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# RELIABILITY ANALYSIS OF FEEDING SYSTEM IN A SUGAR PLANT UNIT

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***Abstract***— The present paper discusses the reliabilty analysis for Feeding System of a Sugar Plant Unit. The Feeding System consists of four subsystems arranged in series and parallel combinations. The subsystems cane unloader units working with parallel unit combinations while remaining three subsystems are prone to failure. The mathematical model of Feeding System has been developed using Markov birth –death Process based upon probabilistic approach. The differential equations have been developed on the basis of probabilistic approach using transition diagram. A transition diagram representing interrelationship among the full working, reduced capacity and failed states has been developed. The effect of failure and repair rates of each subsystem on the system availability has been determined.

**Key words**

Performance Modeling; Probabilistic approach; Markov approach; Transition diagram.

## Introduction

The process industry is becoming increasingly complex, with huge capital investment being made in process automation to enhance the reliability of systems. Invariably, the poor maintenance of such systems and the frequency of maintenance are some of the issue that are gaining importance in the industry. Maintenance is not only performed on the process instruments but also on the equipment from utilities, playing a major role in the smooth running of the process [8]. Due to automation in the process industries, maintenance is considered as an integral part of the production process. It is done by optimal utilization of maintenance resources and by ensuring high performance level. For increasing the productivity, availability and reliability of equipment/subsystems which are in operation, must be maintained at highest order. To achieve high production goals, the units should remain operative (run failure free) for maximum possible duration. However, practically these units are subjected to random failures due to poor design, wrong manufacturing techniques, lack of operative skills, poor maintenance, overload, delay in starting maintenance and human error etc. These causes lead to non-availability of an industrial system resulting into improper utilization of resources (man, machine, material, money and time). So to achieve high production and good quality targets, there should be highest system performance (maximum possible long run system availability) for which maintenance operations should be managed well. For smooth running and high production each system of Sugar Plant should remain in upstate.

In feeding system cane moves from storage through cane unloader to cane carrier. The cane carrier carries the cane to the cutter and leveller. A kicker unit is attached to the cane carrier to remove the excess cane and to maintain the cane specified level. The cane cutter is having a set of mild steel knives which cuts the cane in to small pieces. The leveller is used to increase the cane compactness. It ensures minimum void among the cane pieces and hence maximum juice extraction while crushing.

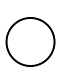
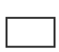
## II DESCRIPTION OF FEEDING SYSTEM

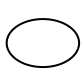
- Three cane unloader units denoted by **A,** connected in parallel, failure of any one unit reduces the capacity of the system. Complete failure occurs only if all the units fail.
- One Cane carrier and kicker unit denoted by **B,** failure of which results in to plant failure.
- One Cane cutter and leveller unit denoted by **C,** failure of which results in to plant failure.
- One Chain conveyor denoted by **D,** failure of which results in to plant failure.

## III. ASSUMPTIONS AND NOTATIONS

- Failure and repair rates are constant and statistically independent.
- A repaired unit is as good as new.
- The stand by units is of the same nature and capacity as the active units.
- The stand by unit is used if any one unit in active system fails.
- System may work at reduced capacity.
- Sufficient repair facilities are provided.

The various notations associated with the transition diagram and for the purpose of mathematical analysis of the system are:

-  indicates the system is in operating condition.
-  indicates the system is in failed condition.

 indicates the system is in reduced capacity state.

- A, B, C, D indicates that respective sub-systems are working at full capacity.
- $A_1$ indicates that one respective subsystem has failed.
- $A_2$ indicates that two respective sub-systems have failed.
- a, b, c, d indicate that respective sub-systems are in failed state.
- $\Phi_1$, $\Phi_2$, $\Phi_3$ and $\Phi_4$ indicate the failure rate of sub-systems A, B, C and D respectively.
- $\lambda_1$, $\lambda_2$, $\lambda_3$ and $\lambda_4$ indicate the repair rate of sub- systems A, B, C and D respectively.
- d/dt indicates derivative w.r.t 't'.
- $P_0(t)$ to $P_{12}(t)$ denotes the corresponding probabilities at time't'.

## IV PERFORMANCE MODELING OF FEEDING SYSTEM

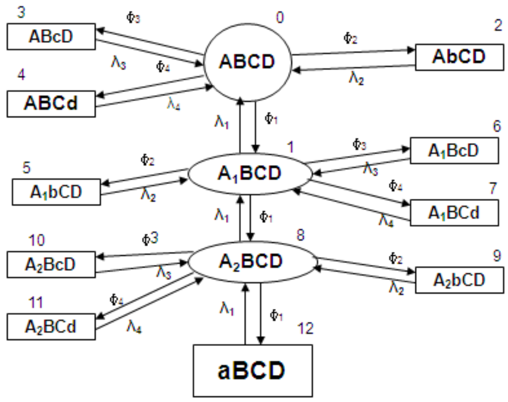



Fig.1. Transition Diagram for Feeding System

Using Markov birth-death process, Simple probabilistic approach gives the different differential equations associated with the feeding system:

$$[d/dt + \sum_{i=1}^{4} \Phi i \,]\, P_0(t) = P_1(t)\,\lambda_1 + P_2(t)\,\lambda_2 + P_3(t)\,\lambda_3 + P_4(t)\,\lambda_4 \qquad (1)$$

$$[d/dt + \sum_{i=1}^{4} \Phi i + \lambda_1]\, P_1(t) = P_8(t)\,\lambda_1 + P_5(t)\,\lambda_2 + P_6(t)\,\lambda_3 + P_7(t)\,\lambda_4 + P_0(t)\O_1 \qquad (2)$$

$$[d/dt + \sum_{i=1}^{4} \Phi i + \lambda_1]\, P_8(t) = P_{12}(t)\,\lambda_1 + P_9(t)\,\lambda_2 + P_{10}(t)\,\lambda_3 + P_{11}(t)\,\lambda_4 + P_1(t)\O_1 \qquad (3)$$

$$[d/dt + \lambda_m]\, P_i(t) = \O_m P_j(t) \qquad (4)$$

By putting d/dt=0 at $t = \infty$

$P_i = P_j\,[\O_m / \lambda_m]$ in equation (5)

Where in equation (5)

When m=1 then i=1, j=0 : i=8,j=1: i=12,j=8

m=2 then i=2,j=0 : i=5,j=1 : i=9,j=8

m=3 then i=3,j=0 : i=6,j=1 : i=10,j=8

m=4 then i=4,j=0 : i=7,j=1 : i=11,j=8

Solving these equations recursively, we get:

$P_1 = P_0{*}\Phi_1/\lambda_1,\ P_2 = P_0{*}\Phi_2/\lambda_2,\ P_3 = P_0{*}\Phi_3/\lambda_3,\ P_4 = P_0{*}\Phi_4/\lambda_4$

$P_5 = P_0{*}\Phi_1/\lambda_1{*}\ \Phi_2/\lambda_2,\ P_6 = P_0{*}\Phi_1/\lambda_1{*}\ \Phi_3/\lambda_3,\ P_7 = P_0{*}\Phi_1/\lambda_1{*}\ \Phi_4/\lambda_4,\ P_8 = P_0\ {*}\Phi_1{}^2/\ \lambda_1{}^2$ , $P_9 = P_0\ {*}\Phi_1{}^2/\ \lambda_1{}^2 {*}\ \Phi_2/\lambda_2$ , $P_{10} = P_0\ {*}\Phi_1{}^2/\ \lambda_1{}^2 {*}\ \Phi_3/\lambda_3,\ P_{11} = P_0\ {*}\Phi_1{}^2/\ \lambda_1{}^2 {*}\ \Phi_4/\lambda_4$ , $P_{12} = P_0\ {*}\Phi_1{}^3/\ \lambda_1{}^3$

Using normalizing condition i.e. sum of all the state probabilities is equal to one i.e.

$\sum_{i=0}^{4} Pi = 1$, we get:

$P_0 = 1/\ [\Phi_1/\lambda_1 + \Phi_2/\lambda_2 + \Phi_3/\lambda_3 + \Phi_4/\lambda_4]\ [1 + \Phi_1/\lambda_1 + \Phi_1^2/\lambda_1^2]$

The steady state availability ($A_0$) of this feeding system is given by summation of all the full working and reduced capacity states i.e.

$A_0 = P_0 + P_1 + P_8$

$$A_0 = 1/ [\Phi_1/\lambda_1+\Phi_2/\lambda_2+\Phi_3/\lambda_3+\Phi_4/\lambda_4] \quad (6)$$

## IV BEHAVIOR ANALYSIS

From maintenance history sheet of feeding system of Sugar Plant and through the discussions with the plant personnel, appropriate failure and repair rates of all the subsystems are taken and availability matrices are prepared by putting these failure and repair rates values in expression for availability. Table 1 to 4 represents the availability matrices for various subsystems of the feeding system. These matrices simply reveal the various performance levels for different combinations of failure and repair rates.

## V RESULT AND DISCUSSION

Table 1 and figures 2, 3 shows the effect of failure/repair rates of cane unloader subsystem on the availability of feeding system. It is observed that for some known value of failure/repair rates of cane carrier and kicker unit, cane cutter and leveller unit and chain conveyor unit ($\Phi_2$=0.016, $\Phi_3$=0.055, $\Phi_4$=0.0275, $\lambda_2$=0.13, $\lambda_3$=0.19, $\lambda_4$=0.06), as failure rates of cane unloader increases from 0.008 (once in 125 hrs) to 0.025 (once in 40 hrs) the unit availability decreases by 26%. Similarly as repair rates of cane unloader increases from 0.04 (once in 25 hrs) to 0.056 (once in 17 hrs) the unit availability increases by about 5%.

Table 1 Decision matrix of Cane unloader Subsystem

| $\lambda_1$ / $\Phi_1$ | 0.04 | 0.044 | 0.048 | 0.052 | 0.066 | Constant Values |
|---|---|---|---|---|---|---|
| 0.008 | 0.934 | 0.950 | 0.964 | 0.976 | 0.995 | $\Phi_2$ = 0.016 |
| 0.012 | 0.854 | 0.875 | 0.892 | 0.908 | 0.922 | $\lambda_2$= 0.13 |
| 0.016 | 0.787 | 0.810 | 0.831 | 0.849 | 0.865 | $\Phi_3$= 0.055 |
| 0.020 | 0.729 | 0.754 | 0.777 | 0.797 | 0.814 | $\lambda_3$= 0.19 |
| 0.025 | 0.668 | 0.695 | 0.718 | 0.740 | 0.759 | $\Phi_4$= 0.0275<br>$\lambda_4$= 0.06 |

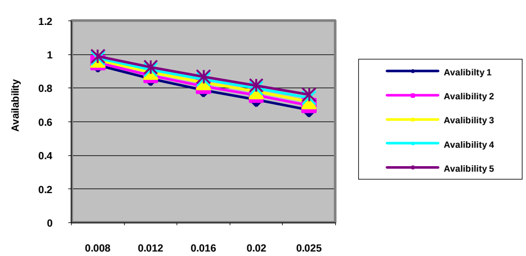



Fig 2: Effect of failure rate of cane unloader

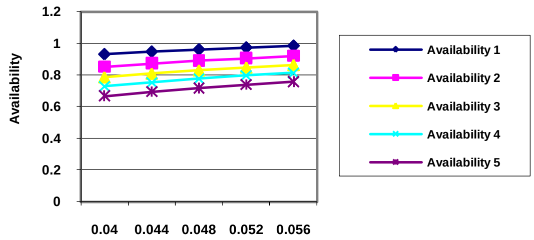



Fig 3: Effect of repair rate of cane unloader

Table 2 and figures 4 & 5 show the effect of failure/repair rates of cane carrier and kicker subsystem on the availability of feeding system. It is observed that for some known value failure/repair rates of cane unloader, cane cutter and leveller unit and chain conveyor ($\Phi_1$=0.016, $\Phi_3$=0.055, $\Phi_4$=0.0275, $\lambda_1$=0.048, $\lambda_3$=0.19, $\lambda_4$=0.06), as failure rate of cane carrier and kicker unit increases from 0.007 (once in 140 hrs) to 0.025 (once in 40hrs) the unit availability decreases by 16%. Similarly as repair rate of cane carrier and kicker unit increases from 0.06 (once in 25 hrs) to 0.20 (once in 5 hrs) the unit availability increases by about 6%.

Table 2: Decision matrix of Cane carrier and kicker subsystem

| $\lambda_2$ \ $\Phi_2$ | 0.06 | 0.095 | 0.13 | 0.165 | 0.2 | Constant Values |
|---|---|---|---|---|---|---|
| 0.007 | 0.835 | 0.866 | 0.881 | 0.890 | 0.896 | $\Phi_1$= 0.016<br>$\lambda_1$= 0.048<br>$\Phi_3$= 0.055<br>$\lambda_3$= 0.19<br>$\Phi_4$= 0.0275<br>$\lambda_4$= 0.06 |
| 0.0115 | 0.786 | 0.832 | 0.855 | 0.869 | 0.879 | |
| 0.016 | 0.742 | 0.801 | 0.831 | 0.849 | 0.862 | |
| 0.020 | 0.707 | 0.774 | 0.810 | 0.832 | 0.847 | |
| 0.025 | 0.668 | 0.744 | 0.785 | 0.812 | 0.829 | |

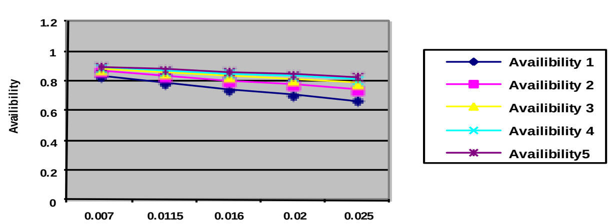



Fig 4: Effect of failure rate of Cane Carrier

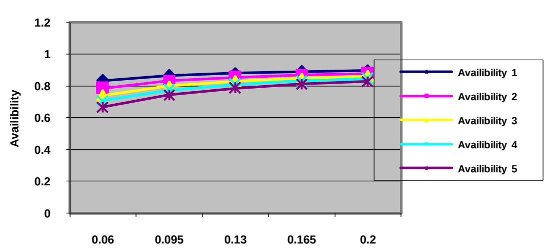



Fig 5: Effect of repair rate Cane Carrier

Table 3 and figure 6 & 7 show the effect of failure/repair rates of cane cutter and leveller subsystem on the availability of feeding system unit .It is observed that for some known values of failure/repair rates of cane unloader, cane carrier and kicker unit and chain conveyor ($\Phi_1$=0.016, $\Phi_2$=0.016, $\Phi_4$=0.0275, $\lambda_1$=0.048, $\lambda_2$=0.13, $\lambda_4$=0.06), as failure rate of cane cutter and leveller unit increases from 0.025(once in 40 hrs) to 0.1 (once in 10hrs) the unit availability decreases by 30%. Similarly as repair rate of cane cutter and leveller unit increases from 0.14 (once in 7 hrs) to 0.25 (once in 4 hrs) the unit availability increases by about 7%

Table 3: Decision matrix of Cane cutter and leveller Subsystem

| $\lambda_3$ / $\Phi_3$ | 0.14 | 0.165 | 0.19 | 0.22 | 0.25 | Constant Values |
|---|---|---|---|---|---|---|
| 0.025 | 0.915 | 0.938 | 0.956 | 0.973 | 0.986 | $\Phi_1$= 0.016 |
| 0.040 | 0.833 | 0.864 | 0.889 | 0.912 | 0.931 | $\lambda_1$= 0.048 |
| 0.055 | 0.765 | 0.801 | 0.830 | 0.859 | 0.881 | $\Phi_2$= 0.016 |
| 0.077 | 0.683 | 0.724 | 0.757 | 0.791 | 0.818 | $\lambda_2$= 0.13 |
| 0.1 | 0.614 | 0.657 | 0.694 | 0.730 | 0.761 | $\Phi_4$= 0.0275<br>$\lambda_4$= 0.06 |

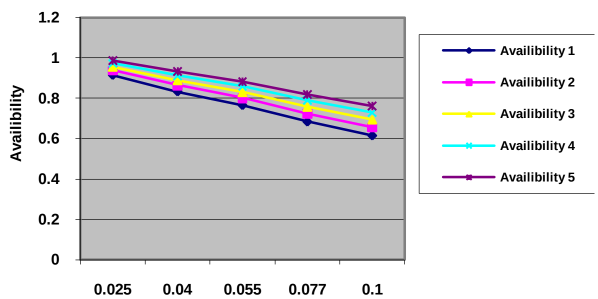



Fig 6: Effect of failure rate of cane cutter

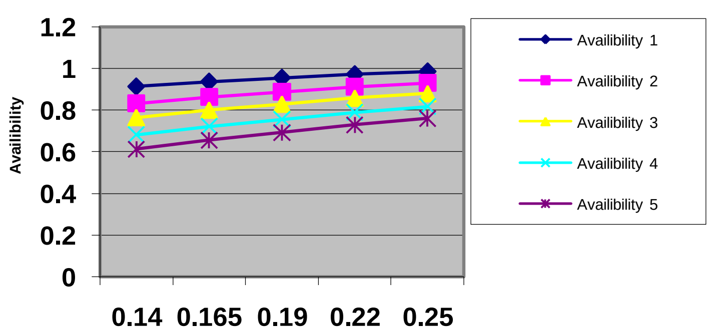



Fig 7: Effect of repair rate Cane Cutter

Table 4 and figure 8 & 9 show the effect of failure/repair rates of chain conveyor subsystem on the availability of feeding system. It is observed that for some known values of failure/repair rates of cane unloader, cane carrier and kicker unit, cane cutter and leveller unit ($\Phi_2$=0.016, $\Phi_3$=0.055, $\Phi_1$=0.016, $\lambda_2$=0.13, $\lambda_3$=0.19, $\lambda_1$=0.048), as failure rate of chain conveyor increases from 0.022 (once in 45 hrs) to 0.033 (once in 30 hrs) the unit availability decreases by 13%. Similarly as repair rate of cane unloader increases from 0.04 (once in 25 hrs) to 0.08 (once in 12 hrs) the unit availability increases by 20%.

Table 4: Decision matrix of Chain conveyor Subsystem

| $\lambda_4$ / $\Phi_4$ | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | Constant values |
|---|---|---|---|---|---|---|
| 0.022 | 0.772 | 0.843 | 0.899 | 0.944 | 0.980 | $\Phi_1$= 0.016 |
| 0.024 | 0.743 | 0.816 | 0.873 | 0.919 | 0.956 | $\lambda_1$= 0.048 |
| 0.0275 | 0.698 | 0.774 | 0.831 | 0.878 | 0.918 | $\Phi_2$= 0.016 |
| 0.030 | 0.668 | 0.743 | 0.803 | 0.852 | 0.892 | $\lambda_2$= 0.13 |
| 0.033 | 0.636 | 0.711 | 0.772 | 0.822 | 0.863 | $\Phi_3$= 0.055, $\lambda_3$= 0.19 |

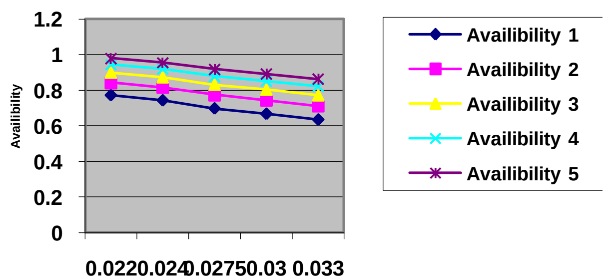



Fig 8: Effect of failure rate of Chain Conveyor

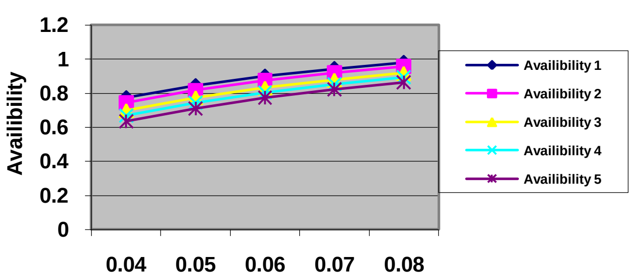



Fig 9: Effect of repair rate of Chain Conveyor

## VII. CONCLUSION

The performance modeling and behavior analysis of Feeding System has been done with the help of mathematical modeling using probabilistic approach. The availability matrices are also developed. These matrices facilitate the maintenance decisions to be made at critical points where repair priority should be given to some particular subsystem of Feeding System. Availability matrix as given in table 3 and plot in figures 6 & 7 clearly indicate that the Cane cutter and leveller unit is most critical subsystem as for as maintenance is concerned. So, Cane cutter and leveller subsystem should be given top priority as the effect of its failure / repair rates on the unit availability is much higher than that of cane unloader, cane carrier and kicker and chain conveyor subsystems. On the basis of repair rates, the relative repair priorities from maintenance point of view should be given as below:

1 First priority should be given to cane cutter and leveller unit.
2 Second priority should be given to cane unloader.
3 Third priority should be given to chain conveyor.
4 Forth priority should be given to cane carrier and kicker unit.

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