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CONTRIBUTIONS TO BOOKS

- Sharma T., Kwatra, G. (2008) Effectiveness of Social Advertising: A Study of Selected Campaigns, Corporate Social Responsibility, Edited by David Crowther & Nicholas Capaldi, Ashgate Research Companion to Corporate Social Responsibility, Chapter 15, pp 287-303.

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- Schemenner, R.W., Huber, J.C. and Cook, R.L. (1987), "Geographic Differences and the Location of New Manufacturing Facilities," Journal of Urban Economics, Vol. 21, No. 1, pp. 83-104.

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COMPOUND EXPONENTIAL LIFETIME DISTRIBUTION-II AND ITS APPLICATIONS

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ABSTRACT
The thrust of the paper is to emphasize and bridge a cause and effect relationship between statistical quality control and reliability aspects of industrial practice. Based on process capability analysis, and the effects of certain trial and error fine-tuning manoeuvres on the part of the producer, leading to certain shifts in process mean (target value), the lifetime distribution of the manufactured product will no more adhere to the conventional models like exponential, gamma, Weibull, etc., discussed in the literature. The results obtained in this paper pertain to the derivation of a new lifetime model, taking into consideration such modifications and manoeuvres. In This model the shifts in process mean are assumed to be triangularly distributed. The theoretical results obtained are illustrated with appropriate practical examples.

KEYWORDS
Compound Distribution, Life Distribution, Process Capability, Reliability and Statistical Quality Control.

INTRODUCTION
In industrial practice, the application of techniques of statistical quality control (SQC) and reliability analysis play a vital role. SQC deals with the maintenance and improvement in the quality of manufactured product, whereas reliability analysis deals with the chance of survival of manufactured product up to specified time. Quality of manufactured product is assessed by defining a suitable quality characteristic. The variation in the quality characteristic of different items manufactured by a production process is characterized by its probability law. The duration of time (lifetime) in which a manufactured product (unit) functions, before it fails, is also a random variable of continuous type, supported on the positive half of the real line.
A synthesis of the two arms of the methodology is not much dealt with, in the literature. One can view these two aspects as the hardware and the software of a manufacturing process, which, both the producer and the consumer should be concerned about.

MODIFIED CONTROL LIMITS
Modified control limits are used in situations where the 6-sigma spread of the process is smaller than the spread in the specification limits. All the results obtained in the paper are based on this premise. In such situations the process mean μ is allowed to vary over an interval $\mu_L \le \mu \le \mu_u$, where μ_L and μ_u are obtained in such a way that the process is still capable of producing items that meet the specification limits. In other words, certain amount of shift in the parameter μ is permissible on either side of the target value of μ. Correspondingly, the upper and lower control limits for the control chart, called the modified control limits, are determined for the statistic.
In the framework of modified control limits discussed above under the assumption that $U - L > 6\sigma$, where U, L are the specification limits, a new life time distribution is derived from the point of view of reliability of the manufactured product.

RELIABILITY ANALYSIS
Important characteristics of reliability theory.
Reliability function:- The probability that the component survives until specified sometime 't' is called as the reliability function (and is denoted by R(t)) of the component. Mathematically, R(t) is expressed as
$R(t) = P(X > t) = 1-F(t)$.
where 'T' is the lifetime or time to failure of a component, F(t) is the distribution function of the lifetime T of the component.
Instantaneous failure rate:- The conditional probability that a component surviving to age 't' will fail in the interval $(t, t+\Delta t)$ is $h(t)\,\Delta t$, where h(t) is the instantaneous failure rate at time 't' and is defined as

$$h(t) = \underset{y\to 0}{Lt} \frac{R(t)-R(t+y)}{y\,R(t)} = \frac{f(t)}{R(t)}$$

The function h(t) is also known as hazard rate, intensity rate, mortality rate. If the above h(t) is an increasing function of t, for $t \ge 0$, the corresponding distribution function F(t) is known as an IFR (increasing failure rate) distribution. If h(t) is a decreasing function of t, then the corresponding distribution is a DFR (decreasing failure rate) distribution.
The Cumulative Failure rate: The cumulative failure rate H(t) is defined as,

$$H(t) = \int_0^t h(x)\,dx,$$

and is also known as the cumulative hazard. Also R(t) in terms of H(t) can be expressed as
$R(t) = e^{-H(t)}$

COMPOUND DISTRIBUTIONS
In applications of statistics, one generally has some apriori information regarding variation in one or more of the parameters of the probability model under consideration such variation also is specified by means of a probability distribution on an appropriate support. When this information about the parameter(s) is made effective and is super imposed on the basic model, and the probability density function is derived, as a marginal, the resulting distribution is termed as the compound distribution of the basic model.

Compound exponential lifetime distribution –IICELD-II) Model

Basic assumptions required for the derivation of the model are

Assumption 1.1 The lifetime (T) of a product is exponential with density f(t) given by

$$f(t) = \begin{cases} \theta e^{-\theta t} & ; \quad 0<t<\infty, \\ 0 & ; \quad elsewhere. \end{cases} \quad \ldots \quad (1.1)$$

Assumption 1.2 The measurable quality characteristic X of the product is normally distributed with mean μ and variance σ^2 i.e., X ~ N (μ, σ^2), in which, σ^2 is known.

Let U, L represent the upper and lower specification limits prescribed by the designing department. Based on the observation of the production process over time, suppose it is concluded that U-L > 6 σ, implying that the process is capable of producing better products, meeting the specifications.

Under this framework, suppose the manufacturer decides to relax certain constraints on the process by fine-tuning the operations of either one or more of the three M's (material, men and machines).

Assumption 1.3 The shift in μ resulting out of fine-tuning follows triangular distribution in [μ_L, μ_U], where

$$\left.\begin{aligned} \mu_U &= U - 3\sigma \\ \text{and} \quad \mu_L &= L + 3\sigma \end{aligned}\right\} \quad \ldots \quad (1.2)$$

It can be observed that the greater the shift in μ which results in a greater deviation from the process mean μ_o, will cause a reduction in the lifetime of the product. This, in turn, results in a reduction in the expected lifetime of the product.

Assumption 1.4 The increase in the absolute deviation of μ from μ_o results in an increase in θ, and the same is represented by the relation

$\theta = C + mU$; $c, m > 0$ ... (1.3)

where $U = | \mu - \mu_o |$

which represents absolute deviation of μ from μ_o.

In this context, one has the following.

Lemma 1.1: The variation in the random variable U is specified by the probability density function g*(U) where

$$g^*(u) = \begin{cases} 2(\delta - u)\delta^{-2} & ; \quad 0 < u < \delta, \\ 0 & ; \quad elsewhere. \end{cases} \quad (1.4)$$

Proof From Assumption 1.3, the pdf of μ is

$$g(\mu) = \begin{cases} 2(\mu_U - \mu_L)^{-1}(\mu - \mu_L)(\mu_o - \mu_L)^{-1} & ; \quad \mu_L \le \mu \le \mu_o, \\ 2(\mu_U - \mu_L)^{-1}(\mu_U - \mu)(\mu_U - \mu_o)^{-1} & ; \quad \mu_o \le \mu \le \mu_U, \\ 0 & ; \quad elsewhere \end{cases} \quad (1.5)$$

where $\mu_o = 2^{-1}(\mu_U + \mu_L)$ and $\delta = 2^{-1}(\mu_U - \mu_L)$.

Due to the symmetry of the triangular distribution around μ_o, $(\mu - \mu_o)$ has a triangular distribution on [–δ, δ] .

Hence, U in (6.3) will be folded triangular distribution with density

$$g^*(u) = \begin{cases} 2(\delta - u)\delta^{-2} & ; \quad 0 < u < \delta, \\ 0 & ; \quad elsehwere \quad . \end{cases}$$

The modified life time distribution of the product is derived in the following

Theorem 1.1 The distribution of the lifetime T under the framework, as explained above, is given by the compound distribution with density f*(t) given by

$$f^*(t) = \begin{cases} 2(m\delta)^{-2}\int_c^{c+m\delta} \upsilon(c + m\delta - \upsilon)e^{-\upsilon t}\, d\upsilon & ; \quad 0 < t < \infty, \\ 0 & ; \quad elsewhere \quad . \end{cases} \quad (1.6)$$

Proof Using the Lemma 1.1, and affecting the transformation

θ = c + mU = V, (say) one has

$$f_1(v) = \begin{cases} 2(m\delta + c - \upsilon)(m\delta)^{-2} & ; \quad c < \upsilon < c + m\delta, \\ 0 & ; \quad elsewhere. \end{cases} \quad (1.7)$$

From the theory of compound distributions, one has the joint density function of V and T, h(υ,t) of the compound distribution as $h(\upsilon, t) = f_1(\upsilon) . f(t/\upsilon)$

$$= \begin{cases} 2(m\delta + c - \upsilon)(m\delta)^{-2}.\upsilon e^{-\upsilon t} & ; \quad 0 < t < \infty,\ c < \upsilon < c + m\delta, \\ 0 & ; \quad elsewhere \quad . \end{cases} \quad (1.8)$$

Thus, the lifetime density of T in (1.6) is obtained as the marginal density, by integrating h(υ,t) w.r.t. υ, in the appropriate range.

Lemma 1.2 The function f*(t) defined in (1.6) is a proper probability density function.

Proof : Follows from (i) f*(t) should be non-negative, which is obvious, since the integrand in f*(t) is positive as, c, m, δ, υ, (c+mδ-υ) are positive.

(ii) Total probability is given by

$$I = \int_0^\infty f^*(t)dt$$

$$= \int_0^\infty 2(m\delta)^{-2}\left[\int_c^{c+m\delta} \upsilon(c+m\delta-\upsilon)e^{-\upsilon t}d\upsilon\right]dt$$

Which leads to 1 on simplification.

PROPERTIES OF CELD-II

Lemma 2.1 The expected value of T for the new distribution (CELD-II) is given by

$E^*(T) = 2(m\delta)^{-2}[(c+m\delta)\log(1+m\delta c^{-1}) - m\delta]$ (2.1)

Proof From the definition of mathematical expectation, one has

$$E^*(T) = \int_0^\infty f^*(t)\,t\,dt = \int_0^\infty 2t(m\delta)^{-2}\left[\int_c^{c+m\delta}\upsilon(c+m\delta-\upsilon)e^{-\upsilon t}d\upsilon\right]dt.$$

By changing the order of integration and $\upsilon t = \omega$; $dt = d\omega\upsilon^{-1}$

E*(T) on simplification yields (2.1).

Lemma 2.2 Expected lifetime of the CELD-II is less than the expected lifetime c^{-1} of the conventional exponential model.

Proof : From (2.1)

$$E^*(T) = 2(m\delta)^{-2}\left[(c+m\delta)\log\left(1+\frac{m\delta}{c}\right)-m\delta\right]$$

$= 2(m\delta)^{-2}[m\delta - m^2\delta^2(2c)^1 + (m\delta)^3(3c^2)^{-1} \ldots\ldots\ldots -m\delta]$

$= \frac{1}{c} - (3c)^{-1}\log(1+m\delta/c)$.

Since $E(T) = c^{-1}$, one has

$E^*(T) - E(T) = -\frac{1}{3c}\log(1+m\delta/c) < 0$.

Hence, the assertion.

Lemma 2.3: Variance of T for CELD-II is

$V^*(T) = 4(m\delta c)^{-1} - 4(m\delta)^{-2}\log(1+m\delta c^{-1}) - 4(m\delta)^{-4}$

$[(c+m\delta)\log(1+m\delta c^{-1}) - m\delta]^2$ (2.2)

Proof $V^*(T) = E^*(T^2) - (E^*(T))^2$, one has

$$E^*(T^2) = \int_0^\infty t^2 f^*(t)dt = \int_0^\infty t^2\, 2(m\delta)^{-2}\left[\int_c^{c+m\delta}\upsilon(c+m\delta-\upsilon)e^{-\upsilon t}d\upsilon\right]dt$$

By changing the order of integration, one has

$$E^*(T^2) = 2(m\delta)^{-2}\int_c^{c+m\delta}\upsilon(c+m\delta-\upsilon)\left[\int_0^\infty t^2e^{-\upsilon t}dt\right]d\upsilon$$

$= 4(m\delta c)^{-1} - 4(m\delta)^{-2}\log(1+m\delta c^{-1})$ . ... (2.3)

Hence, (2.2) follows from (2.3) and (2.1)

Lemma 2.4: The distribution function F*(t) of the CELD-II is given by

$F^*(t) = 1+2(m\delta)^{-2}[e^{-ct}t^{-2}(1-e^{-m\delta t}) - m\delta e^{-ct}t^{-1}]$ (2.4)

Proof : $F^*(t) = \int_0^t f^*(x)\,dx$

which on simplification yields (2.4).

RELIABILITY ASPECTS OF CELD-II

In the following section, certain properties of the lifetime distribution with particular reference to reliability are obtained.

Lemma 3.1 The reliability function R*(t) corresponding to CELD-II is given by

$R^*(t) = 2(m\delta)^{-2}[m\delta e^{-ct}t^{-1} - e^{-ct}t^{-2}(1-e^{-m\delta t})]$ (3.1)

The Proof follows from , $R^*(t) = 1 - F^*(t)$.

Lemma 3.2 The hazard function of the CELD-II is given by

$$h^*(t) = C + \frac{1}{t} + \frac{(tm\delta + 1 - e^{m\delta t})e^{-m\delta t}}{t(tm\delta - 1 + e^{-m\delta t})}.$$ (3.2)

Proof $h^*(t) = f^*(t)R^*(t)^{-1}$

$$=2(m\delta)^{-2}[m\delta e^{-ct}t^{-1} - e^{-ct}t^{-2}(1-e^{-m\delta t})]^{-1}2(m\delta)^{-2}\left[\int_c^{c+m\delta}\upsilon(c+m\delta-\upsilon)e^{-\upsilon t}d\upsilon\right]$$

$$= C + \frac{1}{t} + \frac{(tm\delta + 1 - e^{m\delta t})e^{-m\delta t}}{t(tm\delta - 1 + e^{-m\delta t})}.$$

Lemma 3.3 The cumulative hazard function H*(t) of CELD-II is given by

$$H^*(t) = \int_o^t \left(C + \frac{1}{x} + \frac{(xm\delta + 1 - e^{-m\delta x})e^{-m\delta x}}{x(xm\delta - 1 + e^{-m\delta x})} \right) dx \qquad (3.3)$$

Proof the cumulative hazard function is given by

$$H^*(t) = \int_0^t h^*(x)dx$$

$$= \int_o^t \left(C + \frac{1}{x} + \frac{(xm\delta + 1 - e^{-m\delta x})e^{-m\delta x}}{x(xm\delta - 1 + e^{-m\delta x})} \right) dx.$$

EXAMPLE

The case of manufacturing piston rings for an automotive engine by using certain forging process (Montgomery [6], pp.213) is taken for the purpose of illustration of the theory developed in the preceding sections.

The inside diameter of the ring manufactured by the process is the measurable quality characteristic X, assumed to be normally distributed with mean μ, variance σ^2. The upper and lower specification limits U and L, respectively, are U = 75 mm, L = 73 mm with the process, the target value μ_o = 74.001 mm and the estimated value of σ = 0.00989 mm.

Thus, the process is observed to use up only about 60% of the specification band. Using the theory of modified control charts the following values are obtained.

$$\left.\begin{array}{l} \mu_U = 74.97033 \text{ mm} \\ \text{and} \\ \mu_L = 73.02967 \text{ mm} \end{array}\right\} \qquad (4.1)$$

Hence, as discussed in the previous sections,

$$\delta = \frac{\mu_\mu - \mu_L}{2}$$

$$= \frac{74.97033 - 73.02967}{2}$$

$$= 0.97033 \text{ mm} \qquad (4.2)$$

TABLE 4.1: EXPECTED LIFETIME M*=E*(T) OF THE CELD-II

c c m	0.5	1	1.5	2	2.5	3	M = E(T) =1/c
0.5	1.5546	1.3076	1.1435	1.0242	0.9323	0.8587	2
1	0.8688	0.7773	0.7083	0.6538	0.6092	0.5718	1
1.5	0.6043	0.5567	0.5181	0.4862	0.4592	0.4358	0.6666
2	0.4638	0.4344	0.4097	0.3886	0.3703	0.3541	0.5
2.5	0.3763	0.3564	0.3392	0.3242	0.3109	0.2990	0.4
3	0.3166	0.3022	0.2896	0.2783	0.2682	0.2591	0.3333

From the Table 4.1, it can be observed that the values of expected lifetime under CELD-II are smaller when compared to that of the exponential lifetime distribution. It can also be observed that the rate of this fall in the expected lifetime is decreasing as either each of c or m is increasing (along rows and along columns). f*, F*, R*, h*, f, F, R, h represent the characteristics density function, distribution function, reliability function and hazard function for CELD-II and conventional Exponential Lifetime Distribution respectively and are tabulated in Tables 4.2, 4.3, 4.4 for the example considered. Further, their respective graphs are also presented in figures 4.1,4.2,4.3, 4.4.

TABLE 4.2: COMPOUND EXPONENTIAL LIFE DISTRIBUTION-II AND EXPONENTIAL (c=0.500000 and m=1.000000)

T	f*	F*	R*	h*	f	F	R	h
0.1	0.7538	0.0788	0.9212	0.8182	0.4756	0.0488	0.9512	0.5
0.2	0.6904	0.151	0.849	0.8131	0.4524	0.0952	0.9048	0.5
0.3	0.6327	0.2171	0.7829	0.8081	0.4304	0.1393	0.8607	0.5
0.4	0.5801	0.2777	0.7223	0.8031	0.4094	0.1813	0.8187	0.5
0.5	0.5322	0.3332	0.6668	0.7982	0.3894	0.2212	0.7788	0.5
0.6	0.4885	0.3842	0.6158	0.7933	0.3704	0.2592	0.7408	0.5
0.7	0.4486	0.4311	0.5689	0.7886	0.3523	0.2953	0.7047	0.5
0.8	0.4123	0.4741	0.5259	0.7839	0.3352	0.3297	0.6703	0.5
0.9	0.379	0.5136	0.4864	0.7793	0.3188	0.3624	0.6376	0.5
1	0.3486	0.55	0.45	0.7747	0.3033	0.3935	0.6065	0.5
2	0.1554	0.7882	0.2118	0.7336	0.1839	0.6321	0.3679	0.5
3	0.0724	0.8965	0.1035	0.6998	0.1116	0.7769	0.2231	0.5
4	0.0351	0.9479	0.0521	0.6725	0.0677	0.8647	0.1353	0.5
5	0.0175	0.9731	0.0269	0.6505	0.041	0.9179	0.0821	0.5
6	0.009	0.9858	0.0142	0.6328	0.0249	0.9502	0.0498	0.5
7	0.0047	0.9924	0.0076	0.6184	0.0151	0.9698	0.0302	0.5
8	0.0025	0.9959	0.0041	0.6066	0.0092	0.9817	0.0183	0.5
9	0.0013	0.9977	0.0023	0.5968	0.0056	0.9889	0.0111	0.5
10	0.0007	0.9988	0.0012	0.5885	0.0034	0.9933	0.0067	0.5
15	0	0.9999	0.0001	0.5617	9	0.0013	0.0006	0.5
20	0	1	0	0.5473	0	1	0	0.5
25	0	1	0	0.5383	0	1	0	0.5
30	0	1	0	0.5321	0	1	0	0.5
35	0	1	0	0.5277	0	1	0	0.5
40	0	1	0	0.5243	0	1	0	0.5
45	0	1	0	0.5217	0	1	0	0.5
50	0	1	0	0.5196	0	1	0	0.5
60	0	1	0	0.5164	0	1	0	0.5
70	0	1	0	0.5141	0	1	0	0.5
80	0	1	0	0.5123	0	1	0	0.5
90	0	1	0	0.511	0	1	0	0.5
100	0	1	0	0.5099	0	1	0	0.5
150	0	1	0	0.5066	0	1	0	0.5
200	0	1	0	0.505	0	1	0	0.5

TABLE 4.3: COMPOUND EXPONENTIAL LIFE DISTRIBUTION-II AND EXPONENTIAL (c=1.500000 and m=1.500000)

t	f*	F*	R*	h*	f	F	R	h
0.1	1.6191	0.1796	0.8204	1.9735	1.2911	0.1393	0.8607	1.5
0.2	1.3222	0.3261	0.6739	1.9621	1.1112	0.2592	0.7408	1.5
0.3	1.0811	0.4459	0.5541	1.9509	0.9564	0.3624	0.6376	1.5
0.4	0.885	0.5438	0.4562	1.94	0.8232	0.4512	0.5488	1.5
0.5	0.7253	0.6241	0.3759	1.9293	0.7085	0.5276	0.4724	1.5
0.6	0.5951	0.6899	0.3101	1.9189	0.6099	0.5934	0.4066	1.5
0.7	0.4888	0.7439	0.2561	1.9087	0.5249	0.6501	0.3499	1.5
0.8	0.402	0.7883	0.2117	1.8988	0.4518	0.6988	0.3012	1.5
0.9	0.331	0.8248	0.1752	1.8892	0.3889	0.7408	0.2592	1.5
1	0.2727	0.8549	0.1451	1.8798	0.3347	0.7769	0.2231	1.5
2	0.0416	0.9769	0.0231	1.7997	0.0747	0.9502	0.0498	1.5
3	0.0069	0.9961	0.0039	1.7414	0.0167	0.9889	0.0111	1.5
4	0.0012	0.9993	0.0007	1.6992	0.0037	0.9975	0.0025	1.5
5	0.0002	0.9999	0.0001	1.6683	0.0008	0.9994	0.0006	1.5
6	0	1	0	1.6451	0.0002	0.9999	0.0001	1.5
7	0	1	0	1.6273	0	1	0	1.5
8	0	1	0	1.6133	0	1	0	1.5
9	0	1	0	1.6019	0	1	0	1.5
10	0	1	0	1.5926	0	1	0	1.5
15	0	1	0	1.5635	0	1	0	1.5
20	0	1	0	1.5482	0	1	0	1.5
25	0	1	0	1.5389	0	1	0	1.5
30	0	1	0	1.5326	0	1	0	1.5
35	0	1	0	1.528	0	1	0	1.5
40	0	1	0	1.5246	0	1	0	1.5
45	0	1	0	1.5219	0	1	0	1.5
50	0	1	0	1.5197	0	1	0	1.5
60	0	1	0	1.5165	0	1	0	1.5
70	0	1	0	1.5141	0	1	0	1.5
80	0	1	0	1.5124	0	1	0	1.5
90	0	1	0	1.511	0	1	0	1.5
100	0	1	0	1.5099	0	1	0	1.5
150	0	1	0	1.5066	0	1	0	1.5
200	0	1	0	1.505	0	1	0	1.5

TABLE 4.4 :COMPOUND EXPONENTIAL LIFE DISTRIBUTION-II AND EXPONENTIAL (c=2.500000 and m=2.000000)

T	f*	F*	R*	h*	F	F	R	h
0.1	2.2846	0.2692	0.7308	3.1262	1.947	0.2212	0.7788	2.5
0.2	1.6622	0.4649	0.5351	3.1062	1.5163	0.3935	0.6065	2.5
0.3	1.2119	0.6074	0.3926	3.0867	1.1809	0.5276	0.4724	2.5
0.4	0.8854	0.7114	0.2886	3.0678	0.9197	0.6321	0.3679	2.5
0.5	0.6482	0.7874	0.2126	3.0495	0.7163	0.7135	0.2865	2.5
0.6	0.4755	0.8432	0.1568	3.0318	0.5578	0.7769	0.2231	2.5
0.7	0.3495	0.8841	0.1159	3.0147	0.4344	0.8262	0.1738	2.5
0.8	0.2573	0.9142	0.0858	2.9983	0.3383	0.8647	0.1353	2.5
0.9	0.1898	0.9364	0.0636	2.9824	0.2635	0.8946	0.1054	2.5
1	0.1402	0.9527	0.0473	2.9672	0.2052	0.9179	0.0821	2.5
2	0.0074	0.9974	0.0026	2.845	0.0168	0.9933	0.0067	2.5
3	0.0004	0.9998	0.0002	2.7656	0.0014	0.9994	0.0006	2.5
4	0	1	0	2.7132	0.0001	1	0	2.5
5	0	1	0	2.677	0	1	0	2.5
6	0	1	0	2.651	0	1	0	2.5
7	0	1	0	2.6315	0	1	0	2.5
8	0	1	0	2.6164	0	1	0	2.5
9	0	1	0	2.6044	0	1	0	2.5
10	0	1	0	2.5946	0	1	0	2.5
15	0	1	0	2.5643	0	1	0	2.5
20	0	1	0	2.5487	0	1	0	2.5
25	0	1	0	2.5392	0	1	0	2.5
30	0	1	0	2.5328	0	1	0	2.5
35	0	1	0	2.5281	0	1	0	2.5
40	0	1	0	2.5247	0	1	0	2.5
45	0	1	0	2.522	0	1	0	2.5
50	0	1	0	2.5198	0	1	0	2.5
60	0	1	0	2.5165	0	1	0	2.5
70	0	1	0	2.5142	0	1	0	2.5
80	0	1	0	2.5124	0	1	0	2.5
90	0	1	0	2.511	0	1	0	2.5
100	0	1	0	2.5099	0	1	0	2.5
150	0	1	0	2.5066	0	1	0	2.5
200	0	1	0	2.505	0	1	0	2.5

FIG. 4.1

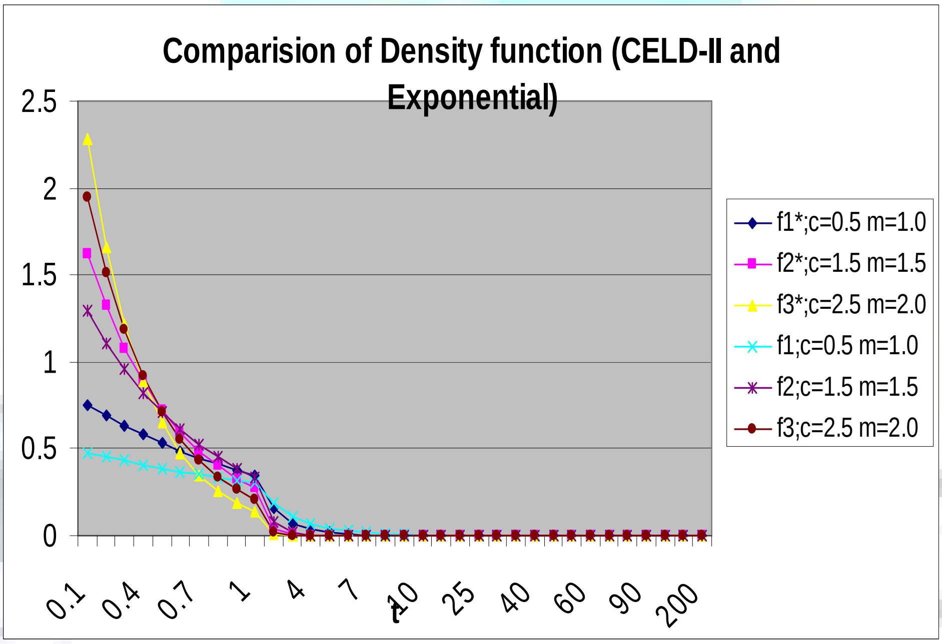


FIG. 4.2

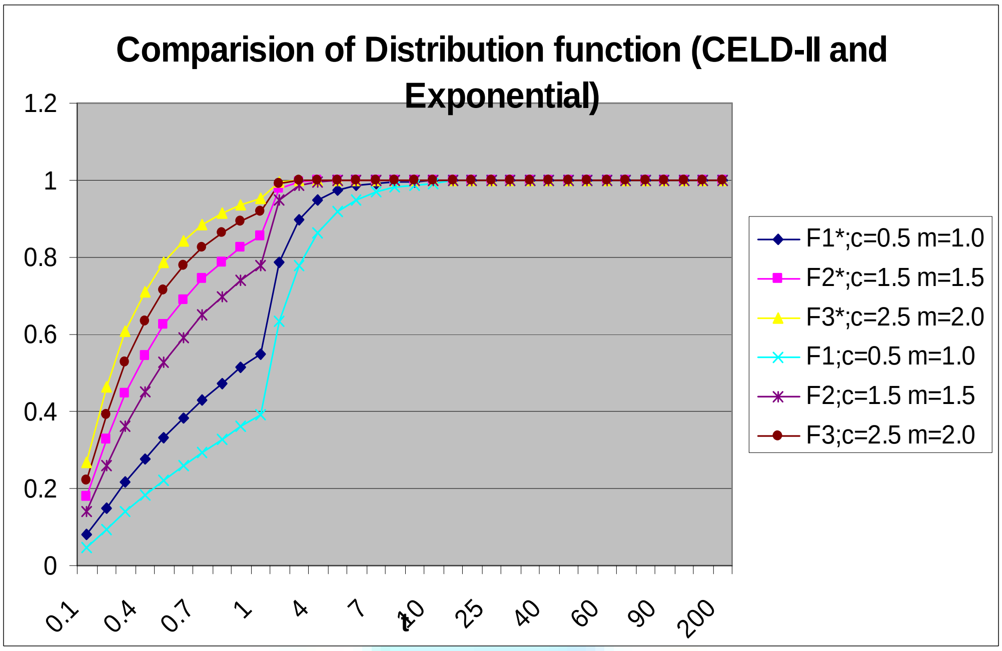


FIG. 4.3

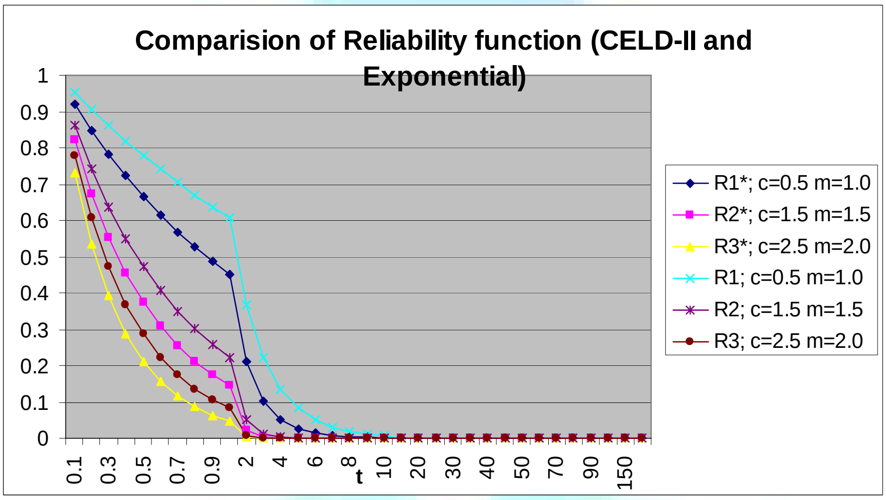
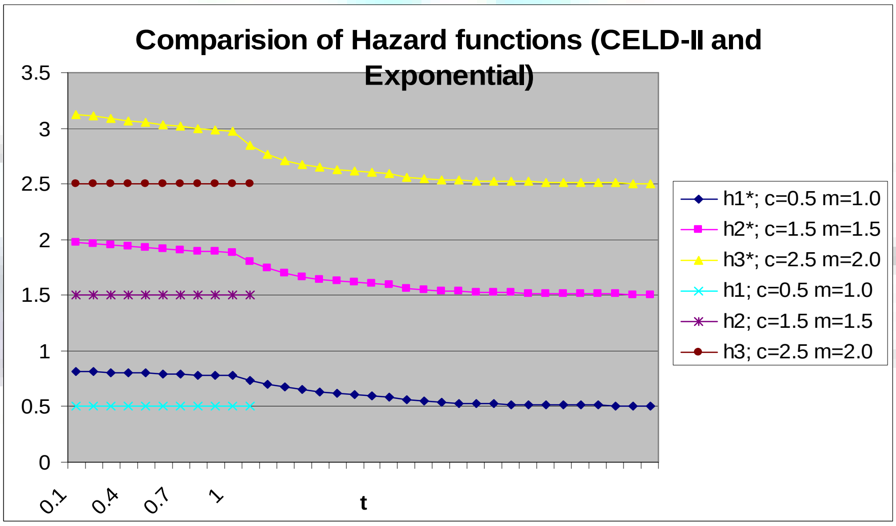


FIG. 4.4



From the graphs and tables one can observe that CELD-II in the example considered above, the life distribution has DFR.
Similar study is carried out, when

- The lifetime of the conventional model is Rayleigh Distribution , the shift in μ is Uniform Distribution, then the resulting new lifetime is CRLD-I.
- The lifetime of the conventional model is Rayleigh Distribution, the shift in μ is Triangular Distribution, then the resulting new lifetime is CRLD-II.
- The lifetime of the conventional model is Weibull Distribution, the shift in μ is Uniform Distribution, then the resulting new lifetime is CWLD-I.

- The lifetime of the conventional model is Weibull Distribution, the shift in μ is Triangular Distribution, then the resulting new lifetime is CWLD-II.

The reliability aspects of all the above models have been obtained and will be published in sequel.

CONCLUSION

Generally, any manufacturer would like to relax the conditions imposed on three M's (material, machines and men) in a situation where there is a possibility of doing so, viz., U-L > 6 σ.

In the process, one may ignore the effect it has on the lifetime of the product, in terms of the product reliability. This, in turn, leads to loss to the customer and to the manufacturer in terms of the number of complaints on warranty period. Hence, a proper lifetime distribution to be used under situation would be the compound lifetime distributions rather than the conventional one, in the derivation of all characteristics for studying the aspects of reliability. This is demonstrated through the example.

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