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Performance Analysis of Port Cranes

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Abstract

The paper presents a performance analysis of the cranes operating at the port. Cranes at the port are generally used for loading and unloading of heavy or stroppy loads/vessels on and off ships. Performance of any system could be gauged in terms of its reliability and availability. Four years maintenance data of a particular crane has been collected. The values of different failure / repair / replacement rates are estimated from the data to be used in this analysis. The crane fails due to the failures which are repairable (minor electrical or mechanical failure) and the failures where only replacement is possible (major electrical or mechanical failure). An inspection is carried out to identify the type of the electrical or mechanical failure. The performance analysis of the crane has been carried out and as a result, measures of cranes effectiveness such as mean time to crane failure and crane availability are estimated numerically by using semi-Markov processes and regenerative point techniques.

Keywords–Port Cranes, failures, repairs, Semi – Markov, regenerative processes

NOTATIONS

O	Operative state of the crane
□	Failed state of the crane
α	Inspection rate
F_{REPAIR}	Minor failure is under inspection
$F_{REPLACEMENT}$	Major failure is under inspection
F_E	Electrical failed unit is under repair/replacement
F_M	Mechanical failed unit is under repair/replacement
$\boldsymbol{\lambda}_1$	Failure rate of the cranes due to minor reasons (repairable)
$\boldsymbol{\lambda}_2$	Failure rate of the cranes due to major reasons (replaceable)
p_1	Probability of electrical failure (repairable)
p_2	Probability of mechanical failure(repairable)
p_1'	Probability of electrical failure (replaceable)
p_2'	Probability of mechanical failure (replaceable)

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p_{ij}, Q_{ij}	Probability density function (p.d.f.), cumulative distribution function (c.d.f.) of the first passage time from a regenerative state *i* to *j* or to a failed state *j* in (0, t].
i(t), I(t)	pdf, cdf of inspection time of a failed unit
$g_1(t), G_1(t)$	p.d.f., c.d.f. of repair time of electrically failed unit
$g_2(t), G_2(t)$	p.d.f., c.d.f. of repair time of mechanically failed unit
$g_3(t), G_3(t)$	p.d.f., c.d.f. of replacement time of electrically failed unit
$g_4(t), G_4(t)$	p.d.f., c.d.f. of replacement time of mechanically failed unit
©	Convolution.
$\varphi_i(t)$	c.d.f. of first passage time from a regenerative state i to a failed state j
*	Laplace Transforms (LT); for any f(t) and g(t); $f(t)*g(t)=\int_0^t f(t-u)g(u)du$

1. Introduction

Complex systems are commonly used in industries and therefore researchers have spent a great deal of efforts in analyzing such systems as to how such complexsystem performs. Performance of any system could be gauged through achieved reliability indiceswhich in turn are the indicative of the overall system behavior.Rizwan et. al [2] analyzed a waste water treatment plant and obtained various reliability indices to gauge the system performance.Mathew et.al [3] analyzed a Continuous casting plant and obtained the reliability indices. Rizwan et.al [4] and Padmavathi et. al[5] have contributed in this area where the performance analysis of a desalination plant was carried out. A book by Kuo&Zuo [1] could be referred for the detailed study of the literature cited. In all these researches, the outcome was mainly focusing on the system performances of the industrial systems using mathematical modeling. The real maintenance situations noted in the data are generally embedded in the model for system analysis.

A potential application of the reliability concepts could also be explored for performance analysis of cranes at the port. The indicators of theanalysiscould be useful in optimizing the existing maintenance policies with a scope of further improvements.Cranes at the port are generally used for loading and unloading of heavy or stroppy loads/vessels on and off ships. Generally, the cranes operate round the clock and are occupied most of the time. Due to the heavy traffic and limited harboring facility at the port, it is quite essential that the cranes keep functioning and keep clearing the transporting ships with in the specified time limit. In order to attain the maximum cranes reliability, their performances need to be monitored and proper preventive maintenance plans need to be in place. For the purpose of this analysis, four years maintenance data of a particular crane has been collected and the real estimated values of various rates (failure/repair/replacement rates) are used for obtaining reliability results.Any major failure brings the crane to a complete halt and stops functioning until restored. Data reveals that the crane fails due to the failures which are repairable (minor electrical or mechanical failure) and the failures where only replacement is possible (major electrical or mechanical failure). An inspection is carried out to identify the type of the electrical or mechanical failure. The performance analysis of the cranes have been carried out and as a result, measures of cranes effectiveness such as mean time to crane failure and cranes availability are estimated numerically. Semi-Markov processes and regenerative point techniques are used in the entire analysis.

Using the data, following values of failure/repair/replacement ratesare estimated for this crane:

Estimated value of repairable failure rate λ_1= 0.000070163/hr.
Estimated value of replaceable failure rate λ_2 = 0.000053457/hr.
Estimated value of electrical repair rate (α_1) = 0.0833/hr.
Estimated value of mechanical repair rate (α_2) = 0.0833/hr.
Estimated value of electrical replacement rate (α_3) = 0.0833/hr.
Estimated value of mechanical replacement rate (α_4) = 0.0833/hr.
Probability that the unit needs electrical repair (p_1) = 0.135
Probability that the unit needs mechanical repair (p_2) = 0.594
Probability that the unit needs electrical replacement (p_3) = 0.027
Probability that the unit needs mechanical replacement (p_4) = 0.243

2. Model Description and Assumptions

- The unit is initially operative at state 0 and transits probabilistically depending on the type of failure / repair to any of the 6 states 1 to 6 with different rates / probabilities as shown in Fig.1.
- All failure times are exponentially distributed whereas other times have general distributions.
- After each repair / replacement, the unit works as good as new.
- Breakdowns are self-announcing but the type of failure is identified through inspection.
- The unit is brought into operation as soon as possible.

3. Transition Probabilities and Mean Sojourn Times

A state transition diagram showing the possible states of transition of the plant is shown in Fig. 1. The epochs of entry into states 0, 1, 2, 3, 4, 5 and 6 are the regenerative points and hence these states are regenerative states. The transition probabilities are given by:

$dQ_{01} = \lambda_1 e^{-\lambda_1 t} dt$
$dQ_{02} = \lambda_2 e^{-\lambda_2 t} dt$
$dQ_{13} = p_1 \alpha e^{-\alpha t} dt$
$dQ_{14} = p_2 \alpha e^{-\alpha t} dt$
$dQ_{25} = p_1^{'} \alpha e^{-\alpha t} dt$

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$dQ_{26} = p_2' \alpha e^{-\alpha t} dt$
$dQ_{30} = \alpha_1 e^{-\alpha_1 t} dt$
$dQ_{40} = \alpha_2 e^{-\alpha_2 t} dt$
$dQ_{50} = \alpha_3 e^{-\alpha_3 t} dt$
$dQ_{60} = \alpha_4 e^{-\alpha_4 t} dt$ (1 - 10)

The non-zero elements p_{ij} are given below:
$p_{01}=p_{02}=1$
$p_{13}=p_1$, $p_{14}=p_2$, $p_{25}=p_1'$, $p_{26}=p_2'$
$p_{30}=p_{40}=p_{50}=p_{60}=1$

By these transition probabilities, it is also verified that:
$p_{01}=p_{02}=1$
$p_{13}+p_{14}=p_1+p_2=1$
$p_{25}+p_{26}=p_1'+p_2'=1$
$p_{30}=p_{40}=p_{50}=p_{60}=1$

The mean sojourn time (μ_i) in the regenerative state 'i' is defined as 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

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

Thus $\mu_0 = \int_0^\infty e^{-(\lambda_1+\lambda_2)t} dt = \frac{1}{\lambda_1+\lambda_2}$;

$$\mu_1 = \mu_2 = \int_0^\infty \bar{H}(t) dt = \frac{1}{\alpha}$$

$$\mu_3 = \int_0^\infty \bar{G}_1(t) dt = \frac{1}{\alpha_1}$$

$$\mu_4 = \int_0^\infty \bar{G}_2(t) dt = \frac{1}{\alpha_2}$$

$$\mu_5 = \int_0^\infty \bar{G}_3(t) dt = \frac{1}{\alpha_3}$$

$$\mu_6 = \int_0^\infty \bar{G}_4(t) dt = \frac{1}{\alpha_4} \qquad (11 - 16)$$

The unconditional mean time taken by the system to transit for any regenerative state '*j*' when it (time) is counted from the epoch of entrance into state '*i* ' is mathematically stated as:

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$$m_{ij} = \int_0^\infty t\,dQ_{ij}(t) = -q_{ij}^{*\prime}(0)$$

Thus,

$$m_{01}=m_{02}=\mu_0$$
$$m_{13}+m_{14}=\mu_1$$
$$m_{25}+m_{26}=\mu_2$$
$$m_{30}=\mu_3$$
$$m_{40}=\mu_4$$
$$m_{50}=\mu_5$$
$$m_{60}=\mu_6$$

(17 -23)

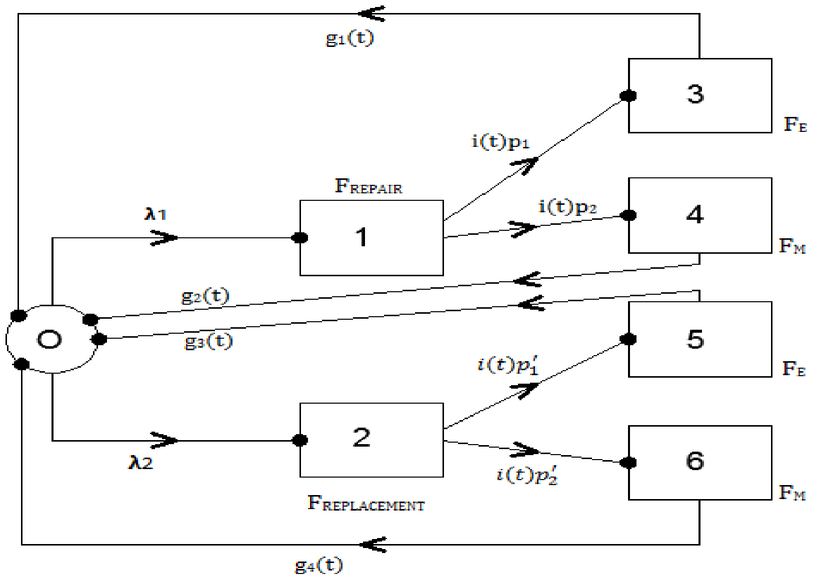

Fig.1. State transition diagram

4. The Mathematical Analysis

4.1 Mean Time to Crane Failure

Regarding the failed states as absorbing states and employing the arguments used for regenerative processes, the following recursive relation for $\phi_i(t)$ is obtained:

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$\phi_0(t) = Q_{01}(t) + Q_{02}(t)$ (26)

Solving the above equation for $\phi_o^{**}(s)$ by taking Laplace Stieltje's Transforms and using the determinant method, the following is obtained:

$$\phi_0^{**}(s) = \frac{N(s)}{D(s)} \quad (27)$$

Where, $N(s)=Q_{01}^{**}(s) + Q_{02}^{**}(s)$ and $D(s)=1$

Now the mean time to crane failure (MTCF) when the unit started at the beginning of state 0, is:

$$MTSF = \lim_{s\to 0} \frac{1-\varphi_0^{**}(s)}{s} = \frac{N}{D} \quad (28)$$

Where, $N=\mu_0$ and $D=1$

4.2 Availability Analysis of Unit of the Plant

Using the probabilistic arguments and defining $A_i(t)$ as theprobability ofunitentering intoupstate at instant t, given that the unit entered in regenerative state i at t=0, the following recursive relations are obtained:

$$A_0(t) = M_0(t) + q_{01}(t) \copyright A_1(t) + q_{02}(t) \copyright A_2(t)$$
$$A_1(t) = q_{13}(t) \copyright A_3(t) + q_{14}(t) \copyright A_4(t)$$
$$A_2(t) = q_{25}(t) \copyright A_5(t) + q_{26}(t) \copyright A_6(t)$$
$$A_3(t) = q_{30}(t) \copyright A_0(t)$$
$$A_4(t) = q_{40}(t) \copyright A_0(t)$$
$$A_5(t) = q_{50}(t) \copyright A_0(t)$$
$$A_6(t) = q_{60}(t) \copyright A_0(t) \quad (29–35)$$

Where, $M_0(t)= e^{-(\lambda_1+\lambda_2)t}$

Taking Laplace Transforms of the above equations and solving them for $A_0^*(s)$, the following is obtained:

$$A_0^*(s) = \frac{N_1(s)}{D_1(s)} \quad (36)$$

Therefore, the steady-state availability of the crane is given by:

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$$A_0 = \lim_{s \to 0} sA_0^*(s) = \frac{N_1}{D_1} \quad (37)$$

Where, $N_1 = \mu_0$, and
$D_1 = \mu_0 p_1 + \mu_1 p_1 + \mu_3 p_1 + \mu_0 p_2 + \mu_1 p_2 + \mu_4 p_2 + \mu_3 p_1 + \mu_0 p_1' + \mu_2 p_1' + \mu_5 p_1' + \mu_0 p_2' + \mu_2 p_2' + \mu_6 p_2'$

5. Particular Case

For the particular case, the following are considered:

$g_1(t) = \alpha_1 e^{-\alpha_1 t}$, $g_2(t) = \alpha_2 e^{-\alpha_2 t}$, $g_3(t) = \alpha_3 e^{-\alpha_3 t}$, $g_4(t) = \alpha_4 e^{-\alpha_4 t}$

$p_{01} = p_{02} = 1$, $p_{13} = p_1$, $p_{14} = p_2$, $p_{25} = p_1'$, $p_{26} = p_2'$, $p_{30} = p_{40} = p_{50} = p_{60} = 1$

$$\mu_0 = \frac{1}{\lambda}, \mu_1 = \mu_2 \frac{1}{\alpha}, \mu_3 = \frac{1}{\alpha_1}, \mu_4 = \frac{1}{\alpha_2}, \mu_5 = \frac{1}{\alpha_3}, \mu_6 = \frac{1}{\alpha_4}$$

Using the data as summarized in section 1 and the reliability expressions obtained in section 4, the following values reflects the crane performance:

Mean time to crane failure = 8089hours

Availability of the crane (A_0) = 0.999351485

6. Conclusions

The model incorporates the actual breakdownsituations and offers a scientific basis for performanceanalysis of the cranes. It has been noted that the expected time for which the crane is in operation before it completely fails is about 8089 hours, which is one of the measure of its reliability. Also, the probability that the crane will be able to operate within the tolerances for a specified period of time is 0.999558.

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