Reliability Engineering and Maintenance

The growth in unit sizes of equipment in most industries with the result that the consequence of failure has become either much more expensive, as in the case of low availability or potentially catastrophic makes the following more important:

Reliability Engineering and Maintenance

1. Prediction of the expected life of plant and its major parts.
2. Prediction of the availability of plant
3. Prediction of the expected maintenance load
4. Prediction of the support system resources needed for effective operation

These predictions can only result from careful consideration of reliability and maintainability factors at the design stage.

The Whole-Life Equipment Failure Profile

In reliability analysis of engineering systems it is often assumed that the hazard or time- dependent failure rate of items follows the shape of a bathtub with three main phases

The Whole-Life Equipment Failure Profile

The burn-in phase (known also as infant morality, break-in , debugging):

- During this phase the hazard rate decrease and the failure occur due to causes such as:

Incorrect use procedures	Poor test specifications	Incomplete final test
Poor quality control	Over-stressed parts	Wrong handling or packaging
Inadequate materials	Incorrect installation or setup	Poor technical representative training
Marginal parts	Poor manufacturing processes or tooling	Power surges

The Whole-Life Equipment Failure Profile

The useful life phase:

- During this phase the hazard rate is constant and the failures occur randomly or unpredictably. Some of the causes of the failure include:

A. Insufficient design margins

B. Incorrect use environments

C. Undetectable defects

D. Human error and abuse

E. Unavoidable failures

The Whole-Life Equipment Failure Profile

The wear-out phase (begins when the item passes its useful life phase):

- During this phase the hazard rate increases. Some of the causes of the failure include:

A. Wear due to aging.

B. Inadequate or improper preventive maintenance
C. Limited-life components

D.Wear-out due to friction, misalignments, corrosion and creep

E. Incorrect overhaul practices.

The Whole-Life Equipment Failure Profile

- The whole-life of failure probability for the generality of components is obtained by drawing the three possible Z(t)
- However, the following will vary by orders magnitude from one sort of item to another:

1. The absolute levels of Z(t)
2. The time scale involved
3. The relative lengths of phases I, II, and III

Some times one or two of the phases could be effectively absent.

The Whole-Life Equipment Failure Profile

- Estimates of the parameters of the whole-life failure probability profile of the constituent components are an essential requirement for the prediction of system reliability.

- Additional information, such as repair-time distribution, then leads to estimates of availability, maintainability, and the level (and cost) of corrective and preventive maintenance.

Reliability Prediction for Complex Systems (plants or equipment)

To predict the reliability of complex plant the following should be performed:

1. Regard the large and complex system (plant) as a hierarchy of units and items (equipment) ranked according to their function and replaceability.
2. At each functional level, the way in which the units and items (equipment) in this level is connected is determine (The equipment in general could be connected in series, in parallel or in some combination of either)

Reliability Prediction for Complex Systems (plants or equipment)

3. The appropriate measure of reliability is calculated for each unit and item (in this analysis The appropriate measure of reliability is the survival probability $P(t)$).

4. The analysis starts from the component level upwards and at the end of the analysis the survival probability of the system $Ps(t)$ is calculated.

Reliability Prediction for Complex Systems (plants or equipment)

5. All the component mean failure rates are calculated. They are either being known or susceptible to estimation.

6. At each level the survival probability calculation takes the functional configuration into account.

7. The result P(t) of the system can be used in the selection of design or redesign alternatives, in the calculation of plant availability, or in the prediction of maintenance work load.

Series-Connected Components

- A system with components connected in series, works if all the components in this system work.

- If the failure behavior of any component in the system is quite uninfluenced by that of the others (failure probabilities are statistically independent), the survival probability of the system $Ps(t)$ at time t is given by the product of the separate survival probabilities, $P1(t)$, $P2(t)$, ….$Pi(t)$ of the components at the time t.

Series-Connected Components

- For a system of n series-connected components (independent and nonidentical), survival probability of the system is:

$$P_s(t) = P_1(t) \,.\, P_2(t) \,.\, P_3(t) \,.\, \ldots\ldots. \, P_n(t)$$

- And the system reliability is:

$$R_s = R_1 .\, R_2 .\, R_3 .\, \ldots.. \, R_n$$

Series-Connected Components

- For a system of n series-connected components (independent and nonidentical), survival probability of the system is:

$$Ps(t) = P1(t) . P2(t) . P3(t) . \ldots\ldots . Pn(t)$$

- And the system reliability is:

$$Rs = R1. R2. R3. \ldots.. Rn$$

- Since survival probabilities must always be less than 100%, it follows that Ps(t) for the system must be less than that of any individual component.

Series-Connected Components

- If the times-to-failure of the components behave according to the exponential p.d.f, then the overall p.d.f of times-to-failure is also exponential:

$$f(t) = (\lambda 1 + \lambda 2 + \ldots.. +\lambda n) \exp(-(\lambda 1+\lambda 2+ \ldots\ldots. +\lambda n)t)$$

- In addition, for exponentially distributed times to failure of unit i, the unit reliability is:

$$Ri(t) = \exp(-\lambda i\ t)$$

Series-Connected Components

- And the series system reliability at time t is:

$$R_s(t) = \exp(-\sum \lambda_i t)$$

- The mean time to failure in this case is:

$$MTTF_s = \int \exp(-\sum \lambda_i t)\, dt$$

$$= 1/\sum \lambda_i$$

- The hazard rate of the series system is :

$$\lambda_s(t) = \sum \lambda_i$$

Parallel-Connected Components

- A system with components connected in parallel, fails if all the components in this system fail. (at least one of the units must work normally for system success)
- If the failure behavior of any component in the system is quite uninfluenced by that of the others (failure probabilities are statistically independent), the failure probability Fps(t) that all components will fail before time t has elapsed is given by the product of the separate failure probabilities,F1(t), F2(t), ….Fi(t).

Parallel-Connected Components

- For a system with n parallel-connected components, the failure probability of the system:

$$Fps(t) = F1(t) \,.\, F2(t) \,.\, \ldots.\, Fi(t) \,.\, \ldots..\, Fn(t)$$

- And the system survival probability is:

$$Pps(t) = 1 - F1(t) \,.\, F2(t) \,.\, \ldots.\, Fi(t) \,.\, \ldots..\, Fn(t)$$

$$= 1 – (1- P1(t))(1 – P2(t)) \ldots\ldots\ldots. (1- Pn(t))$$

Parallel-Connected Components

- This means that system reliability, in this case is:

  Rps = 1 – (1 – R1)(1 – R2)(1 – R3)…..(1 – Rn)

- Since survival probabilities cannot be grater than 100%, it follows that the survival probability P(t) for the system must be grater than that of either of its components.

Parallel-Connected Components

- If the times-to-failure of the components behave according to the exponential p.d.f, then the overall p.d.f of times-to-failure is not a simple exponential. For example, if the system compose of two component, then the system times-to-failure p.d.f :

$$f(t) = \lambda 1 \exp(-\lambda 1 t) + \lambda 2 \exp(-\lambda 2 t) - (\lambda 1 + \lambda 2) \exp(-(\lambda 1 + \lambda 2) t)$$

Parallel-Connected Components

- For exponentially distribution times to failure of unit i, the parallel system reliability is:

$$Rps = 1- \Pi\ (1- \exp\ (-\lambda i\ t))$$

- And for identical units ($\lambda i = \lambda$) the reliability of the parallel system simplifies to:

$$Rps = 1 - (1- \exp\ (-\lambda t))$$

Parallel-Connected Components

- And the mean time to failure for the identical unit parallel system is:

  $$MTTFps = \int [\ 1 - (1 - \exp(-\lambda t))\ ]\ dt = 1/\lambda \sum 1/i$$

- The mean time to failure in this case:

  $$MTTF = \int f(t)\ t\ dt$$

  $$= 1/\lambda 1 + 1/\lambda 2 - 1/(\lambda 1 + \lambda 2)$$

Parallel-Connected Components

- The advantages of connecting equipment in parallel are:

1. To improve reliability of the system by making some of the equipment redundant to the other.
2. Extensive preventive maintenance can be pursued with no loss in plant availability since the separate parallel units can be isolated.
3. In the event of failure corrective maintenance can be arranged under less pressure from production or from competing maintenance tasks.

Parallel-Connected Components

- In the case of very high reliability units, there are only very marginal increments in reliability to be gained by installing redundant capacity unless the safety factors become evident.

Reliability and Preventive Maintenance

- Many components will have a useful life much less than the anticipated life of the system. In this case, the reliability of the system will be maintained only if such components are replaced prior to failure and the replacement should:

1. Interfere as little as possible with the operation of other components.
2. Not interrupt normal operation or production
3. Occur at intervals which exceed, as far as possible, the maximum operational cycle or production run.