Chapter 3 -Inspection Decisions

The purpose of inspections is to determine the state of equipment.

Once indicators such as bearing wear, gage readings, and quality of the product, which are used to describe the state, have been specified, and the inspection made to determine the values of the indicators, some further maintenance action may be taken, depending on the state specified.

When, specifically, the inspection should take place ought to be influenced by the costs of the inspection.

Benefit vs. cost of equipment is important.

The primary goal is to make a system more reliable through inspection.

Optimal Inspection frequency – maximization of profit.

Equipment break down from time to time and that requires repair and leads to downtime → costs money.

To reduce the number of breakdowns, we can periodically inspect the equipment.

Inspection also shuts down the equipment, although for a shorter time.

Need an inspection policy that will give the correct balance between the number of inspections, and the resulting output, such that the profit per unit time for the equipment is maximized out over a long period.

A complex system can fail for many reasons, such as that caused by component 1, component 2, and so on.

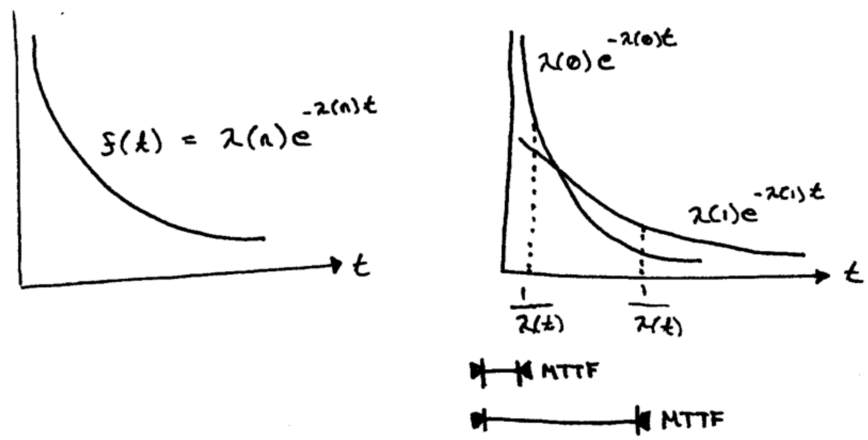
Each of these causes of equipment failure could have its own independent failure distribution.

As the frequency or intensity of inspection increases, there is an exception that the frequency of equipment/system failure will be reduced.

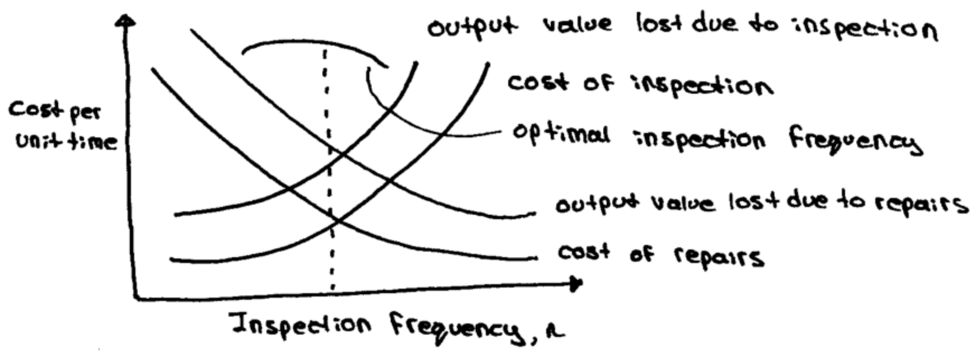
Construction of the Model –

1. Equipment failures occur according to the exponential distribution with mean time to failure (MTTF) = $1/\lambda$, where λ is the mean arrival rate of the failure.
   So, if the MTTF = 0.5 years, then the mean number of failures per year is equal to $\frac{1}{0.5} = 2\ (\lambda = 2)$
2. Repair times are exponentially distributed with a mean time of $\frac{1}{\mu}$
3. The inspection policy is to perform n inspections per unit time
   Inspection times are exponentially distributed with a mean time $\frac{1}{i}$
4. The value of the output in an uninterrupted unit of time has a profit value V (e.g. selling price less material cost less production cost)

   That is, V is the profit value per unit time if there are no downtime issues.
5. The average cost of inspection per uninterrupted unit of time is I
6. The average cost of repairs per uninterrupted unit of time is R
7. The breakdown rate of equipment, λ, is a function of n, the frequency of inspection per unit time.



8. $\lambda(0)$ is the breakdown rate if no inspection is made, and $\lambda(1)$ is the breakdown rate is one inspection is made per unit time.
   So, the effect of performing inspections is to increase the $MTTF$ of the equipment



We can denote the profit per unit time by $P(n)$ ($i.e. P$ is the function of n)

$P(n) =$ Value of output per uninterrupted unit of time
− output value lost due to repairs per unit time
− output value lost due to inspections per unit time
− cost of repair per unit time
− cost of inspections per unit time

Output value lost due to repairs per unit time = value of output per uninterrupted unit of time · number of repairs per unit time · mean time to repair

$$= V\,\lambda(n)/\mu$$

Output value lost due to inspections per unit time = value of output per uninterrupted unit of time · number of inspections per unit time · mean time to inspect

$$= \frac{Vn}{i}$$

Cost of repairs per unit time =
Cost of repairs per uninterrupted unit of time · number of repairs per unit time · mean time to repair

$$= \frac{R\lambda(n)}{\mu}$$

Cost of inspections per unit time =
Cost of inspections per uninterrupted unit time · Number of inspections per unit time · mean time to inspect

$$= \frac{In}{i}$$

So,

$$P(n) = V - \frac{V\lambda(n)}{\mu} - \frac{Vn}{i} - \frac{R\lambda(n)}{\mu} - \frac{In}{i}$$

This is a model of the problem relating inspection frequency n to the profit $P(n)$

Assume $P(n)$ to be a continuous function of n, so

$$\frac{dP(n)}{dn} = -V\frac{\lambda'(n)}{\mu} - \frac{V}{i} - \frac{R\lambda'(n)}{\mu} - \frac{I}{i}$$

(where $\lambda'(n)$ is the derivation of $\lambda(n)$)

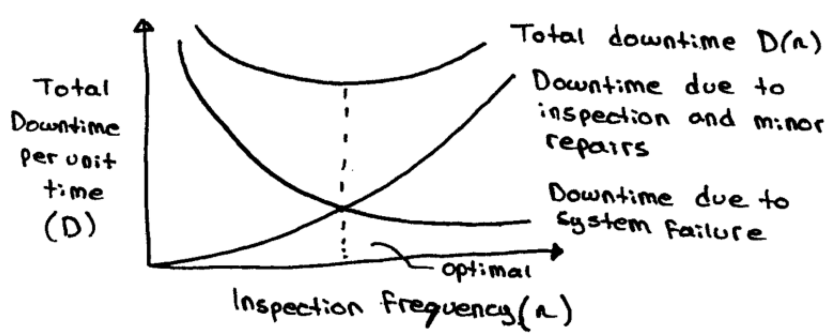
$$\frac{dP(n)}{dn} = 0 = \frac{\lambda' n}{mu}(V + R) + \frac{I}{i}(V + i)$$

$$\lambda'(n) = \frac{\mu}{i}\left[\frac{V + I}{V + R}\right]$$

If values of μ, i, V, R, I and the form of $\lambda(n)$ are known, the optimal frequency can be calculated.

Many time maximization of profit and minimization of downtime are equivalent but not always.

Optimal inspection frequency minimization of downtime.



$f(t)$, $\lambda(n)$, n, $1/\mu$ and $1/i$ are same as before.

The objective is to determine n to minimize total downtime per unit time.

$D(n) =$ Downtime incurred due to minor repairs per unit time + downtime incurred due to inspections per unit time

$$= \frac{\lambda(n)}{\mu} + \frac{n}{i}$$

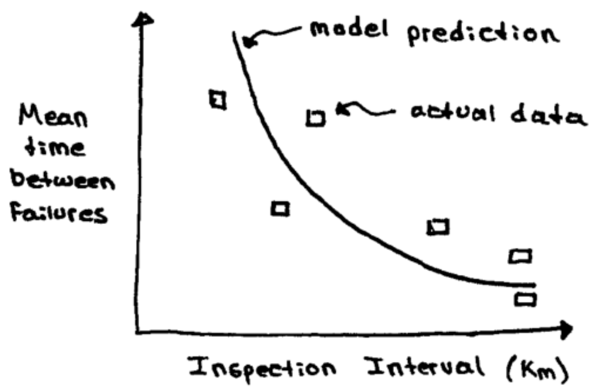
Can not find optimal solution analytically.

An application: Optimal vehicle fixed inspection schedule.

Montreal Transit = 2000 buses in fleet

Inspection policy was to inspect its buses at $5000\ km$ intervals at which an $A, B, C,$ or D depth of inspection took place.

Depth A at $5, 15, 25, 35$ (thousands of km)
Depth B at $10, 30, 50, 70$
Depth C at $20, 40, 60$
Depth D at 80



From trial and error they found $8000\ km$ was optimal for inspection interval instead of $5000\ km$.

Optimal inspection interval to maximize the availability of equipment used in emergency conditions, such as a protective device.

Equipment such as fire extinguishers and many military weapons are stored for use in an emergency.

If the equipment can deteriorate while in storage, there is a risk that it will not function when it is called into use.

To reduce the probability that equipment will be inoperable when required, inspections can be made usually called proof-checking, and if equipment is found to be in failed state, it can be repaired or replaced, this returning it to as-new conditions.

Examples of protective devices:
- Fire hydrants on city streets
- Standby diesel generators for running lights
- Full-face oxygen masks in aircraft
- Automatic transfer switches for power supply
- Methane gas detectors in underground coal mine
- Protective relays in electrical distribution
- Fire suppression equipment on vehicles
- Eyewash station in chemical plant
- Life rafts on ship

We need to establish the optimal inspection interval for protective devices, and this interval is called the failure-finding interval (FFI)

The reliability centered maintenance (RCM) methodology addresses this form of maintenance.

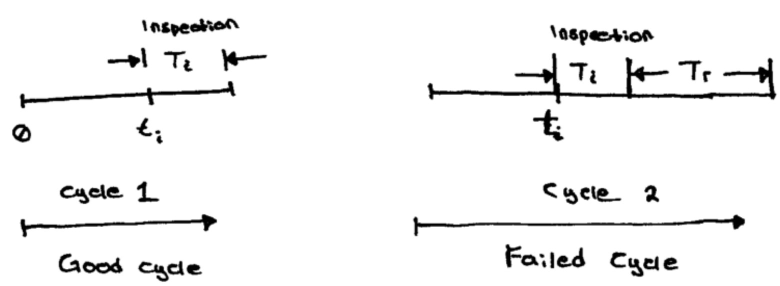
Failure-finding applies only to hidden or unrevealed failures.

Hidden failures in turn only affect protective devices.

Sometimes availability is of importance (which essentially is a function 1-downtime)

For analysis of availability:

1. $f(t)$ is the probability density function of the time to failure of the equipment.
2. T_i is the time required to carry out an inspection. It is assumed that after the inspection, if no major faults are found, the equipment is in the as-new state.
3. T_r is the time required to make a repair or replacement. After the repair or replacement, it is assumed that the equipment is in the as-new state.
4. The objective is to determine the interval t_i between inspections to maximize availability per unit time.



The availability per unit time will be a function of the inspection interval t_i

$$A(t_i) = \frac{Expected\ availability\ per\ cycle}{Expected\ cycle\ length}$$

The expected uptime (the expected availability) per cycle is:

$$t_i \cdot R(t_i) + \frac{\int_o^{t_i} t\, f(t)\, dt}{1 - R(t_i)}[1 - R(t_i)]$$

$$= t_i \cdot R(t_i) + \int_o^{t_i} t\, f(t)\, dt$$

The expected cycle length is:

$$= (t_i + T_c)R(t_i) + (t_i + T_i + T_r)[1 - R(t_i)]$$

$$A(t_i) = \frac{t_i \cdot R(t_i) + \int_o^{t_i} t\, f(t)\, dt}{t_i + T_i + T_r[1 - R(t_i)]}$$