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Fuzzy Availability Analysis of Polytube Industry with General Distribution

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Abstract: **The present investigation discuss the fuzzy availability of a polytube industry with general distribution. A polytube industry consists of four sub-systems such as- Mixture, Extruder, Die and Cutter. These subsystems are working in series. In subsystems Die and Cutter, one unit is operative and another unit is kept as cold standby. Trapezoidal fuzzy numbers are used to find out the availability of the polytube industry. Numerical results for fuzzy availability are obtained by considering exponential, Rayleigh and Weibull distributions by using Mehar's method.**

Keywords: **Fuzzy availability, Polytube industry, Trapezoidal fuzzy numbers, General distribution.**

I. INTRODUCTION

Industrialization and urbanization are contemporary to each other since the time of civilization. Increasing population and limited resources has been the major obstacles to the aim of sustainable industrial development. The goal of optimum production with minimum hazards remains ever the biggest challenge for industry managements. Increasing complexity and multiple tasking of modern systems makes this challenge more difficult. From this prospective, reliability analysis of such systems can be useful. Reliability analysis of such systems provides informations about various system properties such as failure, cause of failures and effects of environmental conditions on systems. Reliability analysis of system had attracted attention of many researchers in recent past. A large number of techniques and modes of analysis have been adopted to analyze various industrial systems. Kumar et al. [5] discussed the availability of the feeding system in sugar industry. Kumar et al. [6] evaluated the reliability of crystallization system of urea fertilizer industry having five subsystems in series. Kumar et al. [7] analyzed the reliability of a desulphurization system in urea fertilizer plant.

Ma et al. [11] discussed Composite performance and availability analysis of wireless communication networks. Gupta et al. [2] studied the mission reliability and availability prediction of flexible polymer powder production system. Garg et al. [3] studied the availability and maintenance scheduling of a repairable block-board manufacturing system. Shakuntala et al. [13] discussed reliability of polytube industry using supplementary variable technique. Hungund and Patil [4] analysed the reliability of thermal power generating units based on working hours. Sharma et al. [14] studied performance modeling and availability of leaf spring manufacturing industry.

In above mentioned analyses of the various industries, analyses were carried out by using crisp set theory. But uncertainty or inexactness present in any physical or mechanical system cannot be represented by a crisp set. To represent uncertainty or inexactness which may be caused by human error, lack of data available or mishandling of systems, a fuzzy set is the natural choice.

Zadeh [15] presented the concept of fuzzy set. Since then a sequential development has been observed in this field. Buckley and Feuring [1] presented two analytical methods to solve nth order fuzzy initial value problem. Using one of this analytical method Lata and Kumar [10] evaluated fuzzy reliability of a piston manufacturing system with J.M.D.

representations of trapezoidal fuzzy numbers. Razak and Rajkumar [12] studied a fuzzy Markov model with fuzzy transition. Zahra et al. [16] studied human blood pressure and body temp analysis using fuzzy logic control system. Komal and Sharma [9] studied the two phase approach for performance analysis and optimisation of industrial systems using uncertain data.

The present paper is devoted to the availability analysis of a polytube industry. Polytube is one among the most important commodities of human need. Benefits and hazards of this commodity directly affect human kind. Therefore, the industries manufacturing these commodities should be analyzed more extensively to meet increasing demand and level of consumer satisfaction. In this paper polytube industry is reinvestigated by using trapezoidal fuzzy numbers. To obtain more flexible information regarding the availability of the industry, the failure and repair rates are generally distributed. Failure and repair rates associated with system are represented by trapezoidal fuzzy numbers. Rest of this paper is organized as follows:

Section I is introductory in nature, Section II introduces the basic definitions and arithmetic operations related to traditional trapezoidal fuzzy numbers and JMD trapezoidal fuzzy numbers. Section III describes the Mehar's method with JMD representation of trapezoidal fuzzy numbers. In section IV, a complete introduction about description of the system along with notations and assumptions of the system is given. Section V discussed the results obtained by the numerical study along with the graphical representation of the numerical results. In section VI, conclusion drawn from analysis is discussed.

II. PRELIMINARIES

Let X be the set of discourse. Then a fuzzy subset of X is a function $\mu : X \to [0,1]$ and it is denoted by μ_X. A fuzzy subset μ_A is called a fuzzy number if A is a subset of the set of real numbers and there exists at least one real number x such that $\mu_A(x) = 1$

Basic Definitions: This section deals with some basic definitions and preliminaries required for the study.

Definition 1 An α-cut of a fuzzy number $\tilde{A}$ is defined as a crisp set $A_\alpha = \{x : \mu_{\tilde{A}}(x) \ge \alpha, x \in X\}$, where $\alpha \in [0,1]$. It is easy to see that if X=**R,** then for each $\alpha \ge 0$, A_α is an interval of **R**.

Definition 2 A fuzzy number $\tilde{A} = (a, b, c, d)$ is said to be a trapezoidal fuzzy number if its membership function is given by

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & -\infty < x \le a \\ \dfrac{x-a}{b-a} & a \le x < b \\ 1 & b \le x \le c \\ \dfrac{x-d}{c-d} & c < x \le d \\ 0 & d \le x < \infty \end{cases}$$

Definition 3 A trapezoidal fuzzy number $\tilde{A} = (a, b, c, d)$ is said to be non-negative trapezoidal fuzzy number iff $a \ge 0$.

Definition 4 Let (a, b, c, d) be a trapezoidal fuzzy number then its JMD representation is $(x, \alpha, \beta, \gamma)_{JMD}$, where $x = a,\ \alpha = b - a \ge 0, \beta = c - b \ge 0,\ \gamma = d - c \ge 0$.

Observe that JMD representation of a trapezoidal fuzzy number is again a trapezoidal fuzzy number.

Definition 5 A trapezoidal fuzzy number $\tilde{A} = (x, \alpha, \beta, \gamma)_{JMD}$ is said to be zero trapezoidal fuzzy number iff $x = 0,\ \alpha = 0,\ \beta = 0, \gamma = 0$.

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Definition 6 A trapezoidal fuzzy number $\tilde{A} = (x, \alpha, \beta, \gamma)_{JMD}$ is said to be non-negative trapezoidal fuzzy number iff $x \geq 0.$

Definition 7 Two trapezoidal fuzzy numbers $\tilde{A} = (x_1, \alpha_1, \beta_1, \gamma_1)_{JMD}$ and $\tilde{B} = (x_2, \alpha_2, \beta_2, \gamma_2)_{JMD}$ are said to be equal i.e. $\tilde{A} = \tilde{B}$ iff $x_1 = x_2,\ \alpha_1 = \alpha_2, \beta_1 = \beta_2,\ \gamma_1 = \gamma_2.$

Arithmetic operations between JMD trapezoidal fuzzy numbers

In this section, arithmetic operations between JMD trapezoidal fuzzy numbers are presented.

Let $\tilde{A}_1 = (x_1, \alpha_1, \beta_1, \gamma_1)_{JMD}$ and $\tilde{A}_2 = (x_2, \alpha_2, \beta_{2,}, \gamma_2)_{JMD}$ be two JMD trapezoidal fuzzy numbers then

(i) $\tilde{A}_1 \oplus \tilde{A}_2 = (x_1 + x_2, \alpha_1 + \alpha_2, \beta_1 + \beta_2, \gamma_1 + \gamma_2)_{JMD}$

(ii) $\tilde{A}_1 \Theta \tilde{A}_2 = (x_1 - x_2 - \alpha_2 - \beta_2 - \gamma_2, \alpha_1 + \gamma_2, \beta_1 + \beta_2, \alpha_2 + \gamma_1)_{JMD}$

(iii) $\lambda\tilde{A}_1 = \begin{cases} (\lambda x_1,\ \lambda\alpha_1, \lambda\beta_1, \lambda\gamma_1)_{JMD} & \text{if } \lambda \geq 0 \\ (\lambda x_1 + \lambda\alpha_1 + \lambda\beta_1 + \lambda\gamma_1, -\lambda\gamma_1 -, \lambda\beta_1, \lambda\alpha_1)_{JMD} & \text{if } \lambda \leq 0 \end{cases}$

(iv) $\tilde{A}_1 \otimes \tilde{A}_2 \cong (\text{minimum}(x), \text{minimum}(y) - \text{minimum}(x),$
$\text{maximum}(y) - \text{minimum}(y), \text{maximum}(x) - \text{maximum}(y))$

Where

$$x = (x_1x_2, x_1x_2 + x_1\alpha_2 + x_1\beta_2 + x_1\gamma_2, x_1x_2 + x_2\alpha_1 + x_2\beta_1 + x_2\gamma_1, x_1x_2 + x_1\alpha_2 + x_1\beta_2 + x_1\gamma_2 + x_2\alpha_1 + \alpha_1\alpha_2 + \alpha_1\beta_2 + \alpha_1\gamma_2 + x_2\beta_1 + \beta_1\alpha_2 + \beta_1\beta_2 + \beta_1\gamma_2 + x_2\gamma_1 + \gamma_1\alpha_2 + \gamma_1\beta_2 + \gamma_1\gamma_2)$$

and

$$y = (x_1x_2 + x_1\alpha_2 + x_2\alpha_1 + \alpha_1\alpha_2, x_1x_2 + x_1\alpha_2 + x_1\beta_2 + x_2\alpha_1 + \alpha_1\alpha_2 + \alpha_1\beta_2, x_1x_2 + x_1\alpha_2 + x_2\alpha_1 + \alpha_1\alpha_2 + x_2\beta_1 + \beta_1\alpha_2, x_1x_2 + x_1\alpha_2 + x_1\beta_2 + x_1\alpha_2 + \alpha_1\alpha_2 + \alpha_1\beta_2 + x_2\beta_1 + \beta_1\alpha_2 + \beta_1\beta_2)$$

III. MEHAR'S METHOD WITH JMD REPRESENTATION OF TRAPEZOIDAL FUZZY NUMBERS

Buckley and Feuring [1] proposed two analytical methods for solving the fuzzy initial value problem for n^{th} order ordinary differential equations. The solution obtained by this method need not be a fuzzy number. Kumar and Kaur [8] proposed Mehar's method to find the exact solution of fuzzy differential equations with the help of JMD representation of trapezoidal fuzzy

numbers. The solution of fuzzy initial value problem for n^{th} order fuzzy linear differential equation (E) can be obtained by using the following steps of Mehar's method:

$$\tilde{a}_n\tilde{y}^{(n)} \oplus \tilde{a}_{n-1}\tilde{y}^{(n-1)} \oplus \ldots \oplus \tilde{a}_1\tilde{y}^{(1)} \oplus \tilde{a}_{0n}\tilde{y} = \tilde{g}(x),$$

$$\tilde{y}(0) = \tilde{\gamma}_0, \tilde{y}^{(1)}(0) = \tilde{\gamma}_1, \ldots, \tilde{y}^{(n-1)}(0) = \tilde{\gamma}_{n-1} \qquad \text{(E)}$$

Where $\tilde{y}^{(i)} = \dfrac{d^{(i)}\tilde{y}}{dx^{(i)}}$ for $i = n, n-1, \ldots, 1,$ $\tilde{a}_n$ is a non-zero trapezoidal fuzzy number and $\tilde{a}_{n-1}, \tilde{a}_{n-2}, \ldots, \tilde{a}_1, \tilde{a}_0$ are any type of trapezoidal fuzzy numbers. We solve this fuzzy differential equation (E) by Mehar's method with JMD representation of trapezoidal fuzzy numbers in following steps:

Step 1: Convert all the parameters of fuzzy differential equations, represented by trapezoidal fuzzy number (a, b, c, d) into JMD trapezoidal fuzzy number $(x,\alpha,\beta,\gamma)_{JMD}$, where $\alpha = b-a \geq 0,\ \beta = c-b \geq 0, \gamma = d-c \geq 0$. Assuming $\tilde{a}_n = (a_{n(1)},\beta_{n(1)},\beta_{n(2)},\beta_{n(3)})_{JMD}$ etc., equation (E) can be transformed into the following fuzzy linear differential equation

$$\tilde{a}_n = (a_{n(1)},\beta_{n(1)},\beta_{n(2)},\beta_{n(3)})_{JMD} \otimes (y_1^{(n)},\alpha_1^{(n)},\alpha_2^{(n)},\alpha_3^{(n)})_{JMD} \oplus (a_{n-1(1)},\beta_{n-1(1)},\beta_{n-1(2)},\beta_{n-1(3)})_{JMD} \otimes$$
$$(y_1^{(n-1)},\alpha_1^{(n-1)},\alpha_2^{(n-1)},\alpha_3^{(n-1)})_{JMD},\ldots,(a_{1(1)},\beta_{1(1)},\beta_{1(2)},\beta_{1(3)})_{JMD} \otimes (y_1^{(1)},\alpha_1^{(1)},\alpha_2^{(1)},\alpha_3^{(1)})_{JMD} \oplus$$
$$(a_{0(1)},\beta_{0(1)},\beta_{0(2)},\beta_{0(3)})_{JMD} \otimes (y_{(1)},\alpha_{(1)},\alpha_{(2)},\alpha_{(3)})_{JMD} = (g,0,0,0)_{JMD}$$
$$(y_{(1)},\alpha_{(1)},\alpha_{(2)},\alpha_{(3)})_{JMD} = (\gamma_{0(1),},\varsigma_{0(1)},\varsigma_{0(2)},\varsigma_{0(3)})_{JMD},\ (y_1^{(n-1)},\alpha_1^{(n-1)},\alpha_2^{(n-1)},\alpha_3^{(n-1)})_{JMD} =$$
$$(\gamma_{0(1),},\varsigma_{0(1)},\varsigma_{0(2)},\varsigma_{0(3)})_{JMD},\ldots,(y_1^{(n-1)},\alpha_1^{(n-1)},\alpha_2^{(n-1)},\alpha_3^{(n-1)})_{JMD} = (\gamma_{n-1(1),},\varsigma_{n-1(1)},\varsigma_{n-1(2)},\varsigma_{n-1(3)})_{JMD}$$

Step 2: The fuzzy differential equations obtained from Step 1 are converted into the following linear differential equations

$$\begin{aligned} &b_n z^{(n)} + b_{n-1} z^{(n-1)} + \ldots + b_1 z^{(1)} + b_0 z = g \\ &y_1 = \gamma_{0(1)}, y_1^{(1)} = \gamma_{1(1)},\ldots, y_1^{(n-1)} = \gamma_{n-1(1)} \end{aligned} \tag{1}$$

$$\begin{aligned} &c_n z^{(n)} + c_{n-1} z^{(n-1)} + \ldots + c_1 z^{(1)} + c_0 z = 0 \\ &\alpha_1 = \varsigma_{0(1)}, \alpha_1^{(1)} = \varsigma_{1(1)},\ldots, \alpha_1^{(n-1)} = \varsigma_{n-1(1)} \end{aligned} \tag{2}$$

$$\begin{aligned} &d_n z^{(n)} + d_{n-1} z^{(n-1)} + \ldots + d_1 z^{(1)} + d_0 z = 0 \\ &\alpha_2 = \varsigma_{0(2)}, \alpha_2^{(1)} = \varsigma_{1(2)},\ldots, \alpha_2^{(n-1)} = \varsigma_{n-1(2)} \end{aligned} \tag{3}$$

$$\begin{aligned} &e_n z^{(n)} + e_{n-1} z^{(n-1)} + \ldots + e_1 z^{(1)} + e_0 z = 0 \\ &\alpha_3 = \varsigma_{0(3)}, \alpha_3^{(1)} = \varsigma_{1(3)},\ldots, \alpha_3^{(n-1)} = \varsigma_{n-1(3)} \end{aligned} \tag{4}$$

Step 3: Solve the ordinary differential equations obtained from step 2 to find the values of $y_1,\alpha_1,\alpha_{2,}$ and α_3 .

Step 4: Put the values of $y_1,\alpha_1,\alpha_{2,}$ and α_3 in $\tilde{y} = (y_1,\alpha_1,\alpha_2,\alpha_3)_{JMD}$ to find the solution of fuzzy differential equation.

Step 5: Convert $\tilde{y} = (y_1,\alpha_1,\alpha_2,\alpha_3)_{JMD}$ into $\tilde{y} = (a,b,c,d)$, where $a = y_1$, $b = y_1 + \alpha_1, c = y_1 + \alpha_1 + \alpha_2$ and $d = y_1 + \alpha_1 + \alpha_2 + \alpha_3$.

IV. CASE STUDY (SYSTEM DESCRIPTION, NOTATIONS AND ASSUMPTIONS)

System description

Polytube industry consists of four sub-systems, namely mixture, extruder, die and cutter. The complete description of the system is as follows:

Sub-system A (Mixture)

This sub-system consists of blade and motor. For manufacturing of pipe, Raw material such as calcium carbonate, PVC rising, wax and other chemicals are made to mix with the help of these subsystems in appropriate proportion. This mixture is then heated upto 130^0C and transported to the extruder by conveyors. Failure of mixture causes complete failure of the system.

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Sub-system B (Extruder)

This sub-system consists of a heater to heat the mixture at different temperature. The quality of the product depends on heating process. Its failure causes the complete failure of the system.

Sub-system C (Die)

This sub-system makes pipes of different sizes. Minor failure of the sub-system reduced the capacity of the system, hence, loss in production. Major failure results in complete failure of the system.

Sub-system D (Cutter)

This sub-system contains two units namely blade and motor arranged in series. The blade cuts the pipe whereas motor cuts the pipe in different size. Failure of blade reduces the capacity of the system while the failure of motor causes the complete failure of the system.

Notations

Following notations are used to analyze the fuzzy availability of the Polytube industry

A, B, C, D — Good conditions of the sub-systems.

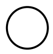
a, b, c, d — Failed state of the sub- systems A, B, C, D.

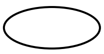
$\tilde{f}_1, \tilde{f}_2, \tilde{f}_3, \tilde{f}_4$ — Fuzzy failure rates of the sub-system.

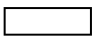
$\tilde{g}_1, \tilde{g}_2, \tilde{g}_3, \tilde{g}_4$ — Fuzzy failure rates of the sub-system.

$\tilde{P}_0(t)$ — Fuzzy probability of the system which is working with full capacity at time t.

$\tilde{P}_i(t)\,(i = 0, 1, 2...15)$ — Fuzzy probability that the system is in state S_i at time t.

 Indicates that the system is in full working state.

 Indicates that the system is in reduced state.

 Indicates that the system is in failed state.

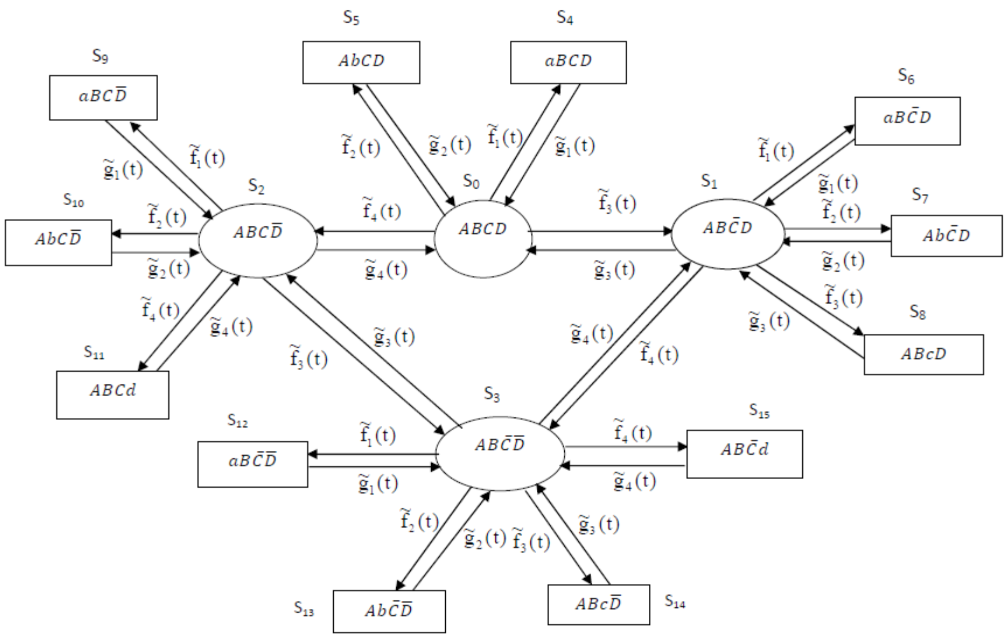


Fig. 1: State transition diagram

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Assumptions

(i) Polytube industry consists of four subsystems such as Mixture, Extruder, Die and Cutter.

(ii) All subsystems work in series.

(iii) Both sub-system C and D have one unit in standby.

(iv) There is a repairman who is always available with the system.

(v) Each subsystem has separate repair facility and there is no waiting time for repair in the system.

(vi) All the subsystems work as good as new after their repair.

(vii) Fuzzy failure and fuzzy repair rates are independent with each other.

(viii) Fuzzy failure and fuzzy repair rates of all the sub-systems follow general distributions.

DATA: Fuzzy failure rates and fuzzy repair rates (represented by trapezoidal fuzzy numbers) used for analyzing the fuzzy availability of polytube industry are given in the following table:

Table 1

Fuzzy failure rates	Fuzzy repair rates
$\tilde{l} = (0.005, 0.007, 0.009, 0.011)$	$\tilde{g} = (0.042, 0.044, 0.046, 0.048)$
$\tilde{l}_1 = (0.007, 0.011, 0.015, 0.019)$	$\tilde{g}_1 = (0.036, 0.042, 0.048, 0.054)$
$\tilde{l}_2 = (0.0023, 0.0025, 0.0027, 0.0029)$	$\tilde{g}_2 = (0.085, 0.087, 0.089, 0.0910)$
$\tilde{l}_3 = (0.0056, 0.0058, 0.0060, 0.0062)$	$\tilde{g}_3 = (0.14, 0.16, 0.18, 0.20)$

Fuzzy Kolmogorov's differential equations associated with the system

In this section, the following sets of fuzzy differential equations are developed by using the system model (Figure 1) of polytube industry as follows:

$$\tilde{P}_0{}'(t) \oplus \tilde{\delta}_0(t)\tilde{P}_0(t) = \tilde{g}_3(t)\tilde{P}_1(t) \oplus \tilde{g}_4(t)\tilde{P}_2(t) \oplus \tilde{g}_1(t)\tilde{P}_4(t) \oplus \tilde{g}_2(t)\tilde{P}_5(t)$$

$$\tilde{P}_1{}'(t) \oplus \tilde{\delta}_1(t)\tilde{P}_1(t) = \tilde{f}_3(t)\tilde{P}_0(t) \oplus \tilde{g}_1(t)\tilde{P}_6(t) \oplus \tilde{g}_2(t)\tilde{P}_7(t) \oplus \tilde{g}_3(t)\tilde{P}_8(t) \oplus \tilde{g}_4(t)\tilde{P}_3(t)$$

$$\tilde{P}_2{}'(t) \oplus \tilde{\delta}_2(t)\tilde{P}_2(t) = \tilde{f}_4(t)\tilde{P}_0(t) \oplus \tilde{g}_3(t)\tilde{P}_3(t) \oplus \tilde{g}_1(t)\tilde{P}_9(t) \oplus \tilde{g}_2(t)\tilde{P}_{10}(t) \oplus \tilde{g}_4(t)\tilde{P}_{11}(t)$$

$$\tilde{P}_3{}'(t) \oplus \tilde{\delta}_3(t)\tilde{P}_3(t) = \tilde{f}_4(t)\tilde{P}_1(t) \oplus \tilde{f}_3(t)\tilde{P}_2(t) \oplus \tilde{g}_1(t)\tilde{P}_{12}(t) \oplus \tilde{g}_2(t)\tilde{P}_{13}(t) \oplus \tilde{g}_3(t)\tilde{P}_{14}(t) \oplus \tilde{g}_4(t)\tilde{P}_{15}(t)$$

$$\tilde{P}_4{}'(t) \oplus \tilde{g}_1(t)\tilde{P}_4(t) = \tilde{f}_1(t)\tilde{P}_0(t)$$

$$\tilde{P}_5{}'(t) \oplus \tilde{g}_2(t)\tilde{P}_5(t) = \tilde{f}_2(t)\tilde{P}_0(t)$$

$$\tilde{P}_6{}'(t) \oplus \tilde{g}_1(t)\tilde{P}_6(t) = \tilde{f}_1(t)\tilde{P}_1(t)$$

$$\tilde{P}_7{}'(t) \oplus \tilde{g}_2(t)\tilde{P}_7(t) = \tilde{f}_2(t)\tilde{P}_1(t)$$

$$\tilde{P}_8{}'(t) \oplus \tilde{g}_3(t)\tilde{P}_8(t) = \tilde{f}_3(t)\tilde{P}_1(t)$$

$$\tilde{P}_9{}'(t) \oplus \tilde{g}_1(t)\tilde{P}_9(t) = \tilde{f}_1(t)\tilde{P}_2(t)$$

$$\tilde{P}_{10}{}'(t) \oplus \tilde{g}_2(t)\tilde{P}_{10}(t) = \tilde{f}_2(t)\tilde{P}_2(t)$$

$$\tilde{P}_{11}{}'(t) \oplus \tilde{g}_4(t)\tilde{P}_{11}(t) = \tilde{f}_4(t)\tilde{P}_2(t)$$

$$\tilde{P}_{12}{}'(t) \oplus \tilde{g}_1(t)\tilde{P}_{12}(t) = \tilde{f}_1(t)\tilde{P}_3(t)$$

$$\tilde{P}_{13}{}'(t) \oplus \tilde{g}_2(t)\tilde{P}_{13}(t) = \tilde{f}_2(t)\tilde{P}_3(t)$$

$$\tilde{P}_{14}{}'(t) \oplus \tilde{g}_3(t)\tilde{P}_{14}(t) = \tilde{f}_3(t)\tilde{P}_3(t)$$

$$\tilde{P}_{15}{}'(t) \oplus \tilde{g}_4(t)\tilde{P}_{15}(t) = \tilde{f}_4(t)\tilde{P}_3(t)$$

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Where

$$\tilde{\delta}_0(t) = \tilde{f}_1(t) \oplus \tilde{f}_2(t) \oplus \tilde{f}_3(t) \oplus \tilde{f}_4(t)$$

$$\tilde{\delta}_1(t) = \tilde{f}_1(t) \oplus \tilde{f}_2(t) \oplus \tilde{f}_3(t) \oplus \tilde{f}_4(t) \oplus \tilde{g}_3(t)$$

$$\tilde{\delta}_2(t) = \tilde{f}_1(t) \oplus \tilde{f}_2(t) \oplus \tilde{f}_3(t) \oplus \tilde{f}_4(t) \oplus \tilde{g}_4(t)$$

$$\tilde{\delta}_3(t) = \tilde{f}_1(t) \oplus \tilde{f}_2(t) \oplus \tilde{f}_3(t) \oplus \tilde{f}_4(t) \oplus \tilde{g}_3(t) \oplus \tilde{g}_4(t)$$

With fuzzy initial conditions

$$\tilde{p}_0(0) = (1, 0, 0, 0)$$

and $\tilde{p}_i(0) = (0,\ 0,\ 0,\ 0)$ for $i = 1,2,3,...15$

V. RESULTS AND DISCUSSION

Weibull distribution has been widely used to model many industrial systems. The two parameter form for pdf of Weibull distribution is given as

$$\tilde{f}_i(t) = kf_i(l_i t)^{k-1} \exp[-(f_i t)^k], \qquad t \geq 0,\ f_i > 0$$

where $i = 1, 2, 3, 4$

$$\tilde{g}_i(t) = kg_i(g_i t)^{k-1} \exp[-(g_i t)^k], \qquad t \geq 0,\ g_i > 0$$

In particular if k=1 or 2, then it represents the exponential and Rayleigh distribution respectively.

The solution of fuzzy initial value problem with JMD representation of polytube industry is shown numerically in TABLES II, III and IV at different time for different distributions. Using the fuzzy probabilities for polytube industry shown in TABLE II, TABLE III and TABLE IV and using the formula $\tilde{A}(t) = \tilde{P}_0(t) \oplus \tilde{P}_1(t) \oplus \tilde{P}_2(t) \oplus \tilde{P}_3(t)$, the corresponding fuzzy availabilities for different distributions at different time are shown in TABLE V.

In TABLE V the behavior of availability for the Weibull, exponential and Rayleigh distributions with respect to time is shown and their graphical representation is shown in Fig. 2, 3 and 4. It is found that with the increases of time, availability of the system decreases for Weibull, exponential and Rayleigh distribution. On the basis of numerical values obtained, it is observed that availability is higher in the case when random variables follow Weibull distribution rather than exponential and Rayleigh distribution.

TABLE II: Solution of fuzzy Kolmogorov's differential equations of Polytube Industry by using Mehar's method for Weibull distribution

	$\tilde{P}_j(t)$ **for t=24**	$\tilde{P}_j(t)$ **for t=48**	$\tilde{P}_j(t)$ **for t=72**	$\tilde{P}_j(t)$ **for t=96**	$\tilde{P}_j(t)$ **for t=120**
J	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$
0	(0.836049, 0.840690, 0.845332,0.849973)	(0.771329,0.775657,0.779985,0.784312)	(0.738903,0.742956, 0.747010,0.751064)	(0.7217340.725547,0.729360,0.733173)	(0.712425,0.716027, 0.018932,0.723231)
1	(0.014334,0.014345, 0.014356,0.014367)	(0.017807,0.017827,0.017847,0.017867)	(0.018631,0.018658, 0.018686,0.018714)	(0.018812,0.018846, 0.018881,0.018916)	(0.018852,0.018932, 0.028399,0.018972
2	(0.026932, 0.026942, 0.026952,0.026962)	(0.029379,0.029396,0.029412,0.029429)	(0.029050,0.029071, 0.029091,0.029112)	(0.028621,0.028667, 0.028691,0.028691)	(0.028349,0.028374, 0.028399,0.028424)
3	(0.000462,0.000462, 0.000462,0.000462)	(0.000679,0.000692,0.000718,0.000742)	(0.000733,0.000734, 0.000735,0.000736)	(0.000747,0.000747, 0.000748,0.000748)	(0.000751,0.000752, 0.000753,0.000754)
4	(0.042084,0.042199, 0.042313,0.042427)	(0.2062991,0.063209,0.063427,0.063644)	(0.073496,0.073808, 0.074120,0.074432)	(0.078745,0.079540, 0.079938,0.079938)	(0.081326,0.081802, 0.082278,0.082754)
5	(0.060965,0.061188, 0.061411,0.061634)	(0.093975,0.094390, 0.094805,0.095220)	(0.112317,0.112897, 0.113477,0.114057)	(0.122630,0.124074, 0.124074,0.124795)	(0.128470,0.129313, 0.130156,0.130999)
6	(0.000443,0.000444, 0.000445,0.000446)	(0.001050,0.001051,0.001052,0.001053)	(0.001499,0.001500, 0.001501,0.001502)	(0.001789,0.001793, 0.001793,0.001795)	(0.001969,0.001971, 0.001974,0.001977)
7	(0.000635,0.000636, 0.000637,0.000638)	(0.001544,0.001545,0.001546,0.001547)	(0.002254,0.002256, 0.002258,0.002260)	(0.002742,0.002749, 0.002750.0.002752)	(0.003065,0.003070, 0.003075,0.003080)

8	(0.000172,0.000173, 0.000174,0.000175)	(0.000350,0.000352,0.000354,0.000356)	(0.000445,0.000448, 0.000451,0.000454)	(0.000485,0.000487, 0.000489,0.000491)	(0.000501,0.000502, 0.000503,0.000504)
9	(0.000894,0.000896, 0.000899,0.000900)	(0.001900,0.001901,0.001902,0.001903)	(0.002526,0.002527, 0.002528,0.002529)	(0.002884,0.002885, 0.002886,0.002888)	(0.003083,0.003085, 0.003087,0.003089)
10	(0.001288,0.001289, 0.001290,0.001292)	(0.002801,0.002802,0.002803,0.002804)	(0.003814,0.003815, 0.003817,0.003819)	(0.004441,0.004443, 0.004446,0.004449)	(0.004824,0.004828, 0.004832,0.004835)
11	(0.000690,0.000691, 0.000692,0.000693)	(0.001070,0.001072,0.001074,0.001076)	(0.001150,0.001151, 0.001152,0.001153)	(0.001158,0.001161, 0.001164,0.001167)	(0.001140,0.001144, 0.001148,0.001152)
12	(0.000011,0.000012, 0.000013,0.000014)	(0.000034,0.000035,0.000036,0.000037)	(0.000055,0.000057, 0.000059,0.000061)	(0.000068,0.000070, 0.000072,0.000074)	(0.000077,0.000079, 0.000081,0.000083)
13	(0.000016,0.000018, 0.000020,0.000022)	(0.000050,0.000051,0.000052,0.000053)	(0.000082,0.000083, 0.000084,0.000085)	(0.000104,0.000108, 0.000112,0.000116)	(0.000119,0.000120, 0.000121,0.000122)
14	(0.000004,0.000005, 0.000006,0.000007)	(0.000012,0.000018,0.000024,0.000029)	(0.000017,0.000019, 0.000021,0.000023)	(0.000019,0.000022, 0.000024,0.000028)	(0.000020,0.000022, 0.000024,0.000026
15	(0.000005,0.000006, 0.000008,0.000009)	(0.000022,0.000023,0.000024,0.000025)	(0.000027,0.000032, 0.000037,0.000042)	(0.000029,0.000034, 0.000039,0.000043)	(0.000030,0.000033, 0.000036,0.000039)

TABLE III: Solution of fuzzy Kolmogorov's differential equations of Polytube Industry by using Mehar's method for exponential distribution

	$\tilde{P}_j(t)$ **for t=24**	$\tilde{P}_j(t)$ **for t=48**	$\tilde{P}_j(t)$ **for t=72**	$\tilde{P}_j(t)$ **for t=96**	$\tilde{P}_j(t)$ **for t=120**
J	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$
0	(0.771328,0.775656, 0.779983,0.784311)	(0.721736,0.725549,0.729362,0.733176)	(0.707316,0.710733,0.714150,0.717566)	(0.702914,0.706024,0.709133,0.712243)	(0.701536,0.704406,0.707276,0.710145)
1	(0.017807,0.017827, 0.017847,0.017868)	(0.018811,0.018846,0.018880,0.018915)	(0.018868,0.018913,0.018958,0.019003)	(0.018899,0.018952,0.019004,0.019056)	(0.018927,0.018984,0.019042,0.019100)
2	(0.029380,0.029397, 0.029413,0.029430)	(0.028619,0.028643,0.028666,0.028689)	(0.028198,0.028223,0.028249,0.028274)	(0.028075,0.028101,0.028127,0.028153)	(0.028043,0.028068,0.028094,0.028119)
3	(0.000679,0.000681, 0.000683,0.000685)	(0.000747,0.000748,0.000749,0.000750)	(0.000753,0.000754,0.000755,0.000756)	(0.000755,0.000756,0.000757,0.000758)	(0.000757,0.000758,0.000759,0.000760)
4	(0.062991,0.063209, 0.063427,0.063644)	(0.078744,0.079142,0.079540,0.079937)	(0.082564,0.083112,0.083660,0.084208)	(0.083381,0.084056,0.084731,0.085406)	(0.083501,0.084284,0.085067,0.085850)
5	(0.093975,0.094390, 0.094805,0.095220)	(0.122630,0.123352,0.124073,0.124795)	(0.131794,0.132741,0.133687,0.134634)	(0.134786,0.135896,0.137007,0.138118)	(0.135778,0.137006,0.138234,0.139463)
6	(0.001050,0.001051, 0.001052,0.001053)	(0.001789,0.001791,0.001793,0.001795)	(0.002078,0.002082,0.002085,0.002089)	(0.002186,0.002192,0.002198,0.002203)	(0.002228,0.002236,0.002244,0.002252)
7	(0.001544,0.001545, 0.001546,0.001547)	(0.002742,0.002745,0.002749,0.002752)	(0.003276,0.003283,0.003289,0.003296)	(0.003505,0.003515,0.003525,0.003535)	(0.003605,0.003619,0.003632,0.003646)
8	(0.000352,0.000353, 0.000354,0.000355)	(0.000485,0.000487,0.000489,0.000491)	(0.000507,0.000509,0.000511,0.000513)	(0.000511,0.000514,0.000516,0.000519)	(0.000512,0.000513,0.000514,0.000515)
9	(0.001900,0.001901, 0.001902,0.001904)	(0.002884,0.002885,0.002887,0.002888)	(0.003195,0.003197,0.003200,0.003202)	(0.003291,0.003295,0.003298,0.003302)	(0.003322,0.003327,0.003331,0.003336)
10	(0.002801,0.002802, 0.002803,0.002804)	(0.004441,0.004444,0.004446,0.004449)	(0.005060,0.005064,0.005069,0.005073)	(0.005295,0.005301,0.005308,0.005314)	(0.005388,0.005395,0.005403,0.005410)
11	(0.001072,0.001074, 0.001076,0.001078)	(0.001151,0.001153,0.001155,0.001157)	(0.001132,0.001133,0.001134,0.001135)	(0.001124,0.001126,0.001128,0.001130)	(0.001122,0.001124,0.001126,0.001128)
12	(0.000035,0.000039, 0.000041,0.000043)	(0.000068,0.000069,0.000070,0.000071)	(0.000082,0.000085,0.000088,0.000090)	(0.000087,0.000088,0.000089,0.000090)	(0.000089,0.000091,0.000092,0.000093)
13	(0.000051,0.000054, 0.000057,0.000060)	(0.000104,0.000107,0.000110,0.000112)	(0.000128,0.000129,0.000130,0.000131)	(0.000139,0.000140,0.000142,0.000142)	(0.000144,0.000146,0.000148,0.000150)
14	(0.000012,0.000013, 0.000014,0.000015)	(0.000019,0.000020,0.000021,0.000022)	(0.000020,0.000023,0.000025,0.000026)	(0.000020,0.000025,0.000030,0.000035)	(0.000022,0.000024,0.000027,0.000029)
15	(0.000022,0.000024, 0.000026,0.000028)	(0.000029,0.000031,0.000033,0.000035)	(0.000030,0.000034,0.000038,0.000042)	(0.000032,0.000035,0.000039,0.000043)	(0.000035,0.000037,0.000040,0.000045)

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TABLE IV: Solution of fuzzy Kolmogorov's differential equations of Polytube Industry by using Mehar's method for Rayleigh distribution

	$\tilde{P}_j(t)$ for t=24	$\tilde{P}_j(t)$ for t=48	$\tilde{P}_j(t)$ for t=72	$\tilde{P}_j(t)$ for t=96	$\tilde{P}_j(t)$ for t=120
j	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$	$(P_{j1}(t), P_{j2}(t), P_{j3}(t), P_{j4}(t))$
0	(0.761387,0.765639, 0.769891,0.774143)	(0.716818,0.720517, 0.724216,0.727915)	(0.705558,0.708844, 0.712131,0.715417)	(0.702568,0.705544, 0.708520,0.711497)	(0.701749,0.704491,0 .707232,0.709974)
1	(0.018154,0.018176, 0.018198,0.018221)	(0.018852,0.018890, 0.018927,0.018965)	(0.018892,0.018940, 0.018988,0.019036)	(0.018927,0.018982, 0.019037,0.019092)	(0.018950,0.019011,0 .019071,0.019132)
2	(0.029377,0.029395, 0.029412,0.029430)	(0.028482,0.028506, 0.028530,0.028555)	(0.028150,0.028175, 0.028201,0.028227)	(0.028072,0.028097, 0.028123,0.028149)	(0.028055,0.028079, 0.028104,0.028129)
3	(0.000701,0.000703, 0.000705,0.000707)	(0.000750,0.000752, 0.000754,0.000756)	(0.000754,0.000756, 0.000758,0.000760)	(0.000756,0.000758, 0.000760,0.000762)	(0.000758,0.000759,0 .000760,0.000761)
4	(0.065943,0.066190, 0.066436,0.066682)	(0.079748,0.080192, 0.080637,0.081081)	(0.082474,0.083081, 0.083688,0.084295)	(0.082907,0.083649, 0.084390,0.085131)	(0.082927,0.083781, 0.084635,0.085489)
5	(0.099702,0.100160, 0.100618,0.101076)	(0.126032,0.126815, 0.127598,0.128381)	(0.133361,0.134373, 0.135385,0.136396)	(0.135451,0.136621, 0.137792,0.138962)	(0.136058,0.137336,0 .138614,0.139892)
6	(0.001174,0.001175, 0.001176,0.001177)	(0.001879,0.001882, 0.001884,0.001886)	(0.002118,0.002122, 0.002127,0.002131)	(0.002197,0.002204, 0.002211,0.002218)	(0.002225,0.002234,0 .002244,0.002254)
7	(0.001748,0.001749, 0.001751,0.001752)	(0.002924,0.002928, 0.002932,0.002937)	(0.003388,0.003395, 0.003403,0.003411)	(0.003567,0.003579, 0.003590,0.003602)	(0.003638,0.003654,0 .003669,0.003685)
8	(0.000383,0.000385, 0.000387,0.000389)	(0.000495,0.000496, 0.000497,0.000498)	(0.000509,0.000510, 0.000511,0.000512)	(0.000511,0.000512, 0.000513,0.000514)	(0.000512,0.000513,0 .000514,0.000515)
9	(0.002079,0.002080, 0.002081,0.002082)	(0.002980,0.002982, 0.002983,0.002985)	(0.003223,0.003226, 0.003229,0.003232)	(0.003288,0.003292, 0.003297,0.003301)	(0.003306,0.003312,0 .003317,0.003322)
10	(0.003106,0.003107, 0.003108,0.003109)	(0.004660,0.004664, 0.004667,0.004670)	(0.005177,0.005182, 0.005187,0.005193)	(0.005353,0.005360, 0.005367,0.005374)	(0.005415,0.005424,0 .005432,0.005440)
11	(0.001108,0.001110, 0.001112,0.001114)	(0.001146,0.001148, 0.001150,0.001152)	(0.001128,0.001129, 0.001130,0.001131)	(0.001123,0.001124, 0.001125,0.001128)	(0.001124,0.001125,0 .001127,0.001129)
12	(0.000041,0.000044, 0.000047,0.000050)	(0.000072,0.000073, 0.000074,0.000075)	(0.000084,0.000087, 0.000090,0.000093)	(0.000087,0.000088, 0.000089,0.000090)	(0.000089,0.000091,0 .000093,0.000095)
13	(0.000060,0.000062, 0.000064,0.000066)	(0.000112,0.000115, 0.000117,0.000119)	(0.000133,0.000134, 0.000135,0.000136)	(0.000142,0.000144, 0.000146,0.000148)	(0.000145,0.000148,0 .000151,0.000154)
14	(0.000014,0.000015, 0.000016,0.000017)	(0.000019,0.000021, 0.000023,0.000025)	(0.000020,0.000023, 0.000026,0.000029)	(0.000023,0.000026, 0.000029,0.000031)	(0.000026,0.000028,0 .000030,0.000033)
15	(0.000024,0.000027, 0.000030,0.000033)	(0.000030,0.000034, 0.000037,0.000040)	(0.000032,0.000035, 0.000038,0.000040)	(0.000035,0.000037, 0.000039,0.000042)	(0.000037,0.000039,0 .000042,0.000045)

TABLE V: Fuzzy Availability of the Polytube Industry

Fuzzy Availability $\tilde{A}(t)$ →	**Weibull Distribution**	**Exponential distribution**	**Rayleigh Distribution**
Time ↓	$(\tilde{A}_1(t), \tilde{A}_2(t), \tilde{A}_3(t), \tilde{A}_4(t))$	$(\tilde{A}_1(t), \tilde{A}_2(t), \tilde{A}_3(t), \tilde{A}_4(t))$	$(\tilde{A}_1(t), \tilde{A}_2(t), \tilde{A}_3(t), \tilde{A}_4(t))$
24	(0.877778,0.882440, 0.887102,0.891764)	(0.819194,0.823558, 0.827923,0.832987)	(0.809618,0.813910, 0.818202,0.822495)
48	(0.819194,0.823558, 0.827923,0.832287)	(0.769913,0.773785, 0.777656,0.781527)	(0.764902,0.768663, 0.772423,0.776184)
72	(0.787317,0.791419, 0.795522,0.799624)	(0.755135,0.758622, 0.762110,0.765597)	(0.753354,0.756715, 0.760075,0.763436)
96	(0.769913,0.773785, 0.777656,0.781527)	(0.750644,0.753832, 0.757020,0.760208)	(0.750322,0.753379, 0.756437,0.759495)
120	(0.760377,0.764044, 0.767712,0.771379)	(0.749262,0.752215, 0.755169,0.758122)	(0.749512,0.752339, 0.755166,0.757994)

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Graphical representation of numerical results:

The variation of fuzzy availability with time is shown graphically (in all three distributions) in following figures:

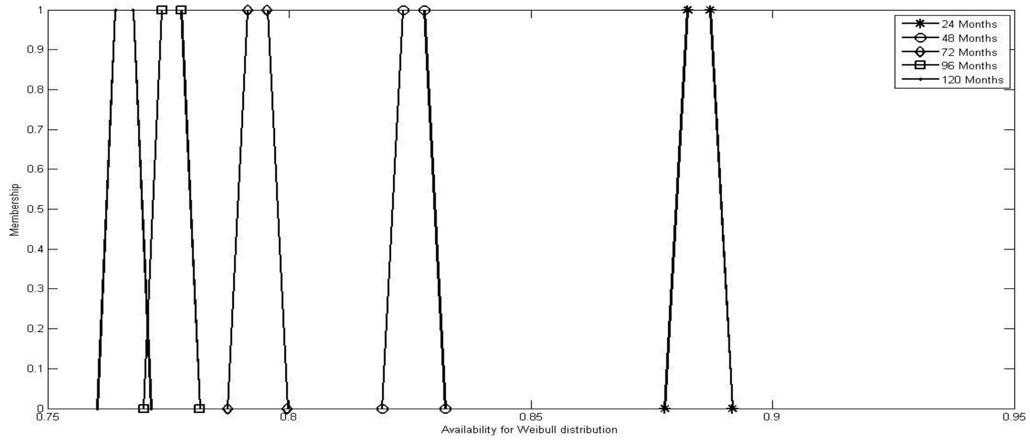

Fig. 2: Fuzzy Availability for Weibull distribution

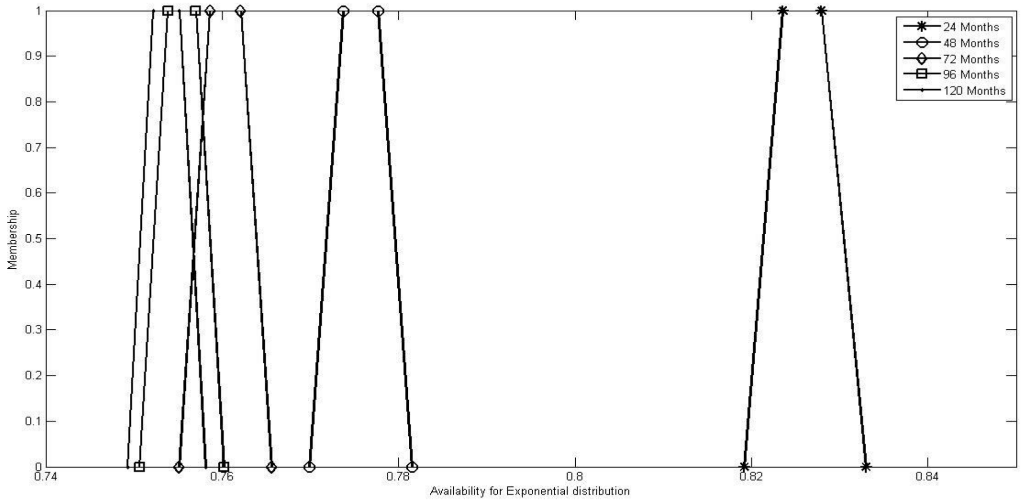

Fig. 3: Fuzzy Availability for Exponential distribution

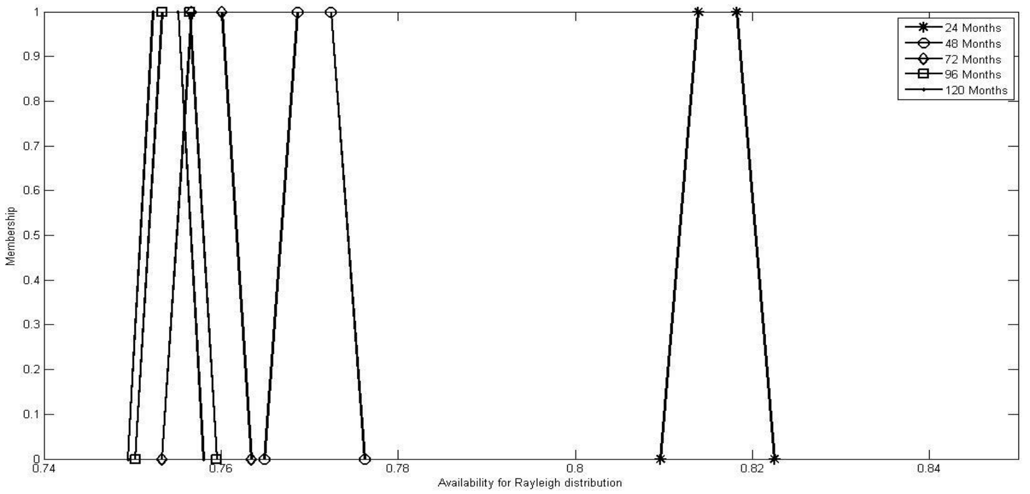

Fig. 4: Fuzzy Availability for Rayleigh distribution

VI. CONCLUSION

Fuzzy reliability of a polytube industry is investigated with arbitrarily distributed random variables. On the basis of numerical results obtained, it is found that solution of fuzzy differential equations, obtained by using the Mehar's method is again a fuzzy number for all the distributions. On the basis of the study, it is concluded that polytube industry can be more profitable and more available if Weibull distributed random variables are used rather than exponential and Rayleigh distributions.

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