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PROCESS MODELING AND NUMERICAL INVESTIGATION OF VENEER CUTTING SYSTEM OF A PLYWOOD PLANT WITH STOCHASTIC APPROACH

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Abstract

Present paper covers performance modelling and performability evaluation of a veneer-cutting system of plywood manufacturing industry. The performability is evaluated as a function of availability. In this system the different subsystems are connected in hybrid mode. Markovian Approach was used for developing the process modeling of the subsystems and to evaluate the performability of said system. MATLAB software was used to perform the numerical computations as well as simulation of results. The current work examines the impact of varied failure rates and repair rates on the long-term availability of the system. A Particle Swarm Optimization (PSO) based technique was used to optimize the results. A Decision Support System (DSS), which can be helpful for making strategic decisions on financial investments in managing the maintenance priorities, spare part management, and human resource requirements, among other things, has been recommended based on the numerical investigation..

Keywords: Availability, DSS, Maintenance, Markov Chain, PSO, RAM Tools

1. Introduction

The manufacturing of plywood is a complex engineering process. It undergoes through several stages like veneer cutting, laying up and gluing operation, hot/cold pressing and trimming process etc. With rapid increase of market competition manufacturers have ensure the progressively improve in their production processes. Use of human labor provides flexibility. Need of varying sizes of the required final product usually interrupt progression in the crucial stage of layup. The availability, cost of production, quality, and, in certain situations, the safety of the operator has all been negatively impacted by the condition. The modern business communities of these fields have taken a positive lesson from it. They grasped as an opportunity to learn from a long list of such failures and their impact in terms of economy and safety.

Regattieri and Bellomi [13] developed a system that reduces the manpower requirements and wastage of materials and improving the operational performance. Use of certain modeling tools in industrial practices can help them in making appropriate decisions on Reliability

Availability and Maintainability (RAM) issues. Various quantitative as well as qualitative tools and techniques are available for these types of analysis. Studies related to RAM facilitates in identifying several maintenance related issues and maintenance planning for smooth system working. Available literature on the subject shows that an equipment maintenance policy generally works in two ways: 1) Corrective Maintenance (CM) which is an offline activity where repair action is taken only after the equipment has failed; and 2) Preventive Maintenance (PM). This plan involves an online maintenance activity well in advance to avoid the frequent failure of system.

In the next sub section usefulness of the certain RAM tools and their typical applications in process industries are suitably discussed. RAM Approaches in Process Industries.

RAM tools reported in the literature in the present study may be classified into two categories namely (i) non state space and (ii) state space models.

The modeling techniques belonging to the non-state space category are Reliability-Block-Diagram, Fault Tree Analysis whereas Petri-Nets (PN) and Markovian processes are coming under the state space models [9,10]. These modeling tools are briefly described as under:

Fault Tree Analysis (FTA): At Bell Telephone Laboratory, this modelling method was created for the first time in 1962. In its original module, a combination of events that might cause a system failure was represented using a visual representation of logical links between events. The system represents top event in the modelling process. Dhillon and Rayapati [3] presented several examples describing successful applications of FTA to modelling of industrial systems. The RAM analysis of a RO desalination plant has also been done by Hajeeh and Chaudhuri [4] using it. Its aptitude for managing complex maintenance operations, which are best handled by state-space approaches like Markov or PN formalisms, is one of its significant drawbacks when employed as a RAM analysis tool.

Reliability-Block-Diagram (RBD): Reliability Block Diagram represents the various connections between the components of system. The two forms of series in Reliability Block Diagram are Series and Parallel Configurations. Based upon the Operational Dependency each component in Reliability Bloc Diagram is represented with help of a block i.e. connected either in series, parallel or hybrid mode. RBD Techniques has proved its effectiveness so far in the analysis of reliability of system. The fundamental flow diagram of the process is used to create a high-level dependability block diagram in this.

Khan and Kabir [6] carried out availability analysis of ammonia plant using Reliability Block Diagram is an example of availability analysis of industrial process systems.

Petri Nets (PN) Model: PN Modeling Technique was first used in 1962 by Dr. Carl Adam Petri in his thesis of doctorate. PN uses bipartite directed graph for process modeling of systems having synchronization, randomness and concurrency simultaneously. It has circles to indicate places, bars to denote transitions, and black dots inside the circles to represent tokens [17]. Sachdeva et al [15] applied Petri Nets for the performance modelling and evaluate long run steady state availability of paper manufacturing plant.

Bahl [2] used PN approach for the availability assessment of various systems of a fertilizer industry. More recently, Angel and Jayaparvathy [1] applied PN approach for developing safety system against occurrence of fire. Kumar et al [7,8] performed availability analysis of different repairable industrial units producing different products however similar in operational nature such as randomness, synchronization and concurrency etc.

Markov Process: It is a great process of stochastic behavior used to develop the performance model of systems that exhibit probabilistic behavior. It has many important applications in time-based reliability as well as availability analysis. Here in Movkov state transition diagrams are used for modelling of stochastic behavior of system. The system is capable of a number of distinct states across time. It is possible to specify the speed at which transitions between these states happen. Regardless of the number of states the system passed through to arrive at this state, the system's transition from one state to another solely depends on the prior one. There are two forms of Markovian Chain models: Discrete-Time-Markov-Chain (DTMC) and Continuous-Time-Markov-Chain (CTMC). Explosion of a number states is the main problem with the markovian chain models which makes difficult to deal with the tedious mathematical calculations.

The work of Singh et al. [16] and Kumar et al. [18,19] uses petri nets for modelling and performance evaluation of subsystems of a thermal power plant. More recently, Malik and Tewari [12] applied Markov Chains for modeling and evaluated availability for different power plants. Kempa [11] dealt with performance modelling of a production system with Markov chains.

Keeping in view of this, in the present study we have considered a Plywood plant facing several challenges as mentioned earlier. The system description and performance modeling is described in subsequent sections here after.

2. System Description

Usually, the plywood manufacturing has nine main steps. These are (i) log collection (ii) debarking (iii) steaming the blocks (iv) peeling blocks into veneers (v) drying veneers (vi) gluing and laying up the veneers one over the another (vii) pressing veneers in a hot press (viii) plywood trimming and (ix) finishing and stamping as shown in Fig.1. The veneer making system is responsible for around 35to 40 % of the total production of the plant. The system under study is a poplar plywood manufacturer situated in the Ganga basin of Northern India. The various subsystems under consideration are as follows:

• Debarking Machine: It used to separate the tree bark and wood without damaging it. Further the logs extracted are into specified lengths. It consists of movable debarking head, roller table, hydraulics mechanism, horizontal and diagonal conveyors and electrically insulated control cabin etc.

• Veneer Lathe: In this subsystem a veneer knife cuts the steamed blocks into veneers of desired thickness usually 3mm. The veneer sheets are further clamped to a usable width, to allow for shrinkage and trim. Veneer peeling knives, mechanical drives, tool holders and chucks are the major components of this sub system.

• Veneer Drier: It is used to dry the veneers obtained from the barks maintaining the desired level of moisture contents (usually 1to 15%). This subsystem comprises of heating and cooling components and process measuring devices. A veneer drier typically has three heating zones followed by a cooling section. Heating zone consists of source of hot air, circulating fans and the ports for exhaust which are used reduce the temperature veneer before exiting to the drier.

• Plywood Scanner: This subsystem is used to inspect, sort, grade and repair of plywood. It has (i) face and back scanners to detect visual 2-D and 3-D defects (ii) edge scanning for panel layup defects (iii) dimensional scanning for checking length and width and (iv) paralleling and guiding robotic movements for precise sorting and stacking etc.

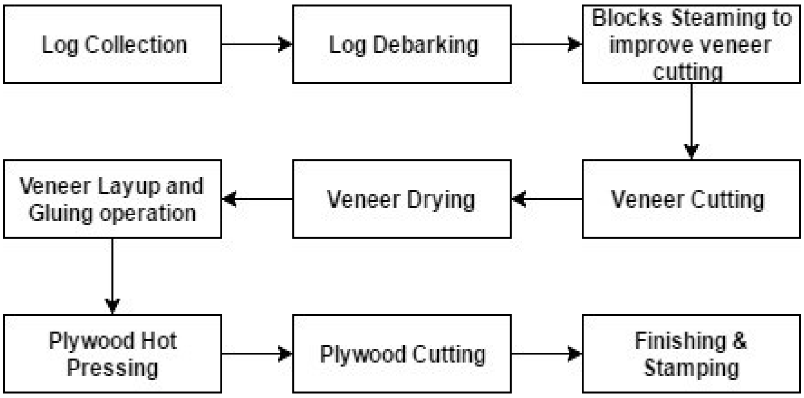

Figure 1: *Flow diagram of Plywood Manufacturing Plant*

3. Performance Modeling

In this study continuous time Markov Chains have been used to represent the transitions among various subsystems and to develop a performance model of the system. Fig. 2 shows the Markov model of the veneer cutting system. The failure and repair rates, among other variables, were taken into account when modelling the system's performance. The maintenance history books of the plant were obtained in discussion with plant's persons for the required data presented in table 1. Additionally, the following presumptions were used for system modelling and analysis.:

- Exponential distributions have been used to express failure and repair rates.
- A unit is as good as new after repair.
- Standby units have the same nature and capacity as active.
- Only the delay in the availability of repair facilities causes a delay in the start of repairs.
- The system can operate in reduced capacity mode as well.

Notations:
A, B, C and D: :All of the subsystems A, B, C, and D are in fine working order.
$\bar{A}$:shows that subsystem A is functioning in a reduced state.
$\bar{B}$:shows that subsystem B is functioning in a reduced state.
$\bar{C}$:shows a reduced state of operation for subsystem C.
a, b, c and d : shows that A, B, C, and D are all in a failed state, correspondingly.
λ_i, i=1,2,3……7 : Failure- Rates (FR) from states A, B, C, D, $\bar{A}$,$\bar{B}$ and $\bar{C}$ to the states $\bar{A}$,$\bar{B}$,$\bar{C}$, d, a, b and c respectively.
μ_i, i=1,2,3……7 : Repair- Rates (RR) from states $\bar{A}$,$\bar{B}$,$\bar{C}$, d, a, b and c to the states A, B, C, D, A, B and C respectively.
$P_j(t)$, j=1,2,3…..27: Probability that all subsystems are functioning properly and the system is in the jth state at time t. $P_j'(t)$ represents the derivative of $P_j(t)$ with respect to time 't'.

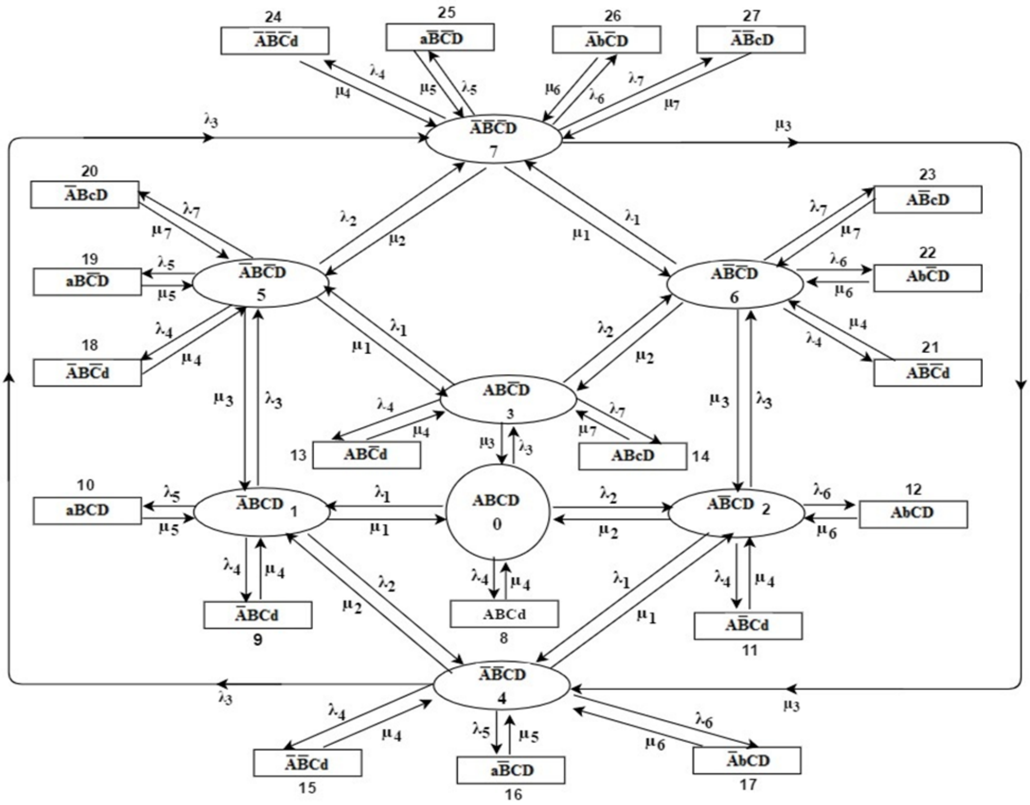

Figure 2: *Performance Model of Veneer Cutting System*

4. Performance Analysis

Using mnemonic rule a set of first order differential equations related to the transition diagram seen above (Fig.2) of the system at Time $(t+\Delta t)$ may be written as follows:

$P0(t+\Delta t) - P0(t) = [-\lambda 1\, \Delta t - \lambda 2\, \Delta t - \lambda 3\, \Delta t - \lambda 4\, \Delta t]P0(t) + P1(t)\mu 1\, \Delta t + P2(t)\mu 2\Delta t + P3(t)\mu 3\Delta t + P8(t)\mu 4\Delta t$

Dividing both sides by Δt, it becomes:

$[P0(t+\Delta t)-P0(t)]/\Delta t=[-\lambda 1-\lambda 2-\lambda 3-\lambda 4]P0(t)+P1(t)\mu 1+P2(t)\mu 2+P3(t)\mu 3+P8(t)\mu 4$

On taking limit as $\Delta t \rightarrow 0$, this obtained as:

$P'0(t)=-X0P0(t)+\mu 1\, P1(t)+\mu 2\, P2(t)+\mu 3\, P3(t)+\mu 4\, P8(t)$

$P'0(t)+X0P0(t)= \mu 1P1(t)+\mu 2P2(t)+\mu 3P3(t)+\mu 4P8(t)$ (1)

Similarly,

$P'1(t)+X1\, P1(t)=\lambda 1P0(t)+\mu 2P4(t)+\mu 3P5(t)+\mu 4P9(t)+\mu 5P10(t)$ (2)

$P'2(t)+X2P2(t)=\lambda 2P0(t)+\mu 1P4(t)+\mu 3P6(t)+\mu 4P11(t)+\mu 6P12(t)$ (3)

$P'3(t)+X3P3(t)=\lambda 3P0(t)+\mu 1P5(t)+\mu 2P6(t)+\mu 4P13(t)+\mu 7P14(t)$ (4)

$P'4(t)+X4P4(t)=\lambda 2\, P1(t)+\lambda 1\, P2(t)+\mu 3P7(t)+\mu 4P15(t)+\mu 5P16(t)+\mu 6P17(t)$ (5)

$P'5(t)+X5P5(t)= \lambda 3P1(t)+ \lambda 1P3(t)+\mu 2P7(t)+\mu 4P18(t)+\mu 5P19(t)+\mu 7P20(t)$ (6)

$P'6(t)+X6P6(t)=\lambda 3P2(t)+\lambda 2P3(t)+\mu 1P7(t)+\mu 4P21(t)+\mu 6P22(t)+\mu 7P23(t)$ (7)

$P'7(t)+X7P7(t)= \lambda 3P4(t)+ \lambda 2P5(t)+ \lambda 1P6(t)+\mu 4P24(t)+\mu 5P25(t)+\mu 6P26(t)+\mu 7P27(t)$ (8)

where, $X0= \lambda 1+\lambda 2+\lambda 3+\lambda 4$

$X1= \lambda 2+\lambda 3+\lambda 4+\lambda 5+\mu 1$

$X2= \lambda 1+\lambda 3+ \lambda 4+\lambda 6+\mu 2$

$X3= \lambda 1+\lambda 2+ \lambda 4+\lambda 7+\mu 3$

$X4= \lambda 3+\lambda 4+\lambda 5+\lambda 6+\mu 1+\mu 2$

$X5= \lambda 2+\lambda 4+\lambda 5+\lambda 7+\mu 1+\mu 3$

$X6= \lambda 1+\lambda 4+\lambda 6+\lambda 7+\mu 2+\mu 3$

$X7= \lambda 4+\lambda 5+\lambda 6+\lambda 7+\mu 1+\mu 2+\mu 3$

$P'8(t) +\mu 4\, P8(t)=\lambda 4P0(t)$ (9)

$P'_i(t)+\mu_j P_i(t)=\lambda_j P_1(t)$, where, i=9,10; j=4,5 (10)

$P'_i(t)+\mu_j P_i(t)=\lambda_j P_2(t)$, here, i=11,12; j=4,6 (11)

$P'_I(t)+\mu_j P_i(t)=\lambda_j P_3(t)$, here, i=13,14; j=4,7 (12)

$P'_I(t)+\mu_j P_i(t)=\lambda_j P_4(t)$, here, i=15,16,17; j=4,5,6 (13)

$P'_i(t)+\mu_j P_i(t)=\lambda_j P_5(t)$, here, i=18,19,20; j=4,5,7 (14)

$P'_i(t)+\mu_j P_i(t)=\lambda_j P_6(t)$, here, i=21,22,23; j=4,6,7 (15)

$P'_i(t)+\mu_j P_i(t)=\lambda_j P_7(t)$, here, i=24,25,26,27; j=4,5,6,7 (16)

Steady State

By imposing the condition, steady state probabilities of the system are derived that as $t\rightarrow\infty$, $d/dt\rightarrow 0$. With this, equations (5.58) to (5.73) the following equation system is reduced to

$X_0P_0=\mu_1P_1+\mu_2P_2+\mu_3P_3+\mu_4P_8$ (17)

Similarly,

$X_1P_1=\lambda_1P_0+\mu_2P_4+\mu_3P_5+\mu_4P_9+\mu_5P_{10}$ (18)

$X_2P_2=\lambda_2P_0+\mu_1P_4+\mu_3P_6+\mu_4P_{11}+\mu_6P_{12}$ (19)

$X_3P_3=\lambda_3P_0+\mu_1P_5+\mu_2P_6+\mu_4P_{13}+\mu_7P_{14}$ (20)

$X_4P_4=\lambda_2P_1+\lambda_1P_2+\mu_3P_7+\mu_4P_{15}+\mu_5P_{16}+\mu_6P_{17}$ (21)

$X_5P_5=\lambda_3P_1+\lambda_1P_3+\mu_2P_7+\mu_4P_{18}+\mu_5P_{19}+\mu_7P_{20}$ (22)

$X_6P_6=\lambda_3P_2+\lambda_2P_3+\mu_1P_7+\mu_4P_{21}+\mu_6P_{22}+\mu_7P_{23}$ (23)

$X_7P_7=\lambda_3P_4+\lambda_2P_5+\lambda_1P_6+\mu_4P_{24}+\mu_5P_{25}+\mu_6P_{26}+\mu_7P_{27}$ (24)

$\mu_4 P_8=\lambda_4P_0$ (25)

$\mu_j P_i=\lambda_jP_1$, where, i=9, 10; j=4, 5 (26)

$\mu_j P_i=\lambda_jP_2$, where, i=11, 12; j=4, 6 (27)

$\mu_j P_i=\lambda_jP_3$, where, i=13, 14; j=4, 7 (28)

$\mu_j P_i=\lambda_jP_4$, where, i=15, 16, 17; j=4, 5, 6 (29)

$\mu_j P_i=\lambda_jP_5$, where, i=18, 19, 20; j=4, 5, 7 (30)

$\mu_j P_i=\lambda_jP_6$, where, i=21, 22, 23; j=4, 6, 7 (31)

$\mu_j P_i(t)=\lambda_jP_7(t)$, where, i=24, 25, 26, 27; j=4 ,5, 6, 7 (32)

It can be found by recursively solving these equations as:

$P_1=(\lambda_1/\mu_1)P_0$; $P_2=(\lambda_2/\mu_2)P_0$; $P_3=(\lambda_3/\mu_3)P_0$; $P_4=[(\lambda_1\lambda_2)/(\mu_1\mu_2)]P_0$;

$P_5=[(\lambda_1\lambda_3)/(\mu_1\mu_3)]P_0$; $P_6=[(\lambda_2\lambda_3)/(\mu_2\mu_3)]P_0$; $P_7=[(\lambda_1\lambda_2\lambda_3)/(\mu_1\mu_2\mu_3)]P_0$

On adding,

$P_1+P_2+P_3+\ldots+P_7$

$=[(\lambda_1/\mu_1)+(\lambda_2/\mu_2)+(\lambda_3/\mu_3)+(\lambda_1\lambda_2)/(\mu_1\mu_2)+(\lambda_1\lambda_3)/(\mu_1\mu_3)+(\lambda_2\lambda_3)/(\mu_2\mu_3)+(\lambda_1\lambda_2\lambda_3)/(\mu_1\mu_2\mu_3)]P_0$

$=KP_0$ (33)

where, $K=[(\lambda_1/\mu_1)+(\lambda_2/\mu_2)+(\lambda_3/\mu_3)+(\lambda_1\lambda_2)/(\mu_1\mu_2)+(\lambda_1\lambda_3)/(\mu_1\mu_3)+(\lambda_2\lambda_3)/(\mu_2\mu_3)+(\lambda_1\lambda_2\lambda_3)/(\mu_1\mu_2\mu_3)]$;

Similarly, $P_9+P_{10}=(\lambda_4/\mu_4+\lambda_5/\mu_5)(\lambda_1/\mu_1)P_0$; $P_{11}+P_{12}=(\lambda_4/\mu_4+\lambda_6/\mu_6)(\lambda_2/\mu_2)P_0$;

$P_{13}+P_{14}=(\lambda_4/\mu_4+\lambda_7/\mu_7)(\lambda_3/\mu_3)P_0$; $P_{15}+P_{16}+P_{17}=(\lambda_4/\mu_4+\lambda_5/\mu_5+\lambda_6/\mu_6)(\lambda_1\lambda_2)/(\mu_1\mu_2)P_0$;

$P_{18}+P_{19}+P_{20}=(\lambda_4/\mu_4+\lambda_5/\mu_5+\lambda_7/\mu_7)(\lambda_1\lambda_3)/(\mu_1\mu_3)P_0$;

$P_{21}+P_{22}+P_{23}=(\lambda_4/\mu_4+\lambda_6/\mu_6+\lambda_7/\mu_7)(\lambda_2\lambda_3)/(\mu_2\mu_3)P_0$;

$P_{24}+P_{25}+P_{26}+P_{27}=(\lambda_4/\mu_4+\lambda_5/\mu_5+\lambda_6/\mu_6+\lambda_7/\mu_7)(\lambda_1\lambda_2\lambda_3)/(\mu_1\mu_2\mu_3)]P_0$ (34)

The sum of all probability must equal one under the normalizing condition., i.e.

$\Sigma P_i=1$, Or, $P_0+P_1+P_2+\ldots+P_{27}=1$ (35)

This implies,

$[P_0+(P_1+P_2+\ldots+P_7)+P_8+(P_9+P_{10})+(P_{11}+P_{12})+(P_{13}+P_{14})+(P_{15}+P_{16}+P_{17})+(P_{18}+P_{19}+P_{20})+(P_{21}+P_{22}+P_{23})+P_{24}+P_{25}+P_{26}+P_{27}]=1$

Or,

$P_0[1+K+\lambda_4/\mu_4+(\lambda_4/\mu_4+\lambda_5/\mu_5)(\lambda_1/\mu_1)+(\lambda_4/\mu_4+\lambda_6/\mu_6)(\lambda_2/\mu_2)+(\lambda_4/\mu_4+\lambda_7/\mu_7)(\lambda_3/\mu_3)+(\lambda_4/\mu_4+\lambda_5/\mu_5+\lambda_6/\mu_6)(\lambda_1\lambda_2)/(\mu_1\mu_2)+(\lambda_4/\mu_4+\lambda_5/\mu_5+\lambda_7/\mu_7)(\lambda_1\lambda_3)/(\mu_1\mu_3)+(\lambda_4/\mu_4+\lambda_6/\mu_6+\lambda_7/\mu_7)(\lambda_2\lambda_3)/(\mu_2\mu_3)+(\lambda_4/\mu_4+\lambda_5/\mu_5+\lambda_6/\mu_6+\lambda_7/\mu_7)(\lambda_1\lambda_2\lambda_3)/(\mu_1\mu_2\mu_3)]=1$

Or, $P_0=[1+K+\lambda_4/\mu_4+(\lambda_4/\mu_4+\lambda_5/\mu_5)(\lambda_1/\mu_1)+(\lambda_4/\mu_4+\lambda_6/\mu_6)(\lambda_2/\mu_2)+(\lambda_4/\mu_4+\lambda_7/\mu_7)(\lambda_3/\mu_3)+(\lambda_4/\mu_4+\lambda_5/\mu_5+\lambda_6/\mu_6)(\lambda_1\lambda_2)/(\mu_1\mu_2)+(\lambda_4/\mu_4+\lambda_5/\mu_5+\lambda_7/\mu_7)(\lambda_1\lambda_3)/(\mu_1\mu_3)+(\lambda_4/\mu_4+\lambda_6/\mu_6+\lambda_7/\mu_7)(\lambda_2\lambda_3)/(\mu_2\mu_3)+(\lambda_4/\mu_4+\lambda_5/\mu_5+\lambda_6/\mu_6+\lambda_7/\mu_7)(\lambda_1\lambda_2\lambda_3)/(\mu_1\mu_2\mu_3)]^{-1}$ (36)

Now, it is possible to determine the system A(∞) availability by utilizing:

$$A(\infty)=P0+P1+P2+P3+\ldots+P7$$
$$=[1+(\lambda1/\mu1)+(\lambda2/\mu2)+(\lambda3/\mu3)+(\lambda1\lambda2)/(\mu1\mu2)+(\lambda1\lambda3)/(\mu1\mu3)+(\lambda2\lambda3)/(\mu2\mu3)+(\lambda1\lambda2\lambda3)/(\mu1\mu2\ \mu3)]P0$$
$$=(1+K)P0 \tag{37}$$

Using Eq. 37, it is possible to determine the long-term availabilities for a variety of permitted pairings of repair and failure rates of veneer manufacturing systems in steady state. Tables 2 provide a summary of the impact of failure and repair rates on system availability. Following is a discussion of how availability affects system performance in relation to the parameters of the subsystems under consideration.

Table 1: *Data of failure and repair of Veneer System*

Name of Sub-System	Mean Failure-Rate/hr (λi)	Mean Repair-Rate / hr (μi)
Debarking Machine (A)	2.0X10-3	1.3X10-2
Veneer cutting lathe (B)	6.0X10-2	14X10-2
Veneer Driers (C)	22.5X10-4	1.2X10-1
Optical Scanner (D)	7.5X10-5	1.2X10-3

Table 2: *Effects of subsystem failure and repair rates variation on system performance*

Subsystem	Variation in failure rates λi (Repair rates μi)	Effect of variation on system availability
1 Debarking machine	0.0016-0.0024 (0.017-0.009)	0.8342-0.8028 (2.14)
2Veneer lathe	0.02-0.10(0.20-0.08)	0.9156-0.5635 (35.21)
3 Drier	0.00025-0.00425(0.20-0.04)	0.8301-0.8187 (1.14)
4 Plywood scanner	0.000035-0.000115 (0.0020-0.0004)	0.8578-0.6964 (16.14)

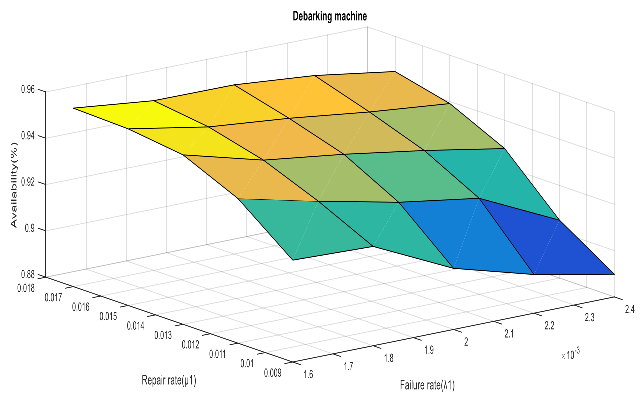

Figure 3: *Effect on availability of the failure and repair rate of the debarking machine*

Fig. 3 reveals that the variation in FRR of debarking machine has moderate impact on performance of system. Overall 2.14 % Changes have been noted in the system's availability, with the debarking machine's failure rate rising from 0.0016 to 0.0024 and its repair rate falling from 0.017 to 0.009.

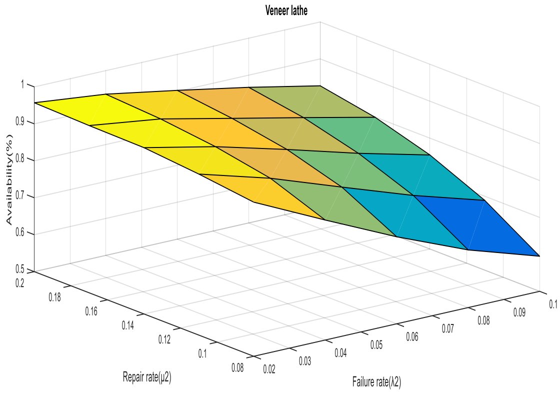

Figure 4: *: Effect on availability of the failure and repair rate of the veneer lathe.*

The failure and repair rates of the veneer lathe are shown to have a significant impact on the system's overall availability in Fig. 4 above. The overall availability varies by 35.20 percent, with the veneer lathe's failure rate rising from 0.02 to 0.10 and its repair rate falling.

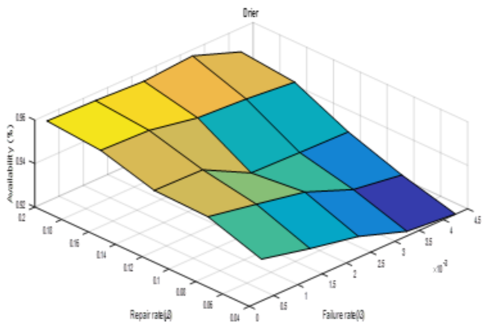

Figure 5: *: Impact of the veneer dryer's repair and failure rates on availability.*

As can be seen from Fig. 5, there is little to no impact on the system's availability when failure and repair rates vary within acceptable bounds. The system's availability varies1.14 %, with the veneer dryer's failure rate rising from 0.00025 to 0.00425 and its repair rate falling from 0.20 to 0.04.

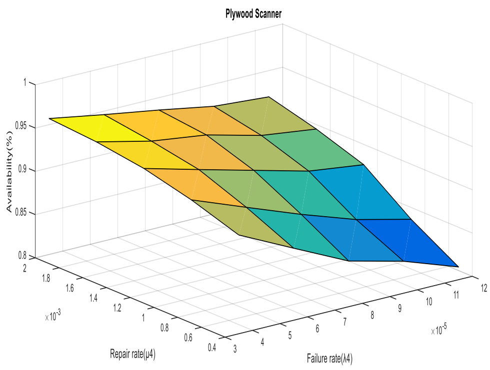

Figure 6: *Impact on availability of the plywood scanner's failure and repair rates.*

According to Fig. 6, changing the failure and repair rates within the given ranges has a significant impact on the system under consideration's overall availability. The plywood scanner's failure rate rose from 0.000035 to 0.000115, while its repair rates fell from 0.0020 to 0.0004, creating a 16.14% difference in the system's availability.

5. Performance Optimization

In the present study, to see the further enhancement in the availability of the system a performance optimization were carried out using Particle Swarm Optimization (PSO) algorithms. The PSO technique was first used by Dr. Kennedy [5] He proposed on the basis of the social behavior of birds or bees called 'particles' in their optimum search for food sources. In this, each bird has its own objective value at present, current position and current velocity. Ever experienced best value by the particle is called p-best i.e. personal best. It also considers the best objective value experienced by any particle ever called g-best i.e. global best.

Thomas Schoene [14] described a standard version of classical PSO which uses the following relations to determine velocity and position of the ith particle:

$$Vi\,(n+1) = w^*Vi\,(n) + C1(n)^*\,R1i\,(n)\,^*\{p\text{-}besti - Xi(n)\} + C2(n)^*\,R2i\,(n)\,^*\{g\text{-}best - Xi(n)\};\quad n = 0, 1\ldots\ldots\ldots\ldots, N-1 \tag{38}$$

$$Xi\,(n+1) = Xi\,(n) + Vi\,(n+1);\ n = 0,1\ldots\ldots\ldots\ldots, N-1; \tag{39}$$

where Vi is the velocity of ith particle, Xi is the position of ith particle. 'n' in parenthesis represents the iteration number, n = 0 refers to the initialization; N is the total no. of performed iterations, C1 and C2 are the personal weight and global weights respectively (preferably C1 = C2 = 2). R1i and R2i are random numbers distributed between 0 and 1 and 'w' the inertia weight that ranges from 0.4 to 1.4.

In PSO, the best solution represents the optimum position of a particle. There is random initialization of particles along with their velocity and position which were evaluated with equations (38) and (39). The main steps involved in optimization process may be depicted as shown in Fig.7 below:

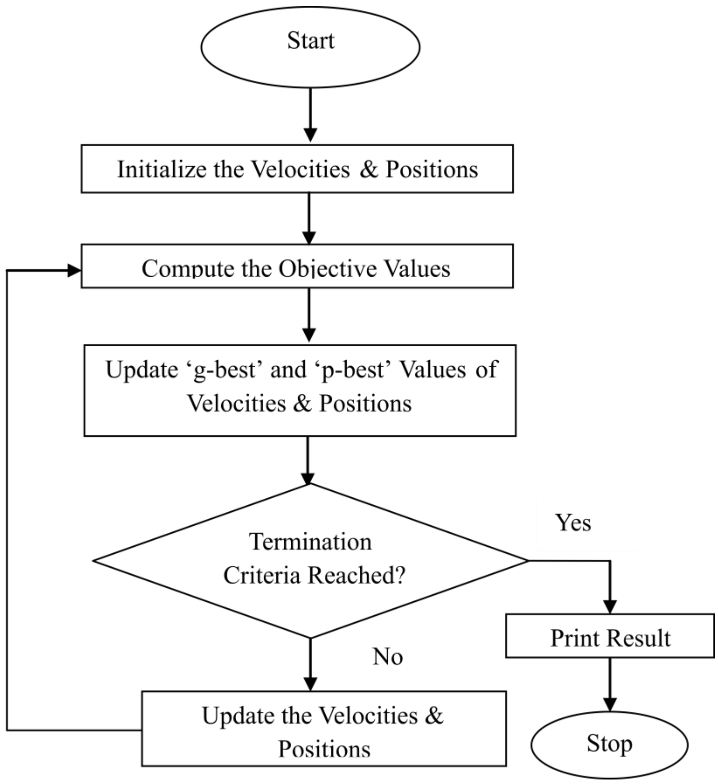

Figure 7: *Flow Diagram PSO*

The best position reached in each iteration is compared with the best previous position and similarly their position of the global best and personal best are updated. Each particle is updated to a new best position considering their previous experience after adjusting their velocities. After reaching to the new position, the particles of swarn are updated. Best optimal solution is obtained by repeating the process in same manner.

Computational Optimized Results of Veneer Making System

Following the procedure mentioned in Fig.7 by varying the failure and repair rate within the permissible limitsthe performance optimization of various subsystems has been carried out These are are shown below:

$\lambda1 \epsilon$ (0.0016-0.0024),, $\mu1 \in$ (0.009-0.017); $\lambda2 \epsilon$ (0.02-0.10), $\mu2 \in$ (0.08-0.20);
$\lambda3 \epsilon$ (0.00025-0.00425), $\mu3 \in$ (0.04-0.20) and $\lambda4 \epsilon$ (0.000035-0.000115), $\mu4 \in$ (0.0004-0.0020)

The effect of population size and the number of iterations on the system performance is shown below in Tables 3 and 4 as given below.

Table 3: *Effect of Population Size (PS) Variation on the Accessibility of Veneer Making System*

Population Size@ no. of GS 100	Failure Rate				Repair rate				Optimum Availability (%)
	$\lambda1$	$\lambda2$	$\lambda3$	$\lambda4$	$\mu1$	$\mu2$	$\mu3$	$\mu4$	
10	0.0019	0.02	0.00092	0.000109	0.010	0.17	0.15	0.0016	0.9123
20	0.0018	0.02	0.00343	0.000067	0.013	0.14	0.10	0.0019	0.9383
50	0.0018	0.02	0.00235	0.000048	0.013	0.16	0.10	0.0016	0.9492
100	0.0018	0.02	0.00246	0.000047	0.013	0.16	0.10	0.0016	0.9498
200	0.0016	0.02	0.00036	0.000041	0.016	0.17	0.10	0.0018	0.9611
1500	0.0018	0.02	0.00235	0.000040	0.015	0.18	0.05	0.0019	0.9614
3000	0.0016	0.02	0.00189	0.000038	0.015	0.20	0.04	0.0018	0.9638
4000	0.0016	0.02	0.00191	0.000038	0.015	0.20	0.04	0.0018	0.9639
6000	0.0016	0.02	0.00186	0.000037	0.015	0.20	0.04	0.0017	0.9641
8000	0.0016	0.02	0.00348	0.000035	0.015	0.19	0.08	0.0020	0.9669
15000	0.0016	0.02	0.00379	0.000035	0.017	0.20	0.10	0.0020	0.9685

Table 4: *The impact of different iteration counts on the accessibility of veneer manufacturing systems*

Generation Size @ no. of PS 50000	Failure Rate				Repair rate				Optimum Availability (%)
	$\lambda1$	$\lambda2$	$\lambda3$	$\lambda4$	$\mu1$	$\mu2$	$\mu3$	$\mu4$	
10	0.0015	0.10	0.0051	0.0016	0.015	0.19	0.05	0.0016	0.9560
20	0.0016	0.02	0.00373	0.000035	0.017	0.20	0.11	0.0020	0.9682
30	0.0016	0.02	0.00379	0.000035	0.017	0.20	0.11	0.0020	0.9684
50	0.0016	0.02	0.00380	0.000035	0.017	0.20	0.11	0.0020	0.9685
80	0.0016	0.02	0.00380	0.000035	0.017	0.20	0.11	0.0020	0.9685
120	0.0016	0.02	0.00380	0.000035	0.017	0.20	0.11	0.0020	0.9685
200	0.0016	0.02	0.00380	0.000035	0.017	0.20	0.11	0.0020	0.9685
250	0.0016	0.02	0.00380	0.000035	0.017	0.20	0.11	0.0020	0.9685

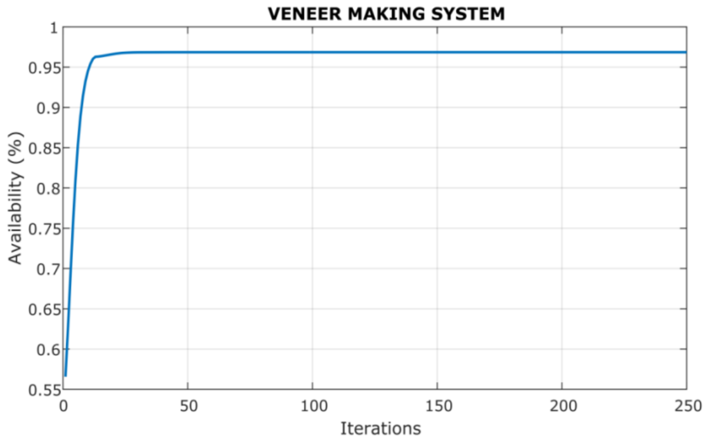

Figure 8: *Optimum Availability of Veneer Making System using PSO*

The Fig. 8 shows the highest achievable availability of system is as much as 96.85%. Based on the detailed investigation a comparative analysis of results is presented in Table 5 in the form of DSS.

6. Conclusions

The detailed investigation carried out on different subsystems here indicates that the veneer cutting lathe needs an utmost maintenance priority as it is the most critical subsystem. The failure of veneer knives is the main reason for the failure is in veneer cutting lathe. The effect of varying repair facilities on the availability of system were carried out which will further help in the allocation of repair facilities among the subsystems. The obtained outcomes also demonstrate the usefulness of the RAM tools. The analysis carried out will further help the maintenance engineers to optimize the overall maintenance cost and overall production cost. Thus it understood that appropriate RAM tools have the direct impact on the maintenance cost and overall production cost [15].

Table 5: *Summary of Results and DSS for Veneer making system of Plywood Manufacturing Plant*

Name of System	Name of subsystem	Varying Failure rates λi and (Repair Rates μi)	Impact of change on availability using Markov (%)	Optimized Availability based on PSO (%)	Suggested Maintenance Priorities*
Veneer Making System	Debarking Machine	0.0016-0.0024 (0.017-0.009)	0.8342-0.8028 (2.14)	96.85 %	III
	Veneer lathe	0.02-0.10 (0.2-0.08)	0.9156-0.5635 (35.21)		I
	Drier	0.00025-0.00425 (0.2-0.04)	0.8301-0.8187 (1.14)		IV
	Plywood Scanner	0.000035-0.000115 (0.0020-0.0004)	0.8578-0.6964 (16.14)		II

* At present being managed on the basis of intuitive decisions of the plant managers

In case it is desired to determine more possible efficient performance of such systems then we recommend the use of PSO type of optimization approach to be used for further optimizing the results obtained using Markov or any other convenient approaches as has been done in the present case study. Here a DSS is proposed (in Table 5) so that a significant amount of wastage in material and manpower involvement can be reduced. Hence, for researchers a lot of opportunity to work on the advancement of veneer layup process so as to achieve an optimum point between cost vs quality ensuring safety and volume of production. In future, It will be of great interest if Petri Nets approach is applied in such cases that supports non constant failure pattern also.

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