Research Article

Availability and Profit Analysis of Gas Turbine System using Fuzzy Trapezoidal Numbers with Different Left Height and Right Height

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Abstract
This paper analyzed a gas turbine system by using method of α-cuts coupled with trapezoidal fuzzy numbers of different left and right height for general distribution.Gas turbine system having six subsystems namely - Air inlet subsystem, Compressor subsystem, Combustion chamber subsystem, Turbine subsystem, Electric generator subsystem and Governing subsystem which are working in series. Subsystems turbine, electric generator and governing fails completely via reduced capacity. Fuzzy failure and fuzzy repair rates of all the subsystems are taken as general. Giving particular values to various parameters and costs, the numerical results for availability and profit are obtained by considering exponential, Rayleigh and Weibulldistributions for all random variables.
Keywords Gas turbine system, Trapezoidal fuzzy numbers with different left and right heights, Fuzzy availability, Fuzzy profit, General distributions.

Introduction

In the present era of modernization and industrial growth, the fabrication of new products is becoming more and more complex in nature. Due to this complexity the comprehensive study of reliability analysis of the system becomes more apparent.But due to innovation and interconnection of different research field, the reliability analysis got exposure to different field of sciences such as electrical, mechanical, electronic and other associated fields. Mathematical aspects have made the reliability more applicable to many industries. Many researchers and engineers discussed reliability models of various industrial systems or subsystems. Kumar et al. (1989) discussed the reliability analysis of feeding system of paper industry. In continuation of this Kumar et al.(1989) evaluated availability of washing system in paper industry with constant failure and repair rates. Kumar et al. (1990) discussed reliability of a refining system in sugar industry. Kumar and Pandey (1993) discussed about maintenance planning in urea fertilizer plant. Kumar et al. (1997) analyzed the steady state behavior of a desulphurization system in urea plant. Using fourth order Runga- Kutta method Gupta et al. (2004) obtained numerical results for reliability and availability of a butter oil processing plant. Using simulated model Gupta and Tiwari (2009) obtained the reliability of a thermal power plant. Suleiman (2013) evaluated the performance of a thermal power plant. Iqbal and Uduman (2016) discussed reliability of paper plant using Boolean function with fuzzy logic technique.

The traditional reliability techniques are dependent on probability obtained by the crisp or precise data values. However in actual practice the data obtained may or may not be precise or certain. Therefore in many industrial problems it may be difficult to derive useful information about reliability of the system where data is imprecise, vague or linguistic in nature. To handle these situations the concept of fuzzy sets may be quite helpful to derive the reliability of the system.

Zadeh (1965) presented the concept of fuzzy set theory. The concept of fuzzy set or fuzzy number can handle all possible states or outcomes associated with a system. Since then a lot of work has been done by many researchers like Singer (1990),Cai et al (1999(a),1999(b)), Cheng and Mon (1993), Chen (1994) and Verma et al.(2002) to determine reliability of various system. Furthermore, Aliev and Kara (2013) discussed fuzzy system reliability using the interval of confidence and time dependent fuzzy set. Buckley and Feuring (2001) proposed two analytical methods for solving n^{th} order fuzzy differential equation. Using one of the method given by Buckley and Feuring, Lata and Kumar (2011)observed that the reliability of markov model need not be a fuzzy number even if the random variable associated with the system are taken as fuzzy number. To overcome this problem Lata and Kumar proposed Mehar's method and evaluated fuzzy reliability of Piston manufacturing system. Verma et al.(2012) studied power system reliability evaluation using Fault tree analysis based on generalized fuzzy numbers. Kumar and Lata (2012) evaluate fuzzy reliability of condensate system. Chen et al (2012) proposed a new approach for analyzing fuzzy risk based on fuzzy numbers with different left and right heights. Verma and Kumar (2014) evaluated the reliability of a gas turbine system using vague λ-τ methodology. Goel and Narain (2018) discussed the fuzzy availability of Polytube industry by taking general distributions of all random variables.Most of the fuzzy reliability techniques available in literature deal with triangular or trapezoidal types of fuzzy numbers. These fuzzy numbers incorporate precision of data on a point or on an interval. But it is quite possible that the data available with an industrial system may be imprecise or uncertain throughout the operating time of the system under consideration.

Thermal industry is one of the most important industry associated with the life of a human being. It meets many commercial and daily life requirements in one or another way. Due to increasing population and urbanization power consumption is increasing per day, but on the other hand natural resources such as coal, fossil fuels and plant woods are limited in abundance. This industry need to be focused from reliability prospective. To achieve optimum reliability, failure hazards should be constrained to minimize as possible. A gas turbine system is a combustion engine that converts natural gas or other liquid fuels to mechanical energy which in turn derives a generator to produce energy. This feature of production of energy makes gas turbine as one of the key components of various industries such as thermal industry, automobile industry and many other mechanical industries.

Keeping in mind the importance of gas turbine system in industries, its availability and profit etc. should be calculated in more flexible and intelligent manner to counter with the technical and economical challenges.To handle these situationsof more fuzziness, fuzzy numbers of different left and right height are used to evaluate fuzzy profit and fuzzyavailability of a gas turbine system. Gas turbine system having six subsystems namely - Air inlet subsystem, Compressor subsystem, Combustion chamber subsystem, Turbine subsystem, Electric generator subsystem and Governing subsystem which are working in series. Subsystems turbine, electric generator and governing fails completely via reduced capacity. Fuzzy failure and fuzzy repair rates of all the subsystems are taken as general. Giving particular values to various parameters and costs, the numerical results for availability and profit are obtained by considering exponential, Rayleigh and Weibull distributions for all random variables.
This paper has been organized as follows: Section 1is introductory in nature,Section 2 introduces the basic definitions and arithmetic operations related to traditional trapezoidal fuzzy numbers and trapezoidal fuzzy numbers with different left and right height. In section 3,comparisonbetween traditional and proposed method has been discussed. In section 4, a complete introduction about description of the system along with notations and assumptions of the system is given. Section 5 discussed the mathematical modeling of gas turbine system is presented. In section 6, fuzzy availability and fuzzy profit has been calculated. Conclusion drawn from analysis is discussed in section 7.

Basic Definitions

In this section, some basic definitions and arithmetic operations related to traditional trapezoidal fuzzy numbers and trapezoidal fuzzy numbers with different left and right height are presented:

Definition2.1:-A trapezoidal fuzzy number $\tilde{A} = (a, b, c, d)$ is said to be zero trapezoidal fuzzy number if and only if $a = 0, b = 0, c = 0, d = 0.$

Definition2.2:- An α-cut of a fuzzy number $\tilde{A}$ is defined as a crisp set $A_\alpha = \{ x : \mu_{\tilde{A}}(x) \geq \alpha, x \in X \},$ where $\alpha \in [0,1]$. For a trapezoidal fuzzy number $\tilde{A} = (a, b, c, d)$ the α-cut $A_\alpha = [a + (b - a)\alpha, d - (d - c)\alpha].$

Definition2.3:-Two α-cuts $A_\alpha = [a, b]$ and $B_\alpha = [c, d]$ are said to be equal i.e. $A_\alpha = B_\alpha$ if and only if $a = b \quad and \quad c = d.$

Definition2.4:-Let $A = [a, b]$ and $B = [c, d]$ be two α-cuts of trapezoidal fuzzy numbers $\tilde{A}$ and $\tilde{B}$ respectively. Then

$$A + B = [a + c, b + d]$$

$$A - B = [a - d, b - c]$$

$$\lambda A = \begin{cases} [\lambda a, \lambda b] & \lambda \geq 0 \\ [\lambda b, \lambda a] & \lambda \leq 0 \end{cases}$$

$$A \times B = [min(ac, bd, bc, bd), max(ac, ad, bc, bd)]$$

$$\frac{[a,b]}{[c,d]}=\left[min\left(\frac{a}{c},\frac{a}{d},\frac{b}{c},\frac{b}{d}\right),max\left(\frac{a}{c},\frac{a}{d},\frac{b}{c},\frac{b}{d}\right)\right]$$

Definition2.5:-A fuzzy number $\tilde{A}=(a,b,c,d)$ is said to be a trapezoidal fuzzy number if its membership function is given by

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

Definition2.6:-A set $\tilde{A}=\{(a,b,c,d);\mu_L,\mu_R\}$ is said to be a trapezoidal fuzzy number with different left and right heights if its membership function is given by

$$\mu_{\tilde{A}}=\begin{cases}\mu_L\frac{x-a}{b-a} & a\le x\le b\\ \mu_L+\frac{x-b}{c-b}(\mu_R-\mu_L) & b\le x\le c\\ \mu_R\frac{x-d}{c-d} & c\le x\le d\\ 0 & otherwise\end{cases}$$

Definition2.7:- An α-cut of a fuzzy number $\tilde{A}=(a,b,c,d)$ with different left height and right height is defined as

$$A_\alpha=\begin{cases}a+(b-a)\frac{\alpha}{\mu_L},\quad d-(d-c)\frac{\alpha}{\mu_R} & \alpha\in[0,\mu_L]\\ b+(c-b)\frac{\alpha-\mu_L}{\mu_R-\mu_L},\ d-(d-c)\frac{\alpha}{\mu_R} & \alpha\in[\mu_L,\mu_R]\end{cases}$$

Comparison between traditional and proposed method

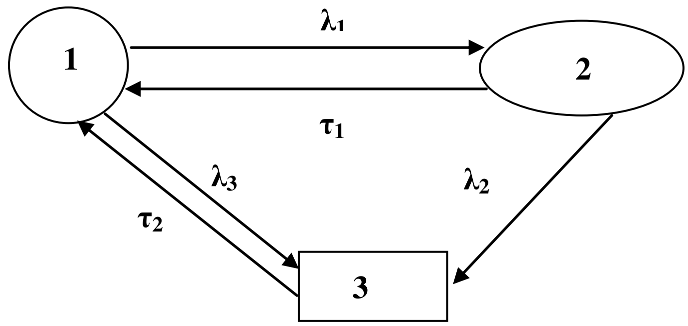
The method ofα-cuts, given by Buckley and Feuring (2001),is one of the most commonly used methodto solve a nth order fuzzy initial value problem.This method involves the use of traditional trapezoidal fuzzy numbers. In our proposed method these traditional fuzzy numbers are replaced by trapezoidal numbers of different left and right height. To illustrate the difference between traditional method and proposed method, we consider a single unit model shown in Fig.1. Fuzzy failure rates $(\tilde{\lambda}_1,\tilde{\lambda}_2,\tilde{\lambda}_3)$ and fuzzy repair rates$(\tilde{\tau}_1,\tilde{\tau}_2)$associated with this system represented by traditional trapezoidal numbers are given by:

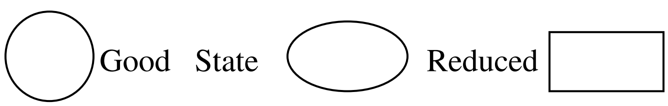
$\tilde{\lambda}_1=(0.00230,0.00258,0.00287,0.00302)$ $\tilde{\lambda}_2=(0.00408,0.00458,0.00484,0.00504)$

$\tilde{\lambda}_3=(0.00265,0.00294,0.00325,0.00352)$

and $\tilde{\tau}_1=(0.456,0.500,0.525,0.580)$ $\tilde{\tau}_2=(0.315,0.360,0.405,0.428)$

Fig. 1: Transition diagram of a single unit system





Fuzzy differential equations associated with the above model are given as:

$\tilde{P}_1{}'(t)+\tilde{\delta}_1\tilde{P}_1(t)=\tilde{\tau}_1\tilde{P}_2(t)+\tilde{\tau}_2\tilde{P}_3(t)$

$\tilde{P}_2{}'(t)+\tilde{\delta}_2\tilde{P}_2(t)=\lambda_1\tilde{P}_1(t)$ $\tilde{P}_3'(t)+\tilde{\tau}_2\tilde{P}_3(t)=\lambda_3\tilde{P}_1(t)$

Where $\tilde{\delta}_1=\tilde{\lambda}_1+\tilde{\lambda}_3, \tilde{\delta}_2=\tilde{\lambda}_2+\tilde{\tau}_1$

With initial conditions

$\tilde{P}_1(0)=(0.945, 0.955, 0.965, 0.975)$ $\tilde{P}_i(0)=(0,0,0,0)$ $\quad for \quad i=2,\ 3$

Fuzzy availability by traditional method

The fuzzy differential equations stated above are solved by the traditional method of α-cuts. The implicit solutions $(\tilde{p}_i,\ \ i=1,2,3)$ thus obtained are used to calculate the fuzzy availability mathematically as $\tilde{A}(t)=\tilde{P}_1(t)\oplus\tilde{P}_2(t)$. The numerical values of the availability are shown in the following table

Table 1

Fuzzy → Availability ↓ α	At t=24		At t=48		At t=72		At t=96		At t=120	
	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	0.94534	0.97552	0.94488	0.97492	0.94442	0.97432	0.94397	0.97372	0.94351	0.97312

0.2	0.947 38	0.9735 5	0.9469 0	0.9729 4	0.946 43	0.972 35	0.945 96	0.971 75	0.945 49	0.971 15
0.4	0.949 41	0.9715 7	0.9489 3	0.9709 7	0.948 44	0.970 37	0.947 96	0.969 77	0.947 47	0.969 17
0.5	0.950 43	0.9705 8	0.9499 4	0.9699 8	0.949 44	0.969 38	0.948 95	0.968 78	0.948 46	0.968 19
0.6	0.951 45	0.9696 0	0.9509 5	0.9690 0	0.950 45	0.968 40	0.949 95	0.967 80	0.949 45	0.967 20
0.8	0.953 48	0.9682 4	0.9529 6	0.9676 4	0.952 45	0.967 04	0.951 94	0.966 44	0.951 42	0.965 84

Graphical representation

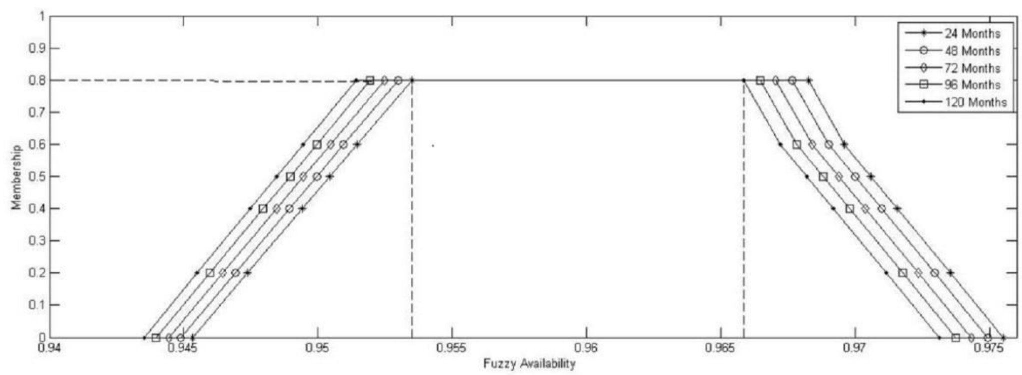


Fig.2: Fuzzy availability by traditional method

3.2.Fuzzy Availability by proposed method

The fuzzy differential equations stated above are solved by the method of α-cuts by replacing the traditional trapezoidal fuzzy numbers with trapezoidal fuzzy numbers of different left and right height. The implicit solutions ($\tilde{p}_i$, $i = 1,2,3$) thus obtained are used to calculate the fuzzy availability mathematically as $\tilde{A}(t) = \tilde{P}_1(t) \oplus \tilde{P}_2(t)$.The numerical values of the availability are shown in the following table. Availability thus obtained is represent graphically in Fig. 3

Table 2

Fuzzy→ Availability↓ A	At t=24		At t=48		At t=72		At t=96		At t=120	
	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	0.945 34	0.975 52	0.944 88	0.974 92	0.944 42	0.974 32	0.943 97	0.973 72	0.943 51	0.973 12
0.2	0.949	0.973	0.948	0.972	0.948	0.971	0.947	0.971	0.947	0.970

	41	05	93	45	44	85	96	25	47	65
0.4	0.953 48	0.970 58	0.952 96	0.969 98	0.952 45	0.969 38	0.951 94	0.968 78	0.951 42	0.968 19
0.5	0.955 51	0.969 35	0.954 98	0.968 75	0.954 45	0.968 15	0.953 92	0.967 55	0.953 39	0.966 95
0.6	0.958 89	0.968 12	0.958 34	0.967 52	0.957 79	0.966 92	0.957 23	0.966 32	0.956 68	0.965 72
0.8	0.965 65	0.965 65	0.965 05	0.965 05	0.964 45	0.964 45	0.963 85	0.963 85	0.963 25	0.963 25

Graphical Representation

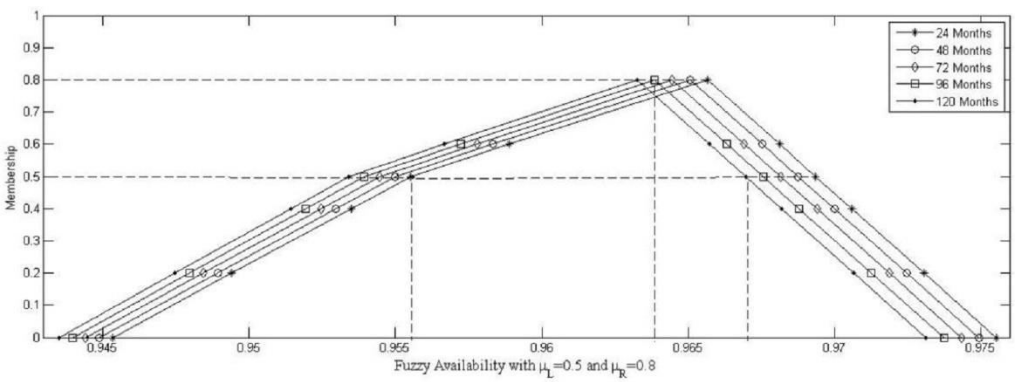


Fig. 3: Fuzzy Availability by proposed method

Advantages of proposed method over traditional method

One may observe that the availability obtained by the proposed method asserts more fuzziness. To include more fuzziness in data available with the system we consider α-cuts for α<1.This deals with those situations when there is no precise information or there is more hesitation with the information available with the system. Fig 2 indicates that only those values of availability are admissible which bear higher degree of membership. Therefore, in traditional method the data must have high degree of acceptance to achieve sustainable availability. On the other handFig 3 indicates that those values of availability are acceptable which has lower degree of membership. This conclude that if we couple λ-τ methodology with trapezoidal number of different left and right height then system can be made available for longer period of its run time.

System description, notations and assumptions of gas turbine system

In this section, a detailed description of the gas turbine system and its subsystem is given along with notations and assumptions which are used to analyze the fuzzy availability and fuzzy profit.

System description

Gas Turbine system is one of the most widely used powergenerating system. It is a type of internal combustion engine which produce hot gases to spin a turbine to produce power. A gas turbine system can utilize a variety of fuels including natural gas, fossil fuel and synthetic fuel. Gas turbine system consists ofsixsub-systems like air inlet subsystem, compressor subsystem, combustion chamber subsystem, turbine subsystem, electric generator or alternator subsystem, governing subsystem.

The operations that are performed on these sub-systems are as follows:

Sub-system A **(Air inlet subsystem):** Air inlet subsystem is essential successful operation of a gas turbine system. It protects gas turbine system from impurities and dust in the air which may reduce the efficiency and output of the plant.It provides clean air into the compressor subsystem. A blade cleaning system comprising of a high pressure pump provides cleaning facility for the compressor blades.

Sub-system B **(Compressor subsystem):** The Role of this system is to sucks air from the atmosphere and compresses it to pressures in the range of 15 to 20 bar and feeds it to the combustion chamber. It consists of a number of rows of blades mounted on a shaft like a series of fans placed one after the other.

Sub-system C **(Combustion chamber subsystem):**A combustion chamber or combustor subsystem is another main component of a gas turbine where combustion takes place. It is typically made up of a ring of fuel injectors that inject a steady stream of fuel into combustion chambers where it mixes with the air. The combustion produces a high temperature, high pressure gas stream that enters and expands through the turbine system.

Sub-system D **(Turbine subsystem):** The turbine subsystem does the main work of energy conversion in a gas power plant. It is intricate array of alternate stationary and rotating aerofoil-section blades. As hot combustion gas expands through the turbine, it spins the rotating blades. The rotating blades perform a dual function as they drive the compressor to draw more pressurized air into the combustion section and they spin a generator to produce electricity.

Sub-system E **(Electric generator or alternator subsystem):** The turbine is linked by an axle to a generator, so the generator spins around with the turbine blades. As it spins, the generator uses the kinetic energy from the turbine to make electricity.

Sub-system F **(Governing /Starting subsystem):**Starting system provides the initial momentum for the gas turbine system to reach the operating speed. The gas turbine system in a power plant runs at 3000 RPM (for the 50 Hz grid - 3600 RPM for the 60 Hz grid). During starting the speed has to reach at least 60 % for the turbine to work on its own inertia. The simple method is to have a starter motor with a torque converter to bring the heavy mass of the turbine to the required speed.

Notations

The following notations are used to analyze the gas turbine system:

A, B, C, D, E, F Good conditions of the sub-systems

$a,\ b,\ c,\ d,\ e,\ f$ Failed state of the sub-systems $A,\ B,\ C,\ D,\ E,\ and\ F$ respectively

$\overline{D}, \overline{E}, and\ \overline{F}$ Indicate that the sub-systems $D, E, and\ F$ are working in reduced capacity.

$\tilde{\lambda}_i\ (i = 1\ to\ 9)$ Fuzzy failure rates of $A,\ B,\ C,\ D,\ E,\ F, \overline{D}, \overline{E}\ and\ \overline{F}$ respectively.

$\tilde{\tau}_i\ (i = 1\ to\ 9)$ Fuzzy repair rates of $A,\ B,\ C,\ D,\ E,\ F, \overline{D}, \overline{E}\ and\ \overline{F}$ respectively.

$\tilde{P}_i(0)$ Fuzzy probability of the system working with full capacity.

$\tilde{p}_i(t),\ i = 1, \ldots 44$ Fuzzy probability that the system is in state S_i at time t.

$\tilde{P}_i'(t)$ Represent the first order derivative with respect to time t.

licates that the system is in good condition.

cates that the system is in reduced state.

cates that the system is in failed state.

Assumptions

(i) Sub-systems D, E and F completely fail through reduced states.
(ii) All the subsystems work as good as new after their repair.
(iii) Fuzzy failure rates and fuzzy repair rates follow general distribution.
(iv) Fuzzy failure rates and fuzzy repair rates are independent with each other.

Mathematical modeling

In this section, Fuzzy differential equations are developed by using the transition diagram of the gas turbine system which are:

$$\tilde{P}_1'(t) + \tilde{\delta}_1(t)\tilde{P}_1(t) = \tilde{g}_1(t)\tilde{P}_9(t) + \tilde{g}_2(t)\tilde{P}_{10}(t) + \tilde{g}_3(t)\tilde{P}_{11}(t) + \tilde{g}_4(t)\tilde{P}_2(t) + \tilde{g}_5(t)\tilde{P}_3(t) + \tilde{g}_7(t)\tilde{P}_{33}(t) + \tilde{g}_8(t)\tilde{P}_{34}(t) + \tilde{g}_9(t)\tilde{P}_{38}(t) + \tilde{g}_6(t)\tilde{P}_6(t)$$

$$\tilde{P}_2'(t) + \tilde{\delta}_2(t)\tilde{P}_2(t) = \tilde{g}_1(t)\tilde{P}_{12}(t) + \tilde{g}_2(t)\tilde{P}_{13}(t) + \tilde{g}_3(t)\tilde{P}_{14}(t) + \tilde{g}_8(t)\tilde{P}_{35}(t) + \tilde{g}_9(t)\tilde{P}_{37}(t) + \tilde{f}_4(t)\tilde{P}_1(t)$$

$$\tilde{P}_3'(t) + \tilde{\delta}_3(t)\tilde{P}_3(t) = \tilde{g}_1(t)\tilde{P}_{15}(t) + \tilde{g}_2(t)\tilde{P}_{16}(t) + \tilde{g}_3(t)\tilde{P}_{17}(t) + \tilde{g}_9(t)\tilde{P}_{39}(t) + \tilde{g}_7(t)\tilde{P}_{36}(t) + \tilde{f}_5(t)\tilde{P}_1(t)$$

$$\tilde{P}_4'(t) + \tilde{\delta}_4(t)\tilde{P}_4(t) = \tilde{g}_1(t)\tilde{P}_{21}(t) + \tilde{g}_2(t)\tilde{P}_{22}(t) + \tilde{g}_3(t)\tilde{P}_{23}(t) + \tilde{g}_9(t)\tilde{P}_{44}(t) + \tilde{f}_4(t)\tilde{P}_3(t) + \tilde{f}_5(t)\tilde{P}_2(t)$$

$$\tilde{P}_5'(t) + \tilde{\delta}_5(t)\tilde{P}_5(t) = \tilde{g}_1(t)\tilde{P}_{24}(t) + \tilde{g}_2(t)\tilde{P}_{25}(t) + \tilde{g}_3(t)\tilde{P}_{26}(t) + \tilde{g}_8(t)\tilde{P}_{42}(t) + \tilde{f}_4(t)\tilde{P}_6(t) + \tilde{f}_6(t)\tilde{P}_2(t)$$

$$\tilde{P}_6'(t) + \tilde{\delta}_6(t)\tilde{P}_6(t) = \tilde{g}_1(t)\tilde{P}_{18}(t) + \tilde{g}_2(t)\tilde{P}_{19}(t) + \tilde{g}_3(t)\tilde{P}_{20}(t) + \tilde{g}_7(t)\tilde{P}_{40}(t) + \tilde{g}_8(t)\tilde{P}_{41}(t) + \tilde{f}_6(t)\tilde{P}_1(t)$$

$$\tilde{P}_7'(t) + \tilde{\delta}_7(t)\tilde{P}_7(t) = \tilde{g}_1(t)\tilde{P}_{27}(t) + \tilde{g}_2(t)\tilde{P}_{28}(t) + \tilde{g}_3(t)\tilde{P}_{29}(t) + \tilde{g}_7(t)\tilde{P}_{43}(t) + \tilde{f}_5(t)\tilde{P}_6(t) + \tilde{f}_6(t)\tilde{P}_3(t)$$

$$\tilde{P}_8'(t)+\tilde{\delta}_8(t)\tilde{P}_8(t)=g_1(t)\tilde{P}_{30}(t)+\tilde{g}_2(t)\tilde{P}_{31}(t)+\tilde{g}_3(t)\tilde{P}_{32}(t)+\tilde{f}_4(t)\tilde{P}_7(t)+\tilde{f}_5(t)\tilde{P}_5(t)+\tilde{f}_6(t)\tilde{P}_4(t)$$

$$\tilde{P}_{8+i}'(t)+\tilde{g}_i(t)\tilde{P}_{8+i}(t)=\tilde{f}_i(t)\tilde{P}_1(t), i=1,2,3$$

$$\tilde{P}_{11+i}'(t)+\tilde{g}_i(t)\tilde{P}_{11+i}(t)=\tilde{f}_i(t)\tilde{P}_2(t), i=1,2,3$$

$$\tilde{P}_{14+i}'(t)+\tilde{g}_i(t)\tilde{P}_{14+i}(t)=\tilde{f}_i(t)\tilde{P}_3(t), i=1,2,3$$

$$\tilde{P}_{17+i}'(t)+\tilde{g}_i(t)\tilde{P}_{17+i}(t)=\tilde{f}_i(t)\tilde{P}_6(t), i=1,2,3$$

$$\tilde{P}_{20+i}'(t)+\tilde{g}_i(t)\tilde{P}_{21+i}(t)=\tilde{f}_i(t)\tilde{P}_4(t), i=1,2,3$$

$$\tilde{P}_{23+i}'(t)+\tilde{g}_i(t)\tilde{P}_{23+i}(t)=\tilde{f}_i(t)\tilde{P}_5(t), i=1,2,3$$

$$\tilde{P}_{26+i}'(t)+\tilde{g}_i(t)\tilde{P}_{26+i}(t)=\tilde{f}_i(t)\tilde{P}_7(t), i=1,2,3$$

$$\tilde{P}_{29+i}'(t)+\tilde{g}_i(t)\tilde{P}_{29+i}(t)=\tilde{f}_i(t)\tilde{P}_8(t), i=1,2,3$$

$$\tilde{P}_{33}'(t)+\tilde{g}_7(t)\tilde{P}_{33}(t)=\tilde{f}_7(t)\tilde{P}_2(t)$$

$$\tilde{P}_{34}'(t)+\tilde{g}_8(t)\tilde{P}_{34}(t)=\tilde{f}_8(t)\tilde{P}_3(t),$$

$$\tilde{P}_{35}'(t)+\tilde{\tau}_8\tilde{P}_{35}(t)=\tilde{\lambda}_8\tilde{P}_4(t)$$

$$\tilde{P}_{36}'(t)+\tilde{g}_7(t)\tilde{P}_{36}(t)=\tilde{f}_7(t)\tilde{P}_4(t)$$

$$\tilde{P}_{37}'(t)+\tilde{g}_9(t)\tilde{P}_{37}(t)=\tilde{f}_9(t)\tilde{P}_5(t)$$

$$\tilde{P}_{38}'(t)+\tilde{g}_9(t)\tilde{P}_{38}(t)=\tilde{f}_9(t)\tilde{P}_6(t)$$

$$\tilde{P}_{38}'(t)+\tilde{g}_9(t)\tilde{P}_{38}(t)=\tilde{f}_9(t)\tilde{P}_6(t)$$

$$\tilde{P}_{39}'(t)+\tilde{g}_9(t)\tilde{P}_{39}(t)=\tilde{f}_9(t)\tilde{P}_7(t)$$

$$\tilde{P}_{40}'(t)+\tilde{\tau}_7\tilde{P}_{40}(t)=\tilde{\lambda}_7\tilde{P}_5(t)$$

$$\tilde{P}_{41}'(t)+\tilde{g}_8(t)\tilde{P}_{41}(t)=\tilde{f}_8(t)\tilde{P}_7(t)$$

$$\tilde{P}_{42}'(t)+\tilde{g}_8(t)\tilde{P}_{42}(t)=\tilde{f}_8(t)\tilde{P}_8(t)$$

$$\tilde{P}_{43}'(t)+\tilde{\tau}_7\tilde{P}_{43}(t)=\tilde{\lambda}_7\tilde{P}_8(t)$$

$$\tilde{P}_{44}'(t)+\tilde{g}_9(t)\tilde{P}_{44}(t)=\tilde{f}_9(t)\tilde{P}_8(t)$$

Where

$$\tilde{\delta}_1(t)=\tilde{f}_1(t)+\tilde{f}_2(t)+\tilde{f}_3(t)+\tilde{f}_4(t)+\tilde{f}_5(t)+\tilde{f}_6(t)$$

$$\tilde{\delta}_2(t)=\tilde{f}_1(t)+\tilde{f}_2(t)+\tilde{f}_3(t)+\tilde{f}_5(t)+\tilde{f}_6(t)+\tilde{f}_7(t)+\tilde{g}_4(t)$$

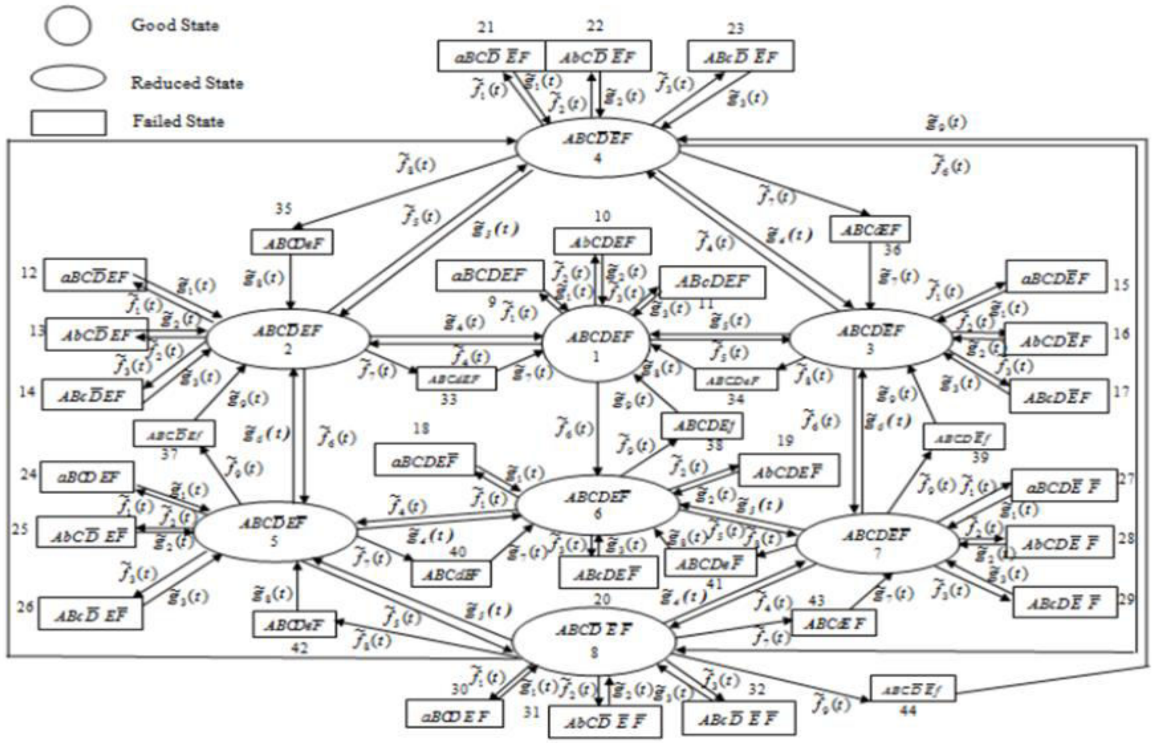


Fig.4: State transition diagram

$$\tilde{\delta}_3(t) = \tilde{f}_1(t) + \tilde{f}_2(t) + \tilde{f}_3(t) + \tilde{f}_4(t) + \tilde{f}_6(t) + \tilde{f}(t)_8 + \tilde{g}_5(t)$$

$$\tilde{\delta}_4(t) = \tilde{f}_1(t) + \tilde{f}_2(t) + \tilde{f}_3(t) + \tilde{f}_6(t) + \tilde{f}_7(t) + \tilde{f}_8(t)$$

$$\tilde{\delta}_5(t) = \tilde{f}_1(t) + \tilde{f}_2(t) + \tilde{f}_3(t) + \tilde{f}_5(t) + \tilde{f}_7(t) + \tilde{f}_9(t)$$

$$\tilde{\delta}_6(t) = \tilde{f}_1(t) + \tilde{f}_2(t) + \tilde{f}_3(t) + \tilde{f}_4(t) + \tilde{f}_5(t) + \tilde{f}_9(t)$$

$$\tilde{\delta}_7(t) = \tilde{f}_1(t) + \tilde{f}_2(t) + \tilde{f}_3(t) + \tilde{f}_4(t) + \tilde{f}_8(t) + \tilde{f}_9(t)$$

$$\tilde{\delta}_8(t) = \tilde{f}_1(t) + \tilde{f}_2(t) + \tilde{f}_3(t) + \tilde{f}_7(t) + \tilde{f}_8(t) + \tilde{f}_9(t)$$

with fuzzy initial conditions

$\tilde{P}_1(0) = (0.985, 0.990, 0.995, 1)$

and

$\tilde{P}_i(0) = (0,0,0,0)\ for\ i = 2,3,4\ .\ .\ .\ 44$

Fuzzy failure rates and repair rates of gas turbine system

Fuzzyfailure and fuzzy repair rates (represented by trapezoidal fuzzy numbers) used for analyzing the fuzzy availability and fuzzy profit of the gas turbine system are given in the following table:

Table 3

Fuzzy failure rates	**Fuzzy repair rates**
$\tilde{\lambda}_1 = (0.000575, 0.000675, 0.000775, 0.000875)$	$\tilde{\tau}_1 = (0.1035, 0.1040, 0.1045, 0.1050)$
$\tilde{\lambda}_2 = (0.000345, 0.000445, 0.000545, 0.000645)$	$\tilde{\tau}_2 = (0.023, 0.024, 0.025, 0.026)$
$\tilde{\lambda}_3 = (0.0026, 0.0027, 0.0028, 0.0029)$	$\tilde{\tau}_3 = (0.0575, 0.0675, 0.0775, 0.0875)$
$\tilde{\lambda}_4 = (0.0010, 0.0011, 0.0013, 0.0014)$	$\tilde{\tau}_4 = (0.0816, 0.0817, 0.0819, 0.0820)$
$\tilde{\lambda}_5 = (0.0030, 0.0034, 0.0038, 0.0042)$	$\tilde{\tau}_5 = (0.01720, 0.01730, 0.01740, 0.01750)$
$\tilde{\lambda}_6 = (0.000115, 0.000215, 0.000315, 0.000415)$	$\tilde{\tau}_6 = (0.03570, 0.03580, 0.03590, 0.03600)$
$\tilde{\lambda}_7 = (0.000805, 0.000810, 0.000815, 0.000820)$	$\tilde{\tau}_7 = (0.0805, 0.0810, 0.0815, 0.0820)$
$\tilde{\lambda}_8 = (0.000575, 0.000675, 0.000775, 0.000875)$	$\tilde{\tau}_8 = (0.0280, 0.0285, 0.0290, 0.0295)$
$\tilde{\lambda}_9 = (0.0010, 0.0011, 0.0013, 0.0014)$	$\tilde{\tau}_9 = (0.1035, 0.1040, 0.1045, 0.1050)$

Results and discussion

To show the importance of results and characterize the behavior of availability and profit of the gas turbine system, here we assume that all random variables as Weibull distributed with two parameters. Probability density function of Weibull distribution with two parameters is given by

$$\tilde{f}_i(t) = k\lambda_i(\lambda_i t)^{k-1} exp[-(\lambda_i t)^k], \quad t \geq 0, \quad \lambda > 0$$

where i=1,2………9

$$\tilde{g}_i(t) = k\tau_i(\tau_i t)^{k-1} exp[-(\tau_i t)^k], \quad t \geq 0, \quad \lambda > 0$$

Where k and λ are positive constants and are known as shape and scale parameters respectively. From the properties of Weibull distribution,If k=1, it become the exponential distribution and when k=2, it become the Rayleigh distribution and if k<1 it is Weibull distribution.

Fuzzy availability analysis of gas Turbine system

Using the fuzzy probabilities for the gas turbine system, the α-cuts for α<1 corresponding to fuzzy availability $\tilde{A}(t) = \tilde{P}_1(t) \oplus \tilde{P}_2(t) \oplus \tilde{P}_3(t) \oplus \tilde{P}_4(t) \oplus \tilde{P}_5(t) \oplus \tilde{P}_6(t) \oplus \tilde{P}_7(t) \oplus \tilde{P}_8(t)$ of gas turbine system are computed at different time with $\mu_L = 0.5$ and $\mu_R = 0.8$ are:

Table 4: Fuzzy availability of gas turbine system at 24 months

Fuzzy Availability → α ↓	$\tilde{A}(t)$ of exponential distribution		$\tilde{A}(t)$ of Rayleigh distribution		$\tilde{A}(t)$ of Weibull distribution	
	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	0.946022	0.965050	0.943684	0.962917	0.960251	0.978721
0.2	0.948589	0.963126	0.946283	0.960992	0.962987	0.976616
0.4	0.951128	0.961616	0.948850	0.959486	0.965073	0.975293
0.5	0.952388	0.960842	0.950125	0.958714	0.966278	0.974551
0.6	0.954534	0.959997	0.952275	0.957948	0.968327	0.973796
0.8	0.958574	0.958574	0.956408	0.956408	0.972293	0.972293

Table 5: Fuzzy availability of gas turbine system at 48 months

Fuzzy → Availability α ↓	$\tilde{A}(t)$ of exponential distribution		$\tilde{A}(t)$ of Rayleigh distribution		$\tilde{A}(t)$ of Weibull distribution	
	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	0.934289	0.954527	0.932899	0.953075	0.945996	0.965023
0.2	0.937257	0.952615	0.935876	0.951197	0.949024	0.962876
0.4	0.940106	0.951115	0.938731	0.949721	0.951093	0.961593
0.5	0.941493	0.950311	0.940115	0.948962	0.952359	0.960842
0.6	0.943792	0.949472	0.942401	0.948201	0.954480	0.960088
0.8	0.948028	0.948028	0.946657	0.946657	0.958563	0.958564

Table 6: Fuzzy availability of gas turbine system at 72 months

Fuzzy → Availability α ↓	$\tilde{A}(t)$ of exponential distribution		$\tilde{A}(t)$ of Rayleigh distribution		$\tilde{A}(t)$ of Weibull distribution	
	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	0.930147	0.950077	0.929330	0.948944	0.938476	0.958365
0.2	0.933217	0.948250	0.932358	0.947162	0.941800	0.956204
0.4	0.936105	0.946836	0.935203	0.945777	0.943996	0.954912
0.5	0.937489	0.946046	0.936563	0.945060	0.945332	0.954146
0.6	0.939761	0.945255	0.938795	0.944339	0.947579	0.953393
0.8	0.943879	0.943879	0.942874	0.942874	0.951829	0.951829

Table 7: Fuzzy availability of gas turbine system at 96 months

Fuzzy → Availability α ↓	$\tilde{A}(t)$ of exponential distribution		$\tilde{A}(t)$ of Rayleigh distribution		$\tilde{A}(t)$ of Weibull distribution	
	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	0.928276	0.947581	0.927743	0.946680	0.934253	0.954485

0.2	0.931314	0.945817	0.930715	0.944961	0.937762	0.952364
0.4	0.934143	0.944465	0.933488	0.943643	0.940044	0.951084
0.5	0.935491	0.943702	0.934807	0.942957	0.941421	0.950322
0.6	0.937687	0.942954	0.936964	0.942268	0.943724	0.949588
0.8	0.941645	0.941645	0.940866	0.940866	0.948027	0.948027

Table 8: Fuzzy availability of gas turbine system at 120 months

Fuzzy Availability → α ↓	$\tilde{A}(t)$ of exponential distribution		$\tilde{A}(t)$ of Rayleigh distribution		$\tilde{A}(t)$ of Weibull distribution	
	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	0.927260	0.946039	0.926887	0.945319	0.931723	0.951904
0.2	0.930242	0.944317	0.929799	0.943638	0.935316	0.949834
0.4	0.933006	0.943010	0.932515	0.942365	0.937627	0.948581
0.5	0.934319	0.942262	0.933796	0.941699	0.939012	0.947829
0.6	0.936451	0.941544	0.935888	0.941032	0.941314	0.947129
0.8	0.940283	0.940283	0.939671	0.939671	0.945594	0.945594

Graphical representation

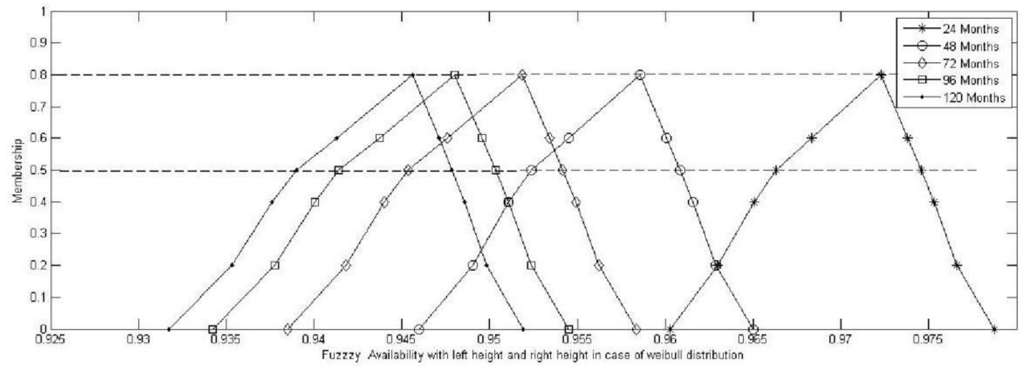


Fig. 5: Fuzzy availability of gas turbine systemfor weibull distribution

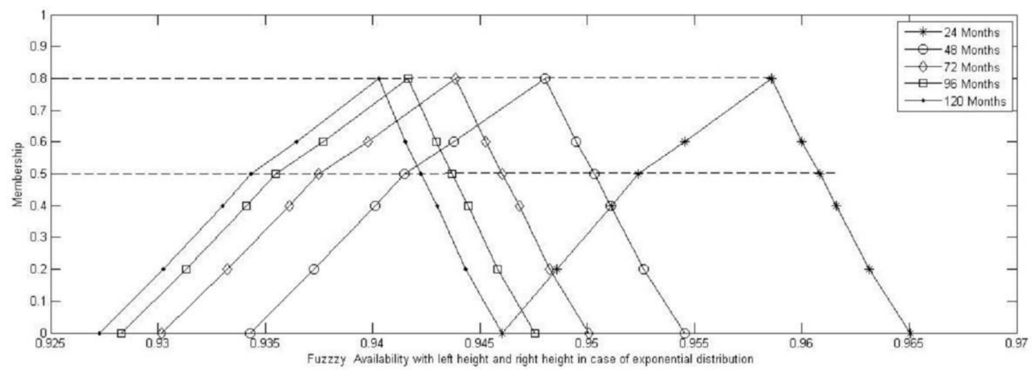


Fig. 6: Fuzzy availability of gas turbine systemfor exponential distribution

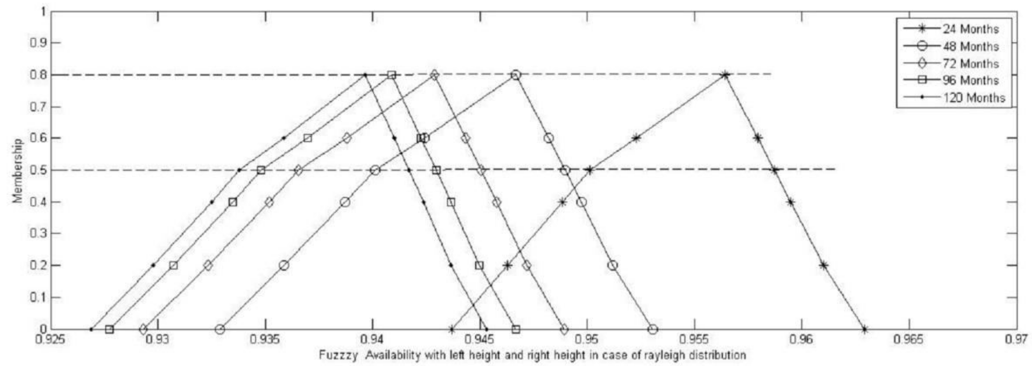


Fig. 7: Fuzzy availability of gas turbine systemfor Rayleigh distribution

Profit Analysis

Any manufacturing industry is basically a profit making organization and no organization can survive for long without minimum financial return for its investment .There must be an optimal balance between the reliability aspect of a product and its cost. The revenue and cost function leads to profit function of an organization, as the profit is excess of revenue over the cost of production. Profit equation is given as

$P=K_0A_0-R$

where P= Profit per unit time incurred to the system.

$K_{0=}$ The revenue per unit up time of the system.

$A_{0=}$ The total fraction of time for which the system is up.

R= Total repair cost.

Trapezoidal Fuzzy numbers associated with revenue per unit up time and total repair cost are :

$\tilde{K}_0 = (2000,2400,2800,3200)$ $\tilde{R} = (500,520,540,560)$

Table 9: Fuzzy profit gas turbine systemat different time for exponential distribution

Fuzzy → Profit α ↓	At t=24		At t=48		At t=72		At t=96		At t=120	
	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$

0	1332.04	2395.15	1308.57	2363.56	1300.29	2350.23	1296.55	2342.74	1294.52	2338.11
0.2	1493.95	2333.22	1469.47	2302.21	1460.74	2289.33	1456.63	2282.16	1454.32	2277.73
0.4	1656.61	2272.68	1631.04	2242.23	1621.76	2229.80	1617.21	2222.94	1614.57	2218.72
0.5	1737.73	2242.42	1711.57	2212.14	1701.97	2199.88	1697.17	2193.14	1694.36	2189.00
0.6	1872.82	2208.99	1845.62	2178.99	1835.41	2166.97	1830.16	2160.41	1827.03	2156.40
0.8	2144.00	2144.00	2114.47	2114.47	2102.86	2102.86	2096.60	2096.60	2092.79	2092.79

Table 10: Fuzzy profit gas turbine system at different time for Rayleigh distribution

Fuzzy Profit → α ↓	At t=24		At t=48		At t=72		At t=96		At t=120	
	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$
0	1327.36	2388.75	1305.79	2359.21	1298.66	2346.83	1295.48	2340.04	1293.77	2335.95
0.2	1488.97	2326.92	1466.49	2298.03	1458.89	2286.12	1455.34	2279.63	1453.36	2275.73
0.4	1651.33	2266.49	1627.85	2238.19	1619.67	2226.75	1615.69	2220.56	1613.42	2216.85
0.5	1732.28	2236.30	1708.26	2208.26	1699.75	2197.04	1695.53	2191.00	1693.11	2187.38

0.6	1867.11	2203.15	1842.10	2175.37	1832.96	2164.36	1828.32	2158.46	1825.60	2154.93
0.8	2137.94	2137.94	2110.64	2110.64	2100.04	2100.04	2094.42	2094.42	2091.07	2091.07

Table 11: Fuzzyprofit gas turbine systemat different time for Weibull distribution

Fuzzy Profit → α ↓	At t=24		At t=48		At t=72		At t=96		At t=120	
	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$	$\tilde{P}_1(t,\alpha)$	$\tilde{P}_2(t,\alpha)$
0	1360.50	2436.16	1331.99	2395.06	1316.95	2375.08	1308.50	2363.45	1303.44	2355.71
0.2	1525.05	2373.01	1494.89	2332.48	1479.28	2312.80	1470.56	2301.47	1465.28	2294.01
0.4	1688.96	2312.35	1656.53	2272.62	1640.07	2253.24	1630.90	2242.14	1625.29	2234.88
0.5	1771.06	2281.83	1737.64	2242.42	1720.79	2223.17	1711.41	2212.17	1705.62	2205.00
0.6	1907.77	2248.31	1872.69	2209.25	1855.21	2190.17	1845.44	2179.32	1839.34	2172.31
0.8	2182.42	2182.42	2143.96	2143.96	2125.12	2125.12	2114.47	2114.47	2107.66	2107.66

Graphical representation

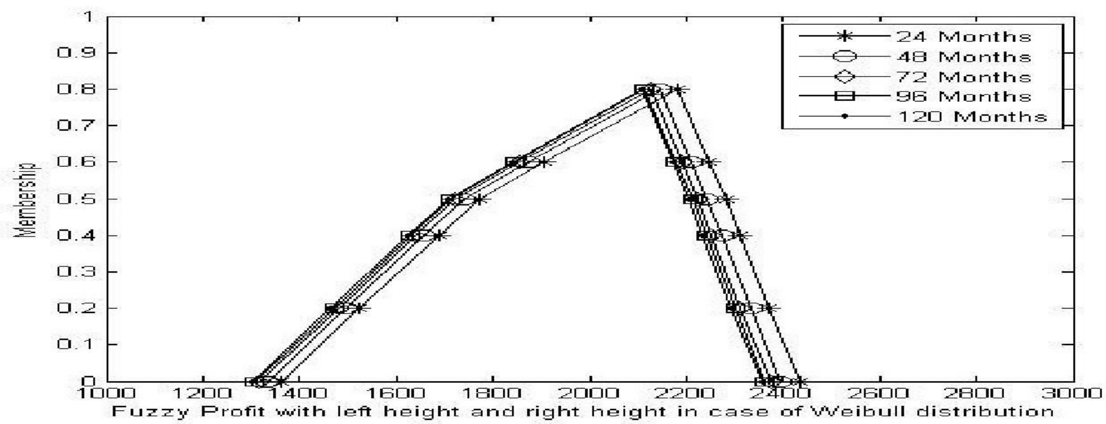


Fig. 8: Fuzzy profit of gas turbine system for weibull distribution

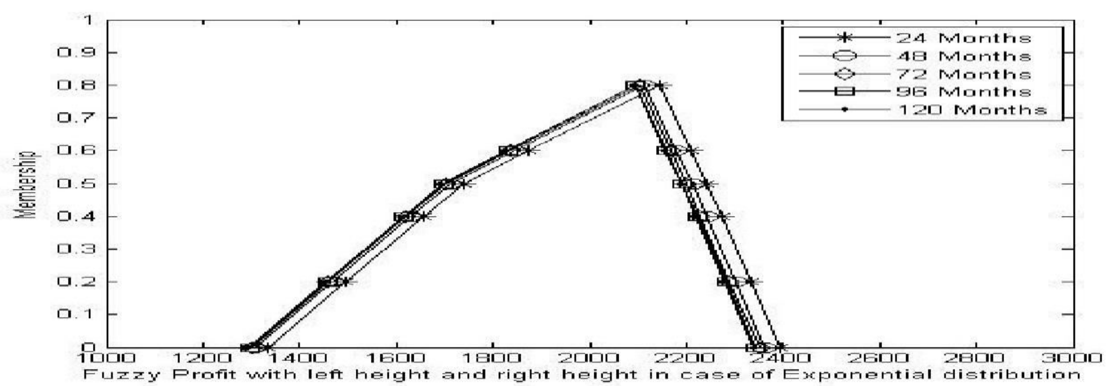


Fig. 9: Fuzzy profit of gas turbine system for exponential distribution

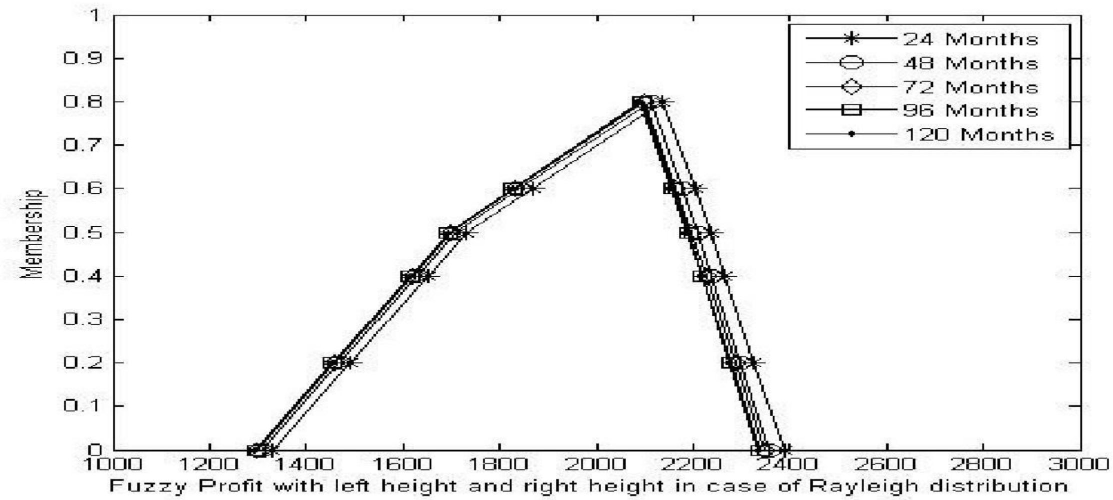


Fig. 10: Fuzzy profit of gas turbine system for rayleigh distribution

Table 12: Effect of fuzzy failure rates of sub-systems on availability of gas turbine system

Fuzzy → Availability α ↓		$\tilde{\lambda}_1=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_2=(0.000345,0.000445,0.000545,0.000645)$ $\tilde{\lambda}_3=(0.0026,0.0027,0.0028,0.0029)$ $\tilde{\lambda}_4=(0.0010,0.0011,0.0013,0.0014)$ $\tilde{\lambda}_5=(0.0030,0.0034,0.0038,0.0042)$ $\tilde{\lambda}_6=(0.000115,0.000215,0.000315,0.000415)$ $\tilde{\lambda}_7=(0.000805,0.000810,0.000815,0.000820)$ $\tilde{\lambda}_8=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_9=(0.0010,0.0011,0.0013,0.0014)$		$\tilde{\lambda}_1=(0.000625,0.000725,0.000825,0.000925)$ $\tilde{\lambda}_2=(0.000345,0.000445,0.000545,0.000645)$ $\tilde{\lambda}_3=(0.0026,0.0027,0.0028,0.0029)$ $\tilde{\lambda}_4=(0.0010,0.0011,0.0013,0.0014)$ $\tilde{\lambda}_5=(0.0030,0.0034,0.0038,0.0042)$ $\tilde{\lambda}_6=(0.000115,0.000215,0.000315,0.000415)$ $\tilde{\lambda}_7=(0.000805,0.000810,0.000815,0.000820)$ $\tilde{\lambda}_8=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_9=(0.0010,0.0011,0.0013,0.0014)$		$\tilde{\lambda}_1=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_2=(0.000415,0.000495,0.000575,0.000655)$ $\tilde{\lambda}_3=(0.0026,0.0027,0.0028,0.0029)$ $\tilde{\lambda}_4=(0.0010,0.0011,0.0013,0.0014)$ $\tilde{\lambda}_5=(0.0030,0.0034,0.0038,0.0042)$ $\tilde{\lambda}_6=(0.000115,0.000215,0.000315,0.000415)$ $\tilde{\lambda}_7=(0.000805,0.000810,0.000815,0.000820)$ $\tilde{\lambda}_8=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_9=(0.0010,0.0011,0.0013,0.0014)$		$\tilde{\lambda}_1=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_2=(0.000345,0.000445,0.000545,0.000645)$ $\tilde{\lambda}_3=(0.0035,0.0040,0.0045,0.0050)$ $\tilde{\lambda}_4=(0.0010,0.0011,0.0013,0.0014)$ $\tilde{\lambda}_5=(0.0030,0.0034,0.0038,0.0042)$ $\tilde{\lambda}_6=(0.000115,0.000215,0.000315,0.000415)$ $\tilde{\lambda}_7=(0.000805,0.000810,0.000815,0.000820)$ $\tilde{\lambda}_8=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_9=(0.0010,0.0011,0.0013,0.0014)$		$\tilde{\lambda}_1=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_2=(0.000345,0.000445,0.000545,0.000645)$ $\tilde{\lambda}_3=(0.0026,0.0027,0.0028,0.0029)$ $\tilde{\lambda}_4=(0.0020,0.0030,0.0040,0.0050)$ $\tilde{\lambda}_5=(0.0030,0.0034,0.0038,0.0042)$ $\tilde{\lambda}_6=(0.000115,0.000215,0.000315,0.000415)$ $\tilde{\lambda}_7=(0.000805,0.000810,0.000815,0.000820)$ $\tilde{\lambda}_8=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_9=(0.0010,0.0011,0.0013,0.0014)$	
		$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	Exponential Distribu	0.92970169	0.94221283	0.92927765	0.94179043	0.92787228	0.94196393	0.91679650	0.92150361	0.92960717	0.94178958

	tion										
	Rayleigh Distribution	0.92832880	0.94095025	0.92790669	0.94053304	0.92638006	0.94069186	0.91330026	0.9221829	0.92628438	0.94061092
	Weibull Distribution	0.94137688	0.95264360	0.94097908	0.95224726	0.94019671	0.95249336	0.93065564	0.93346229	0.94131311	0.95241622
0.2	Exponential Distribution	0.93165802	0.94147258	0.93123401	0.94089921	0.93004790	0.94094648	0.91729189	0.92105192	0.93150524	0.94092742
	Rayleigh Distribution	0.93023826	0.94110385	0.92981656	0.93967213	0.92852640	0.93976125	0.91581400	0.92203428	0.93010716	0.94003421
	Weibull Distribution	0.94295280	0.95176245	0.94255518	0.95168902	0.94191282	0.95146279	0.93079322	0.93327610	0.94286620	0.95184527
0.4	Exponential Distribution	0.93353209	0.94042551	0.93310816	0.94000243	0.93213861	0.93992354	0.91786900	0.92062260	0.93333722	0.94005864
	Rayleigh Distribution	0.93223864	0.94002315	0.93181785	0.93843875	0.93075872	0.`9383245	0.91638271	0.92148932	0.93207232	0.93947621

	Weibull Distribution	0.94347058	0.95109452	0.94439774	0.95047824	0.94301410	0.95038726	0.93119012	0.93304627	0.94396141	0.95038721
0.5	Exponential Distribution	0.93442920	0.93989191	0.93400533	0.93946863	0.93314307	0.93932526	0.91817221	0.92035134	0.93421313	0.93953916
	Rayleigh Distribution	0.93303856	0.93978658	0.93261794	0.93785612	0.93167395	0.93790654	0.91669250	0.92093521	0.93285463	0.93885612
	Weibull Distribution	0.94587290	0.95018968	0.94659320	0.94992568	0.94490725	0.94978265	0.93158340	0.93267839	0.94564782	0.94938746
0.6	Exponential Distribution	0.93589297	0.93917573	0.93546835	0.93907203	0.93477414	0.93886536	0.91866708	0.92019021	0.93564565	0.93932929
	Rayleigh Distribution	0.93448425	0.93865497	0.93406422	0.93711382	0.93330974	0.93702165	0.91723024	0.91984723	0.93427470	0.93814903
	Weibull Distribution	0.94740050	0.94997624	0.94806214	0.94918720	0.94673983	0.94918362	0.93198672	0.93228734	0.94687358	0.94902837
0.8	Exponential	0.93864320	0.93864320	0.93821980	0.93821980	0.93788388	0.93788388	0.91986464	0.91986464	0.93839440	0.93839440

	Distribution										
	Rayleigh Distribution	0.93731577	0.93731577	0.93689681	0.93689681	0.93651480	0.93651480	0.91847511	0.91847511	0.93705654	0.93705654
	Weibull Distribution	0.94902415	0.94902415	0.94862728	0.94862728	0.94853609	0.94853609	0.93213314	0.93213314	0.94885331	0.94885331

Fuzzy Availability ⟶ α ↓		$\tilde{\lambda}_1=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_2=(0.000345,0.000445,0.000545,0.000645)$ $\tilde{\lambda}_3=(0.0026,0.0027,0.0028,0.0029)$ $\tilde{\lambda}_4=(0.0010,0.0011,0.0013,0.0014)$ $\tilde{\lambda}_5=(0.0056,0.0065,0.0074,0.0083)$ $\tilde{\lambda}_6=(0.000115,0.000215,0.000315,0.000415)$ $\tilde{\lambda}_7=(0.000805,0.000810,0.000815,0.000820)$ $\tilde{\lambda}_8=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_9=(0.0010,0.0011,0.0013,0.0014)$		$\tilde{\lambda}_1=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_2=(0.000345,0.000445,0.000545,0.000645)$ $\tilde{\lambda}_3=(0.0026,0.0027,0.0028,0.0029)$ $\tilde{\lambda}_4=(0.0010,0.0011,0.0013,0.0014)$ $\tilde{\lambda}_5=(0.0030,0.0034,0.0038,0.0042)$ $\tilde{\lambda}_6=(0.000140,0.000220,0.000300,0.000420)$ $\tilde{\lambda}_7=(0.000805,0.000810,0.000815,0.000820)$ $\tilde{\lambda}_8=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_9=(0.0010,0.0011,0.0013,0.0014)$		$\tilde{\lambda}_1=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_2=(0.000345,0.000445,0.000545,0.000645)$ $\tilde{\lambda}_3=(0.0026,0.0027,0.0028,0.0029)$ $\tilde{\lambda}_4=(0.0010,0.0011,0.0013,0.0014)$ $\tilde{\lambda}_5=(0.0030,0.0034,0.0038,0.0042)$ $\tilde{\lambda}_6=(0.000115,0.000215,0.000315,0.000415)$ $\tilde{\lambda}_7=(0.000850,0.000870,0.000890,0.000920)$ $\tilde{\lambda}_8=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_9=(0.0010,0.0011,0.0013,0.0014)$		$\tilde{\lambda}_1=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_2=(0.000345,0.000445,0.000545,0.000645)$ $\tilde{\lambda}_3=(0.0026,0.0027,0.0028,0.0029)$ $\tilde{\lambda}_4=(0.0010,0.0011,0.0013,0.0014)$ $\tilde{\lambda}_5=(0.0030,0.0034,0.0038,0.0042)$ $\tilde{\lambda}_6=(0.000115,0.000215,0.000315,0.000415)$ $\tilde{\lambda}_7=(0.000805,0.000810,0.000815,0.000820)$ $\tilde{\lambda}_8=(0.000600,0.000650,0.000700,0.000900)$ $\tilde{\lambda}_9=(0.0010,0.0011,0.0013,0.0014)$		$\tilde{\lambda}_1=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_2=(0.000345,0.000445,0.000545,0.000645)$ $\tilde{\lambda}_3=(0.0026,0.0027,0.0028,0.0029)$ $\tilde{\lambda}_4=(0.0010,0.0011,0.0013,0.0014)$ $\tilde{\lambda}_5=(0.0030,0.0034,0.0038,0.0042)$ $\tilde{\lambda}_6=(0.000115,0.000215,0.000315,0.000415)$ $\tilde{\lambda}_7=(0.000805,0.000810,0.000815,0.000820)$ $\tilde{\lambda}_8=(0.000575,0.000675,0.000775,0.000875)$ $\tilde{\lambda}_9=(0.0025,0.0035,0.0045,0.0055)$	
		$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	Exponential Distribution	0.92902689	0.94068170	0.92969741	0.94221056	0.92969636	0.94219335	0.92966516	0.94216341	0.92967322	0.94173555
	Rayleigh Distribution	0.92560687	0.93925016	0.92637541	0.94094895	0.92637455	0.94093340	0.92633679	0.94089232	0.92635019	0.94067239

	Weibull Distribution	0.94111632	0.95204227	0.94137444	0.95264024	0.94137329	0.95263254	0.94136329	0.95262497	0.94136039	0.95248649
0.2	Exponential Distribution	0.93087248	0.93987153	0.93165220	0.94131729	0.93165086	0.94130388	0.93165032	0.94124920	0.93157136	0.94089514
	Rayleigh Distribution	0.92935556	0.93893217	0.93023487	0.93971837	0.93023178	0.93965235	0.93022885	0.94056475	0.93018911	0.93994520
	Weibull Distribution	0.94265812	0.95064532	0.94295108	0.95178253	0.94294858	0.95176250	0.94295049	0.95157346	0.94292536	0.95196572
0.4	Exponential Distribution	0.93264527	0.93905068	0.93352890	0.94041893	0.93352374	0.94040924	0.93352404	0.94033062	0.93340328	0.94004675
	Rayleigh Distribution	0.93124299	0.93839217	0.93223677	0.93926543	0.93223115	0.93923715	0.93223386	0.93997345	0.93216441	0.93893251
	Weibull Distribution	0.94414084	0.95018356	0.94446964	0.95118934	0.94246569	0.95067823	0.94545591	0.95029816	0.94462964	0.95118093
0.5	Exponential	0.93348993	0.93855609	0.93442740	0.93988430	0.93442022	0.93987631	0.93442098	0.93978627	0.93427644	0.93954027

	Distribution										
	Rayleigh Distribution	0.93198481	0.93758125	0.93303485	0.93887537	0.93303055	0.93857325	0.93300278	0.93857806	0.93274087	0.93847340
	Weibull Distribution	0.946527375	0.94975428	0.94573924	0.95048732	0.94493652	0.94967354	0.94694536	0.94978674	0.94627092	0.95067823
0.6	Exponential Distribution	0.93486083	0.93832828	0.93589068	0.93959477	0.93588258	0.93958662	0.93588276	0.93948423	0.93569924	0.93941551
	Rayleigh Distribution	0.93317444	0.93639457	0.93430674	0.93816759	0.93430327	0.93806934	0.93432316	0.93782353	0.93394485	0.93764219
	Weibull Distribution	0.94784536	0.94918536	0.94769835	0.94937634	0.94716945	0.94917634	0.94143265	0.94927862	0.947756934	0.94956724
0.8	Exponential Distribution	0.93744760	0.93744760	0.93863773	0.93863773	0.93863177	0.93863177	0.93850850	0.93850850	0.93848372	0.93848372
	Rayleigh Distribution	0.93595273	0.93595273	0.93731297	0.93731297	0.93730447	0.93730447	0.93729737	0.93729737	0.93725805	0.93725805

	ution										
	Weibull Distribution	0.94854974	0.94854974	0.94902164	0.94902164	0.94901392	0.94901392	0.94901892	0.94901892	0.94893001	0.94893001

Table 13: Effect of fuzzy repair rates of sub-systems on availability of gas turbine system

Fuzzy Availability → α ↓		$\tilde{\tau}_1=(0.1035,0.1040,0.1045,0.1050)$ $\tilde{\tau}_2=(0.023,0.024,0.025,0.026)$ $\tilde{\tau}_3=(0.0575,0.0675,0.0775,0.0875)$ $\tilde{\tau}_4=(0.0816,0.0817,0.0819,0.0820)$ $\tilde{\tau}_5=(0.01720,0.01730,0.01740,0.01750)$ $\tilde{\tau}_6=(0.03570,0.03580,0.03590,0.03600)$ $\tilde{\tau}_7=(0.0805,0.0810,0.0815,0.0820)$ $\tilde{\tau}_8=(0.0280,0.0285,0.0290,0.0295)$ $\tilde{\tau}_9=(0.1035,0.1040,0.1045,0.1050)$		$\tilde{\tau}_1=(0.1100,0.1150,0.1200,0.1250)$ $\tilde{\tau}_2=(0.023,0.024,0.025,0.026)$ $\tilde{\tau}_3=(0.0575,0.0675,0.0775,0.0875)$ $\tilde{\tau}_4=(0.0816,0.0817,0.0819,0.0820)$ $\tilde{\tau}_5=(0.01720,0.01730,0.01740,0.01750)$ $\tilde{\tau}_6=(0.03570,0.03580,0.03590,0.03600)$ $\tilde{\tau}_7=(0.0805,0.0810,0.0815,0.0820)$ $\tilde{\tau}_8=(0.0280,0.0285,0.0290,0.0295)$ $\tilde{\tau}_9=(0.1035,0.1040,0.1045,0.1050)$		$\tilde{\tau}_1=(0.1035,0.1040,0.1045,0.1050)$ $\tilde{\tau}_2=(0.040,0.045,0.050,0.055)$ $\tilde{\tau}_3=(0.0575,0.0675,0.0775,0.0875)$ $\tilde{\tau}_4=(0.0816,0.0817,0.0819,0.0820)$ $\tilde{\tau}_5=(0.01720,0.01730,0.01740,0.01750)$ $\tilde{\tau}_6=(0.03570,0.03580,0.03590,0.03600)$ $\tilde{\tau}_7=(0.0805,0.0810,0.0815,0.0820)$ $\tilde{\tau}_8=(0.0280,0.0285,0.0290,0.0295)$ $\tilde{\tau}_9=(0.1035,0.1040,0.1045,0.1050)$		$\tilde{\tau}_1=(0.1035,0.1040,0.1045,0.1050)$ $\tilde{\tau}_2=(0.023,0.024,0.025,0.026)$ $\tilde{\tau}_3=(0.0600,0.0700,0.0800,0.0900)$ $\tilde{\tau}_4=(0.0816,0.0817,0.0819,0.0820)$ $\tilde{\tau}_5=(0.01720,0.01730,0.01740,0.01750)$ $\tilde{\tau}_6=(0.03570,0.03580,0.03590,0.03600)$ $\tilde{\tau}_7=(0.0805,0.0810,0.0815,0.0820)$ $\tilde{\tau}_8=(0.0280,0.0285,0.0290,0.0295)$ $\tilde{\tau}_9=(0.1035,0.1040,0.1045,0.1050)$		$\tilde{\tau}_1=(0.1035,0.1040,0.1045,0.1050)$ $\tilde{\tau}_2=(0.023,0.024,0.025,0.026)$ $\tilde{\tau}_3=(0.0575,0.0675,0.0775,0.0875)$ $\tilde{\tau}_4=(0.0840,0.0850,0.0860,0.0870)$ $\tilde{\tau}_5=(0.01720,0.01730,0.01740,0.01750)$ $\tilde{\tau}_6=(0.03570,0.03580,0.03590,0.03600)$ $\tilde{\tau}_7=(0.0805,0.0810,0.0815,0.0820)$ $\tilde{\tau}_8=(0.0280,0.0285,0.0290,0.0295)$ $\tilde{\tau}_9=(0.1035,0.1040,0.1045,0.1050)$	
		$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	Exponential Distribution	0.92967322	0.94229474	0.92995571	0.94346520	0.93211365	0.94856348	0.93099170	0.94306751	0.92967548	0.94230161
	Rayleigh Distribution	0.92638006	0.94067239	0.92666484	0.94184958	0.92972250	0.94766684	0.92776553	0.94147263	0.92638248	0.94067893
	Weibull Distribution	0.94137688	0.95248649	0.94159892	0.95343633	0.94235965	0.95526355	0.94210408	0.95303077	0.94137788	0.95248937
0.2	Exponential	0.93170291	0.94144339	0.93208251	0.94252618	0.93459501	0.94737876	0.93292275	0.94185059	0.93170559	0.94144978

	Distribution										
	Rayleigh Distribution	0.92796125	0.93972170	0.92792656	0.94047629	0.93092675	0.94642873	0.92926175	0.94031658	0.92845627	0.94013627
	Weibull Distribution	0.94378436	0.95126439	0.94382674	0.95226145	0.94482513	0.95451482	0.94427156	0.95251673	0.94256173	0.95172509
0.4	Exponential Distribution	0.93358695	0.94053811	0.93407106	0.94154172	0.93695320	0.94611329	0.93471782	0.94087843	0.93359005	0.94054417
	Rayleigh Distribution	0.93087256	0.93918251	0.92967124	0.93998265	0.93462756	0.94577528	0.93281672	0.93996235	0.93159267	0.93971624
	Weibull Distribution	0.94527128	0.95013628	0.94538719	0.95148762	0.94724517	0.95382671	0.94691736	0.95198267	0.94492517	0.95027153
0.5	Exponential Distribution	0.93448928	0.94000233	0.93502833	0.94096685	0.93810023	0.94542776	0.93919393	0.93979895	0.93810356	0.94000817
	Rayleigh Distrib	0.93158154	0.93851835	0.93267526	0.93956218	0.93672638	0.94486274	0.93462714	0.93967214	0.93328165	0.93892716

	ution										
	Weibull Distribution	0.94694509	0.94957231	0.94791630	0.95026715	0.94896725	0.95317628	0.94861936	0.95147825	0.94621862	0.94962715
0.6	Exponential Distribution	0.93596405	0.93959923	0.93660031	0.94052213	0.94000290	0.94483367	0.93777083	0.93914530	0.93596798	0.93960493
	Rayleigh Distribution	0.93432465	0.93826706	0.93495933	0.93918938	0.93885589	0.94413095	0.93635141	0.93945430	0.93433418	0.93827249
	Weibull Distribution	0.94798435	0.94916548	0.94887210	0.94982763	0.94992561	0.95245187	0.94971672	0.951178236	0.947621854	0.94917254
0.8	Exponential Distribution	0.93864320	0.93864320	0.93948108	0.93948108	0.94354165	0.94354165	0.93955527	0.93955527	0.93864830	0.93864830
	Rayleigh Distribution	0.93742627	0.93742627	0.93826799	0.93826799	0.94292111	0.94292111	0.93898938	0.93898938	0.93743138	0.93743138
	Weibull Distribution	0.94893001	0.94893001	0.94960161	0.94960161	0.95103456	0.95103456	0.95099461	0.95099461	0.94893221	0.94893221

Fuzzy Availability → α ↓		$\tilde{\tau}_1=(0.1035,0.1040,0.1045,0.1050)$ $\tilde{\tau}_2=(0.023,0.024,0.025,0.026)$ $\tilde{\tau}_3=(0.0575,0.0675,0.0775,0.0875)$ $\tilde{\tau}_4=(0.0816,0.0817,0.0819,0.0820)$ $\tilde{\tau}_5=(0.01760,0.01770,0.01780,0.01790)$ $\tilde{\tau}_6=(0.03570,0.03580,0.03590,0.03600)$ $\tilde{\tau}_7=(0.0805,0.0810,0.0815,0.0820)$ $\tilde{\tau}_8=(0.0280,0.0285,0.0290,0.0295)$ $\tilde{\tau}_9=(0.1035,0.1040,0.1045,0.1050)$		$\tilde{\tau}_1=(0.1035,0.1040,0.1045,0.1050)$ $\tilde{\tau}_2=(0.023,0.024,0.025,0.026)$ $\tilde{\tau}_3=(0.0575,0.0675,0.0775,0.0875)$ $\tilde{\tau}_4=(0.0816,0.0817,0.0819,0.0820)$ $\tilde{\tau}_5=(0.01720,0.01730,0.01740,0.01750)$ $\tilde{\tau}_6=(0.03625,0.03650,0.03675,0.03700)$ $\tilde{\tau}_7=(0.0805,0.0810,0.0815,0.0820)$ $\tilde{\tau}_8=(0.0280,0.0285,0.0290,0.0295)$ $\tilde{\tau}_9=(0.1035,0.1040,0.1045,0.1050)$		$\tilde{\tau}_1=(0.1035,0.1040,0.1045,0.1050)$ $\tilde{\tau}_2=(0.023,0.024,0.025,0.026)$ $\tilde{\tau}_3=(0.0575,0.0675,0.0775,0.0875)$ $\tilde{\tau}_4=(0.0816,0.0817,0.0819,0.0820)$ $\tilde{\tau}_5=(0.01720,0.01730,0.01740,0.01750)$ $\tilde{\tau}_6=(0.03570,0.03580,0.03590,0.03600)$ $\tilde{\tau}_7=(0.0850,0.0855,0.0860,0.0865)$ $\tilde{\tau}_8=(0.0280,0.0285,0.0290,0.0295)$ $\tilde{\tau}_9=(0.1035,0.1040,0.1045,0.1050)$		$\tilde{\tau}_1=(0.1035,0.1040,0.1045,0.1050)$ $\tilde{\tau}_2=(0.023,0.024,0.025,0.026)$ $\tilde{\tau}_3=(0.0575,0.0675,0.0775,0.0875)$ $\tilde{\tau}_4=(0.0816,0.0817,0.0819,0.0820)$ $\tilde{\tau}_5=(0.01720,0.01730,0.01740,0.01750)$ $\tilde{\tau}_6=(0.03570,0.03580,0.03590,0.03600)$ $\tilde{\tau}_7=(0.0805,0.0810,0.0815,0.0820)$ $\tilde{\tau}_8=(0.0320,0.0340,0.0360,0.0380)$ $\tilde{\tau}_9=(0.1035,0.1040,0.1045,0.1050)$		$\tilde{\tau}_1=(0.1035,0.1040,0.1045,0.1050)$ $\tilde{\tau}_2=(0.023,0.024,0.025,0.026)$ $\tilde{\tau}_3=(0.0575,0.0675,0.0775,0.0875)$ $\tilde{\tau}_4=(0.0816,0.0817,0.0819,0.0820)$ $\tilde{\tau}_5=(0.01720,0.01730,0.01740,0.01750)$ $\tilde{\tau}_6=(0.03570,0.03580,0.03590,0.03600)$ $\tilde{\tau}_7=(0.0805,0.0810,0.0815,0.0820)$ $\tilde{\tau}_8=(0.0280,0.0285,0.0290,0.0295)$ $\tilde{\tau}_9=(0.1165,0.1170,0.1175,0.1180)$	
		$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$	$\tilde{A}_1(t,\alpha)$	$\tilde{A}_2(t,\alpha)$
0	Exponential Distribution	0.92967822	0.94230516	0.92967361	0.94229618	0.92967755	0.94230075	0.92971856	0.94248678	0.92967789	0.94230409
	Rayleigh Distribution	0.92638660	0.94068664	0.92638025	0.94067842	0.92638476	0.94067892	0.92643747	0.94090735	0.92638214	0.94071052
	Weibull Distribution	0.94137785	0.95248851	0.94137693	0.95248817	0.94137882	0.95248916	0.94138613	0.95252645	0.94137766	0.95250141
0.2	Exponential Distribution	0.93170836	0.94145243	0.93170315	0.94144463	0.93170735	0.94144926	0.93176536	0.94161340	0.93171001	0.94145201
	Rayleigh	0.92881654	0.93998256	0.92887162	0.94008276	0.92836715	0.94002856	0.92902735	0.94028736	0.92883652	0.93992084

	Distribution										
	Weibull Distribution	0.94282671	0.95162823	0.94382776	0.95187463	0.94307288	0.95172882	0.94352471	0.95187564	0.94345287	0.95167263
0.4	Exponential Distribution	0.93359316	0.94054845	0.93358730	0.94053931	0.93359162	0.94054399	0.93365941	0.94069463	0.93359041	0.94054612
	Raleigh Distribution	0.93041562	0.93927614	0,92998472	0.93927616	0.93027461	0.93962718	0.93038726	0.93972625	0.92992763	0.93922874
	Weibull Distribution	0.94492615	0.95072614	0.94527783	0.95025563	0.94572836	0.95037286	0.94572654	0.95065472	0.94489654	0.95046725
0.5	Exponential Distribution	0.93810678	0.94001301	0.93810062	0.94000438	0.93810500	0.94000234	0.93818080	0.94015060	0.93810412	0.94001027
	Rayleigh Distribution	0.93261782	0.93871625	0.93271562	0.93892736	0.93291736	0.93902873	0.93287356	0.93903752	0.93198376	0.93872674
	Weibull Distribution	0.94627183	0.94951628	0.94645273	0.94946254	0.94719733	0.94972637	0.94687362	0.94995642	0.94597643	0.94992784
0.6	Expone	0.935971	0.9396106	0.9359646	0.9396003	0.9359691	0.939604	0.9360597	0.939740	0.935968	0.9396065

	ntial Distribution	67	7	3	7	2	93	6	29	80	8
	Rayleigh Distribution	0.93433553	0.93827897	0.93432641	0.93826823	0.93433765	0.93827328	0.93445728	0.93844536	0.93434190	0.93827511
	Weibull Distribution	0.94782671	0.94917362	0.94783746	0.94918736	0.948372994	0.94926745	0.94798265	0.94907453	0.94745345	0.94928746
0.8	Exponential Distribution	0.93865145	0.93865145	0.93864407	0.93864407	0.93864880	0.93864880	0.93877040	0.93877040	0.93864985	0.93864982
	Rayleigh Distribution	0.93743676	0.93743676	0.93742730	0.93742730	0.93743240	0.93743240	0.93757666	0.93757666	0.93743361	0.93743361
	Weibull Distribution	0.94893164	0.94893164	0.94893091	0.94893091	0.94893249	0.94893249	0.94895683	0.94895683	0.94893938	0.94893938

Conclusion

The main objective of this study is to develop a framework for analyzing and predicting the behavior of the gas turbine system by using general distributions. The results for fuzzy availability with different time and different left and right height for Weibull, exponential and Rayleigh distributions are shown in tables 4, 5, 6, 7 and 8. Tables 9, 10 and 11 show the behavior of fuzzy profit of the gas turbine system with different time and different left and right height for Weibull, exponential and Rayleigh distribution. Numerical results obtained for availability and profit of gas turbine system are shown graphically in figures 5, 6, 7 and figures 8, 9 and 10 respectively and it is observed that when the time increases the fuzzy availability and fuzzy profit decreases .From Table 12 and 13 depict the behavior of availability of gas turbine system with respect to fuzzy failure and fuzzy repair rates which are taken as Weibull, exponential and Rayleigh distributed. It is observed that availability of the gas turbine system go on decreasing with the increase of fuzzy failure rates of the sub-systems A, B, C, D, E and F. However, the effect of fuzzy failure rates of the sub-systems B and C is much more as compare to the fuzzy failure rates of the sub-systems A, D, E and F. Table 13, indicate that availability of the gas turbine system increases with the increase of repair rates. The effect of fuzzy repair rates of sub-systems B and C is much high as compare to the other sub-systems. On the basis of result obtained, it also concluded that traditional fuzzy number gives the same degree of acceptance for all values of availability lying in a particular interval, whereas on the same time, the use of proposed approach provides large range of degree of acceptance for different values of availability and profit lying in a particular interval. Therefore in many industrial problems availability and profit of repairable systems can be analyzed in more elastic and effective manner by using proposed method. In case of gas turbine system, there is need to control the failure rates and repair rates of sub-systems B and C in order to make the gas turbine system more reliable.

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References

1. Aliev, I.M., Zohre, K.(2013): Fuzzy system reliability analysis using time dependent fuzzy set. Control Cybern. 33(4), 653-662.
2. Buckley, J. J., Feuring, T.(2001): Fuzzy initial value problem for Nth -order fuzzy linear differential equations. Fuzzy Set Syst. 121, 247-255.
3. Cai, K.Y., Wen, C.Y., Zhang, M L.(1991a): Fuzzy reliability modeling of gracefully degradable computing systems. Reliab. Eng. Syst. Safe. 33(1),141-157.

4. Cai, K. Y., Wen, C Y., Zhang, M. L.(1991b): Posbist reliability behavior of typical systems with two types of failure. Fuzzy Set Syst. 43(1), 17-32.
5. Cheng, C.H., Mon, D.L.(1993): Fuzzy system reliability analysis by interval of confidence. Fuzzy Set Syst. 56, 29 35.
6. Chen, S.M.(1994): Fuzzy system reliability analysis using fuzzy number arithmetic operations. Fuzzy Set Syst. 64(1), 31-38.
7. Chen, S. M., Munif, A., Chen, G. S., Liu, H. C., Kuo, B. C.(2012): Fuzzy risk analysis based on ranking generalized fuzzy numbers with different left and right heights. Expert Syst. Appl. 39(7), 6320-6334.
8. Goel, M & Narain, S (2018): Fuzzy Availability Analysis of Polytube Industry with General Distribution.International Journal of Interdisciplinary Research and Innovations. 6(2), 412-422.
9. Gupta, P.(2004): Numerical analysis of reliability and availability of the serial processes in butter-oil processing plant. Int. J. Qual. Reliab. Manag. 22(3), 303-316.
10. Gupta, S., Tiwari, P. C.(2009): Simulation modeling and analysis of complex system of thermal power plant. J. Ind. Eng. Manag. 2(2), 387-406.
11. Iqbal, P., Uduman, P. S. S.(2016): Reliability analysis of paper plant using Boolean function with fuzzy logic technique. Int. J. Appl. Eng. Res. 11(1), 573-577.
11. Kumar, D., Singh, I. P., Singh, J.(1989): Reliability analysis of the feeding system in the paper industry. Microelectron Reliab. 28(2), 213-215.
12. Kumar, D., Singh, J., Pandey, P. C.(1989): Availability of a washing system in the paper industry. Microelectron Reliab. 29(5),775-778.
13. Kumar, D., Pandey, P. C., Singh, J.(1990): Design and cost analysis of a refining system in a Sugar industry. Microelectron Reliab. 30(6),1025-1028.
14. Kumar, D., Pandey, P. C.(1993): Maintenance planning and resource allocation in urea fertilizer plant. Qual. Reliab. Eng. Int.9(5), 411-423.
15. Kumar, S., Mehta, N. P., Kumar, D.(1997): Steady state behavior and maintenance planning of a desulphurization system in a urea fertilizer plant Microelectron Reliab. 37(6), 949-953.
16. Kumar, A., Lata, S.(2012): Reliability evaluation of condensate system using fuzzy markov model. Ann. Fuzzy Math. Inform. 4(2), 281-291.
17. Singer, D.(1990): A fuzzy set approach to fault tree and reliability analysis. Fuzzy Set Syst. 34(2), 145-155.
18. Lata,S., Kumar, A.(2011): Mehar's method for analyzing the fuzzy reliability of piston manufacturing system. Eksploatacja Niezawodnosc – Maint. Reliab. 51, 26-39.
19.Suleiman, K., Ali, U. A.: Yusuf I.(2013):Stochastic analysis and performance evaluation of a complexthermal power plant. Innov. Syst. Design Eng. 4 (15), 21-32.
20. Verma, A. K., Srividya, A., Ravi Kumar, H. M.(2002): A framework using uncertainties in the composite power system reliability evaluation. Electr. Pow. Compo. Sys. 30(7), 679-691.

21. Verma, M., Kumar, A., Singh, Y.(2012): Power system reliability evaluation using fault tree approach based on generalized fuzzy number. J. Fuzzy Set Val. Anal. 2012(1),1-13.
22. Verma, M., Kumar, A.(2014): A novel general approach to evaluating the reliability of gas turbine system. Eng. Appl. Artif. Intel. 28, 13-21.
23. Zadeh, L A.(1965): Fuzzy sets. Inform. Control. 8(3), 338-353.