The Journal of CPRI,
Vol. 6, No. 1, March 2010 pp. 43–49

# Availability Simulation Modeling and Performance Optimization of the Screening Unit in a Paper Plant

Rajiv Khanduja*, Tewari P C** and Chauhan R S***

*This paper deals with the availability simulation modeling and performance optimization of the screening unit in a paper plant. The screening unit of a paper industry has four main subsystems, arranged in series and parallel configurations. Considering exponential distribution for the probable failures and repairs, the mathematical formulation of the problem is done using probabilistic approach and differential equations are developed on the basis of Markov birth-death process. These equations are then solved using normalizing conditions so as to determine the steady state availability of the screening unit. The performance of each subsystem of the screening unit in a paper plant has also been optimized using genetic algorithm. So, the findings of the present paper will be highly useful to the plant management for the timely execution of proper maintenance decisions and hence to enhance the system performance.*

***Keywords:*** *Availability Simulation Modeling, Screening Unit, Performance Optimization, Genetic Algorithm*

## 1.0 INTRODUCTION

The paper plant comprises of large complex engineering systems arranged in series, parallel or a combination of both the configurations. Some of these systems are chipping, cooking, washing, bleaching, screening, stock preparation and paper production etc. The important process of a paper plant, upon which the quality of paper depends, is the screening process. In the process of paper formation, the chips from storage are fed in to a digester to form the pulp which is processed through various subsystems called knotter, decker, opener and washers. These systems have been discussed in detail in [5-7]. The washed pulp is kept in a chamber where chlorine, at a controlled rate, is pressed through the pulp for a few hours. The pulp is passed over filter and washer in four stages to get chlorine free white pulp. The white bleached pulp so obtained, is first passed through a screen to separate out oversize and odd shape particles. It is then processed through a cleaner and finally sent to paper making machine [8,9].

## 2.0 THE SCREENING UNIT

It consists of four subsystems in hydrid configuration with the following description:

- **Subsystem $E_1$ :** It consists of a medium consistency (m.c.) pump unit used to flow the pulp from washer with consistency 4-5% with fresh water. Its failure can cause a sudden and complete failure of the system.

*Assistant Professor, Department of Mechanical Engineering, SKIET, Kurukshetra-136118 (Haryana), INDIA.
email: rajiv_khanduja@rediffmail.com
**Assistant Professor, Department of Mechanical Engineering, National Institute of Technology, Kurukshetra-136119 (Haryana), INDIA.
email: pctewari1@rediffmail.com
***Assistant Professor, Department of Electronic and Communication Engineering, JMIT, Radaur, Yamuna Nagar-135133 (Haryana), INDIA.
email: Chauhan443@yahoo.co.in

- **Subsystem $E_2$ :** It consists of a screen unit used for removing the knots and other undesirable foreign materials from the pulp. Its failure can cause a sudden and complete failure of the system.
- **Subsystem $E_3$ :** It consists of three cleaner units connected in parallel to mix the water with the pulp by centrifugal action. Failure of anyone cleaner results in poor quality of paper. Complete failure of this system reduces the efficiency of the plant but the system remains operative.
- **Subsystem $E_4$ :** It consists of a decker unit used to reduce the blackness of the pulp if any by controlling the water contents. Its failure causes complete failure of the system.

## 3.0 ASSUMPTIONS

The assumptions used in the probabilistic model are:

i. Failure / repair rates are constant over time and statistically independent.

ii. A repaired unit is as good as new, performance wise for a specified duration.

iii. Sufficient repair facilities are provided, i.e. no waiting time to start the repairs.

iv. Standby units (if any) are of same nature and capacity as active units.

v. System failure/repair follow exponential distribution.

vi. System may work at a reduced capacity.

## 4.0 NOTATIONS

The following notations are associated with the screening unit:

$E_1$, $E_2$, $E_3$, $E_4$: Represent good working states of respective m.c.pump, screen, cleaner and decker.

$e_1, e_2, e_3, e_4$: Represent failed states of respective m.c pump, screen, cleaner and decker.

$\lambda_{19}, \lambda_{20}, \lambda_{21}, \lambda_{22}$: Respective mean constant failure rates of $E_1$, $E_2$, $E_3$, $E_4$.

$\mu_{19}, \mu_{2}, \mu_{21}, \mu_{22}$ : Respective mean constant repair rates of $e_1$, $e_2$, $e_3$, $e_4$.

$P_0(t)$: State probability that the system is working at full capacity at time t.

$P_i(t)$: State probability that the system is in the $i^{th}$ state at time t.

$P^1_i(t)$: First-order derivative of the probabilities.

## 5.0 AVAILABILITY SIMULATION MODELING

The availability simulation modeling is carried out using simple probabilistic considerations and differential equations associated with the transition diagram (Fig. 1) are developed on the basis of Markov birth-death process [2, 4, 10, 11]. These equations are further solved for determining the steady state availability of the screening unit. Various probability considerations give the following differential equations associated with the screening unit:

State 0 shows the full capacity working with no standby.

States 1 to 2 show the system in reduced capacity working.

States 3 to 11 represent the system in failed state.

$$P^1_0(t) + \sum_{i=19}^{22}\lambda_i \; P_0(t) = \sum_{i=19}^{20}\mu_i \; P_{i-16}(t) + \mu_{21} \; P_1(t) + \mu_{22} \; P_5(t) + \mu_{21} \; P_2(t) \ldots\ldots\ldots (1)$$

$$P^1_1(t) + \sum_{i=19}^{22}\lambda_i \; P_1(t) + \mu_{21} P_1(t) = \sum_{i=19}^{20}\mu_i \; P_{i-13}(t) + \mu_{22} \; P_8(t) + \lambda_{21} \; P_0(t) \ldots\ldots\ldots (2)$$

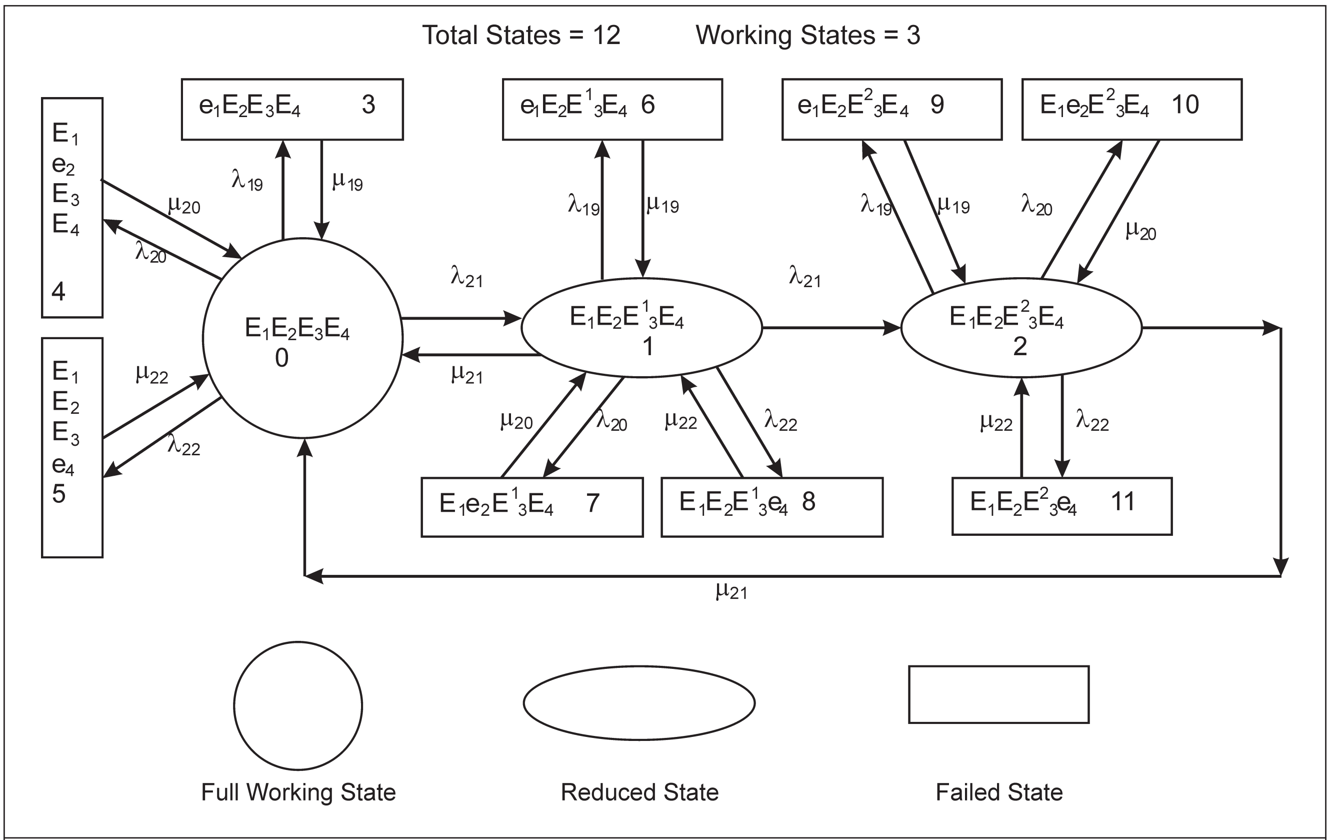


FIG. 1 STATE TRANSITION DIAGRAM OF THE SCREENING UNIT

$P^1_2(t) + \sum_{i=19}^{20}\lambda_i P_2(t)+\lambda_{22} P_2(t)+\mu_{21}P_2(t) = \sum_{i=19}^{20}\mu_i P_{i-10}(t)+ \mu_{22} P_{11}(t)+\lambda_{21}P_1(t)$……………...........(3)

$P^1_i(t) +\mu_{19}P_i(t)=\lambda_{19}P_j(t)$

where i=3, 6,9 j=0, 1,2…….……….......(4)

$P^1_i(t)+\mu_{20}P_i(t)=\lambda_{20}P_j(t)$.

where i=4, 7,10 j=0, 1,2…….................(5)

$P^1_i(t) +\mu_{22}P_i(t)=\lambda_{22}P_j(t)$

where i=5,8,11 j=0,1,2…………….........(6)

With initial conditions at time t = 0

$P_i(t) = 1$ for $i = 0$

$= 0$ for $i \neq 0$

Since the paper plant is a process industry, its every unit should be available for long period. Therefore, steady state behaviour of the system is analyzed by substituting $d/dt\rightarrow 0$ and as $t\rightarrow\infty$ for equations (1)-(6) and solving them recursively.

| | | |
|---|---|---|
| $P_1=BP_0$ | $P_2=B_3BP_0$ | $P_3=B_1P_0$ |
| $P_4=B_2P_0$ | $P_5=B_4P_0$ | $P_6=B_1BP_0$ |
| $P_7=B_2BP_0$ | $P_8=B_4BP_0$ | $P_9= B_1B_3BP_0$ |
| $P_{10}= B_2B_3BP_0$ | | $P_{11}= B_4B_3BP_0$ |

Where $B_i = \lambda_i/\mu_i$ i=19,20,21,22 and $B= \lambda_{21} /(\lambda_{21} +\mu_{21})$

Using normalizing condition i.e. sum of all the state probabilities is equal to one $[\sum_{i=0}^{11} Pi=1]$, we get:

$P_0+BP_0+B_3BP_0+B_1P_0+B_2P_0+B_4P_0+B_1BP_0+B_2B P0+B_4BP_0+B_1B_3BP_0+B_2B_3BP_0+B_4B_3BP_0=1$

$P_0[1+B+B_3B+B_1+B_2+B_4+B_1B+B_2B+B_4B+B_1B_3B+B_2B_3B+B_4B_3B] =1$

$P_0=1/[1+B+B_3B+B_1+B_2+B_4+B_1B+B_2B+B_4B+B_1B_3B+B_2B_3B+B_4B_3B]$

$P_0 = 1/ [(1+B_1 +B_2+B_4 )(1+B +B_3B)]$

The steady state availability (Av.) of this screening unit is given by summation of all the full working and reduced capacity states.

$Av. = P_0 + P_1 + P_2$

$Av. = [1+B+B_3B] / [(1+B_1 + B_2 + B_4)(1+B + B_3B)]$

$\text{Availability (Av.)} = 1/ [1+B_1 + B_2 + B_4]$

Here, the unit performance has been evaluated in terms of availability [12-14].

## 6.0 GENETIC ALGORITHM

Genetic algorithms are computerized search and optimization algorithms based on the mechanics of natural genetics and natural selection [1,3]. Genetic algorithms have become important because they are found to be potential search and optimization techniques for complex engineering optimization problems.

The action of genetic algorithm for parameter optimization in the present problem can be stated as follows:

1. Initialize the parameters of the genetic algorithm.
2. Randomly generate the initial population and prepare the coded strings.
3. Compute the fitness of each individual in the old population.
4. Form the mating pool from the old population.
5. Select two parents from the mating pool randomly.
6. Perform the crossover of the parents to produce two offsprings.
7. Mutate if required.
8. Place the child strings to new population.
9. Compute the fitness of each individual in new population.
10. Create best-fit population from the previous and new population.
11. Repeat the steps 4 to 10 until the best individuals in new population represent the optimum value of the performance function (Unit Availability).

## 7.0 PERFORMANCE OPTIMIZATION USING GENETIC ALGORITHM

The performance behaviour of the screening unit is highly influenced by the failure and repair parameters of each subsystem. These parameters ensure high performance of the screening unit. Genetic algorithm is hereby proposed to coordinate the failure and repair parameters of each subsystem for stable unit performance i.e. high availability. Here, number of parameters is six (three failure parameters and three repair parameters). The design procedure is described as follows:

To use genetic algorithm for solving the given problem, the chromosomes are to be coded in real structures. Unlike, unsigned fixed point integer coding parameters are mapped to a specified interval $[X_{min}, X_{max}]$, where $X_{min}$ and $X_{max}$ are the minimum and maximum values of unit parameters . The maximum value of the availability function corresponds to optimum values of unit parameters. These parameters are optimized according to the performance index i.e. desired availability level. To test the proposed method, failure and repair rates are determined simultaneously for optimal value of unit availability. Effect of population size and crossover probability on the availability of the screening unit is shown in Tables 1-2 and Figs. 2-3. To specify the computed simulation more precisely, trial sets are also chosen for genetic algorithm and system parameters. The performance [availability] of the screening unit is evaluated by using the designed values of the unit parameters [15-17].

Failure and repair rate parameter constraints are: $(\lambda_{19}, \mu_{19}, \lambda_{20}, \mu_{20}, \lambda_{22}, \mu_{22})$

$\lambda_{19}$ ε [0.05, 0.10] $\lambda_{20}$ ε [0.01, 0.09]

$\lambda_{22}$ ε [0.02, 0.08]

$\mu_{19}$ ε [0.10, 0.50] $\mu_{20}$ ε [0.05, 0.45]

$\mu_{22}$ ε [0.10, 0.30]

Here, real-coded structures are used.

The simulation is done to maximum number of population size which is varying from 20 to 100.

Number of generations - 40

Crossover probability - 0.85

Mutation probability - 0.015

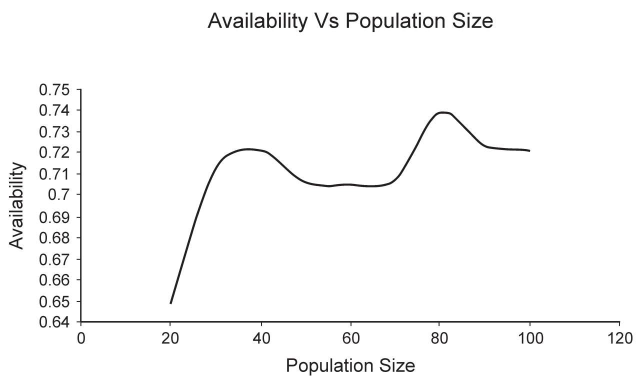


FIG. 2 EFFECT OF POPULATION SIZE ON THE SCREENING UNIT AVAILABILITY USING GENETIC ALGORITHM

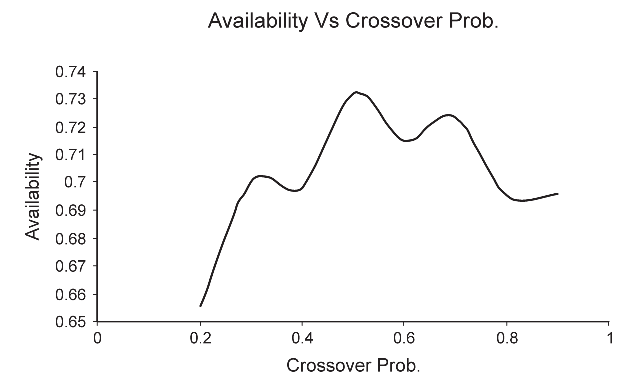


FIG. 3 EFFECT OF CROSSOVER PROBABILITY ON THE SCREENING UNIT AVAILABILITY USING GENETIC ALGORITHM

TABLE 1

EFFECT OF POPULATION SIZE ON AVAILABILITY OF THE SCREENING UNIT USING GENETIC ALGORITHM

| **Pop.Size** | **Av.** | $\lambda_{19}$ | $\mu_{19}$ | $\lambda_{20}$ | $\mu_{20}$ | $\lambda_{22}$ | $\mu_{22}$ |
|---|---|---|---|---|---|---|---|
| 20 | 0.6488 | 0.0505 | 0.50 | 0.0111 | 0.3962 | 0.02 | 0.2592 |
| 30 | 0.7127 | 0.0527 | 0.4947 | 0.01 | 0.3808 | 0.02 | 0.30 |
| 40 | 0.7211 | 0.05 | 0.50 | 0.01 | 0.4450 | 0.02 | 0.2992 |
| 50 | 0.7068 | 0.05 | 0.4832 | 0.01 | 0.45 | 0.02 | 0.30 |
| 60 | 0.7055 | 0.0535 | 0.50 | 0.01 | 0.45 | 0.02 | 0.30 |
| 70 | 0.7076 | 0.05 | 0.50 | 0.0107 | 0.45 | 0.02 | 0.30 |
| 80 | 0.7390 | 0.05 | 0.50 | 0.01 | 0.4403 | 0.02 | 0.2938 |
| 90 | 0.7230 | 0.05 | 0.50 | 0.01 | 0.4401 | 0.02 | 0.30 |
| 100 | 0.7210 | 0.05 | 0.50 | 0.01 | 0.4416 | 0.02 | 0.2718 |

TABLE 2

EFFECT OF CROSSOVER PROBABILITY ON AVAILABILITY OF THE SCREENING UNIT USING GENETIC ALGORITHM

| **Crossover Probability** | **Av.** | $\lambda_{19}$ | $\mu_{19}$ | $\lambda_{20}$ | $\mu_{20}$ | $\lambda_{22}$ | $\mu_{22}$ |
|---|---|---|---|---|---|---|---|
| 0.20 | 0.6550 | 0.0525 | 0.4137 | 0.0117 | 0.4276 | 0.0224 | 0.2970 |
| 0.30 | 0.7007 | 0.0583 | 0.4871 | 0.0110 | 0.4403 | 0.0306 | 0.2563 |
| 0.40 | 0.6982 | 0.0504 | 0.3848 | 0.0104 | 0.3422 | 0.0249 | 0.2693 |
| 0.50 | 0.7321 | 0.05 | 0.5 | 0.01 | 0.4473 | 0.02 | 0.3 |
| 0.60 | 0.7154 | 0.0513 | 0.5 | 0.01 | 0.45 | 0.0201 | 0.3 |
| 0.70 | 0.7238 | 0.05 | 0.5 | 0.01 | 0.45 | 0.02 | 0.2764 |
| 0.80 | 0.6953 | 0.05 | 0.5 | 0.01 | 0.45 | 0.0258 | 0.2781 |
| 0.90 | 0.6960 | 0.05 | 0.4997 | 0.01 | 0.4485 | 0.0201 | 0.2991 |

The effect of population size on availability of the screening unit is shown in Fig. 2. It is well indicated that at population size 80, the performance level of the Screening Unit is 73.90%. It is the optimum availability of the unit. The corresponding values of failure and repair parameters are $\lambda_{19}$ =0.05, $\mu_{19}$ =0.50, $\lambda_{20}$ =0.01 $\mu_{20}$ =0.4403, $\lambda_{22}$ =0.02, $\mu_{22}$ =0.2938 as given in Table 1. This is the best possible combination of failure and repair rates with respect to optimum availability of the unit.

Now the simulation is done for maximum number of crossover probability which is varying from 0.20 to 0.90.

Population size - 40

Number of generations - 40

Mutation probability - 0.015

The effect of crossover probability on availability of the screening unit is shown in Fig. 3. The optimum value of unit's performance is 73.21%, for which the best possible combination of failure and repair rates are $\lambda_{19}$ =0.05, $\mu_{19}$ =0.50, $\lambda_{20}$ =0.01 $\mu_{20}$ =0.4473, $\lambda_{22}$ =0.02, $\mu_{22}$ =0.3 at crossover probability 0.50 as clearly shown in Table 2.

## 8.0 CONCLUSION

The performance optimization of the screening unit of a paper plant has been carried out in this paper. Genetic Algorithm Technique is hereby proposed to select the various feasible values of the unit failure and repair parameters along with unit availability levels. Finally, Genetic Algorithm Technique is successfully applied to coordinate simultaneously these parameters for determining an optimum level of unit availability. Besides, the effect of Genetic Algorithm parameters such as population size and crossover probability on the unit performance i.e. availability has also been analyzed. By varying the above mentioned parameters of Genetic Algorithm the optimum unit availability achieved is about 73.90% with best possible combinations of the failure and repair rates of all the subsystems of the screening unit. Then, the findings of this paper are discussed with the concerned paper plant management. Such results are found highly beneficial for the purpose of performance optimization of a screening unit in the paper plant concerned.

## 9.0 REFERENCES


[1] Chales C and Kondo A. "Availability Allocation to Repairable Systems with Genetic Algorithms: A Multi-objective formulation", *Reliability Engineering and System Safety*, Vol. 82, No. 3, pp. 319–330, 2003.

[2] Dhillon B S and Singh C. Engineering Reliability—New Techniques and Applications. John Willey and Sons, New York (1981).

[3] Goldberg D E. Genetic Algorithm in Search, Optimization and Machine Learning., Pearson Edition. Asia, (2001).

[4] Fricks M F and Trivedi K S. "Importance Analysis with Markov Chains," *Proceedings of the 49th Annual Reliability and Maintainability Symposium*, pp. 89–95, 2003.

[5] Kumar D, Singh I P, and Singh J. "Reliability Analysis of the Feeding System in the Paper Industry", *Microelectron Reliability*, 28(2), pp. 213–215, 1988.

[6] Kumar, Dinesh, Singh, Jai and Pandey, P.C., "Availability Analysis of the Washing System in the Paper Industry", **Microelectron Reliability**, Vol. 29, pp. 775–778, 1989.

[7] Kumar, Dinesh, Singh, Jai, Pandey and P C. "Operational Behaviour and Profit Function for a Bleaching and Screening System in the Paper Industry", *Microelectron Reliability*, Vol. 33, pp. 1101–1105, 1993.

[8] Rajiv Khanduja, Tewari P C and Dinesh Kumar. "Development of Performance Evaluation System for Screening Unit of Paper Plant", *International Journal of Applied Engineering Research*, Vol. 3, Number 3, pp. 451–460, 2008.

[9] Rajiv Khanduja, Tewari P C and Dinesh Kumar. "Availability Analysis of Bleaching System of Paper Plant", *Journal of Industrial Engineering*, Udyog Pragati, N.I.T.I.E. Mumbai (India), 32(1), 24–29, 2008.

[10] Sanjeev Kumar *et al.,* "Simulation Model for Evaluating the Performance of Urea Decomposition System in a Fertilizer Plant", *International Journal of Industrial Engineering and Practices (I.J.I.E.P.)*, Vol. 1(1), pp. 10–14, 2009.

[11] Srinath L S. Reliability Engineering. 3$^{rd}$ edition, East-West Press Pvt. Ltd., New Delhi, India, 1994.

[12] Shooman M L. "Reliability Computation for Systems with Dependents Failures", *Proceedings of IEEE Annual Symposium on Reliability*, pp. 44–56, 1996.

[13] Sunand Kumar, Dinesh Kumar, Mehta and N P. "Maintenance Management for Ammonia Synthesis System in a Urea Fertilizer Plant", *International Journal of Management and System* (IJOMAS), 15(3), pp. 211–214, 1999.

[14] Sunand Kumar, Tewari P C and Sharma Rajiv. "Simulated Availability of $CO_2$

Cooling System in a Fertilizer Plant", *Industrial Engineering Journal (Indian Institution of Industrial Engineering, Mumbai)*, 36(10), pp. 19–23, 2007.

[15] Tewari P C, Joshi D and Sreenivasa Rao M. "Mathematical Modeling and Behavioural Analysis of a Refining System using Genetic Algorithm", *Proceedings of National Conference on Competitive Manufacturing Technology and Management for Global Marketing*, Chennai, pp. 131–134, 2005.

[16] Tewari P C, Kumar D and Mehta N P. "Decision Support System of Refining System of Sugar Plant", *Journal of Institution of Engineers (India)*, 84, pp. 41–44, 2003.

[17] Tsai Y T, Wang K S and Teng H Y. "Optimizing Preventive Maintenance for Mechanical Components using Genetic Algorithms", *Reliability Engineering and System Safety*, Vol. 74, No. 1, pp. 89–97, 2001.

*Readers are invited to offer their comments on the article. Please fill in the Reader's Forum.*