GENERAL MODEL FOR RELIABILITY ANALYSIS OF A DOMESTIC WASTE WATER TREATMENT PLANT

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This paper covers the Technical & Analytical aspects of the Plant

Complex systems are commonly used in industries

Therefore, the reliability analysis of such systems would be of great importance to plant engineers for effective plant maintenance.

Many researchers have addressed the issue in many forms under different stipulated conditions and the analysis of such systems have been carried out [1]-[3]
Schematic of wastewater treatment plant
general model have been discussed for analyzing a domestic wastewater treatment plant from reliability perspective.

This treatment plant operates on biological aerobic process

Plant is built for a population of 50000

Plant operates at a minimum capacity during the non-touristic months (for about 10000 population)

At full capacity during touristic months which is roughly for about 6 months in a year.
There are 6 pumps with a capacity of 168 cu. m./hr. for pumping the waste from the primary settling tank for pretreatment.

There are 4 pumps for supply of ferric chloride, works at intervals and 5 pumps used for back washing and to pump out the treated effluent.

There is no alternative way to store the waste water other than treating the effluents and rejecting to the sea.

Hence, the reliability of these pumps/components is useful in order to carry on the whole process without the component failures of tolerable limits.
Three years of maintenance data for this treatment plant have been analyzed and some reliability indices are obtained:

- **Mean Time to Plant Failure**
- **Plant Availability**
- **Expected Busy Period for Repair**

Semi-Markov process and regenerative point techniques are used in the entire analysis.
$\lambda$: Failure rate of units

$p_1$: Probability of occurrence minor failure

$p_2$: Probability of occurrence major failure

$\beta$: Rate of shutting down of 3 pumps during off peak season

$r$: Rate of recovery after shut down during peak season

$g_1(t), G_1(t)$: pdf and cdf of minor repair rate

$g_2(t), G_2(t)$: pdf and cdf of major repair rate
DATA SUMMARY

- Estimated rate of failure of any component of the unit ($\lambda$) = 0.0000134 per hr.

- Estimated rate of the plant moving from peak to offpeak season ($\beta$) = 0.000114 per hr. [$1/(365 \times 24)$; once in a year]

- Estimated rate of Maintenance ($\gamma$) = 0.000232 per hr. [$1/(6 \times 30 \times 24)$; 6 months time for maint. during offpeak season]

- Probability of occurrence of Minor failure ($p_1$) = 0.8462

- Probability of occurrence of Major Repair ($p_2$) = 0.1231

- Estimated value of repair rate of Minor repairs ($\alpha_1$) = 0.08351 per hour

- Estimated value of repair rate of major repairs ($\alpha_2$) = 0.029701 per hr
MODEL DESCRIPTION AND ASSUMPTIONS

- There are six pumps in the plant, of which 6 operate at any given time and one pump is always kept as standby.

- Maintenance of no pump is done if the repair of some other pump is going on.

- The plant goes for annual maintenance during off peak season for six month and works on reduced capacity with 3 pumps working.

- If a unit is failed in one season, it gets repaired in that season only.

- Not more than two pumps get failed at a time.

- During the maintenance of one pump, more than one of the other pumps cannot get failed.

- All failure times are assumed to have exponential distribution with failure rate $\lambda$ whereas the repair times have general distributions.
\[
\begin{align*}
\text{d}Q_{12} &= p_1 \lambda e^{-(\lambda + \beta)t} \, dt \\
\text{d}Q_{13} &= p_2 \lambda e^{-(\lambda + \beta)t} \, dt \\
\text{d}Q_{14} &= \beta e^{-(\lambda + \beta)t} \, dt \\
\text{d}Q_{21} &= e^{-\beta t} g_1(t) \, dt \\
\text{d}Q_{31} &= e^{-\beta t} g_2(t) \, dt \\
\text{d}Q_{24} &= \beta e^{-\beta t} \overline{G_1(t)} \, dt \\
\text{d}Q_{34} &= \beta e^{-\beta t} \overline{G_2(t)} \, dt \\
\text{d}Q_{41} &= \gamma e^{-\gamma t} \, dt
\end{align*}
\]
The **mean sojourn time** \( (\mu_i) \) in the regenerative state \( 'i' \) is the time of stay in that state before transition to any other state.

If \( T \) denotes the sojourn time in the regenerative state \( i \), then

\[
\mu_i = E(T) = \Pr [T > t] \, dt
\]

Thus,

\[
\mu_1 = \int_0^\infty e^{-(\lambda+\beta)t} \, dt = \frac{1}{\lambda+\beta};
\]

Similarly, for states 2, 3 and 4 could be found
MEAN TIME TO SYSTEM FAILURE

- This measure is the expected time for which the system is in operation before it completely fails.

- Regarding the failed states as absorbing states and employing the arguments used for regenerative processes, the following recursive relation for $\phi_i(t)$ are obtained (c. d. f. of first passage time from a regenerative state $i$ to a failed state $j$)

  \[
  \Phi_1(t) = Q_{12}(t)\Phi_2(t) + Q_{13}(t)\Phi_3(t) + Q_{14}(t)
  \]

  \[
  \Phi_2(t) = Q_{21}(t)\Phi_1(t) + Q_{24}(t)
  \]

  \[
  \Phi_3(t) = Q_{31}(t)\Phi_1(t) + Q_{34}(t)
  \]
Solving these equations for $\phi_0^{**(s)}$ by taking Laplace Stieltje’s transforms, the **Mean Time to System Failure** (MTSF) when the system started at the beginning of state 0, is

\[
\text{MTSF} = \lim_{s \to 0} \frac{1 - \phi_0^{**(s)}}{s} = \frac{N}{D}
\]
Availability Analysis

Steady State Availability – This is the probability that the system will be able to operate within the tolerances for a specified period of time.

Using the probabilistic arguments and defining $A_i(t)$ as the probability of unit entering into upstate at instant $t$, given that the unit entered in regenerative state $i$ at $t=0$, the following recursive relations are obtained:

- $A_1(t) = M_1(t) + q_{12}(t) \circ A_2(t) + q_{13}(t) \circ A_3(t) + q_{14}(t) \circ A_4(t)$
- $A_2(t) = q_{21}(t) \circ A_1(t) + q_{24}(t) \circ A_4(t)$
- $A_3(t) = q_{31}(t) \circ A_1(t) + q_{34}(t) \circ A_4(t)$

Where $M_1(t) = e^{-\lambda t}$
AVAILABILITY ANALYSIS (Contd..)

- Taking L.T. of the above equations and solving them for $A_0*(s)$, we get:

\[ A_0*(s) = \frac{N(s)}{D(s)} \]

- Therefore, the steady-state availability of the system is given by

\[ A_0 = \lim_{s \to 0} s A_0*(s) = \frac{N_1}{D_1} \]

Similarly, the recursive relations for other reliability measures of the evaporator could be obtained.
PARTICULAR CASE & CALCULATIONS

- It is assumed that the failure times follow exponential distribution, whereas the other times follow arbitrary distributions.

- Using the DATA SUMMARY and the resulting expressions of RELIABILITY INDICES, the following measures of system effectiveness are obtained:

  Mean Time to Plant Failure = 429 days

  Availability of the Plant = 0.991790084

  Expected busy period for repair = 0.0020280

Similarly, many other reliability measures of the plant such as expected no. of minor repairs, major repairs, replacements, minor replacements and major replacements could be obtained.
Expected Total Profit in steady-state

\[ P = C_0A - C_1B - C_2V \]

- \( C_0 \) = revenue per unit up time of the system.
- \( C_1 \) = cost per unit time for which the repairman is busy in minor repair.
- \( C_2 \) = cost per unit time for which the repairman is busy in major repair.
- \( A \) = the total fraction of time for which the system is up.
- \( B \) = the total fraction of time for which the repairman is busy in minor repair.
- \( V \) = the total fraction of time for which the repairman is busy in major repair.
The value of this research and future scope:

- **Development of the robust model** embedding the real failure situations as depicted in the data for analysis
- Case study using the **real values of various failure rates and probabilities** for achieving the related reliability indicators
- These reliability indicators are meaningful in **determining & understanding different factors affecting the plant/unit availability** and also **useful to industries for failure analysis of complex system**
- Scope of direct application to industries & **comparative analysis** among models developed under different maintenance situations as to which model is better than the other under the stipulated conditions
REFERENCES:


Thank You

Any Question please?