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Availability Analysis for Ethanol Manufacturing Unit in Distillery Plant Using Petri Nets

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***Abstract*- In the present study availability as performance measure is analyzed for the distillery plant. Petri Nets (PN) module in licensed GRIF software is used for modeling the ethanol manufacturing unit pertaining to the real environment of the industry among all components/subsystems. The model has been shaped considering the exponential distribution of failure as well as repair rate. The ethanol manufacturing system consists of seven components/subsystems namely Overhead Pump, Fermentation tank, Bear Heater, Heat exchanger, Degasser, Rectifier and Cooler pump. The effect of the variables like failure and repair rates (FRR), also repair facilities on the behaviour of the system is examined. An effort has been done to identify the most critical component of system. Here, Overhead Pumps comes out to be the most critical component which affects the system availability as compared with other components. Also effect of number of repair facilities is studied and minimum number of repair men required is obtained. The outcomes of the analysis will help the practitioners in deciding effective maintenance strategies.**

Keywords - Availability, Markov method, Petri nets, Performance modelling.

INTRODUCTION

To withstand with current world's business situation, the industry has to follow the routes of rapid advancements in technology. Huge automated systems have become the vital requirement for business survival. The failure of such huge systems is inevitable but can be minimized by making the systems more available. Therefore, Availability of these systems, have become the foremost significant feature in process industries. In view of this, several researchers have implemented the Reliability, Availability, and Maintainability (RAM) methods to meet the above requirements and improve revenues. Among these methods, Markov method is well-known modeling and analysis tool which is used by most of the authors as seen from literature. But there occurs state explosion when system consists of large number of subsystem. This limitation of the Markov Method (MM) can easily be addressed Petri Net technique.

LITERATURE SURVEY

It has been seen from the literature survey that Markov Method has been largely used by the scientists and researchers for the performance analysis of the process industries. Markov analysis is being used for estimating the system availability was discussed. Okafor et al.[2016], Kumar and Tewari [2017], Gupta and Tewari [2009], Kumar[2018], N. Tomsaz et al.[2018], and Gupta et al. [2020] applied Markov method to make system transition diagram and assess its performance. Azaron et al. [2009] have been developed the reliability evaluation and optimization method for non-repairable different subsystems which were cold standby. Arabi et al. [2012] suggested an availability model for performance optimization SA technique. Bose et al. [2012] on the basis of the Preventive Maintenance (PM) schedule of a power plant examined the RAM. The finding of the paper was that economizer was the most critical subsystem. Khanduja et al [2012] applies MM for estimation and optimization for performance of stock preparation unit of paper plant using genetic algorithm. Sachdeva et al. [2008, 2013] estimates the performance of paper industry by using PN. Modgil et al. [2013] developed a performance model for shoe upper manufacturing system using MA of a Shoe Manufacturing industry. Kumar P. et al. [2017] done the performance analysis of Carbonated soft drink glass bottle filling system of brewery plant using Markov method and further optimization is done with PSO. Ahmadi et al. [2019] performed the reliability evaluation of materials hauling system of the earth pressurized balance tunnel boring machine using the failure and repair data followed by the statistical techniques used for performance modeling. In the present study, comprehensive study of realistic situations in industrial system of a distillery unit is conducted. Petri Nets (PN) approach is used to model and estimate the availability.

SYSTEM DESCRIPTION

Molasses (byproduct of Sugar Plant) is used as raw material for the distillery unit. The molasses has massive amount of sugar, which on fermentation through bacteria fragmented into ethanol & CO_2 gas. The ethanol manufacturing process contains seven sub-systems situated in mixed configuration. The flow chart of ethanol making unit is exhibit in Figure 1.

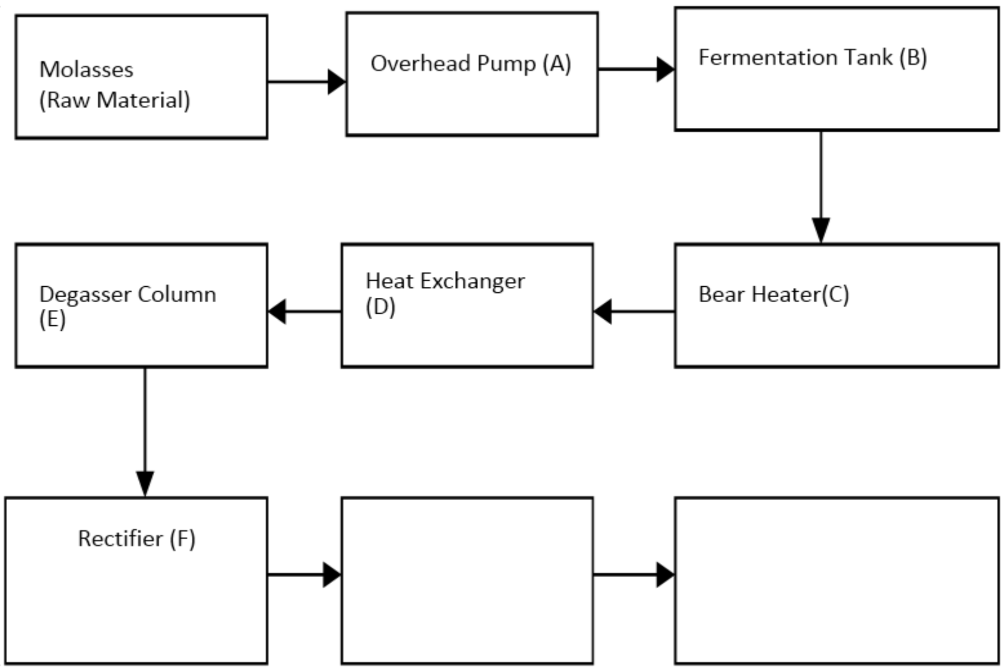

FIGURE 1
FLOWCHART OF ETHANOL MANUFACTURING UNIT

The molasses is first being fed to the overhead pump, whose function is to pump it to the fermentation tank through a dilutor which adds suitable amount of water in it. After fermentation process the molasses is fed to the bear heater with the help of fermentation pumps, which are two in numbers. The function of bear heater is to supply heat to the fermented mix using the rectified vapours. Further it is fed to degasser column through heat exchanger whose function is to remove remaining volatiles from the preheated wash. Finally, the treated mix is pumped by the coolers to excerpt the ethanol. For each of the above discussed subsystems. The complete system failure takes place when units come to breakdown. The productivity of plant is decreased upon failure of single unit if the subsystems have more than one.

PETRI NET MODELING OF THE SYSTEM

This Performance modeling of the system is performed using Petri Nets based modeling method. The Petri Net model for the ethanol making unit is shown in figure 2. In this model the black dots (Tokens) are used to indicate the state and system availability and repair facility respectively. The quantity of tokens at a place represents the number of sub-systems and number of repair facilities. The various places with token represent the current state of the system and availability of repair facility whereas various transitions are responsible for the token repositioning from one place to other. The direction of arc represents the direction of movement. The timed transition and immediate transition are used in the current model. The timed transitions are associated with the variables failure and repair rates and follow exponential distribution whereas immediate transitions have their own guard function. The places and transitions for various stations have the following meaning:

Places

- $PSup$ represents the system is in working state.
- $PSfull$ represents the system is in full operating state.
- $PSred$ represents the system is in reduced state.

- *PSdn* represents the system is in breakdown.
- *PAup,PBup,PCup,PDup,PEup,PFup* and *PGup* represent the working states of sub-systems.

i.e. overhead pump (A), fermentation pump (B), bear heater (C), heat exchanger (D), analyzer (E), rectifier (F), and the cooler pump (G) respectively.

- *PAdn, PBdn, PCdn, PDdn, PEdn, PFdn* and *PGdn* represent the failed states of sub-systems i.e.overhead pump (A), fermentation pump (B), bear heater (C), heat exchanger (D), analyzer (E), rectifier (F), and the cooler pump (G)respectively.
- *PArep, PBrep, PCrep, PDrep, PErep, PFrep* and *PGrep* represent the sub-systems i.e. overhead pump (A), fermentation pump (B), bear heater (C), heat exchanger (D), analyzer (E), rectifier (F), and the cooler pump (G) respectively, are under repair.
- *Prep* represents the repair facility.

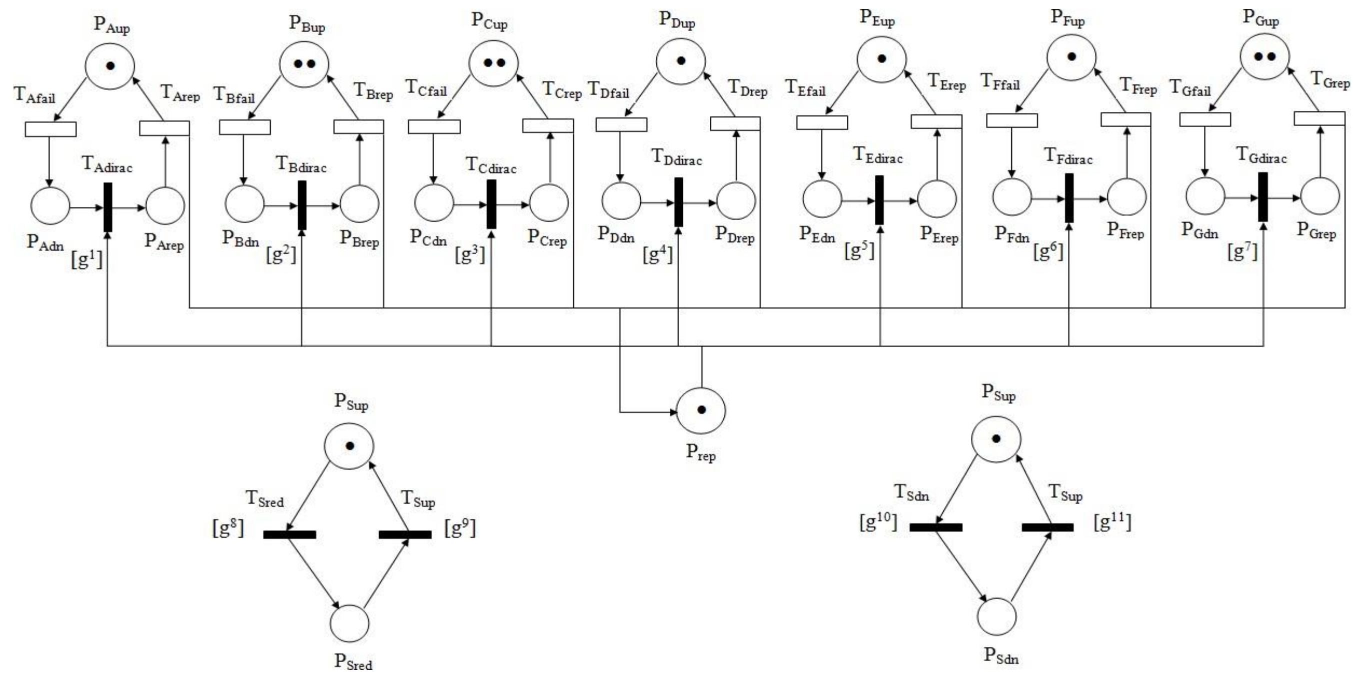

FIGURE 2
PETRI NETS MODEL OF ETHANOL MANUFACTURING SYSTEM

Transitions

- *TAfail, TBfail, TCfail, TDfail, TEfail, TFfail* and *TGfail* are the timed transitions associated with the failure rates ($\lambda1$=0.0045, $\lambda2$=0.0039, $\lambda3$=0.0069, $\lambda4$=0.0034, $\lambda5$=0.0074, $\lambda6$=0.0071 and $\lambda7$=0.0034) of overhead pump (*A*), fermentation pump (B), bear heater (C), heat exchanger (D), analyzer (E), rectifier (F), and the cooler pump (G)respectively.
- *TArep, TBrep, TCrep, TDrep, TErep, TFrep* and *TGrep* are the timed transitions associated with the repair rates ($\mu1$=0.21, $\mu2$=0.27, $\mu3$=0.57, $\mu4$= 0.39, $\mu5$=0.79, $\mu6$=0.68 and $\mu7$=0.33) of overhead pump (*A*), fermentation pump (B), bear heater (C), heat exchanger (D), analyzer (E), rectifier (F), and the cooler pump (G)respectively.
- *TAdirec, TBdirec, TCdirec, TDdirec, TEdirec, TFdirec* and *TGdirec* are the immediate transitions activated without delay if its guard function is satisfied and move the token from *PAdn, PBdn, PCdn, PDdn, PEdn, PFdn*and *PGdn*to *PArep, PBrep, PCrep, PDrep, PErep, PFrep* and *PGrep* respectively.
- *TSred, TSfull, TSdn,* and *TSup* are also the immediate transitions activated without delay if its guard function is satisfied and move the token from *PSfull, PSred, PSup* and *PSdn*to *PSred, PSfull, PSdn* and *PSup* respectively.

Guard Functions

The guard functions of various immediate transitions associated with the Petri Nets model of the ethanol manufacturing system are as follows:

- [g1]= # $PAdn$>0and# $Prep$ >0 activates the transition $TAdirec$ for the repair of sub-system

(A) and moves the token from $PAdn$ to $PArep$.

- [g2]= # $PBdn$>0and# $Prep$ >0 activates the transition $TBdirec$ for the repair of sub-system

(B) andmoves the token from $PBdn$ to $PBrep$.

- [g3]= # $PCdn$>0and# $Prep$ >0 activates the transition $TCdirec$ for the repair of sub-system

(C) And moves the token from $PCdn$ to $PCrep$.

- [g4]= # $PDdn$>0and# $Prep$ >0 activates the transition $TDdirec$ for the repair of sub-system

(D) and moves the token from $PDdn$ to $PDrep$.

- [g5] = # $PEdn$>0and# $Prep$ >0 activates the transition $TEdirec$ for the repair of sub-system

(E) and moves the token from $PEdn$ to $PErep$.

- [g6] = # $PFdn$>0and# $Prep$ >0 activates the transition $TFdirec$ for the repair of sub-system

(F) and moves the token from $PFdn$ to $PFrep$.

- [g7] = # $PGdn$>0and# $Prep$ >0 activates the transition $TGdirec$ for the repair of sub- system (G) and moves the token from $PGdn$ to $PGrep$.
- [g8]= (#$PBdn$>0or# $PBrep$>0)or(#$PCdn$>0or# $PCrep$>0)or(#$PGdn$>0or# $PGrep$>0) activates the transition $TSred$ and moves the token from $PSfull$ to $PSred$.
- [g9]=(#$PAup$>0and#$PBup$>1and#$PCup$>1and# $PDup$>0and#$PEup$>0and# $PFup$>0and#

$PGup$>1) activates the transition $TSfull$ and moves the token from $PSred$ to $PSfull$.

- [g10]=((#$PAdn$>0or#$PArep$>0)or(#$PBdn$>0and#$PBrep$>0)or(#$PBdn$>1or#$PBrep$>1)or(#$PCdn$>0and# $PCrep$>0)or(#$PCdn$>0or# $PCrep$>0)or(#$PDdn$>1or# $PDrep$>1)or(#$PEdn$>0or#$PErep$

>0)or(#$PFdn$>0or#$PFrep$>0)or(#$PGdn$>0and#$PGrep$>0)or(#$PGdn$>1or# $PGrep$>1)) activates the transition $TSdn$and moves the token from $PSup$ to $PSdn$.

- [g11]=(#$PAup$>0and#$PBup$>0and #$PCup$>0and#$PDup$>0and#$PEup$>0and# $PFup$

>0and# $PGup$>0) activates the transition $TSup$ and reposition the token from PS_{dn} to $PSup$.

RESULTS AND DISCUSSION

In the present study, Petri Nets model is modeled in the Petri Module of GRIF2018.15-x32 Simulation Package with the use of above places, transitions and guard functions. This module uses the MOCA-Computation engine based on the Monte-Carlo simulation. In this analysis, the Moca-computation time is taken as 10000 hours at the confidence range of 90%.

The required data for various variable is gathered from the industry. This data is further transformed into the parametric form as λ_1=0.0045, μ_1=0.21, λ_2=0.0039, μ_2=0.27, λ_3=0.0069, μ_3=0.57, λ_4=0.0034, μ_4= 0.39, λ_5=0.0074, μ_5=0.79, λ_6=0.0071, μ_6=0.68, λ_7=0.0034, μ_7=0.33 for the components A, B, C, D, E, F and G correspondingly. The system availability is found to be 94.88% substituting the above value of variables in the timed transitions of each sub-system. Further, the system behavior pattern is studied by varying the various parameters of different sub-systems one by one within a constrained range, considering the other sub-systems parameters constant. The outcomes are presented in tables 1 to 8. Also the effect on availability of concerned system is studied with respect to increases in repair facility i.e. number of repair persons shown in figure 3.

Table. 1 demonstrates that the availability is diminished by 2.64% with the raising of failure rate from 0.0045 to 0.0105. Similarly, the availability is improved by 1.78% with the raising of repair rate from 0.21 to 0.81 and availability can be attained maximum to 96.66%. Other sub-systems parameters are kept constant.

TABLE 1
THE SYSTEM BEHAVIOUR PATTERN AGAINST THE VARIATION IN THE PARAMETERS OF OVERHEAD PUMP (A)

λ_1 \ μ_1	0.21	0.41	0.61	0.81
0.0045	0.9488	0.9515	0.9648	0.9666
0.0065	0.9380	0.9470	0.9516	0.9640

0.0085	0.9377	0.9425	0.9510	0.9618
0.0105	0.9264	0.9421	0.9505	0.9590

Table 2 expresses that, the availability is decreased marginally by 0.08% with the rising of failure rate from 0.0039 to 0.0099 of component B. Likewise, it is improved by 0.02% with the changing of repair rate from 0.27 to 0.87 and availability can be attained as 94.90%.

TABLE 2
THE SYSTEM BEHAVIOR PATTERN AGAINST THE VARIATION IN THE PARAMETERS OF FERMENTATION PUMP (B)

λ_2 \ μ_2	0.27	0.47	0.67	0.87
0.0039	0.9488	0.9488	0.9489	0.9490
0.0059	0.9486	0.9487	0.9488	0.9490
0.0079	0.9482	0.9486	0.9487	0.9490
0.0099	0.9480	0.9482	0.9486	0.9489

Table 3 depicts that the availability is reduced by 0.07% with the raising of failure rate from 0.0069 to 0.0129. Similarly, the availability gets better by 0.5% with the raising of repair rate from 0.57 to 1.17 and maximum availability can be attained as 95.38%.

TABLE 3
THE SYSTEM BEHAVIOR PATTERN AGAINST THE VARIATION IN THE PARAMETERS OF HEATER (C)

λ_3 \ μ_3	0.57	0.77	0.97	1.17
0.0069	0.9488	0.9495	0.9521	0.9538
0.0089	0.9487	0.9490	0.9520	0.9530
0.0109	0.9485	0.9493	0.9518	0.9528
0.0129	0.9481	0.9482	0.9520	0.9527

Table 4 indicates that the availability is decreased by 1.62% with the raising of failure rate from 0.0034 to 0.0094. Similarly, the availability is improved by 0.74% with the raising of repair rate from 0.39 to 0.99 and maximum availability can be achieved as 95.62%.

TABLE 4
THE SYSTEM BEHAVIOUR PATTERN AGAINST THE VARIATION IN THE PARAMETERS OF HEAT EXCHANGER (D)

λ_4 \ μ_4	0.39	0.59	0.79	0.99
0.0034	0.9488	0.9521	0.9539	0.9562
0.0054	0.9473	0.9510	0.9530	0.9548
0.0074	0.9359	0.9480	0.9506	0.9535
0.0094	0.9326	0.9350	0.9495	0.9520

Table 5 implies that the availability is cut by 1.52% with the raising of failure rate from 0.0074 to 0.0164. Likewise, the availability is increased by 0.38% with the raising of repair rate from 0.79 to 1.69 and supreme availability achieved is 95.26%.

TABLE 5
THE SYSTEM BEHAVIOR PATTERN AGAINST THE VARIATION IN THE PARAMETERS OF ANALYZER (E)

λ_5 \ μ_5	0.79	1.09	1.39	1.69
0.0074	0.9488	0.9502	0.9522	0.9526
0.0104	0.9456	0.9510	0.9518	0.9516
0.0134	0.9406	0.9454	0.9495	0.9512
0.0164	0.9336	0.9342	0.9491	0.9505

Table 6 describes that the availability is decreased by 1.4% with the raising of failure rate from 0.0071 to 0.0161. Similarly, the availability gets better by 0.76% with the raising of repair rate from 0.68 to 1.58 and availability can be attained as 95.64%.

TABLE 6: THE SYSTEM BEHAVIOR PATTERN AGAINST THE VARIATION IN THE PARAMETERS OF RECTIFIER (F)

λ_6 \ μ_6	0.68	0.98	1.28	1.58
0.0071	0.9488	0.9546	0.9556	0.9564
0.0101	0.9438	0.9516	0.9552	0.9554
0.0131	0.9388	0.9488	0.9513	0.9536
0.0161	0.9348	0.9466	0.9477	0.9523

Table 7 reveals that the performance is decreased by 0.82% with the raising of failure rate from 0.0034 to 0.0094. Also, 0.01% increase in availability with the raising of repair rate from 0.33 to 0.93 and highest availability can be attained as 94.89%.

TABLE 7

THE SYSTEM BEHAVIOR PATTERN AGAINST THE VARIATION IN THE PARAMETERS OF COOLER PUMP (G)

λ_7 \ μ_7	0.33	0.53	0.73	0.93
0.0034	0.9488	0.9488	0.9488	0.9489
0.0054	0.9456	0.9457	0.9467	0.9480
0.0074	0.9416	0.9456	0.9466	0.9479
0.0094	0.9406	0.9455	0.9456	0.9476

It is observed in the behavior pattern of ethanol manufacturing system that the percentage decrease and increase in steady-state availability of ethanol making unit is highly affected by sub-system (A) and least influenced by sub-system (C & G) when compared with other sub-systems as shown in Table .8.

TABLE 8

BEHAVIORAL STUDY FINDINGS THROUGH PETRI NETS MODEL

SYSTEM	REPAIR RATES	PERFORMANCE IMPROVEMENT	**Suggested Repair Priorities**
A	0.21– 0.81	0.9488-0.9666 **(1.78%)**	**I**
B	0.27– 0.87	0.9488-0.9490 (0.02%)	VII
C	0.57– 1.17	0.9488-0.9538 (0.5%)	V
D	0.39– 0.99	0.9488-0.9562 (0.74%)	III
E	0.79– 1.69	0.9488-0.9526 (0.38%)	IV
F	0.68– 1.58	0.9488-0.9564 (0.76%)	II
G	0.33– 0.93	0.9488-0.9489 (0.01%)	VI

In Petri Nets simulation model the system availability can be analyzed against the number of repair facilities. Figure 3 illustrates the repair facilities effect on the system availability. The system availability is increased by 0.34% when the repair facilities increased from one repairman to two but it got stabilized with further increment. So, it can be suggested to the maintenance personnel to use two repair facilities instead of one with acceptable maintenance cost.

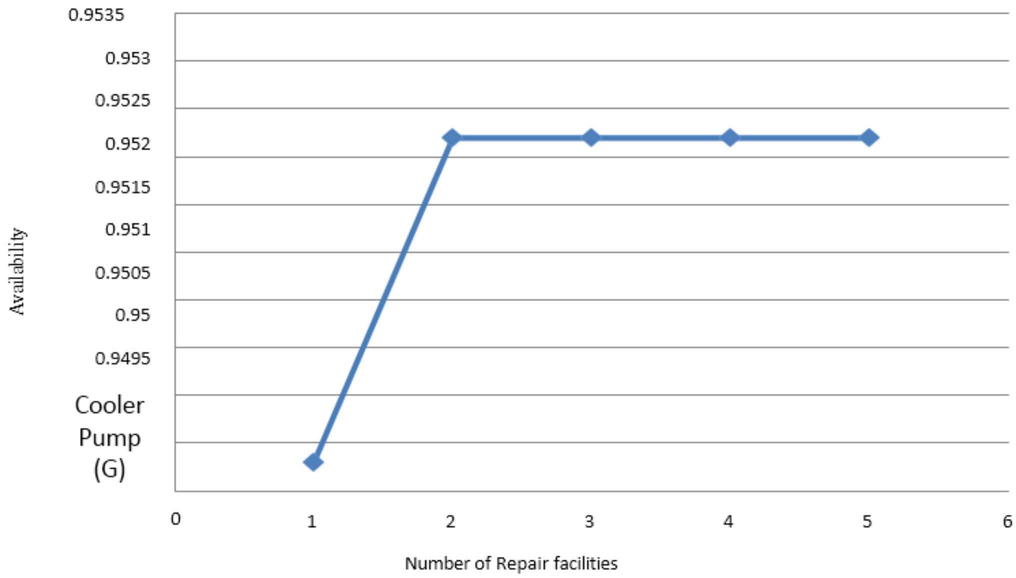

FIGURE 3
EFFECT OF NUMBER OF REPAIR FACILITIES ON ETHANOL MAKING SYSTEM AVAILABILITY

It is seen that system performance through Petri Nets Model is 94.8% with initial variables. However, it is increased 96.6% by considering improved repair priorities.

CONCLUSION

The detailed research studies conceded out here that the Overhead Pumps are the most critical subsystems that need supreme attention when selecting maintenance strategies. In pumps, failure mainly occurs due to the failure of pump seals and bearings. The analysis of the effect of repair facilities on the system's availability will help in deciding the maintenance resource allocation. It has also been realized that the way of Petri nets removes the inadequacies and reduces the tedious computational efforts required in the case of Markov Modeling. The selection of an appropriate RAM tool has a direct impact on the operational and maintenance costs.

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