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AVAILABILITY ANALYSIS FOR ESTIMATION OF REPAIR RATE OF PERFORMANCE BASED LOGISTICS UNDER OPERATING CONDITION

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Abstract

In this paper, the availability analysis for repair rate of critical aircraft components such as aircraft engine, propeller and avionics under Performance based logistics (PBL) have been examined. The concept of Performance based logistics (PBL) is employed to enhance the system availability. Weibull distribution is used to analyze the system availability. The objective of this article is to provide an instrument for normative decision making for contracting military logistic services as well as to improve the capacity of repair facilities. Desired availability of critical aircraft components can not be achieved without repair. The numerical illustrations are carried out to highlight the effects of repair rate and failure rate for aircraft components by considering different parameters of availability, probability density function of repair rate and cumulative distribution function of repair rate which validate our results.

AMS Classification -90B25

Key Words: Availability, Weibull Distribution, Performance Based Logistics, Repair Rate.

1. Introduction

The two-parameter Weibull distribution is a very popular distribution. It has been vastly used since nineteen century for modeling data in reliability, engineering studies. It is well-known that the big frailty of the Weibull distribution its inability to accommodate non-monotonic failure rate. Reliability testing is usually required in product development to evaluate product reliability. Product's life is becoming longer than in previous decades because of the improvement of reliability. Performance based logistics PBL is a preferred approach to improve the product's reliability. Performances of products are improving to maintain the capital-intensive industries where the systems and subsystems are required high availability. This issue is more useful for industries, where the defected parts need to be repaired and cannot be scrapped because of their high cost and long life time/longevity. The Weibull distribution has been used to model, many real life utility for example degradation of mechanical components such as pistons, crankshafts of diesel engines as well as breakdown of insulating fluid etc.

Therefore, renovated parts inventory are required to support such systems. Since last two decades the investigator have considered and developed so many models to work out these issues. Andrzejczak [1] explained why stochastic modeling is needed for repairable system. Chauhan et al. [4] determined reliability measures of a series system with Weibull failure laws. Dhakar et al. [5] considered the failure rate of the functions which depend on the number of tool and find for excessive cost with low demand of spare parts. Diaz and Fu [6] examined the limited facilities to repair of spare. Kontrec et al. [11] considered stochastic approach for determining the rate of repairing for components of unrepair aircraft to accomplish the desirable accessiblity. Kiureghian et al. [10] derived the steady state availability, mean rate of failure, mean duration of downtime and lower bound reliability of a general system with randomly and independently failing repairable components. Krawczyk [12] examined technical conditions for operation of aircraft reliability. Kang et al [9] explained by using arena simulation for one random occurring simulation and double spreadsheet, out of which starting models evaluate the support lifecycle cost and nature wise it's static and another model describes the reliability, time to overhaul and working accessiblity of the system. MI-Damcese [13] evaluated reliability and mean time to system failure of Series-Parallel system using Weibull distribution. Mustafa et al. [14] discussed reliability equivalence factors of a general parallel system with mixture of lifetime. Mirzahosseinian and Piplani [15] MOD-METRIC has given good result in simulation. Nandal et al. [16] proved that a parallel system is more reliable to use a series system having constant failure rate of the components. Sarkar and Biswas [19] considered a system consisting of one operating unit, n-1 spares and r repair facilities, as soon as the operating unit fails one of the spare if available takes over the operation. Shinde [20] to enhance the efficiency and effectiveness of the availability of the system with or without provision of spares have been examined. Smith [21] described a process for planning and estimating the cost of a reliability improvement program under a performance based logistic. Tao and Wen [22] and Wong [24] with the objective to reduce the lead time and transportation cost for maintaining the stock level of logistics have been extended. Wang et al [23] studied condition based maintenance strategy to analyze the spare parts ordering and equipment maintenance policy.

In this paper, we describe the availability and reliability enhancement under a performance based logistic (PBL). The remainder of the article is arranged as follows. Reliability analysis for performance based logistic (PBL) is discussed in section 2.In section 3, we described notation and assessment model. In section 4, sensitivity analysis has been discussed with the several parameters along with graphical presentation is described. Finally, the discussion of the paper is provided in section 5.

2. Reliability Planning Process for performance based logistics (PBL)

In 1998, Lockheed Martin gave the idea of Performance based logistics (PBL) to American army for better improvement of fighter plane as well as also used in private concerns. User and supplier implement the PBL contract with their mutual concern. Objective of PBL reliability performance require helping at every stage. Requirement of process in each step has been depicted in figure 1, to annihilate the contract on lower cost and improve the delivery system between user and supplier. The reliability of the product must be applied from origin to destination of the level for getting future prospects. Supplier must be assured for improving the system reliability.

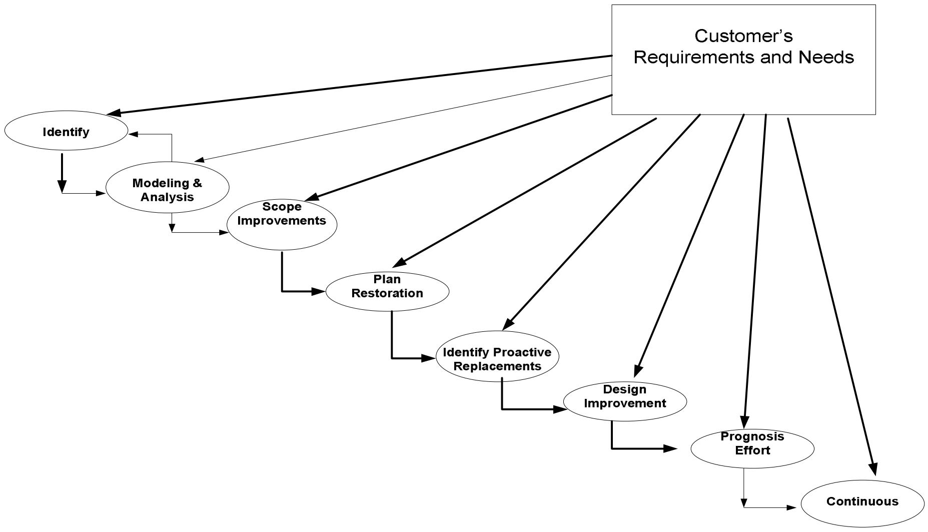

Figure 1: Reliability Planning Process Flow

3. Notation and Model for assessment of expected time to repair

We assume the following nomenclature

u	Failure rate and
μ_r	Repair rate
λ	Scale Parameter for Weibull random
K	Shape parameter
T	Failure time
R	Repair time
Y	Uniform distribution
A	Availability
$p(\mu)$	Probability density function of repair rate
$f(\mu_r)$	Cumulative distribution function of repair rate
MTBF	Mean time between failure
MTTR	Mean time to repair
λ_0	Annual repair rate of Aircraft Engine
λ_1	Annual repair rate of Aircraft Propeller
λ_2	Annual repair rate of Avionics

We considered that the system is in operative mode at the certain period else it is in non operative mode. In this state failure time T and repair time R and after repairing the system are returned in working mode and renewal cycle of this period T+R. It is also considered that after fettling the system act as new one. Weibull distribution is used to evaluate the failure time. When mean time between failure (MTBF) then the aim of the system is to optimize the performance of repair rate. In this system, steady state availability is applied for availability measurement as:

$$A = \lim_{t \to \infty} A(t) \tag{1}$$

Renewal process is applied to evaluate the limit of probability:

$$\lim_{t \to \infty} A(t) = \frac{E[T]}{E[T] + E\,[R]} \tag{2}$$

Which describe one renewal cycle. This can also written as:

$$A = \frac{MTBF}{MTBF + MTTR} \tag{3}$$

Failed component required repair and its expected value is described by MTBF as:

$$MTBF = \int_0^\infty t f(t)\, dt \tag{4}$$

Since we assumed that the failure time has Weibull distribution with probability density function. The Weibull distribution is one of the most commonly applied distributions in reliability evaluation due to of its ability to take on various forms by adjusting its parameters. The two parameter Weibull distribution is defined as

$$f(t) = \frac{k}{\lambda}\left(\frac{t}{\lambda}\right)^{k-1} e^{-\left(\frac{t}{\lambda}\right)^{k}} \;, t \geq 0$$

$$E(t) = \lambda,$$

The previous equation is

$$MTBF = \int_0^\infty \frac{k}{\lambda}\left(\frac{t}{\lambda}\right)^{k-1} e^{-\left(\frac{t}{\lambda}\right)^{k}} \, dt \tag{5}$$

After simplification of equation (5), we have

$$MTBF = \frac{\lambda}{k}\, \Gamma(1/k) \tag{6}$$

The repair rate can be noticed as a reciprocal value of MTTR. Therefore, we introduce the changes in order to simplify further evaluation:

$$u = \frac{1}{MTBF} = \frac{k}{\lambda\, \Gamma(1/k)} \tag{7}$$

$$\mu_r = \frac{1}{MTTR}$$

By (7), it can be written as

$$\lambda = \frac{k}{u\, \Gamma(1/k)} \tag{8}$$

Availability can now be expressed using (3) as

$$A = \frac{\mu_r}{\mu_r + u} \tag{9}$$

Equation (9) can be used to obtain the repair rate for availability, particularly when MTBF is given. It is observed that MTTR is a probabilistic approach and it's PDF characteristic can be obtained with certain predefined availability parameters. However it is observed that $\frac{1}{MTTR}$ repair rate is stochastic process, which is more effective to analyze the repair process for system.

Due to complication of process for estimating the failure rate of component's with time also a probabilistic approach of the observed process, the parameter λ considered as a random variable that goes down the random variable described with the Weibull model. When $\lambda \approx t$, decelerate changes of variable λ. It can be discussed with the probabilistic approach with exponential distribution as:

$$f_\lambda(\lambda) = \frac{\exp\left(-\lambda/_{\lambda_0}\right)}{\lambda_0}, \ \lambda > 0 \tag{10}$$

where $\lambda_0 = E(\lambda)$

Since the aim of this paper is to obtain the repair rate for desired level of availability when MTBF is known and we have already expressed Weibull random variable λ in (8), then the following transformation is usable:

$$f(u) = f_\lambda\left(\frac{k}{u\ \Gamma(1/k)}\right)|J| \tag{11}$$

where $|J|$ = Jacobian transformation of random variable λ, is defined as

$$|J| = \left|\frac{d\lambda}{du}\right| = \frac{k}{u^2\ \Gamma(1/k)} \tag{12}$$

putting (12) in (11), we get

$$f(u) = \frac{k}{u^2 \lambda_0\ \Gamma(1/k)}\ exp\left(\frac{-k}{u\,\lambda_0\ \Gamma(1/k)}\right) \tag{13}$$

Now, based on (9) the repair rate μ_r can be presented as $\mu_r = \frac{Au}{1-A}$ with PDF function:

$$f(\mu_r) = f_u\left(\frac{Au}{1-A}\right)|J| \tag{14}$$

$$|J| = \frac{du}{d\mu_r} = \frac{A}{1-A} \tag{15}$$

According to last, PDF function of repair rate can be stated as:

$$f(\mu_r) = \frac{kA}{\mu_r{}^2\lambda_0(1-A)\,\Gamma(1/k)}\,exp\left(\frac{-kA}{\mu_r\lambda_0(1-A)\,\Gamma(1/k)}\right) \tag{16}$$

PDF property provides exact modeling of repair rate process, which can be obtained by generating exact repair rate sample values with respect to availability and MTBF. In such a way, simulation of repair rate of system performance is served by dynamical prediction through generating samples.

Now, consider cumulative distribution function (CDF) of repair rate as:

$$F(\mu_r) = \int_0^{\mu_r} f(\mu_r)d\mu_r = 1 - exp\left(\frac{-kA}{\mu\lambda_0(1-A)\,\Gamma(1/k)}\right) \tag{17}$$

With the use of inverse sampling $= F(\mu_r)$, the inverse CDF is $F^{-1}(\mu_r) = y^{-1}$ and repair rate samples μ_r can be expressed as:

$$\mu_r = \frac{-\lambda_0(1-A)\,\Gamma(1/k)}{kA}\ln(1-y) \tag{18}$$

where y is uniformly distributed in [0, 1]and replacing $U = 1 - y$, equation (18) can be rewritten as:

$$\mu_r = \frac{-\lambda_0(1-A)\,\Gamma(1/k)}{kA}\ln(U)$$

where y is uniformly distributed in interval [0, 1].

Through equation (16), we can determine the expected repair rate of component $\overline{\mu_r}$ in relation to the preferred level of availability as:

$$\overline{\mu_r} = \int_0^{\infty} \mu_r f(\mu_r)d\mu_r \tag{19}$$

After interchanging (16) into (19) the last expression is reduced to:

$$\overline{\mu_r} = \frac{kA}{\lambda_0(1-A)\,\Gamma(1/k)} \tag{20}$$

This measure characterizes MTTR random process is stated as the function of availability and MTBF.

4. Sensitivity Analysis

To validate our approach, we consider the data from [9,15] due to lack of reliability in civil aviation an unmanned aerial vehicle (UAV) is not utilized such phenomena is highlighted. Wherein UAV exists four air buses, two base monitor stations, interchangeable mission pay loads, data link, unmanned stations and an self activating landing sub system have been examined. [12] high level probability of failure phenomena has studied. In this regard, we assumed the critical repairable parts such as aircraft's engine, propeller and avionics have been examined the MTBF.

Flying time per aircraft is 120 hours per month; it means 1440 hrs per year.

Consider the MTBF for avionics, propeller and engine are 800, 600 400 flight hours respectively with corresponding time 1440 hrs.
For the avionics $MTBF_a = 800/1440$
For the propeller $MTBF_p = 600/1440$
For the engine $MTBF_e = 400/1440$
Numerical illustrations are obtained to evaluate the annually probabilistic approach of repair time and availability of the system are shown in tables of this process.

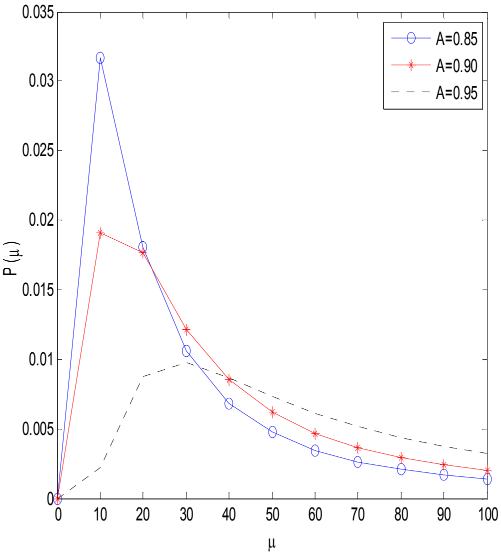

Figure 2: PDF of engine repair rate VS repair rate

	A=0.85	A=0.90	A=0.95
μ	$P(\mu)$	$P(\mu)$	$P(\mu)$
0	0	0	0
10	0.031721	0.019117	0.002205
20	0.018072	0.017681	0.008724
30	0.01057	0.012153	0.009736
40	0.00682	0.008502	0.008677
50	0.00474	0.006202	0.00732
60	0.003477	0.004699	0.006111
70	0.002657	0.003674	0.005121
80	0.002095	0.002948	0.004327
90	0.001694	0.002415	0.003691
100	0.001397	0.002014	0.003179

Table 1: PDF of engine repair rate

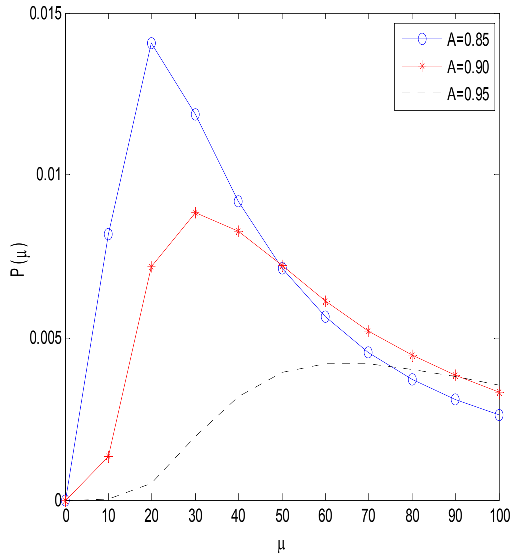

Figure 3: PDF of aircraft's avionics repair rate VS repair rate

	A=0.85	A=0.90	A=0.95
μ	$P(\mu)$	$P(\mu)$	$P(\mu)$
0	0	0	0
10	0.008194	0.001352	3.20E-06
20	0.014041	0.007187	0.000508
30	0.011854	0.00885	0.001941
40	0.00919	0.008286	0.003201
50	0.00713	0.0072	0.003906
60	0.00563	0.00613	0.004171
70	0.004533	0.00521	0.004167
80	0.003718	0.004449	0.004017
90	0.003099	0.003827	0.003797
100	0.00262	0.003318	0.00355

Table 2: PDF of aircraft's avionics repair rate

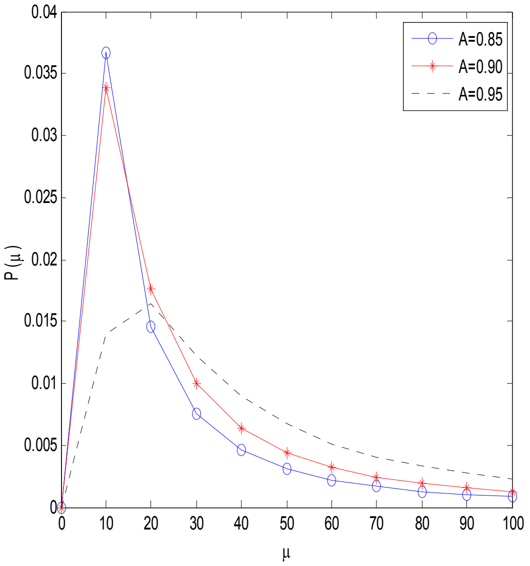

Figure 4: PDF of aircraft's propeller repair rate VS repair rate

	A=0.85	A=0.90	A=0.95
μ	$P(\mu)$	$P(\mu)$	$P(\mu)$
0	0	0	0
10	0.036675	0.033832	1.40E-02
20	0.014551	0.017612	0.016458
30	0.007543	0.009996	0.012256
40	0.004583	0.006354	0.008924
50	0.003071	0.004376	0.006668
60	0.0022	0.003191	0.005134
70	0.001652	0.002428	0.004061
80	0.001286	0.001908	0.003286
90	0.001029	0.001539	0.00271
100	0.000842	0.001267	0.002272

Table 3: PDF of aircraft's propeller repair rate

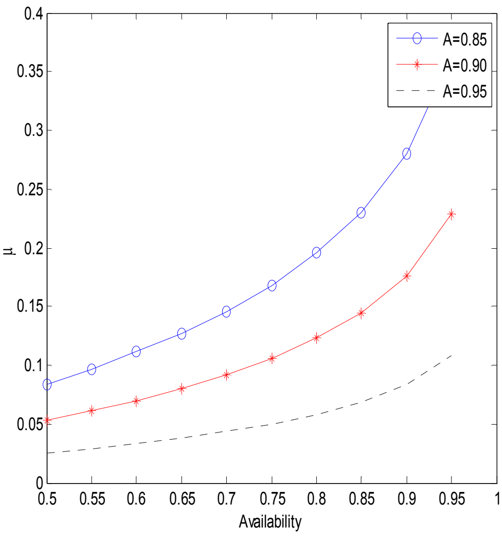

Figure 5: Aircraft's engine repair rate VS Uniform distribution

	A=0.85	A=0.90	A=0.95
y	μ	μ	μ
0.5	0.084156	0.052987	0.025099
0.55	0.096948	0.061042	0.028914
0.6	0.111248	0.070045	0.033179
0.65	0.127461	0.080253	0.038015
0.7	0.146176	0.092037	0.043597
0.75	0.168312	0.105975	0.050198
0.8	0.195405	0.123033	0.058279
0.85	0.230333	0.145024	0.068696
0.9	0.279561	0.17602	0.083378
0.95	0.363717	0.229007	0.108477
1	∞	∞	∞

Table 4: Annual Level of aircraft's engine repair rate in relation to availability

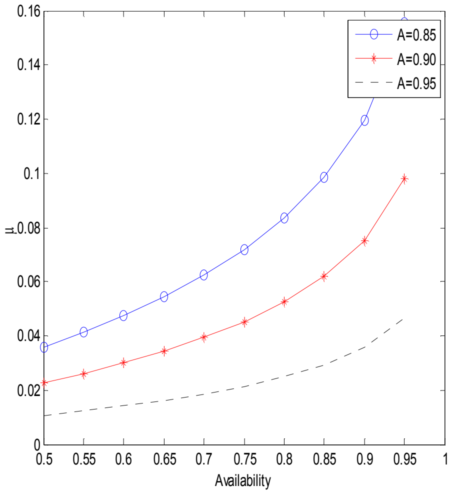

Figure 6: Aircraft's propeller repair rate VS Uniform distribution

	A=0.85	A=0.90	A=0.95
y	μ	μ	μ
0.50	0.036011	0.022674	0.01074
0.55	0.041485	0.02612	0.012373
0.60	0.047604	0.029973	0.014198
0.65	0.054541	0.034341	0.016267
0.70	0.06255	0.039383	0.018655
0.75	0.072022	0.045347	0.02148
0.80	0.083615	0.052647	0.024938
0.85	0.098561	0.062057	0.029395
0.90	0.119626	0.07532	0.035678
0.95	0.155637	0.097994	0.046418
1	∞	∞	∞

Table 5: Annual Level of Aircraft's propeller repair rate in relation to availability

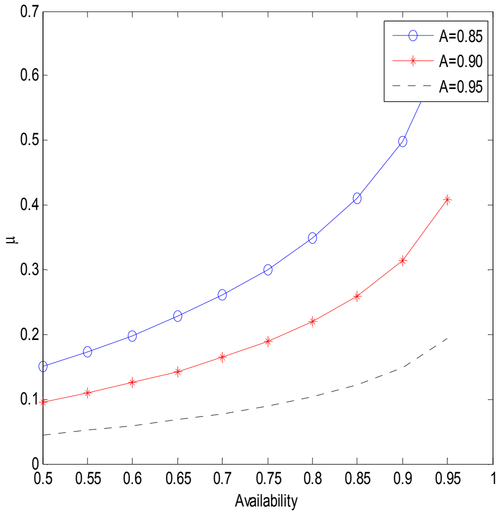

Figure 7: Avionics repair rate VS Uniform distribution

	A=0.85	A=0.90	A=0.95
y	μ	μ	μ
0.5	0.150097	0.094505	0.044766
0.55	0.172912	0.10887	0.05157
0.6	0.198417	0.124929	0.059177
0.65	0.227332	0.143135	0.067801
0.7	0.260713	0.164152	0.077756
0.75	0.300193	0.18901	0.089531
0.8	0.348513	0.219434	0.103943
0.85	0.410809	0.258658	0.122522
0.9	0.49861	0.31394	0.148708
0.95	0.648706	0.408445	0.193474
1	∞	∞	∞

Table 6: Annual Level of Avionics repair rate in relation to availability

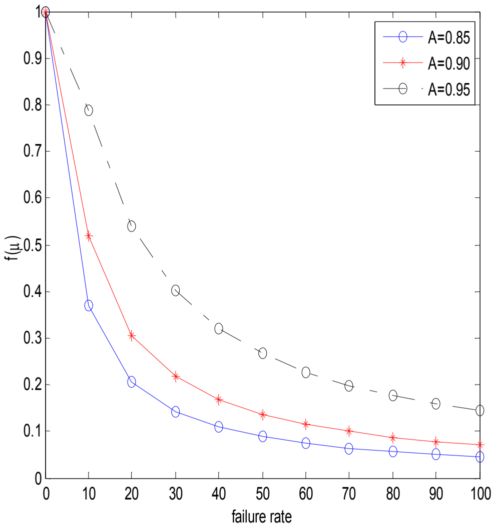

Figure 8: CDF of aircraft engine repair rate function VS failure rate

	A=0.85	A=0.90	A=0.95
u	$f(\mu_r)$	$f(\mu_r)$	$f(\mu_r)$
0	1	1	1
10	0.56117	0.729677	0.936811
20	0.337558	0.480075	0.748626
30	0.240084	0.353412	0.601697
40	0.186094	0.278941	0.498628
50	0.151876	0.230203	0.42439
60	0.128269	0.195893	0.368888
70	0.111005	0.170454	0.325995
80	0.097833	0.150848	0.291924
90	0.087453	0.135279	0.264237
100	0.079064	0.122619	0.241311

Table 7: Cumulative Distribution of aircraft engine repair rate and failure rate

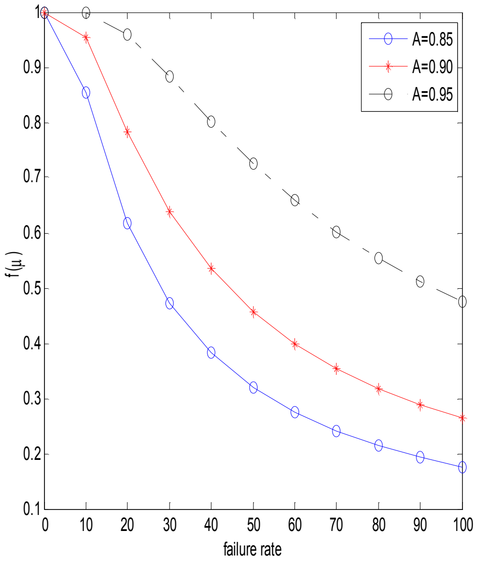

Figure 9: CDF of aircraft propeller repair rate VS failure rate

	A=0.85	A=0.90	A=0.95
u	$f(\mu_r)$	$f(\mu_r)$	$f(\mu_r)$
0	1	1	1
10	0.854098	0.952974	0.998425
20	0.618029	0.783146	0.96032
30	0.473554	0.639052	0.883663
40	0.381962	0.534325	0.800801
50	0.319525	0.457416	0.724939
60	0.274434	0.399211	0.658919
70	0.240408	0.35385	0.602266
80	0.213846	0.317596	0.553683
90	0.192546	0.287998	0.511829
100	0.175091	0.263397	0.475537

Table 8: Cumulative Distribution function of aircraft propeller repair rate and failure rate

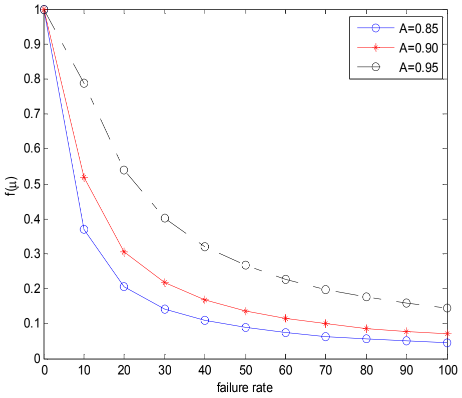

Figure 10: CDF of avionics repair rate VS failure rate

	A=0.85	A=0.90	A=0.95
u	$f(\mu_r)$	$f(\mu_r)$	$f(\mu_r)$
0	1	1	1
10	0.369852	0.51975	0.78741
20	0.206182	0.306999	0.538926
30	0.142671	0.216891	0.403174
40	0.109035	0.167533	0.320975
50	0.088223	0.136438	0.266317
60	0.074079	0.115065	0.227455
70	0.063843	0.099476	0.198443
80	0.056091	0.087604	0.17597
90	0.050017	0.078262	0.158057
100	0.04513	0.07072	0.143447

Table 9: Cumulative Distribution function of avionics repair rate and failure rate

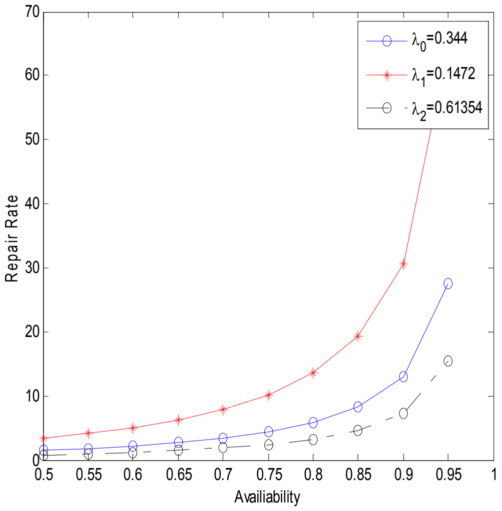

Fig.11: Repair rate of component and availability

	Aircraft	Aircraft	Avionics
	$\lambda_0 = 0.344$	$\lambda_1 = 0.147$	$\lambda_2 = 0.613$
Avail-ability	$\overline{\mu_r}$	$\overline{\mu_r}$	$\overline{\mu_r}$
0.50	1.45349	3.39674	0.814943
0.55	1.77649	4.15157	0.996041
0.60	2.18023	5.09511	1.22241
0.65	2.69934	6.30823	1.51347
0.70	3.39147	7.92572	1.90153
0.75	4.36047	10.1902	2.44483
0.80	5.81395	13.587	3.25977
0.85	8.23643	19.2482	4.61801
0.90	13.0814	30.5707	7.33449
0.95	27.6163	64.538	15.4839
1.00	∞	∞	∞

Table 10: Repair rate of component and availability

To validate our data, we analyze the probability density function for varying repair rate with respect to availability of engine in fig. 1, aircraft avionics in fig.2, and aircraft propeller in fig. 3 have shown. In fig. 1, 2, 3 it has been observed that repair rate is increasing corresponding to PDF function there after it is decreasing. Fig. 4, 5 and 6 depict the value of uniform distribution is in increasing order with respect to repair rate by taking the different intervals in between [0,1] for annual repair rate of aircraft's engine, aircraft propeller and avionics respectively. Cumulative distribution function of aircraft engine, aircraft propeller and aircraft avionics corresponding to failure rate is appeared in decreasing manner, which are demonstrated in fig. 7, 8, 9 respectively. Wherein, we achieve better results of cumulative distribution function vs failure rate. Finally in fig. 10, we described the value of repair rate of component and availability is depicted in ascending fashion.

5. Discussion

In this investigation, we obtained repair rate and failure rate of critical air craft components by using Weibull distribution and Jacobian transformation. Mathematical model is employed to enhance the performance based logistic (PBL) of availability, MTBF and MTTR. We determined the expected repair rate for better selection and more reliable results. Numerical illustrations have been determined to optimize the repair rate and failure rate of the critical air craft components for the system availability and to improve the performance based logistic (PBL). Further, this paper can be extended to achieve the desire level of performance of system availability.

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