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Development of Simulation Model for Performance Evaluation of Refining System in a Sugar Plant

KEYWORDS: Simulation model; Probabilistic approach; Availability matrices; Maintenance decisions

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ABSTRACT *This paper deals with development of a simulation model for the performance evaluation of refining system of a sugar plant using Markov Birth-Death process and probabilistic approach. The refining system consists of four subsystems. After drawing transition diagram for refining system, differential equations are developed and then solved recursively using probabilistic approach. Then to predict the steady state availability i.e. measure of performance of refining system, normalizing conditions are used. Thus, availability simulation model has been developed. After that, the availability matrices and plots of failure/repair rates of all subsystems are prepared to decide the availability trends*

1. INTRODUCTION

System availability gives a measure of how well a system performs or meets its design objective. For increasing the productivity, availability and reliability of equipment in operation must be maintained at highest order. To achieve high production goals, the system should run failure free for maximum possible duration. A sugar plant is a complex engineering system comprises of various systems: feeding, crushing, steam generation, refining, crystallization and evaporation. For regular and economical cleaning of juice, it is necessary to maintain each subsystem of refining system. So to achieve high production and good quality, there should be highest system availability. Performance analysis consists of three major activities:

1. Defining the problem,
2. Analyzing data to identify gaps between the desired and actual state, and their causes,
3. Selecting the appropriate solution blend that will address those causes.

2. NOTATIONS

○ : Indicates the system is in full workings state.

⬭ : Indicates the system in reduced capacity.

□ : Indicates the system in failed state.

E_w, F_x, G_y, H_z : Denotes full working states of Filter, Clarifier, Sulphonation unit and Heater.

e, f, g, h : Denotes failed states of Filter, Clarifier Sulphonation unit and Heater.

$P_0(t)$: Probability of the system in working with full capacity at time t.

$P_3(t)$, $P_4(t)$, $P_8(t)$: Probabilities of the system in reduced capacity (working) state.

$P_1(t)$, $P_2(t)$, $P_5(t)$, $P_6(t)$, $P_8(t)$-$P_{15}(t)$: Probabilities of the system in failed state.

Φ_i, i=7-10 : Mean failure rate of E_w, F_x, G_y, H_z respectively.

λ_i, i=7-10 : Mean repair rate of E_w, F_x, G_y, H_z respectively.

d/dt : Represents derivative w.r.t time (t).

3. THEORY

Refining system ensures the complete cleaning of juice for sound functioning of sugar plant. The raw juice available from a crushing system contains fibres, refuse and mud. It is refined by using a number of filters in series to ensure the complete removal of bagasse from the juice. The bagasse free juice is diluted with water to increase its fluidity and is heated by steam in the heated unit. The juice boils in the heater for a definite period to achieve a definite period to achieve a desired pH value and sent to the sulphonation unit. Here sulphur dioxide is passed through the juice to remove the mud. The process is repeated to ensure complete removal of mud from the juice and thus to ensure proper cleaning of the juice.

4. EXPERIMENT

The transition diagram as given in figure 1 of the refining system shows the various possible states. Based on the transition diagram, a simulation model will be developed. The failures and repairs for this purpose have been modeled as a birth and death process. The failure and repair rates are statistically independent and these are obtained with the help of history cards and maintenance sheets of various subsystems of the refining system available with maintenance personnel of the sugar plant. The description of system and assumptions associated with the transition diagram[9] of refining system are as follows:

4.1 SYSTEM DESCRIPTION

The refining system consists of four subsystems, which are as follows:

1. Filter (E_w): This subsystem consists of two filters in series. Failure of any one causes complete failure of the system.
2. Clarifier (F_x): This subsystem consists of three clarifiers in series. Failure of any one causes complete failure of the system.
3. Sulphonation (G_y): This subsystem consists of two sulphonation units in parallel. Failure of one reduces the capacity of the system. The system failure occurs when both the sulphonation units fail.
4. Heater (H_z): This subsystem consists of two heaters in parallel. Failure of one reduces the capacity of the system. System failure occurs when both units fail.

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4.2. ASSUMPTIONS

The assumptions used in developing the probabilistic simulation model are:

1. There is no simultaneous failure. (Khanduja, 2008),
2. A repaired system is as good as new, performance wise, for a specified duration. (Gupta *et al*. 2008),
3. Service includes repair and /or replacement. (Tewari *et al*., 2003),
4. The system may work at reduced capacity. (Kumar *et al*. 2007),
5. Sufficient repair facilities are provided.
6. Standby systems are of the same nature as that of active systems (Tewari and Sharma, 2004),
7. Failure/repair rates are constant over time and statistically independent. (Gupta *et al*., 2000).
8. System time between failure and repair time follows an exponential distribution.

4.3. SIMULATION MODELING

The simulation model for refining system of sugar plant has been developed to predict operational availability of the system. The failure and repair rates of the different subsystems are used as standard input information to the model. The flow of states for the system under consideration has been described in a state transition diagram as shown in figure 1, which is logical representation of all possible state's probabilities encountered during the failure analysis of a sugar plant.

Formulation is carried out using the joint probability functions based on the transition diagram (Gupta *et al*., 2009). The system starts from a particular state at time 't' and reaches another state (failed) or remain in the same state (operative) during the time interval Δt. The transition probability depends upon the preceding state of the system. The state of the system defines the condition at any instant of time and the information is useful in analyzing the current state and in the prediction of the failure state of the system. The mathematical modeling is done using a simple probabilistic consideration and following differential equations are developed using a Markov birth-death process: (Kumar *et al*. 2007).

$P0(t)(d/dt+\Phi7+\Phi8+\Phi9+\Phi10) = P1(t)\lambda7 + P2(t)\lambda8 + P3(t)\lambda9 + P4(t)\lambda10$ ……………….,………………………….1

$P3(t)(d/dt+\Phi7+\Phi8+\Phi9+\Phi10+\lambda9) = P0(t)\Phi9 + P13(t)\lambda7 + P14(t)\lambda8 + P15(t)\lambda9 + P7(t)\lambda10$…………2

$P4(t)(d/dt+\Phi7+\Phi8+\Phi9+\Phi10+\lambda10) = P5(t)\lambda7 + P6(t)\lambda8 + P7(t)\lambda9 + P8(t)\lambda10 + P0(t)\Phi10$…………..3

$P7(t)(d/dt+\Phi7+\Phi8+\Phi9+\Phi10+\lambda9+\lambda10) = P3(t)\Phi10 + P4(t)\Phi9 + P12(t)\lambda10 + P11(t)\lambda9 + P10(t)\lambda8 + P9(t)\lambda7$……………………………………………...4

$P1(t)(d/dt + \lambda7) = P0(t)\Phi7$..………………………….5

$P2(t)(d/dt + \lambda8) = P0(t)\Phi8$……………………….….6

$P5(t)(d/dt + \lambda7) = P4(t)\Phi7$……………………….....7

$P6(t)(d/dt + \lambda8) = P4(t)\Phi8$……………………..…...8

$P8(t)(d/dt + \lambda10) = P4(t)\Phi10$………………………...9

$P9(t)(d/dt + \lambda7) = P7(t)\Phi7$………………………...10

$P10(t)(d/dt+\lambda8) = P7(t)\Phi8$………………………...11

$P11(t)(d/dt+\lambda9) = P7(t)\Phi9$………………………...12

$P12(t)(d/dt + \lambda10) = P7(t)\Phi10$……………………..13

$P13(t)(d/dt + \lambda7) = P3(t)\Phi7$………………………..14

$P14(t)(d/dt+\lambda8) = P3(t)\Phi8$………………………..15

$P15(t)(d/dt + \lambda9) = P3(t)\Phi9$…….............................16

Since any sugar plant is a process industry where raw material is processed through various subsystems continuously till the final product is obtained. Thus putting derivative of all probability equal to zero as attains the long run availability of the system of a sugar plant. Therefore by putting d/dt = 0 at t = ∞ into differential equations, one gets:

$P0(\Phi7+ \Phi8+ \Phi9 + \Phi10) = P1\lambda7 + P2\lambda8 + P3\lambda9 + P4\lambda10$

$P3(\Phi7+\Phi8+\Phi9+\Phi10+ \lambda9) = P0\Phi9 + P13\lambda7 + P14\lambda8 + P15\lambda9 + P7\lambda10$

$P4(\Phi7+\Phi8+\Phi9+\Phi10+\lambda10) = P5\lambda7 + P6\lambda8 + P7\lambda9+ P8\lambda10+ P0\Phi10$

$P7(\Phi7+\Phi8+\Phi9+\Phi10 + \lambda9+\lambda10)=P3\Phi10 + P4\Phi9+ P12\lambda10+ P11\lambda9+ P10\lambda8+ P9\lambda7$

P1 = P0L7

P2 = P4L8

P5 = P4L7

P6 = P4L8

P8 = P4L10

P9 = P7L7

P11 = P7L9

P12 = P7L10

P13 = P3L7

P14 = P3L8

P15 = P3L9

Where,

$Li = \Phi i / \lambda i \quad i = 7, 8, 9, 10$

By solving these equations recursively, we can find the values of all state probabilities in terms of full working state probability i.e. P_0.

P1 = P0L7

P2 = P0L8

P3 = P0M4

P4 = P0M5

P5 = P0M5L7

P6 = P0M5L8

P7 = P0M3

P8 = P0M5L10

P9 = P0M3L7

P10 = P0M3L8

P11 = P0M3L9

P12 = P0M3L10

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P13 = P0M4L7

P14 = P0M4L8

P15 = P0M4L9

Where,

M1 = (λ10Φ10 + λ9λ10)

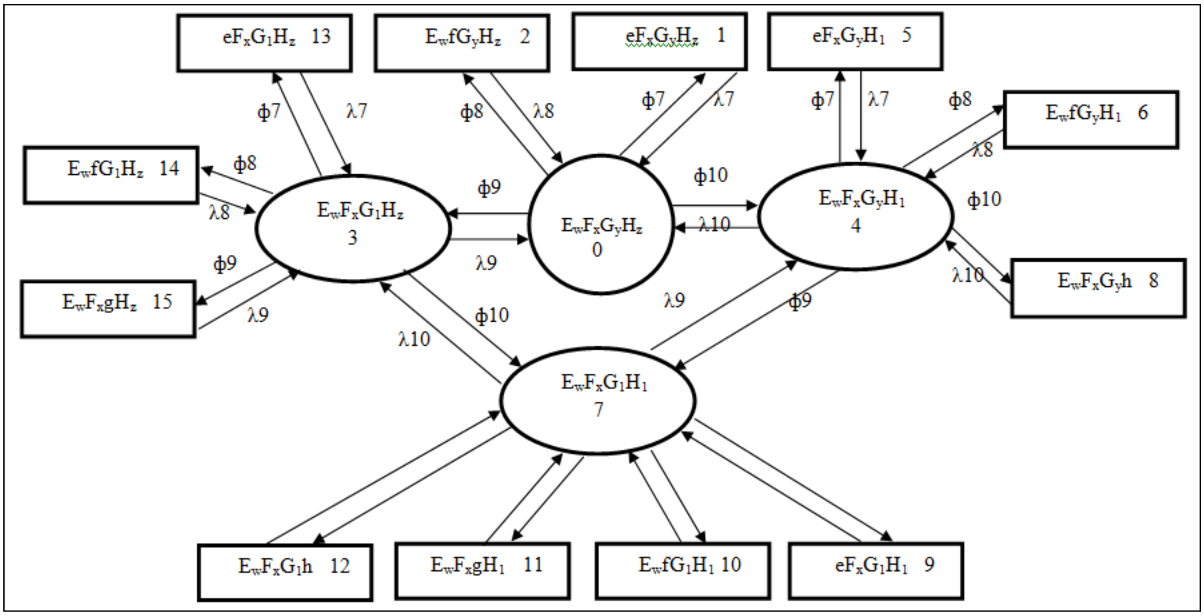
M2 = Φ9Φ10 + Φ10Φ10 + Φ10λ9

M3 = (M2Φ9 + M2λ10 – M1Φ10) / (M1λ9- λ9λ10Φ9 - λ9λ10λ10)

M4 = (Φ9 + M3λ10) / (Φ10 + λ9)

M5 = (Φ9 + Φ10 – M4λ9) / (λ10)

Figure 1 Transition Diagram of Refining System



λ8 ϕ8 λ7 ϕ7

4.4 STEADY STATE AVAILABILITY USING NORMALIZING CONDITION

The probability of full working capacity (without standby systems), namely P0 is determined using normalizing condition: (i.e. sum of the probabilities of all working states, reduced capacity and failed states is equal to 1, Tewari *et al.*, 2003).

$$\sum_{i=0}^{15} Pi = 1$$

Therefore,

P0 + P1+ P2 + P3 + P4 + P5 + P6 + P7 + P8 + P9 + P10 + P11 + P12 + P13 + P14 + P15 = 1

P0 + P0L7+ P0L8 + P0M4 + P0M5 + P0M5L7 + P0M5L8 + P0M3 + P0M5L10 + P0M3L7 + P0M3L8 + P0M3L9 + P0M3L10 + P0M4L7 + P0M4L8 + P0M4L9 = 1

P0 [1 + L7+ L8 + M4 + M5 + M5L7 + M5L8 + M3 + M5L10 + M3L7 + M3L8 + M3L9 + M3L10 + M4L7 + M4L8 + M4L9] = 1

P0 = 1 / N

Where,
N = [1 + L7+ L8 + M4 + M5 + M5L7 + M5L8 + M3 + M5L10 + M3L7 + M3L8 + M3L9 + M3L10 + M4L7 + M4L8 + M4L9]

Now, the steady state availability (AV) of refining system may be obtained as summation of all working and reduced capacity state probabilities.

AV = P0 + P3 + P4 + P7

AV = P0 + P0M4 +P0M5 + P0M3

AV = P0 [1 + M4 + M5 + M3]

AV = [1/N] [1 + M4 + M5 + M3]

Table 1 Availability matrices for 'filter' subsystem of refining system

Taking, Φ8 = 0.001, Φ9 = 0.001, Φ10 = 0.001, λ8 = 0.50, λ9 = 0.05, λ10 = 0.05

AV →

λ7 / Φ7	0.050	0.075	0.100	0.125	0.150
0.01	0.805153	0.850822	0.875657	0.891266	0.901984
0.02	0.693481	0.764137	0.805153	0.831947	0.850822
0.03	0.609013	0.693481	0.745156	0.780031	0.805153
0.04	0.542888	0.634786	0.693481	0.734214	0.764137
0.05	0.489716	0.585252	0.648508	0.693481	0.727096

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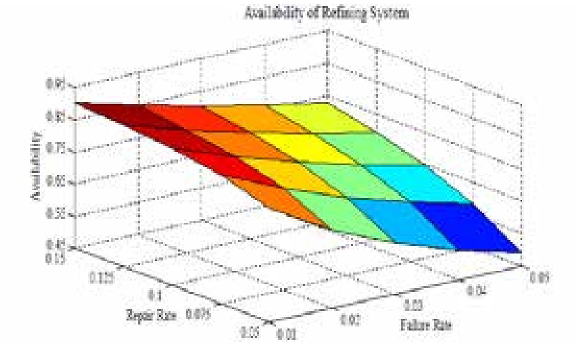

Figure 2 Effect of failure and repair rate of 'filter' subsystem on system availability

Table 2 Availability matrices for 'clarifier' subsystem of refining system

Taking, Φ7 = 0.04, Φ9 = 0.001, Φ10 = 0.001, λ7= 0.125, λ9 = 0.05, λ10 = 0.05

λ8 / Φ8	0.125	0.150	0.175	0.200	0.225
0.001	0.730994	0.731707	0.732218	0.732601	0.732899
0.002	0.726744	0.728155	0.729167	0.729927	0.730519
0.003	0.722543	0.724638	0.726141	0.727273	0.728155
0.004	0.718391	0.721154	0.723140	0.724638	0.725806
0.005	0.714286	0.717703	0.720165	0.722022	0.723473

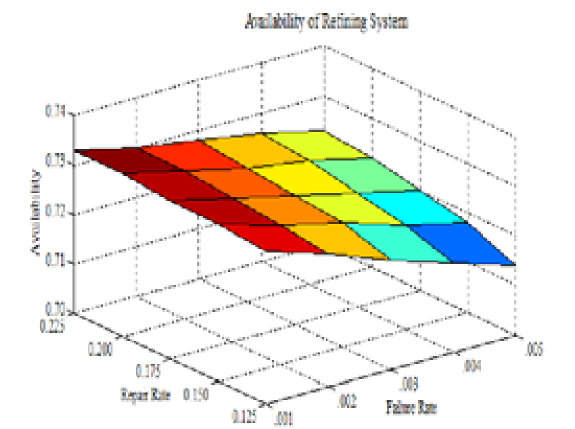

Figure 3 Effect of failure and repair rate of 'clarifier' subsystem on system availability

Table 3 Availability matrices for 'sulphonation' subsystem of refining system

Taking, Φ7 = 0.04, Φ8 = 0.001, Φ10 = 0.001, λ7= 0.125, λ8 = 0.50, λ10 = 0.05

λ9 / Φ9	0.10	0.15	0.20	0.25	0.30
0.005	0.709220	0.717703	0.722022	0.724638	0.726392
0.010	0.684932	0.700935	0.709220	0.714286	0.717703
0.015	0.662252	0.684932	0.696864	0.704225	0.709220
0.020	0.641026	0.669643	0.684932	0.694444	0.700935
0.025	0.621118	0.655022	0.673401	0.684932	0.692841

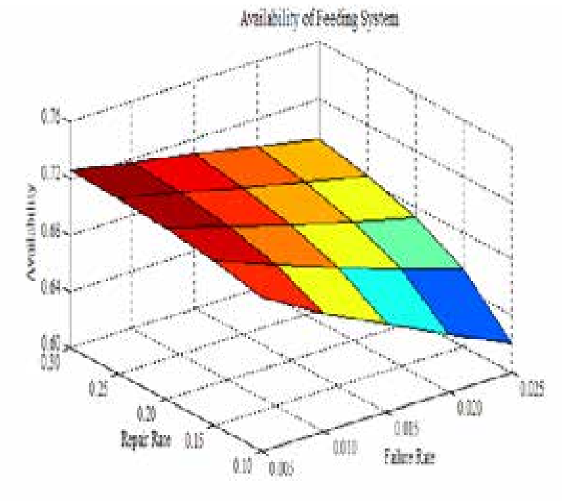

Figure 4 Effect of failure and repair rate of 'sulphonation' subsystem on system availability

Table 4 Availability Matrix for 'Heater' subsystem of Refining System

Taking, Φ7 = 0.04, Φ8 = 0.001, Φ9 = 0.001, λ7= 0.125, λ8 = 0.50, λ9 = 0.05

AV →

λ10 / Φ10	0.20	0.25	0.30	0.35	0.40
0.01	0.728863	0.734214	0.737826	0.740427	0.742390
0.02	0.703235	0.713267	0.720115	0.725088	0.728863
0.03	0.679348	0.693481	0.703235	0.710371	0.715820
0.04	0.657030	0.674764	0.687128	0.696240	0.703235
0.05	0.636132	0.657030	0.671742	0.682660	0.691085

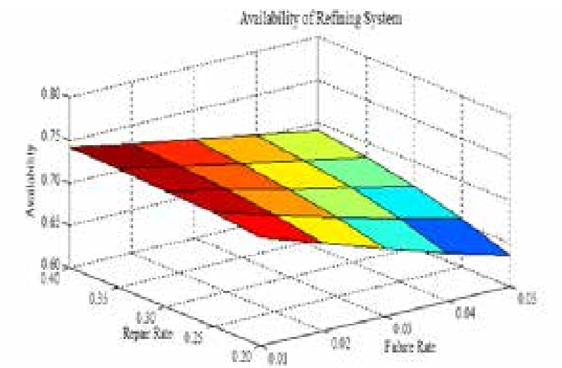

Figure 5 Effect of failure and repair rate of 'heater' subsystem on system availability

5. PERFORMANCE EVALUATION

Performance evaluation forms the foundation for all other performance improvements activities (e.g. solution design and development, implementation and analysis. From maintenance history sheet of refining system of sugar plant and through the discussions with the plant personnel, appropriate failure and repair rates of all four subsystems are taken and availability matrix for different availability values are prepared accordingly by putting these failure and repair rates values in the availability expression for availability (AV). Table 1 depicts the availability levels for various subsystems of the refining system. These availability values are then plotted.

Figures 2, 3, 4 and 5 represents the plots for various subsystems of refining system, depicting the effect of failure/ repair rate of various subsystems on refining system availability. This model includes all possible states of nature, that is, failure events (ϕ) and the identification of all the courses of action, that is, repair priorities (λ). This model is used to implement the maintenance policies for a refining system in a sugar plant. The various availability levels may be computed for different combinations of failure and repair rates / priorities. On the basis of analysis, one may select the best possible combination (ϕ, λ) that is, optimal maintenance strategies, to get the maximum availability.

6. RESULTS AND DISCUSSION

Table 1 and Figure 2 reveal the effect of failure rates (Φ7) and repair rates (λ7) of filter subsystem on the availability of refining system. It is observed that as failure rate of filter (Φ7) increases from 0.01 (once in 100 hrs) to 0.05 (once in 20 hrs), the availability of the system decreases drastically 31%. Similarly, as the repair rate (λ7) increases from 0.050 (once in 20 hrs) to 0.150 (once in 6 hrs), availability of the system increases appreciably by 10%.

Table 2 and Figure 3 shows the effect of failure rates (Φ8) and repair rates (λ8) of clarifier on the availability of refining system. It is observed that as failure rate of clarifier (Φ8) increases from 0.001 (once in 1000 hrs) to 0.005 (once in 200 hrs), the availability of the system negligibly by 2%. Also, as the repair rate (λ8) increases from 0.125 (once in 8 hrs) to 0.225 (once in 4 hrs), availability of the system increases merely by .0019%.

Table 3 and Figure 4 shows the effect of failure rates (Φ9) and repair rates (λ9) of sulphonation plant on the availability of refining system. It is observed that as the failure rate of sulphonation plant (Φ9) increases from 0.005 (once in 200 hrs) to 0.025 (once in 40 hrs), the availability of the system decreases by 8%. Similarly, as the repair rate (λ9) increases from 0.10 (once in 10 hrs) to 0.30 (once in 3 hrs), availability of the system increases considerably by 2%.

Table 4 and Figure 5 shows the effect of failure rates (Φ10) and repair rates (λ10) of heater upon the availability of refining system. As failure rate of heater (Φ10) increases from 0.01 (once in 100 hrs) to 0.05 (once in 20 hrs), availability of the system decreases marginally by 11%. Similarly, as the repair rate (λ10) increases from 0.20 (once in 5 hrs) to 0.40 (once in 2 hrs), availability of the system increases considerably by 2%.

7. CONCLUSION

The performance evaluation of various subsystems of the refining system of a sugar plant can be effectively done with the help of developed simulation model. It provides the various availability levels (AV) for different combinations of failure and repair rates for each and every subsystem.

One may select the best possible combination of failure events and maintenance priorities for each subsystem. The optimum values of failure and repair rates help in determining the optimal maintenance strategies, which will ensure the maximum overall availability of refining system of a sugar plant. The findings of this paper are discussed with concerned sugar plant management. These results are found to be highly beneficial to the plant management for evaluation of performance and analysis of availability of feed water system and hence to decide about maintenance priorities of various subsystems of the system concerned in a sugar plant.

REFERENCE

Gertsbakh, I., (2000), Reliability theory-with applications to preventive maintenance. Berlin Springer.| Barata, J., Guedes, S.C., Marseguerra, M. and, E., (2002), Simulation modeling of repairable multi-component deteriorating systems for on-condition maintenance optimization. Journal of reliability engineering and system safety,76(3), 255-267.|Tewari, P.C., and Kumar, D. and Mehta, N.P (2003), Decision support system for refining system of a sugar plant. Journal of Institution of Engineers (India), 84, 41-44.|Samrout, M., Yalaoui, F., Chatelet, E. and Chebbo, N., (2005), Few methods to minimize the preventive maintenance cost of series-parallel systems using ant colony optimization. Reliability engineering and system safety, 89 (3), 346-354.|Joseph, R., Douglas, S., Douglas, I., (2006), A conceptual integration of performance analysis, knowledge management and technology: from concept to prototype. Journal of knowledge management, 10 (6), 81-99.|Gupta,S., Tewari, P.C. and Sharma, A.K. (2007), Performance modeling and decision support system for feed water system of a thermal power plant. Proceedings of International Conference on advances in manufacturing engineering, Manipal institute of technology, Manipal, India.|Khanduja, R., Tewari, P.C. and Kumar, D., (2008), Availability analysis of bleaching system of a paper plant. Journal of industrial engineering, Udyog Pragati, N.I.T.I.E, Mumbai (India), 32(1), 24-29.|Khanduja, R., Tewari,P.C. and Chauhan, R.S., (2009), Performance analysis of screening unit in a paper using genetic algorithm. Journal of industrial and systems engineering, vol 3, No 2, pp 140-151.|Gupta, S., and Tewari, P.C. (2009), Simulation modeling and analysis of a complex system of a thermal power plant. JIEM, 2009 – 2(2): 387-406 – ISSN: 2013-0953| Khanduja,R., Tewari, P.C., Kumar, D., (2011), Steady state behavior and maintenance planning of bleaching system in a paper plant. Journal of Industrial Engineering International, 7(12), 39-44.| Gupta, S., and Tewari, P.C., and Sharma, A.K., (2011), Development of simulation model for performance evaluation of feed water system in a typical thermal power plant. J. Ind.Eng. Int., 7 (12), 1-9 winter 2011.|Tewari, P.C., Khanduja, R. and Gupta, M. (2012), Performance enhancement for crystallization unit of a sugar plant using genetic algorithm technique. Journal of industrial engineering international 2012, 8:1, doi: 10.1186/2251-712X-8-1.| Khanduja, R., and Tewari, P.C. (2013), Performance modeling and optimization for the stock preparation unit of a paper plant using genetic algorithm", International Journal of Quality & Reliability Management, Vol. 30 Iss: 5, pp.480 – 494.|