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Profit Analysis for Single Unit Computerized Numerical Control Machine (CNC Machine) Having Different Types of Faults with Single Repairman Facility

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Abstract:
The Reliability analysis of a single unit CNC machine run by mechanical and electrical engineers (repairmen) under certain inspection protocols is the focus of this research work. The facility has just one repairman. Both total and partial system breakdowns occur. The repairman first examines the system, classifies the issue as either repairable or non-repairable, and then performs the necessary replacement or repair. Different types of machine faults are categorized as major, minor, and deterioration. The Semi Mark0v process and the Regenerative P0int approach were used to analyze the system. Every computation was performed using actual data that was gathered from Shivam Auto-tech Limited, IMT Rohtak.
Keywords: CNC Machine, MTSF, Semi Markov Process, Regenerative Point Technique.

Introduction:

Numerous scholars have conducted several studies in the topic of reliability modeling. For a two-unit system having exponential failure and with general repair time, Branson and Shah demonstrated in 1971 that reliability modeling of the system using the Semi Markov Process was feasible. As a result, they developed a number of formulas for transition probability, waiting time distribution, and mean time for different states. Arora J.R. (1977) used two distinct repairman facilities to test the reliability of multiple standby redundant systems. A multistate system with many modes of failure including cold standby units was examined by Yamashiro (1980). Murari and Goyal (1983) assumed several kinds of repair facilities in order to compare the dependability metrics of a cold standby structure. Malik S.C. conducted a cost analysis in 1992 for a single unit reliability model that included various repair facilities and inspection protocols. Taneja G. and Tyagi, V.K. (2004) examined a single unit logic controller's profit analysis. Gitanjali investigated reliability models for a parallel system with the longest maintenance time in 2012. Taneja (2013) looked into the economics and reliability of a power plant with fluctuating demand. Barak, M.S. and Malik, S.C. conducted economic analysis for a weather-dependent system in 2009. The cost study of two separate units damaged by rain and partially operational following repairs was covered by Singh et al. (2017).

The working of the CNC Machine in SHIVAM AUTOTECH PRIVATE LIMITED was observed and real data of different types of faults/failures, maintenance and repair are collected. The system has various types

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of minor and major faults including M/C Frame damage, Bering fault, Fault in M/C spindle, leakage in hydraulic tank, coolant tank leakage, fault in Turret assembly and Tail stock including shaft damage, overheating and abnormal sounds etc., which leads to complete or partial failure of the structure. Some of these defects are non-repairable whereas others are repairable. Various measures of failure rates, maintenance rates, busy period for repairman etc. are estimated from the data collected for CNC machine. No researcher has examined such a CNC machine in reliability modeling by taking into account various defect types. In order to close this gap, the current study examined a single CNC machine while taking into account a number of flaws. Some of the faults are classified as minor because they result in partial system failure, such as coolant tank or hydraulic tank leaks, while others are classified as major because they result in total system failure and are more expensive to fix than minor faults, such as software errors or shaft breakage. MTSF, mean sojourn time, profit analysis, transition probability, and other system usefulness measures are assessed using the Semi-Mark0v Process and Regenerative P0int Technique.

Assumptions:

1) It is possible to identify system flaws without the use of extra detection techniques.
2) A single repairman facility is required to fix a malfunctioning subsystem.
3) The system pauses for a few minutes while undergoing maintenance.
4) The system is like new once any parts have been maintained and replaced.
5) The engineer (repairman) is always on call.
6) All random variables are independent of each other.

Notations

O: operating state

λ_1 / λ_2 / λ_3 : Failure rate of major faults, minor faults and power degradation.

$i_1^*(t)$/ $I_1^*(t)$: pdf/cdf of major fault's inspection rate w.r.t. time.

$g_1^*(t)$/$G_1^*(t)$: pdf/cdf of major fault's repair rate w.r.t. time.

$k_m^*(t)$/$K_m^*(t)$: pdf/cdf of minor fault's maintenance rate w.r.t. time.

$h_1^*(t)$/$H_1^*(t)$: pdf/cdf of major fault's replacement rate w.r.t. time.

$h_2^*(t)$/$H_2^*(t)$: pdf/cdf of replacement rate for degradation w.r.t. time.

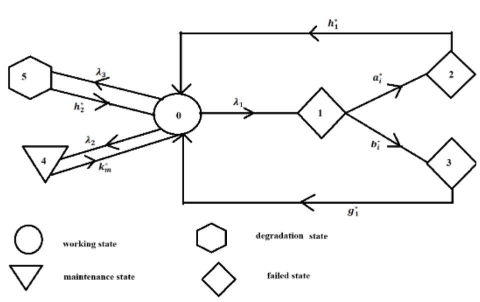

Fig. 1

Fig. 1 is a transition figure that displays different transition states in which all the states are regenerative, means that the ep0chs of entrance int0 0, 1, 2, 3, 4, and 5 states are regenerative points.

Model Description:

The following are some of the model's states based on Semi Mark0v Process and regenerative point techniques:

State 0: Initial operating state.

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State 1: Operating unit failed due to some major faults (defects).
State 2: The unit is inspected, major defects are replaced, reset, etc., and the system is again put into functioning condition.
State 3: After inspection unit undergoes for repair of the faults and system is again in functioning condition.
State 4: Unit temporary failed due to minor defects and then system is in functioning condition again.
State 5: Unit failed due to power failure or degradation.
In this case, state 0 is a fully functional operational state, whereas state 4 is operating state with maintenance and state 5 is operating state with power degradation. 3, 2 and 1 are failed states.

Transiti0n Probability and Mean Sojourn Time:

$p_{01}=\frac{\lambda_1}{\lambda_1+\lambda_2+\lambda_3}$, $p_{04}=\frac{\lambda_2}{\lambda_1+\lambda_2+\lambda_3}$, $p_{05}=\frac{\lambda_3}{\lambda_1+\lambda_2+\lambda_3}$, $p_{12} = a_i^*$, $p_{13} = b_i^*$, $p_{20} = h_1^*(0) = 1$,
$p_{30} = g_1^*(0) = 1$, $P_{40} = k_m^*(\lambda_2) = 1$, $p_{50} = h_2^*(\lambda_3) = 1$, $p_{12} + p_{13} = 1$, $p_{01} + p_{04} + p_{05} = 1$,
$p_{01} + p_{04} + p_{05} = p_{12} + p_{13} = p_{40} = p_{30} = p_{20} = p_{50} = 1$.

The unconditional mean time taken by the given system to transit for epoch generative state j, when it is counted from epoch of entrance into the state i, is mathematically stated as

$$m_{ij} = \int_0^\infty t dQ_{ij}(t)dt = -Q_{ij}^{**'}(0)$$

Then,

$$m_{01} + m_{04} + m_{05} = \mu_0\, ,\ m_{12} + m_{13} = \mu_1\, ,\ m_{20} = \mu_2\, ,\ m_{30} = \mu_3\, ,\ m_{40} = \mu_4\, ,\ m_{50} = \mu_5\, .$$

In the i[th] regenerative stage, the mean sojourn time (μ_i) are found as

$$\mu_0 = \frac{1}{\lambda_1 + \lambda_2+\lambda_3}\, ;\ \mu_1 = -i_1^{*'}(0)\, ;\ \mu_2 = -h_1^{*'}(0)\, ;\ \mu_3 = -g_1^{*'}(0)\, ;\ \mu_4 = -k_m^{*'}(0)\, ;$$

$$\mu_5 = -h_2^{*'}(0)$$

Several measures of System effectiveness:

The following momentous system usefulness measures are obtained by solving a number of recursive relations using probabilistic arguments for regenerative processes:

Mean time to system failure $(T_0^*) = \frac{\mu_0 + \mu_4 p_{04} + \mu_5 p_{05}}{1-p_{04}p_{40}-p_{05}p_{50}}$

Expected operating time of the system $(A_0^*) = \frac{\mu_0}{\mu_0+p_{01}\mu_1+p_{04}\mu_4+p_{05}\mu_5+p_{01}p_{12}\mu_2+p_{01}p_{13}\mu_3}$

Expected d**0**wn time (Reduced capacity) **0**f the system

$$(A_{01}^*) = \frac{p_{04}\mu_4+p_{05}\mu_5}{\mu_0+p_{01}\mu_1+p_{04}\mu_4+p_{05}\mu_5+p_{01}p_{12}\mu_2+p_{01}p_{13}\mu_3}$$

Busy Period for Repairman (Inspection time only)

$$(B_0^*) = \frac{p_{01}\mu_1}{\mu_0+p_{01}\mu_1+p_{04}\mu_4+p_{05}\mu_5+p_{01}p_{12}\mu_2+p_{01}p_{13}\mu_3}$$

Busy Period for Repair-man (Repair time only)

$$(B_{R_0}^*) = \frac{p_{01}p_{13}\mu_3}{\mu_0+p_{01}\mu_1+p_{04}\mu_4+p_{05}\mu_5+p_{01}p_{12}\mu_2+p_{01}p_{13}\mu_3}$$

Busy Period f**0**r Repair-man (Replacement time **0**nly)

$$(B_{R_{p_0}}^*) = \frac{p_{01}p_{12}\mu_2+p_{05}\mu_5}{\mu_0+p_{01}\mu_1+p_{04}\mu_4+p_{05}\mu_5+p_{01}p_{12}\mu_2+p_{01}p_{13}\mu_3}$$

Expected period for Degradation $(D_0^*) = \frac{p_{05}\mu_5}{\mu_0+p_{01}\mu_1+p_{04}\mu_4+p_{05}\mu_5+p_{01}p_{12}\mu_2+p_{01}p_{13}\mu_3}$

Busy deterrent (Periodic) Maintenance $(K_m^*) = \frac{P_{04}\mu_4}{\mu_0+p_{01}\mu_1+p_{04}\mu_4+p_{05}\mu_5+p_{01}p_{12}\mu_2+p_{01}p_{13}\mu_3}$

Profit Analysis:

The projected profit for the system is

$$P^* = C_0^*A_0^* - C_1^*A_{0_1}^* - C_2^*B_0^* - C_3^*B_{R_0}^* - C_4^*B_{R_{p_0}}^* - C_5^*K_m^* - C_6^*D_0^* - C_7^*, \text{ where}$$

C_0^*	C_1^*	C_2^*	C_3^*	C_4^*	C_5^*	C_6^*	C_7^*
RAFCS	CARCS	CIF	CRF	CRPF	CM	PD	Misc. C

Here we assumed (RAFCS) as revenue per unit availability with full capacity **0**f the system, (CARCS) as charges per unit availability with reduced capacity **0**f the system, (CIF) as per unit inspection charges of the nonfunctional unit, (CRF) as per unit repairment charges of the nonfunctional (failed) unit, (CRPF) per unit charges for replacement of the nonfunctional unit, (MC) as Charges for Maintenance, (PD) as charges for power failure or degradation, (Misc. C) as Miscellaneous Charges.

Particular Cases

The specific cases listed below are taken into consideration:

$i_1(t) = \delta_1 e^{-\delta_1(t)}$; $g_1(t) = \beta_1 e^{-\beta_1(t)}$; $k_m(t) = \eta_1 e^{-\eta_1(t)}$; $h_1(t) = \gamma_1 e^{-\gamma_1(t)}$;

$h_2(t) = \gamma_2 e^{-\gamma_2(t)}$

Considering the following supposed values from collected data for CNC system i.e.

$\lambda_1 = 0.033$, $\lambda_2 = 0.017$, $\lambda_3 = 0.025$, a = 0.313, b = 0.687, $\delta_1 = 1.53$, $\beta_1 = 3.41$, $\eta_1 = 0.6$,

$\gamma_1 = 2.35$, $\gamma_2 = 7.31$

The obtained system's effectiveness values are as follows:

T_0^* (MTSF)	A_0^* EUS	A_{01}^* EDS	B_0^* BPR	$B_{R_0}^*$ BPRR	$B_{R_{p_0}}^*$ BPRRP	K_m^* BPM	D_0^* EPD
31.2653	0. 93953	0.02983308	0. 02026	0.00625	0.00734	0.00734	0.00321

Where, EUS and EDS stands for Expected Uptime and Downtime for the system resp., BPR for repairman's busy period, BPRR and BPRRP as repairman's busy period for repair and replacement resp., BPM for busy deterrent (periodic) maintenance, EPD for expected degradation period, and MTSF for mean time to system failure.

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Graphical Interpretation and Conclusion

Using the stated arithmetical values, several graphs for MTSF and Profit versus rates of maj**0**r and min**0**r faults (λ_1 ,λ_2), various probabilities of major faults, minor faults (a, b), several inspection rate (δ_1), repair rate (β_1), replacement rate (γ_1, γ_2) and maintenance rate (η_1) and considering the following numerical values C_0^* = 400, C_1^* = 700, C_2^* = 975, C_3^* = 1000, C_4^* = 820, C_5^* = 900, C_6^* = 535, C_7^* = 1150 are drawn.

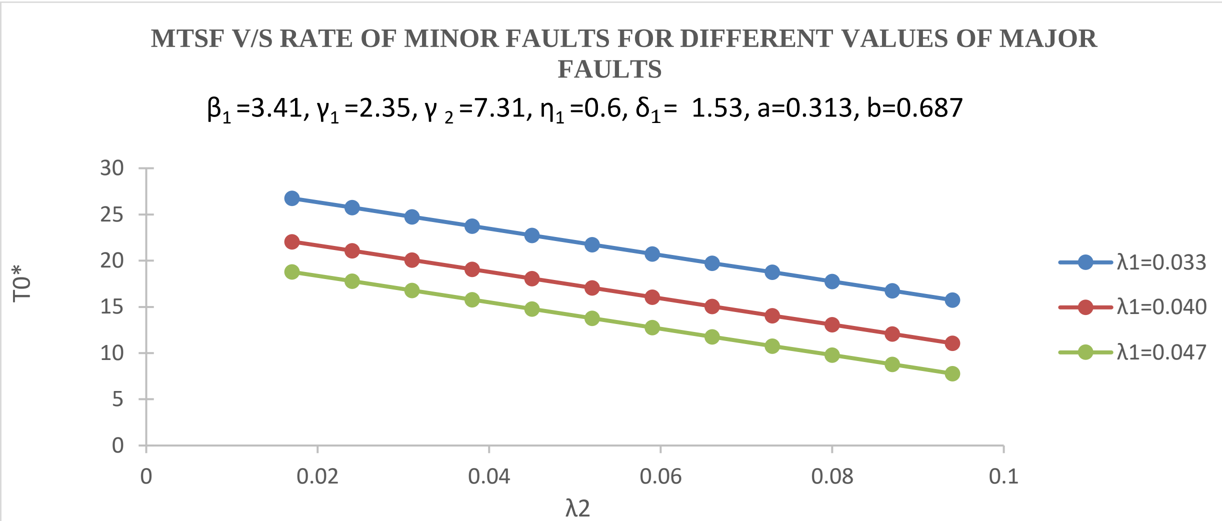

Fig. 2

Fig. 2 establishes the chart b/w MTSF and the rate of minor faults (λ_2) for distinct values of major faults.

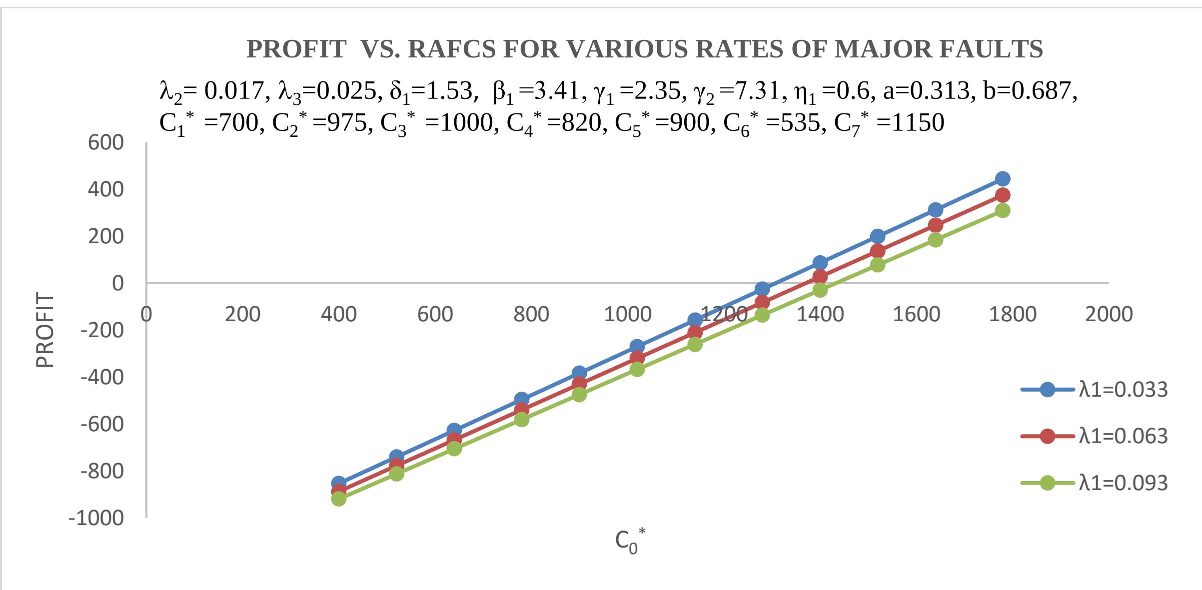

Fig.3 : The graph in fig. 3 is b/w profit and RAFCS (C_0^*) (Revenue of availability with full capacity) for several rates of major faults (λ_1).

From graph we deduce the following conclusions:

1. The profit has lesser values for larger values of the rate of major faults and rises with the revenue of availability at full capacity.
2. The profit is either pos, zero, or negative, for λ_1 = 0.033, accordingly as C_0^* ≤ or ≥ Rs. 1307.66382117. Machine will generate profit of ≥ Rs.1307.66382117.
3. The profit is either positive, zero, or negative, for λ_1 = 0.063, accordingly as C_0^* ≤ or ≥ Rs. 1370.1966844289. Machine will generate profit of ≥ Rs. 1370.1966844289.
4. The profit is either positive, zero, or negative, for λ_1 = 0.093, accordingly as C_0^* ≤ or ≥ Rs. 1432.7295404789. Machine will generate profit of ≥ Rs. 1432.7295404789.

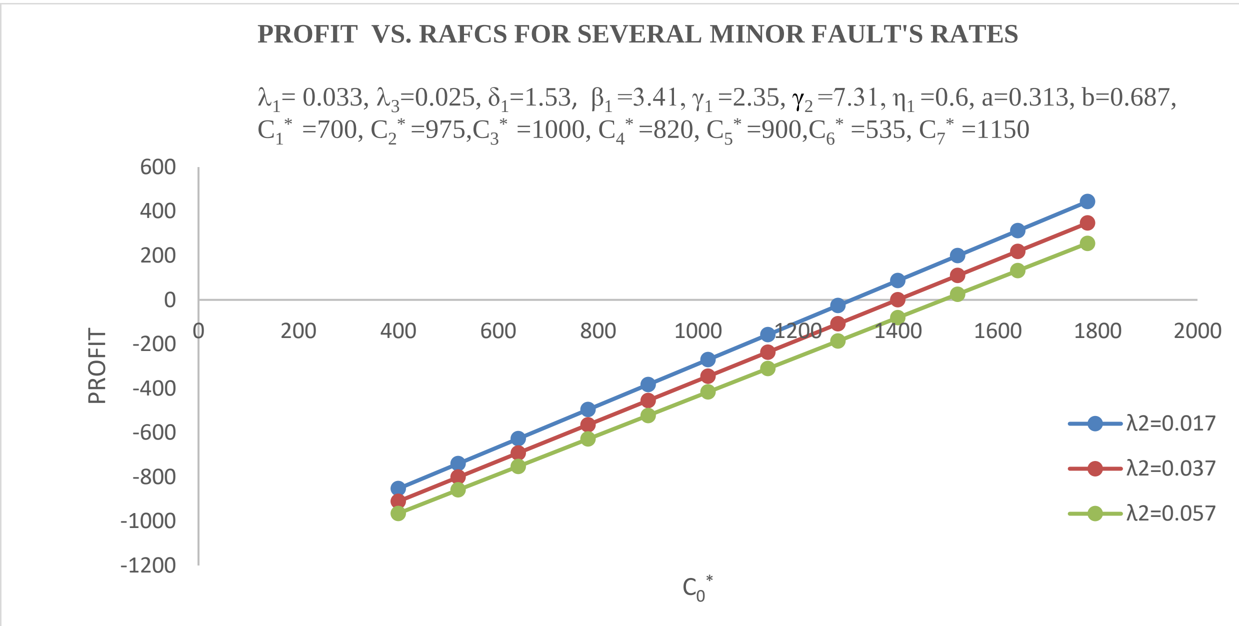

Fig. 4

The graph in fig. 4 is b/w Profit and RAFCS (Revenue of availability with full capacity) (C_0^*) for various minor fault rates (λ_2).

From graph we deduce the following conclusions:

1. The profit has lesser values for larger values of the rate of minor faults and rises with the revenue of availability with full capacity.
2. The profit is either positive, zero, or negative, for λ_2 = 0.017, accordingly as C_0^* ≤ or ≥ Rs. 1307.66382117. Machine will generate profit of ≥ Rs.1307.66382117.
3. The profit is either positive, zero or negative, for λ_2 = 0.037, accordingly as C_0^* ≤ or ≥ Rs.1399.33049238. Machine will generate profit of ≥ Rs. 1399.33049238.
4. The profit is either positive, zero or negative, for λ_2 = 0.057, accordingly as C_0^* ≤ or ≥ Rs. 1490.99716573. Machine will generate profit of ≥ Rs. 1490.99716573.

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