreases approximately by 0.000008838 to 0.000062588 with the increase in failure rate from 0.0002 to 0.0005 (with increment of 0.0001) for different values of system coverage factor and repair rates. Also fuzzy availability of system increases approximately by 0.000004419 to 0.000018297 with the increase in coverage factor from 0.0002 to 0.0005 (with increment of 0.0001) for different values of system coverage factor and repair rates.

\[
N_7 = L_7 - \frac{\lambda_3 \mu_3 C}{L_8}, \quad Z_1 = \mu_3 + \frac{\mu_6 L_9}{N_7}, \quad Z_2 = \lambda_3 C + \frac{L_4 \lambda_4 C}{N_7}
\]

\[
Z_3 = \frac{\lambda_6 C L_4}{N_7}, \quad Z_4 = L_{10} + \frac{L_4 L_9}{N_7}, \quad Z_5 = \frac{\mu_6 Z_2}{Q_6}
\]

\[
Z_6 = \frac{\mu_6 Z_3}{Q_6}, \quad Z_7 = \mu_1 + \frac{\mu_6 Z_4}{Q_6}, \quad Z_8 = \frac{\lambda_4 C L_4}{N_7}
\]

\[
Z_9 = \lambda_3 C + \frac{L_4 \lambda_6 C}{N_7}, \quad Z_{10} = L_{12} + \frac{L_4 M_2}{N_7}, \quad \delta_i = \frac{\lambda_i (1 - c)}{\mu_i} \quad i = 1, 2, \ldots, 9
\]
(iii) Effect of failure rates and repair rates of Moulder and Cutter on fuzzy availability of the System: Here, the effect of failure and repair rates of sub-system moulder and cutter on fuzzy availability of the system is studied by varying their values as: \( \lambda_3 = 0.005, 0.006, 0.007 \) and \( \mu_3 = 0.47, 0.48, 0.49 \) and 0.5.

The failure and repair rates of other sub-systems have been taken as: \( \lambda_4 = 0.006, \lambda_2 = 0.0001, \lambda_4 = 0.0015, \lambda_5 = 0.0052, \lambda_6 = 0.0002, \lambda_7 = 0.0001, \lambda_8 = 0.008, \lambda_9 = 0.0047, \mu_1 = 0.5, \mu_2 = 0.01, \mu_4 = 0.1, \mu_5 = 0.08, \mu_6 = 0.009, \mu_7 = 0.002, \mu_8 = 0.31, \mu_9 = 0.5. \)

The table 3 (given in appendix-A) shows that the fuzzy availability of the system decreases approximately by 0.000129569 to 0.002404845 with the increase in failure rate from 0.005 to 0.008 (with increment of 0.001) for different values of system coverage factor and repair rates. Also fuzzy availability of system increases approximately by 0.000074646 to 0.000249464 with the increase in repair rates from 0.47 to 0.50 (with increment of 0.01) and increase of coverage factor with an increment of 0.1.

(iv) Effect of failure rates and repair rates of Baking Oven on fuzzy availability of the System: Here, we have varied the failure and repair rates of baking oven as: \( \lambda_4 = 0.0016, 0.0017, 0.0018, 0.0019 \) and \( \mu_4 = 0.2, 0.3, 0.4, 0.5. \) Other failure and repair rates of the sub-systems have been taken as: \( \lambda_1 = 0.005, \lambda_2 = 0.0001, \lambda_3 = 0.008, \lambda_4 = 0.0052, \lambda_6 = 0.0002, \lambda_7 = 0.0001, \lambda_8 = 0.008, \lambda_9 = 0.0047, \mu_1 = 0.5, \mu_2 = 0.01, \mu_3 = 0.52, \mu_5 = 0.08, \mu_6 = 0.009, \mu_7 = 0.002, \mu_8 = 0.31, \mu_9 = 0.5. \)

The table 4 (given in appendix-A) shows that the fuzzy availability of the system decreases approximately by 0.000019216 to 0.000388274 with the increase in failure rate from 0.0016 to 0.0019 (with increment of 0.0001) for different values of system coverage factor and repair rates. Also fuzzy availability of system increases approximately by 0.000076866 to 0.002700307 with the increase in repair rates from 0.2 to 0.5 (with increment of 0.1) and increase of coverage factor with an increment of 0.1.

(v) Effect of failure rates and repair rates of Cooling Conveyor on fuzzy availability of the System: We have also calculated the fuzzy availability of the system after varying the failure and repair rates of cooling conveyor sub-system. Following data has been used and results are shown in Table 5 (given in appendix-A).

| Failure Rate | Repair Rate | Fuzzy Availability |
|--------------|-------------|--------------------|
| \( \lambda_5 \) | \( \mu_5 \) | \( \Lambda_5 \) |
| 0.0053 | 0.0054 | 0.0055 |
| 0.0056 and \( \mu_5 \) = 0.06, 0.07, 0.08, 0.9 | |

These rates for other sub-systems have been taken as: \( \lambda_1 = 0.007, \lambda_2 = 0.0001, \lambda_3 = 0.008, \lambda_4 = 0.0014, \lambda_6 = 0.0002, \lambda_7 = 0.0001, \lambda_8 = 0.008, \lambda_9 = 0.0047, \mu_1 = 0.5, \mu_2 = 0.01, \mu_3 = 0.52, \mu_4 = 0.6, \mu_6 = 0.009, \mu_7 = 0.002, \mu_8 = 0.31, \mu_9 = 0.7. \)

The table 5 shows that the fuzzy availability of the system decreases approximately by 0.000107294 to 0.001363717 with the increase in failure rate from 0.0053 to 0.0056 (with increment of 0.0001) for different values of system coverage factor and repair rates. Also fuzzy availability of system increases approximately by 0.004585538 to 0.01046051 with the increase in repair rates from 0.06 to 0.09 (with increment of 0.01) and increase of coverage factor with an increment of 0.1.

(vi) Effect of failure rates and repair rates of Packing on fuzzy availability of the System: The effect of fuzzy availability on the system is studied by varying the values of \( \Lambda_6 \) & \( \mu_6 \). The failure and repair rates of other sub-systems have been taken as: \( \lambda_1 = 0.007, \lambda_2 = 0.0001, \lambda_3 = 0.008, \lambda_4 = 0.0014, \lambda_5 = 0.0057, \lambda_7 = 0.0001, \lambda_8 = 0.008, \lambda_9 = 0.0047, \mu_1 = 0.5, \mu_2 = 0.01, \mu_3 = 0.52, \mu_4 = 0.6, \mu_5 = 0.09, \mu_7 = 0.002, \mu_8 = 0.31, \mu_9 = 0.9. \)

The table 6 (given in appendix-A) shows that the fuzzy availability of the system decreases approximately by 0.000055922 to 0.000967576 with the increase in failure rate from 0.0006 to 0.0009 (with increment of 0.0001) for different values of system coverage factor and repair rates. Also fuzzy availability of system increases approximately by 0.00008106 to 0.000780625 with the increase in repair rates from 0.06 to 0.09 (with increment of 0.01) and increase of coverage factor with an increment of 0.1.

CONCLUSION

Detailed study of Table 1 to Table 6 reveals that failure rates of mixing sub-system & repair rates of baking oven sub-system (also shown in figure 2 and figure 3 which are given in appendix-1) has maximum effect on fuzzy availability of the complete system. Other sub-systems are almost equally effective. Thus, we can make an inference that we should take the most care of these sub-systems in order to improve the overall fuzzy availability of the system.
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APPENDIX-1

Fig. 2 Effect of failure rates of mixing subsystem on fuzzy availability for different values of system coverage factor

Fig. 3 Effect of repair rates of baking oven subsystem on fuzzy availability for different values of system coverage factor

Table 1: Effect of failure rates and repair rates of mixing on fuzzy availability

| System Coverage Factor | $\mu_1$ | $\lambda_1$ | 0.001 | 0.002 | 0.003 | 0.004 |
|------------------------|---------|------------|-------|-------|-------|-------|
| C=0.0                  | 0.5     | 0.924214418 | 0.922509225 | 0.920810313 | 0.919117647 | 0.92608256 |
|                        | 0.6     | 0.924499230 | 0.923076923 | 0.921658986 | 0.920245399 | 0.927143154 |
|                        | 0.7     | 0.924702774 | 0.923482850 | 0.92266140 | 0.921052632 | 0.927899686 |
|                        | 0.8     | 0.924855491 | 0.923787529 | 0.92272030 | 0.921658986 | 0.928467966 |
| C=0.1                  | 0.5     | 0.930921693 | 0.929303735 | 0.927691934 | 0.92608256 | 0.927143154 |
|                        | 0.6     | 0.931183139 | 0.929832177 | 0.928485522 | 0.927143154 | 0.927899686 |
|                        | 0.7     | 0.931369988 | 0.930210038 | 0.929053275 | 0.928467966 | 0.93185745 |
|                        | 0.8     | 0.931510181 | 0.930493654 | 0.929479585 | 0.928467966 | 0.933185745 |
| C  | System Coverage Factor | μ^2 | λ^2 → 0.0002 | 0.0003 | 0.0004 | 0.0005 |
|----|------------------------|-----|--------------|--------|--------|--------|
| 0.0| 0.02                   | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 |
|    | 0.03                   | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 |
|    | 0.04                   | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 |
| 0.3| 0.5                    | 0.944665762 | 0.943244541 | 0.941829130 | 0.940419491 |
|    | 0.6                    | 0.944878235 | 0.943689900 | 0.942505694 | 0.941325590 |
|    | 0.7                    | 0.945030087 | 0.944008357 | 0.942989734 | 0.941974201 |
|    | 0.8                    | 0.945144024 | 0.944247389 | 0.943353195 | 0.942461428 |
| 0.4| 0.5                    | 0.951707942 | 0.950396749 | 0.949091112 | 0.947790993 |
|    | 0.6                    | 0.951894745 | 0.950798138 | 0.949705507 | 0.948616825 |
|    | 0.7                    | 0.952028254 | 0.951085156 | 0.950145073 | 0.949207987 |
|    | 0.8                    | 0.952128428 | 0.951300590 | 0.950475140 | 0.949652063 |
| 0.5| 0.5                    | 0.958867288 | 0.957674266 | 0.956484744 | 0.955303873 |
|    | 0.6                    | 0.959027593 | 0.958029967 | 0.957036100 | 0.956045967 |
|    | 0.7                    | 0.959142165 | 0.958284315 | 0.957429331 | 0.956577193 |
|    | 0.8                    | 0.959228132 | 0.958475228 | 0.957724606 | 0.956976249 |
| 0.6| 0.5                    | 0.966146722 | 0.965080306 | 0.964018707 | 0.962961890 |
|    | 0.6                    | 0.966279664 | 0.965388518 | 0.964500836 | 0.963616593 |
|    | 0.7                    | 0.966347682 | 0.966089099 | 0.964845777 | 0.964052666 |
|    | 0.8                    | 0.966459799 | 0.965774335 | 0.965104792 | 0.964437366 |
| 0.7| 0.5                    | 0.973549260 | 0.972618191 | 0.971691426 | 0.970768935 |
|    | 0.6                    | 0.973653942 | 0.972877031 | 0.972103192 | 0.971332406 |
|    | 0.7                    | 0.973728765 | 0.973062119 | 0.972397793 | 0.971735776 |
|    | 0.8                    | 0.973784910 | 0.973201046 | 0.972619010 | 0.972038793 |
| 0.8| 0.5                    | 0.981078021 | 0.980291360 | 0.979508375 | 0.978729047 |
|    | 0.6                    | 0.981153509 | 0.980498855 | 0.979846770 | 0.979197247 |
|    | 0.7                    | 0.981207469 | 0.980647230 | 0.980088881 | 0.979532421 |
|    | 0.8                    | 0.981247962 | 0.980758602 | 0.980270684 | 0.979784212 |
| 0.9| 0.5                    | 0.988736231 | 0.988103372 | 0.987473433 | 0.986846415 |
|    | 0.6                    | 0.988781552 | 0.988257459 | 0.987735302 | 0.987215094 |
|    | 0.7                    | 0.988813955 | 0.988367645 | 0.987922665 | 0.98749033 |
|    | 0.8                    | 0.988839276 | 0.988450353 | 0.988063358 | 0.987677313 |
| 1.0| 0.5                    | 0.996527226 | 0.996057912 | 0.995590622 | 0.995125386 |
|    | 0.6                    | 0.996541368 | 0.996156429 | 0.995772651 | 0.995390077 |
|    | 0.7                    | 0.996551492 | 0.996226883 | 0.995902896 | 0.995579583 |
|    | 0.8                    | 0.996559098 | 0.996279769 | 0.996000703 | 0.995721953 |

Table 2: Effect of failure rates and repair rates of forming on fuzzy availability
| C   | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | 1.0 |
|-----|------|------|------|------|------|------|------|------|-----|
| 0.05| 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 | 0.917431193 |
| 0.2  | 0.922861911 | 0.922861911 | 0.922861911 | 0.922861911 | 0.922861911 | 0.922861911 | 0.922861911 | 0.922861911 | 0.922861911 |
| 0.3  | 0.928548094 | 0.928548094 | 0.928548094 | 0.928548094 | 0.928548094 | 0.928548094 | 0.928548094 | 0.928548094 | 0.928548094 |
| 0.4  | 0.934486041 | 0.934486041 | 0.934486041 | 0.934486041 | 0.934486041 | 0.934486041 | 0.934486041 | 0.934486041 | 0.934486041 |
| 0.5  | 0.940672842 | 0.940672842 | 0.940672842 | 0.940672842 | 0.940672842 | 0.940672842 | 0.940672842 | 0.940672842 | 0.940672842 |
| 0.6  | 0.947106313 | 0.947106313 | 0.947106313 | 0.947106313 | 0.947106313 | 0.947106313 | 0.947106313 | 0.947106313 | 0.947106313 |
| 0.7  | 0.953784943 | 0.953784943 | 0.953784943 | 0.953784943 | 0.953784943 | 0.953784943 | 0.953784943 | 0.953784943 | 0.953784943 |
| 0.8  | 0.960707842 | 0.960707842 | 0.960707842 | 0.960707842 | 0.960707842 | 0.960707842 | 0.960707842 | 0.960707842 | 0.960707842 |
| 0.9  | 0.967874706 | 0.967874706 | 0.967874706 | 0.967874706 | 0.967874706 | 0.967874706 | 0.967874706 | 0.967874706 | 0.967874706 |
| 1.0  | 0.975285777 | 0.975285777 | 0.975285777 | 0.975285777 | 0.975285777 | 0.975285777 | 0.975285777 | 0.975285777 | 0.975285777 |

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Table 3: Effect of failure rates and repair rates of moulder and cutter on fuzzy availability

| System Coverage Factor | $\mu_3$ | $\lambda_3 \rightarrow 0.005$ | 0.006 | 0.007 | 0.008 |
|------------------------|---------|-------------------------------|-------|-------|-------|
| C=0.0                  | 0.47    | 0.915750916                   | 0.915750916 | 0.915750916 | 0.915750916 |
|                        | 0.48    | 0.915750916                   | 0.915750916 | 0.915750916 | 0.915750916 |
|                        | 0.49    | 0.915750916                   | 0.915750916 | 0.915750916 | 0.915750916 |
|                        | 0.50    | 0.915750916                   | 0.915750916 | 0.915750916 | 0.915750916 |
| C=0.1                  | 0.47    | 0.921117547                   | 0.920982848 | 0.920845816 | 0.920706376 |
|                        | 0.48    | 0.921123716                   | 0.920990790 | 0.920855568 | 0.920717974 |
|                        | 0.49    | 0.921129705                   | 0.920998488 | 0.920865010 | 0.920729197 |
|                        | 0.50    | 0.921135521                   | 0.921005952 | 0.920874156 | 0.920740059 |
| C=0.2                  | 0.47    | 0.926778735                   | 0.926491577 | 0.926194296 | 0.925886227 |
|                        | 0.48    | 0.926789125                   | 0.926505199 | 0.926211280 | 0.925906710 |
|                        | 0.49    | 0.926799223                   | 0.926518412 | 0.926227734 | 0.925926540 |
|                        | 0.50    | 0.926809037                   | 0.926531230 | 0.926243680 | 0.925945741 |
| C=0.3                  | 0.47    | 0.932728700                   | 0.932276181 | 0.931799389 | 0.931295890 |
|                        | 0.48    | 0.932741492                   | 0.932293302 | 0.931821098 | 0.931322470 |
|                        | 0.49    | 0.932753941                   | 0.932309925 | 0.931842146 | 0.931348216 |
|                        | 0.50    | 0.932766054                   | 0.932326066 | 0.931862557 | 0.931373162 |
| C=0.4                  | 0.47    | 0.938962760                   | 0.938363290 | 0.937664559 | 0.936941288 |
|                        | 0.48    | 0.938976243                   | 0.938354837 | 0.937688489 | 0.936971084 |
|                        | 0.49    | 0.938989889                   | 0.938372833 | 0.937711715 | 0.936999969 |
|                        | 0.50    | 0.939002207                   | 0.938390330 | 0.937734262 | 0.937027980 |
| C=0.5                  | 0.47    | 0.945477220                   | 0.944672250 | 0.943793708 | 0.942828881 |
|                        | 0.48    | 0.945489777                   | 0.944690094 | 0.943817348 | 0.942858902 |
|                        | 0.49    | 0.945502062                   | 0.944707482 | 0.943804331 | 0.942880045 |
|                        | 0.50    | 0.945514077                   | 0.944724424 | 0.943862676 | 0.942916341 |
| C=0.6                  | 0.47    | 0.952269289                   | 0.951284714 | 0.950191185 | 0.948965708 |
|                        | 0.48    | 0.952279387                   | 0.951299890 | 0.950212006 | 0.948992839 |
|                        | 0.49    | 0.952289331                   | 0.951314738 | 0.950232307 | 0.949019237 |
|                        | 0.50    | 0.952299113                   | 0.951329259 | 0.950252098 | 0.949044921 |
| C=0.7                  | 0.47    | 0.959337009                   | 0.958175006 | 0.956861792 | 0.955359438 |
|                        | 0.48    | 0.959343186                   | 0.958185551 | 0.956877237 | 0.955380417 |
|                        | 0.49    | 0.959349377                   | 0.958195965 | 0.956892391 | 0.955400927 |
|                        | 0.50    | 0.959355566                   | 0.958206239 | 0.956907252 | 0.955420970 |
| C=0.8                  | 0.47    | 0.966769186                   | 0.965344915 | 0.963810796 | 0.962018431 |
|                        | 0.48    | 0.966680040                   | 0.965348895 | 0.963818270 | 0.962029826 |
|                        | 0.49    | 0.966681129                   | 0.965353014 | 0.963825778 | 0.962041142 |
|                        | 0.50    | 0.966682421                   | 0.965357245 | 0.963833299 | 0.962052360 |
### Table 4: Effect of failure rates and repair rates of baking oven on fuzzy availability

| System Coverage Factor | \( \mu_4 \) | \( \lambda_4 \) | 0.0016 | 0.0017 | 0.0018 | 0.0019 |
|------------------------|-------------|-------------|--------|--------|--------|--------|
| C=0.0                  | 0.2         | 0.923361034 | 0.922934933 | 0.922509225 | 0.922083910 |
|                        | 0.3         | 0.925640234 | 0.925354719 | 0.925069380 | 0.924784217 |
|                        | 0.4         | 0.926784059 | 0.926569377 | 0.926354794 | 0.926140310 |
|                        | 0.5         | 0.927471712 | 0.927299703 | 0.927127758 | 0.926955877 |
| C=0.1                  | 0.2         | 0.927826681 | 0.927438407 | 0.927050458 | 0.926662834 |
|                        | 0.3         | 0.929029777 | 0.929642932 | 0.929383032 | 0.929123278 |
|                        | 0.4         | 0.930944614 | 0.930749129 | 0.930553727 | 0.930384066 |
|                        | 0.5         | 0.931570717 | 0.931411112 | 0.931257560 | 0.931101061 |
| C=0.2                  | 0.2         | 0.932415344 | 0.932065836 | 0.931716590 | 0.931367606 |
|                        | 0.3         | 0.934283823 | 0.934049854 | 0.933816002 | 0.933582267 |
|                        | 0.4         | 0.935220874 | 0.935045034 | 0.934869260 | 0.934693552 |
|                        | 0.5         | 0.935784007 | 0.935643160 | 0.935502356 | 0.935361594 |
| C=0.3                  | 0.2         | 0.937128779 | 0.936819018 | 0.936509462 | 0.936200110 |
|                        | 0.3         | 0.938784303 | 0.938577042 | 0.938369874 | 0.938162796 |
|                        | 0.4         | 0.939614260 | 0.939458531 | 0.939302854 | 0.939147229 |
|                        | 0.5         | 0.940112939 | 0.939988220 | 0.939863533 | 0.939738880 |
| C=0.4                  | 0.2         | 0.941968736 | 0.941699749 | 0.941430915 | 0.941162235 |
|                        | 0.3         | 0.943405932 | 0.943226043 | 0.943046222 | 0.942866470 |
|                        | 0.4         | 0.944126176 | 0.943991047 | 0.943855956 | 0.943720904 |
|                        | 0.5         | 0.944558851 | 0.944450645 | 0.944342464 | 0.944234308 |
| C=0.5                  | 0.2         | 0.946936946 | 0.946709807 | 0.946482777 | 0.946255855 |
|                        | 0.3         | 0.948150199 | 0.947998373 | 0.947846595 | 0.947694865 |
|                        | 0.4         | 0.948757993 | 0.948643972 | 0.948529979 | 0.948416013 |
|                        | 0.5         | 0.949123043 | 0.949031754 | 0.948940482 | 0.948849229 |
| C=0.6                  | 0.2         | 0.952035103 | 0.951850934 | 0.951668637 | 0.951482810 |
|                        | 0.3         | 0.953018542 | 0.952895501 | 0.952772492 | 0.952649515 |
|                        | 0.4         | 0.953511024 | 0.953418645 | 0.953326284 | 0.953233941 |
|                        | 0.5         | 0.953806758 | 0.953732807 | 0.953658868 | 0.953584941 |
| C=0.7                  | 0.2         | 0.957264833 | 0.957124809 | 0.956984825 | 0.956844883 |
|                        | 0.3         | 0.958012323 | 0.957918823 | 0.957825341 | 0.957731877 |
| System Coverage Factor | $\mu_s$ | $\lambda_5$ | 0.0053 | 0.0054 | 0.0055 | 0.0056 |
|------------------------|--------|------------|--------|--------|--------|--------|
| C=0.0                  | 0.06   | 0.90525043 | 0.90386713 | 0.90252706 | 0.90117523 |
|                        | 0.07   | 0.91571094 | 0.91451465 | 0.91332146 | 0.91213147 |
|                        | 0.08   | 0.92371649 | 0.92265108 | 0.92158824 | 0.92052776 |
|                        | 0.09   | 0.93004032 | 0.92908211 | 0.92812100 | 0.92716596 |
| C=0.1                  | 0.06   | 0.91106051 | 0.90981399 | 0.90856923 | 0.90732873 |
|                        | 0.07   | 0.92061456 | 0.91952265 | 0.91843332 | 0.91734691 |
|                        | 0.08   | 0.92791263 | 0.92694183 | 0.92597307 | 0.92500633 |
|                        | 0.09   | 0.93366402 | 0.93279569 | 0.93192344 | 0.93105219 |
| C=0.2                  | 0.06   | 0.91717551 | 0.91604832 | 0.91492389 | 0.91380216 |
|                        | 0.07   | 0.92579735 | 0.92481269 | 0.92383013 | 0.92284672 |
|                        | 0.08   | 0.93237083 | 0.93149682 | 0.93062453 | 0.92975314 |
|                        | 0.09   | 0.93754846 | 0.93676277 | 0.93597841 | 0.93519536 |
| C=0.3                  | 0.06   | 0.92360005 | 0.92259692 | 0.92159573 | 0.92059718 |
|                        | 0.07   | 0.93126294 | 0.93038773 | 0.92951501 | 0.92864393 |
|                        | 0.08   | 0.93709257 | 0.93631774 | 0.93554193 | 0.93477191 |
|                        | 0.09   | 0.94167811 | 0.94098249 | 0.94028790 | 0.93954331 |
| C=0.4                  | 0.06   | 0.93033938 | 0.92946453 | 0.92859133 | 0.92771976 |
|                        | 0.07   | 0.93701218 | 0.93625134 | 0.93549171 | 0.93473331 |
|                        | 0.08   | 0.94207994 | 0.94106832 | 0.94073484 | 0.94006349 |
|                        | 0.09   | 0.94605985 | 0.94546085 | 0.94485355 | 0.94425193 |
| C=0.5                  | 0.06   | 0.93739944 | 0.93665736 | 0.93591645 | 0.93517624 |
|                        | 0.07   | 0.94305154 | 0.94207624 | 0.94176458 | 0.94112342 |
|                        | 0.08   | 0.94733555 | 0.94676867 | 0.94619865 | 0.94563154 |
|                        | 0.09   | 0.95069456 | 0.95018537 | 0.94967626 | 0.94916824 |
| C=0.6 | 0.06 | 0.944786830 | 0.944182306 | 0.943578555 | 0.942975575 |
|       | 0.07 | 0.949384695 | 0.948661348 | 0.948338578 | 0.947816383 |
|       | 0.08 | 0.952682570 | 0.952401178 | 0.951940231 | 0.951479730 |
|       | 0.09 | 0.955585251 | 0.955172691 | 0.954760487 | 0.954348638 |
| C=0.7 | 0.06 | 0.952508876 | 0.952047000 | 0.951585572 | 0.951124990 |
|       | 0.07 | 0.956016776 | 0.955617866 | 0.955219287 | 0.954821041 |
|       | 0.08 | 0.958647057 | 0.958313643 | 0.957962838 | 0.957612289 |
|       | 0.09 | 0.960734367 | 0.960420897 | 0.959745659 | 0.958752346 |
| C=0.8 | 0.06 | 0.960573635 | 0.960259828 | 0.959946226 | 0.959632828 |
|       | 0.07 | 0.962953541 | 0.962631666 | 0.962412942 | 0.962142871 |
|       | 0.08 | 0.964762244 | 0.964508711 | 0.964271315 | 0.964034036 |
|       | 0.09 | 0.966145154 | 0.965933373 | 0.965721686 | 0.965510090 |
| C=0.9 | 0.06 | 0.968989926 | 0.968829955 | 0.968670037 | 0.968510171 |
|       | 0.07 | 0.970201384 | 0.970063892 | 0.969926439 | 0.969789025 |
|       | 0.08 | 0.971111966 | 0.970991409 | 0.970870881 | 0.970750384 |
|       | 0.09 | 0.971821380 | 0.971714038 | 0.971606720 | 0.971499426 |
| C=1.0 | 0.06 | 0.977767362 | 0.977767362 | 0.977767362 | 0.977767362 |
|       | 0.07 | 0.977767362 | 0.977767362 | 0.977767362 | 0.977767362 |
|       | 0.08 | 0.977767362 | 0.977767362 | 0.977767362 | 0.977767362 |
|       | 0.09 | 0.977767362 | 0.977767362 | 0.977767362 | 0.977767362 |

Table 6: Effect of failure rates and repair rates of packing on fuzzy availability

| System Coverage Factor | $\mu_6$ | $\lambda_6$ | 0.0005 | 0.0006 | 0.0007 | 0.0008 |
|------------------------|--------|------------|--------|--------|--------|--------|
| C=0.0                  | 0.06   | 0.926211794 | 0.926211794 | 0.926211794 | 0.926211794 |
|                        | 0.07   | 0.926211794 | 0.926211794 | 0.926211794 | 0.926211794 |
|                        | 0.08   | 0.926211794 | 0.926211794 | 0.926211794 | 0.926211794 |
|                        | 0.09   | 0.926211794 | 0.926211794 | 0.926211794 | 0.926211794 |
| C=0.1                  | 0.06   | 0.931952716 | 0.931857703 | 0.931762769 | 0.931667916 |
|                        | 0.07   | 0.932053820 | 0.931975631 | 0.931987497 | 0.93189418 |
|                        | 0.08   | 0.932129115 | 0.932063461 | 0.931997846 | 0.931932270 |
|                        | 0.09   | 0.932187221 | 0.932131241 | 0.932075291 | 0.932019369 |
| C=0.2                  | 0.06   | 0.937817745 | 0.937627461 | 0.937437497 | 0.937247852 |
|                        | 0.07   | 0.938016496 | 0.937859718 | 0.937703160 | 0.937546822 |
|                        | 0.08   | 0.938164578 | 0.938032793 | 0.937901166 | 0.937769696 |
|                        | 0.09   | 0.938278900 | 0.938166424 | 0.938054065 | 0.937941823 |
| C=0.3                  | 0.06   | 0.943830862 | 0.943523761 | 0.943238620 | 0.942954197 |
|                        | 0.07   | 0.943866795 | 0.943631489 | 0.943396677 | 0.94306677 |
|                        | 0.08   | 0.943924497 | 0.943726789 | 0.943726789 | 0.943726789 |
|                        | 0.09   | 0.944150880 | 0.944150880 | 0.944150880 | 0.944150880 |
| C=0.4                  | 0.06   | 0.949931185 | 0.949549393 | 0.949168882 | 0.948789644 |
|                        | 0.07   | 0.950314993 | 0.949999698 | 0.949685286 | 0.949371752 |
| C=0.5 | 0.06 | 0.956185377 | 0.955707251 | 0.955231125 | 0.954756987 |
| | 0.07 | 0.956656659 | 0.956261365 | 0.955867452 | 0.955474912 |
| | 0.08 | 0.957008236 | 0.956674936 | 0.956342628 | 0.956011307 |
| | 0.09 | 0.95729972 | 0.956994691 | 0.956710146 | 0.956426334 |

| C=0.6 | 0.06 | 0.962575245 | 0.962000334 | 0.961428302 | 0.960859129 |
| | 0.07 | 0.963130670 | 0.962654836 | 0.962180992 | 0.961709127 |
| | 0.08 | 0.963545179 | 0.963143572 | 0.962743398 | 0.962344648 |
| | 0.09 | 0.963865669 | 0.963521605 | 0.963178603 | 0.962836660 |

| C=0.7 | 0.06 | 0.969103950 | 0.968431751 | 0.967763473 | 0.967099081 |
| | 0.07 | 0.969740215 | 0.969183260 | 0.96862902 | 0.968077474 |
| | 0.08 | 0.970215229 | 0.969744699 | 0.969276124 | 0.968809494 |
| | 0.09 | 0.970582627 | 0.970179146 | 0.96977119 | 0.969376539 |

| C=0.8 | 0.06 | 0.975774769 | 0.975004730 | 0.974239815 | 0.973479972 |
| | 0.07 | 0.97648591 | 0.975849900 | 0.975214760 | 0.974583143 |
| | 0.08 | 0.977021697 | 0.976481597 | 0.975944061 | 0.975409070 |
| | 0.09 | 0.977434163 | 0.976970610 | 0.976508964 | 0.976049214 |

| C=0.9 | 0.06 | 0.982591097 | 0.981722617 | 0.980860625 | 0.98005049 |
| | 0.07 | 0.983379219 | 0.982658136 | 0.981941557 | 0.981229441 |
| | 0.08 | 0.983968013 | 0.983357668 | 0.982750577 | 0.982146716 |
| | 0.09 | 0.984423712 | 0.983899405 | 0.983377522 | 0.982858048 |

| C=1.0 | 0.06 | 0.989556460 | 0.988588884 | 0.987629325 | 0.986677684 |
| | 0.07 | 0.990415642 | 0.989611472 | 0.988812876 | 0.988019797 |
| | 0.08 | 0.991057730 | 0.990376431 | 0.989699164 | 0.989025885 |
| | 0.09 | 0.991554832 | 0.990969061 | 0.990386298 | 0.989806520 |

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