STATISTICAL METHODS FOR THE STUDY OF FIELD FAILURES

FIELD PERFORMANCE

(1) Actual use conditions and the resulting experiences in customer hands.

(2) Basic theory of failure and survival processes in real life.

(3) How can these failure and survival processes be systematically studied ?

(4) Is it possible to set up a universal and standard procedure for evaluating and predicting field performances ?

(5) Yes, there is a basic law in the universe of entities subject to failure and survival processes, including the life and death processes in biological systems.

(6) What is a failure process ?

(A) Deterioration
(B) Accumulated Hazard (rising risk) (entropy)
(C) Probability of Interuption of normal health operation

(7) How can deterioration or break-down of successful operation be measured ?

(8) How is such a measure related to Weibull statistics ?

(9) There is a scientific concept which easily handles all failure and survival or life and death processes. What is it ?

(10) This same concept is an important law in Thermodynamics.

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THE SECRET OF EVALUATING A PRODUCT'S FIELD PERFORMANCE

(11) How is performance measured ?

(A) Service time must be kept track of. (clock or hour meter or odometer)

(B) Failure must be counted, i.e., failures per machine or failures per system in service for a given time.

(C) In general, a machine or system will have several failures during its course of service, and not just one failure.

(12) How can Failure per Machine be scientifically measured ?

THE SCIENTIFIC BASIS OF MEASURING PROGRESS OF A FAILURE PROCESS

(13) A failure process in real life is most conveniently measured by a measurement concept which has been used in scientific studies for many centuries.

(14) This handy measurement concept applicable to failure processes is the concept called **E N T R O P Y** .

(15) What in the world is **Entropy** ?

(16) It is the natural logarithm of a probability with a minus sign in front to make it positive.

(17) What type of probability is used in calculating **Entropy** ?

A probability of success (i.e., probability of survival in real life or service)

(18) What is the common name for survival probability to a specified time target ?

Reliability (for that time in service)

(19) So, **E N T R O P Y** for any service period is expressed as

ENTROPY(for serv. period) =−ln(RELIABILITY)(for serv. period)

(20) The symbol for Entropy is ϵ .

(21) The symbol for Reliability is R .

(22) So, $\epsilon = -\ln R$

(23) How are logarithms of numbers related to the logarithms of corresponding reciprocals ?

Answer: Same numerical values , but opposite signs

(24) So, $-\ln R = +\ln 1/R$

(25) So, $\mathcal{E} = \ln 1/R$

(26) The symbol for the variable service time is x .

(27) So, if we talk about the Entropy at service time x we write $\mathcal{E}(x)$

(28) Likewise, if we talk about the Reliability for service time x we write $R(x)$.

(29) So, $\mathcal{E}(x) = \ln[1/R(x)]$.

(30) What is Reliability for a service period ?

Answer: The survival probability for that period .

(31) What then is failure probability during the same service period ?

Answer: 1 - Survival Probability or 1 - Reliability

(32) Thus,

$$F = 1 - R$$

Failure Probability = 1 - Reliability

(33) How can we find R (Reliability) from $\mathcal{E}$ (Entropy) ?

(34) Answer: By solving the basic formula $\mathcal{E} = \ln 1/R$ for R

(35) This yields $1/R = e^{\epsilon}$ or $R = e^{-\epsilon}$

$$\text{RELIABILITY} = e^{-\text{FAILURES PER MACHINE}}$$

(36) So, according to (32) above

$$F = 1 - e^{-\epsilon}$$

(37) What does an **F** formula give us ?

It gives us a graph showing how failure probability grows with time in service. We put **Time in Service** along the x-axis (since x is our service time variable). We put the failure probability in the service time x as an ordinate $F(x)$ along the y-axis of our graph paper. In this way the failure process in the product being studied becomes fully described in terms of probabilities.

(38) Another name for failure probability in a given service time is <u>fraction of population failed</u> in service time

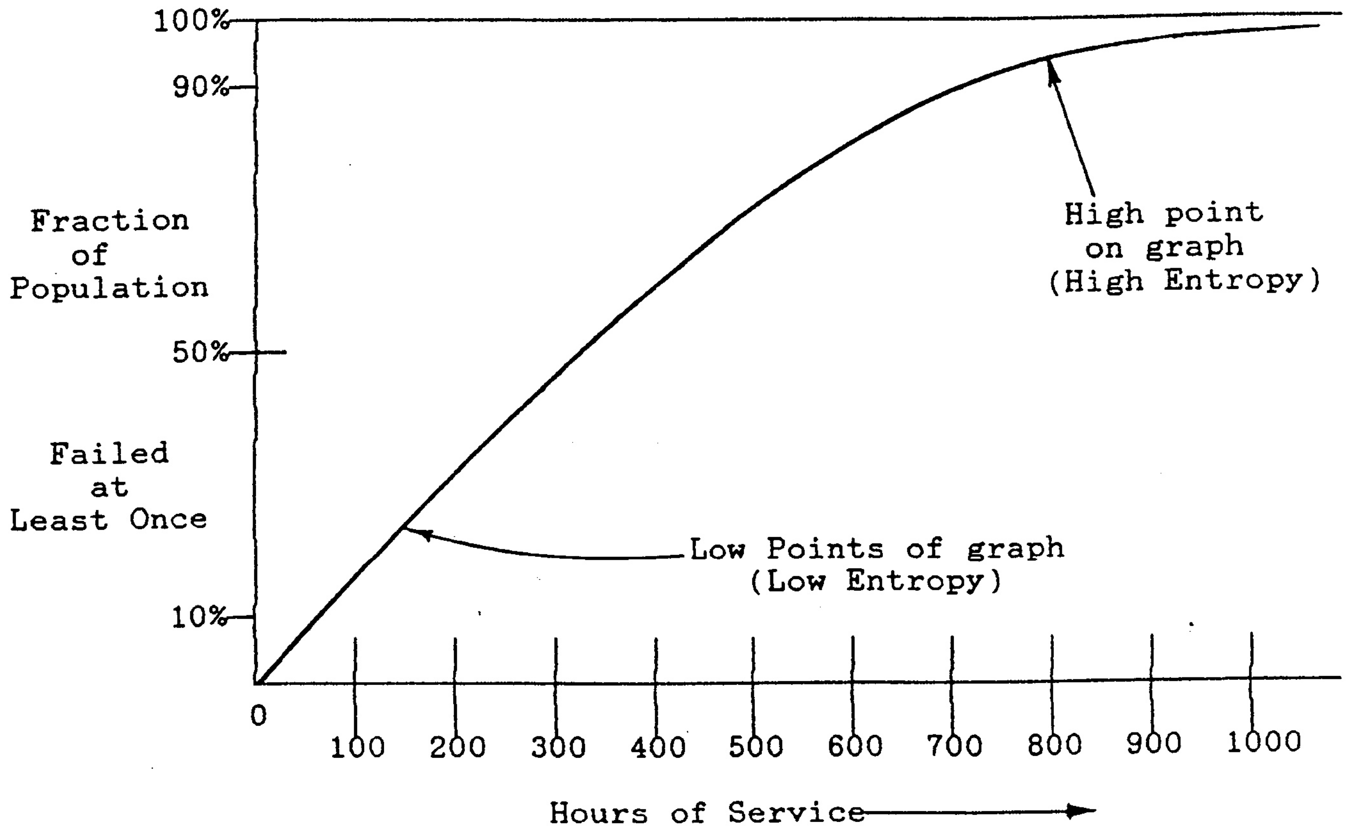
(39) Failed means <u>"failed at least once"</u> (considering repairable systems)

(40) As service time increases, so does the fraction of the population failed. (i.e., the longer the service time the larger the fraction of population which to be failed at least once.)

(41) The more failures in a population the larger the **ENTROPY**

(42) Thus, **Entropy** increases with service time --- because there are more failures in a population with increased service time.

(43) The higher we move up on an **F** graph the greater the Entropy



(44) The formula for Entropy in terms of the Failure Fraction F is

$$\mathcal{E} = \ln \frac{1}{1 - F}$$

INVERSE:

$$F = 1 - e^{-\mathcal{E}}$$

(45) So, we can construct the Table $F = 1 - e^{-\varepsilon}$

F Fraction of Population (at least once)	ε (Entropy)
0%	0
1%	.01005
5%	.05129
10%	.10536
20%	.22314
30%	.35667
39.25%	.50000
40%	.51038
50% (Median Entropy to a Failure)	.69315
60%	.91629
63.2% (Ave. Entropy to Failure)	1.00000
70%	1.20397
80%	1.60944
90%	2.30259
95%	2.99573
99%	4.60517
100%	∞

$$F = 1 - e^{-(\varepsilon/1)} \qquad \varepsilon = \ln \frac{1}{1 - F}$$

$1 = \text{MEBF}$

(46) According to the relation $F = 1 - e^{-\mathcal{E}}$, what is the **Average Entropy to a Failure** ?

Answer: 1 Unit of Entropy .

(47) Why is this ?

Answer: Because the formula $F = 1 - e^{-(\mathcal{E}/1)}$ is an exponential distribution of Entropy with an average value of **unity** for the Entropy.

(48) Since the Average Entropy per Failure is unity, how can Entropy be used as a measurement of field failure rates.

Answer: Simply by remembering that the Average No. of Failures per Machine or system in service is equal to the Accumulated Entropy in any service time .

(49) What did Weibull do that made him so famous in studying failure processes ?

Answer: He took **Entropy** to be a simple power function, of the form $\mathcal{E}(x) = (x/\theta)^b$. This give us the Weibull distribution

$$F(x) = 1 - e^{-(x/\theta)^b}$$

2-parameters: where b = Weibull slope
θ = Characteristic Life

(50) There is also the 3-parameter Weibull distribution

$$F(x) = 1 - e^{-[(x - a)/(\theta - a)]^b}$$

Whose Entropy function is

$$\mathcal{E}(x) = \left[\frac{x - a}{\theta - a}\right]^b$$

where a = Minimum Life ; b = Weibull slope ; θ = Characteristic Li

(51) In a Weibull distribution what identifies the Characteristic Life ?

Answer

At the Characteristic Life θ the Entropy ε = 1. (In other words, by the time the Characteristic Life has expired there is on the average one failure per machine)

(52) If an F curve has a 2-parameter Weibull formula, what can be said of the Entropy plot versus service time ?

Answer

The Entropy plot vs. Service Time is **linear** on **log-log paper**. This is because the relation

$$\varepsilon = (x/\theta)^b$$

yields $\ln \varepsilon = b \ln x - b \ln \theta$

Which comes out as a straight line if Time x is made abscissa on log-log paper and the Entropy (i.e. Failure per Machine) is made into the ordinate on log-log paper.

(53) Multiple Weibull processes will show changing slopes on log-log paper plots of Failure per Machine vs. Time in Service .

(54) So, the secret of mathematically describing the failure process of a machine or consumer product in the field is to take log-log paper and make the horizontal axis to represent Service Time and the vertical axis represent Ave. Failure per Machine (as actually observed within that service time).

(55) The field data plot will look as follows: