# BEHAVIORAL ANALYSIS AND MAINTENANCE DECISIONS OF WOOD INDUSTRIAL SUBSYSTEM USING STOCHASTIC PETRI NETS SIMULATION MODELING

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**Abstract**

*This study aims to optimize the productivity of the plywood manufacturing system within the wood industry. A Petri nets simulation-based technique has been used to evaluate the availability analysis of the plywood manufacturing system. A Petri nets model is created to represent the modeling of the plywood system. The model is subsequently simulated using the licensed program Petri Nets (PN) GRIF 2023.7. This simulation is used to evaluate the performance of the system. In the PN simulation model, timed transitions are fired based on the failure and repair rate of the system. Immediate transitions, on the other hand, have their own guard function for firing which is coded using a logical AND-OR gate. This study also assesses the impact of the repairman on the system's availability. The system's availability is optimized by increasing the number of repairmen. However, once a specific number of repairmen is reached, the system's availability remains constant. This research is highly valuable for determining the optimal number of maintenance staff needed for the wood industrial system.*

**Keywords:** Availability, Maintenance, Performance, Petri-Nets, Repairman, Simulation.

## 1. Introduction

In the context of engineering, reliability is the average time between failures (MTBF), which indicates how consistently a system performs without malfunctioning. To attain a high level of reliability and availability, it is necessary to implement a strong design, utilize high-quality components, and employ effective fault detection methods to reduce the amount of time that the system is not operational. These indicators are essential in sectors where system failures can have major effects on the economy and public safety, such as manufacturing and energy. Prior studies have extensively investigated diverse facets of designing industrial systems in the realm of reliability, applying varied methodologies to enhance system performance. The subsequent part presents a concise overview of the literature that encompasses the study undertaken by several scholars in the domain of reliability.

Tan and Kramer [1] provided an approximation for the financial impact of an unexpected plant shutdown, stating that it results in a revenue loss ranging from 500 to 100,000 USD per hour. Angela and David [2] have presented a method utilizing the Petri Net approach to analyze the dependability and safety of an industrial-scale production system. Regattieri and Bellom [3] implemented the Innovative lay-up system in the plywood production process leading to a substantial boost in productivity (about 19%) and a significant reduction in the number of personnel (-54%). Bansal and Tyagi [4] assessed the reliability of the screws mill production system by employing a combination of standby and parallel arrangement, and using the orthogonal matrix strategy. Kumar Amit et al. [5] maximized the efficiency of the ethanol manufacturing system and conducted a comparative analysis between the genetic algorithm (GA) and particle swarm optimization algorithm (PSO). The findings indicate that the PSO method outperforms the genetic algorithm in optimizing the system. Kumar Narendra et al. [6] enhanced the efficiency and assessed the reliability of milk pasteurization by the utilization of a probabilistic Petri net methodology. Narendra et al. [7] assessed the efficiency of the veneer gluing system using a stochastic Petri net methodology and determined that the thermal press is the most important component in this system. Malik and Tewari [8] utilized the particle swarm optimization technique to enhance the efficiency of the coal handling system. They achieved a performance improvement of 99.33% with an average population of 40 and 93.31% with an average generation size of 70. Tyagi et al. [9, 10] assessed the availability of every component in the leaf spring production facility by utilizing the matrix method and Markov birth-death methodology. They employ the C programming language to solve mathematical problems. Kalaivani and Kannan [11] evaluating reliability properties of a linear consecutive k-out-of-n: The F system in this uses asymptotic confidence intervals, mean time to failure, and reliability function for different sample sizes and parameter combinations using likelihood estimation, Monte Carlo (MC) training, and real data visualization. Chaudhary and Bansal [12] evaluated the reliability of the hydroelectric power station using the Laplace transformation method. Kumar Sudhir and Tewari [13] utilized the Petri module of GRIF to assess the performance of the coal handling system by manipulating the failure and repair rates. Subsequently, the performance was optimized using the particle swarm optimization strategy. Godara and Bansal [14] assessed the availability of a multi-state machine using an artificial neural network methodology, where neural weights are determined based on the system's failure and repair rate. Tyagi and Bansal [15] enhanced the efficiency of the wastewater treatment process by employing the Runge-Kutta numerical technique. They develop a mathematical model utilizing a probabilistic strategy and a Markovian technique. Rathi et al.[16] assessed the dependability of the parallel and cold standby unit in the system. Godara and Bansal [17] assessed the dependability as well as the availability of the steam turbine generating facility using a neural network methodology and boolean function technology. Urvashi and Shikha Bansal [18] assessed the dependability factor and availability of the threshing machine plant system using both a general and copula distribution. They found that the copula distribution yielded superior results compared to the general distribution.

The research provides a comprehensive examination of the behavior and performance of the standby plywood manufacturing system. In this work, the performance of the system is enhanced through the utilization of the stochastic Petri nets simulation method. After enhancing the system's performance, an analysis is conducted to determine the impact of the number of repairmen on the system's availability. The goal is to identify the optimal number of repairmen required to efficiently repair the system and maximize its availability.

The subsequent sections of this paper are structured in the following way: Section 2 provides a comprehensive overview of the plywood manufacturing system, including a detailed explanation of each subsystem within the system. Section 3 explains how the system is modeled using Petri nets. This section specifically details the process of formulating the Petri nets model for the plywood system. Section 4 focuses on optimizing the performance of the system. This is achieved by varying the failure repair rate and increasing the number of repairmen to enhance system performance. The conclusion of this research is provided in Section 5.

## 2. System description

The plywood system plays a crucial role in the wood industry. Plywood is a flexible type of manufactured wood that is created by bonding together small pieces or pieces of wood, referred to as layers or sheets. The layers are often arranged with their grain horizontal to neighboring layers, so augmenting the reliability and stability of the eventual product. The manufacture of the plywood system involves multiple processes and steps.
Figure 1 displays the schematic representation of this. The subsystems of this system are organized in a hybrid structure, with each subsystem described as follows.

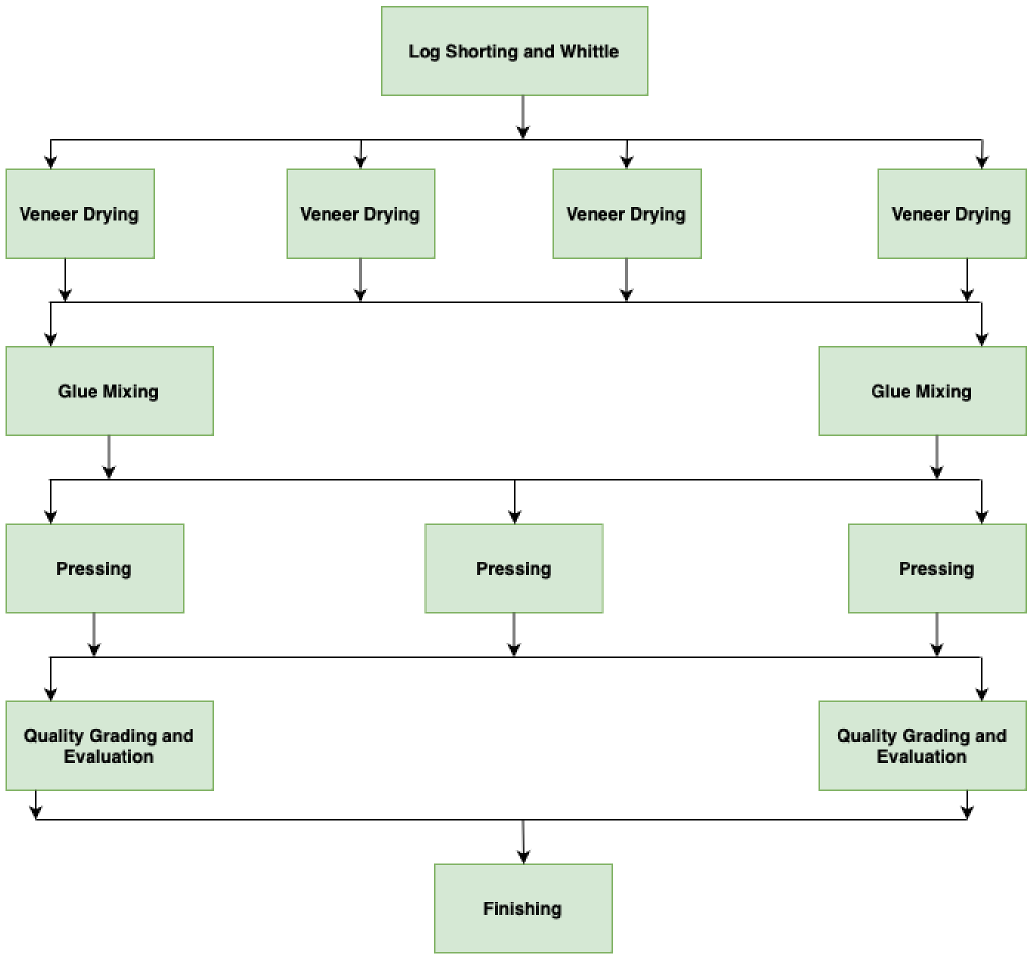


**Figure 1:** *Block Diagram of Plywood Manufacturing System*

- **Log Shorting and Whittle (LSW) :-** This is the first phase of the plywood production process, wherein a carefully chosen log of high-quality wood is picked based on the desired type of plywood to be produced. This piece of wood is commonly referred to as whittle. The whittle is straight and has a substantial size, making it ideal for creating an enormous amount of layers.
- **Veneer Drying (VD) :-** This subsystem is essential in the plywood fabrication process as its main objective is to decrease the wetness of the wood layers. Effectively dry veneers are crucial for guaranteeing the excellence, durability, and constancy of the ultimate hardwood goods. This subsystem consists of two types of drier equipment: a spinning dryer and a continuous veneer dryer. These dryers are designed to achieve consistent drying by controlling the heat and airflow. This subsystem consists of four units that are arranged in a

standby configuration.

- **Glue Mixing (GM) :-** The veneer layers in this subsystem are bonded together through the use of adhesive or glue. The subsystem consists of two machines, namely the glue distributors and the blending machine, which is arranged in standby mode.
- **Pressing :-** Once the veneer layer is bonded using glue, it is subjected to pressure and heat in a machine. Specifically, three machines are arranged in a standby configuration for this purpose.
- **Quality Assurance and Evaluation (QSE) :-** This subsystem consists of two units that are arranged in standby mode, wherein the plywood's quality and grade are checked and evaluated. This part of the system contains the methodical evaluation of the plywood products according to specified requirements and standards. By conducting a thorough examination, flaws such as empty spaces, separation, blemishes, and other irregularities are detected and categorized.
- **Finishing :-** This subsystem entails creating art, coloring, varnishing, or laminating the plywood sheets with a variety of coatings and finishes. By enhancing plywood's aesthetic appeal and functional qualities, the finishing subsystem plays a crucial role in raising the value of the finished product and enhancing its overall quality. There is only one unit in this subsystem, and it is arranged in series with other subsystems.

## 3. Petri nets modeling

The Petri nets has developed as an effective graphical modeling tool that encompasses both the static and dynamic behavior of systems. Petri nets are essentially directed graphs that are bipartite and have powerful mathematical representations that allow allocation, timing, and concurrency. They are made up of places, transitions, arcs, and tokens, which are denoted by circles, rectangular bars, arrows, and large circular dots that are centered in the places, respectively.

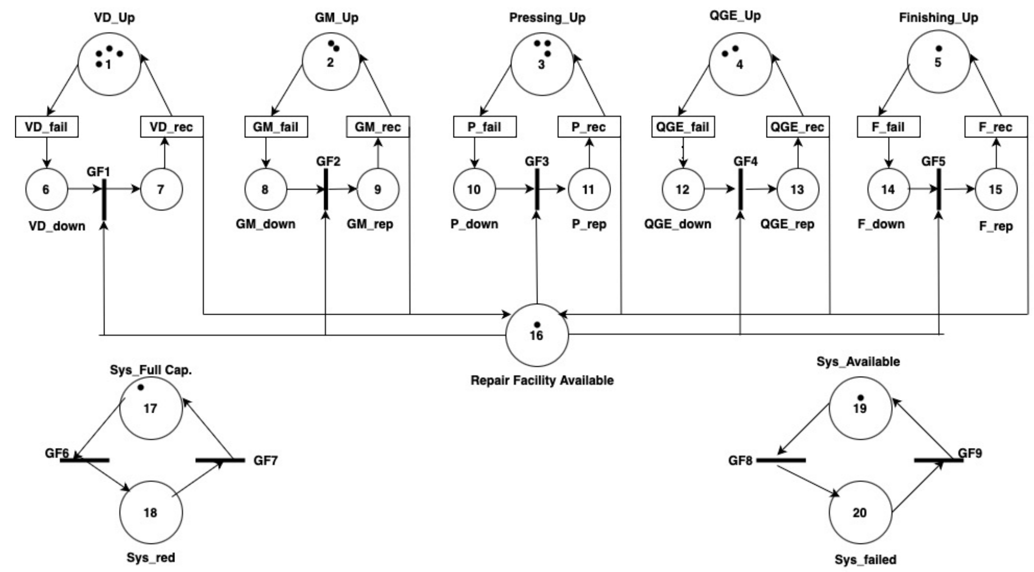


**Figure 2:** *Petri Nets Model of Plywood Manufacturing System*

Figure 2 displays the Petri net structure model of the plywood manufacturing system. The black dots, referred to as Tokens in this model, serve to represent the status and availability of the system/sub-systems and maintenance facility, correspondingly.

**Places**: In the Petri net are denoted by the circle at P=($P_1 to P_{12}$); these are the only tokens that are

provided based on the subsystem's unit number.
**Timed Transition**: This model represents VD-fail VD-rec, GM-fail GM-rec, P-fail P-rec, QGE-fail QGE-rec, and F-fail F-rec. The timed transitions are connected to the variable failure $\Omega_i$, which follows an exponential distribution.
**Immediate Transition**: Immediate transitions possess a personal guard function. In this model represents GF1, GF2, GF3, GF4, GF5, GF6, GF7, GF8 and GF9. The immediate transitions are connected to the variable repair $\Psi_i$, which follows an exponential distribution.
The following are special notations used in the plywood Petri net model:

- **Sys_Full Cap.** indicate that the plywood system is in a fully functional state.
- **Sys_red** indicate the lower capacity state of the system.
- **Sys_Available** represent the system available for working.
- **Sys_failed** indicate that the plywood system is in a failed state.

## 4. Performance Optimization

Appropriate performance optimization is essential in the plywood industry since it directly affects manufacturing expenses and the utilization of resources. An efficiently optimized system facilitates improved coordination across different phases of production, ranging from the acquisition of raw materials to the distribution of the final product. This leads to enhanced overall efficiency and strength in the market.

This section evaluates the system's availability and provides information on the system's behavior or performance. To assess the system's availability or performance, a mathematical model of the system has been developed using stochastic Petri nets simulation. This modeling was conducted using the licensed GRIF2023.7 the program's software. Failure and repair rate parameters of each subsystem affect the availability of the system.
The parameters were obtained from the maintenance history sheet, and their range is defined by $\Omega_1 \in (0.0035, 0.0173)$ $\Psi_1 \in (0.51, 1.1)$, $\Omega_2 \in (0.005, 0.014)$ $\Psi_2 \in (0.7, 2)$, $\Omega_3 \in (0.0028, 0.0058)$ $\Psi_3 \in (0.21, 0.82)$, $\Omega_4 \in (0.0059, 0.0128)$ $\Psi_4 \in (0.57, 1.19)$, $\Omega_5 \in (0.007, 0.01)$ $\Psi_5 \in (0.61, 1.2)$. The influence of the failure rate ($\Omega_i$) and repair rate ($\Psi_i$) of each subsystem on the availability of the system is illustrated in Table 1 to Table 5.

The effect of the system performance due to variation in failure and repair rate parameters of the veneer drying subsystem is shown in Table 1.

**Table 1:** *The Effects of Veneer Drying Subsystem Repair and Failure Rates on System Availability*

| | Repair rate $\Psi_1$ | | | | |
|---|---|---|---|---|---|
| Failure rate $\Omega_1$ | 0.51 | 0.71 | 0.91 | 1.1 | Constant Parameters |
| 0.0035 | 0.9615 | 0.9635 | 0.9646 | 0.9652 | $\Omega_2 = 0.005, \Omega_3 = 0.0028$ |
| 0.0081 | 09604 | 0.9623 | 0.9636 | 0.9644 | $\Omega_4 = 0.0059, \Omega_5 = 0.0071$ |
| 0.0127 | 0.9514 | 0.9559 | 0.9585 | 0.9600 | $\Psi_2 = 0.7, \Psi_3 = 0.21$ |
| 0.0173 | 0.9366 | 0.9457 | 0.9507 | 0.9539 | $\Psi_4 = 0.57, \Psi_5 = 0.61$ |

Upon analyzing the data in Table 1, it is evident that when the failure rate of the veneer drying subsystem increases from 0.0035 to 0.0173, the availability of the plywood system reduces from 0.9615 to 0.9366, in a comparable way the repair rate of this subsystem increases from 0.51 to 1.1, and the availability of the system increases from 0.9615 to 0.9652. The system's availability is reduced by 2.49% due to fluctuations in the failure rate of the veneer drying subsystem. Conversely, the system's availability is increased by 0.37% due to variations in the repair rate of this subsystem. The graphical representation of the effect of variations in the parameter of the veneer drying subsystem on system availability is depicted in Figure 3.

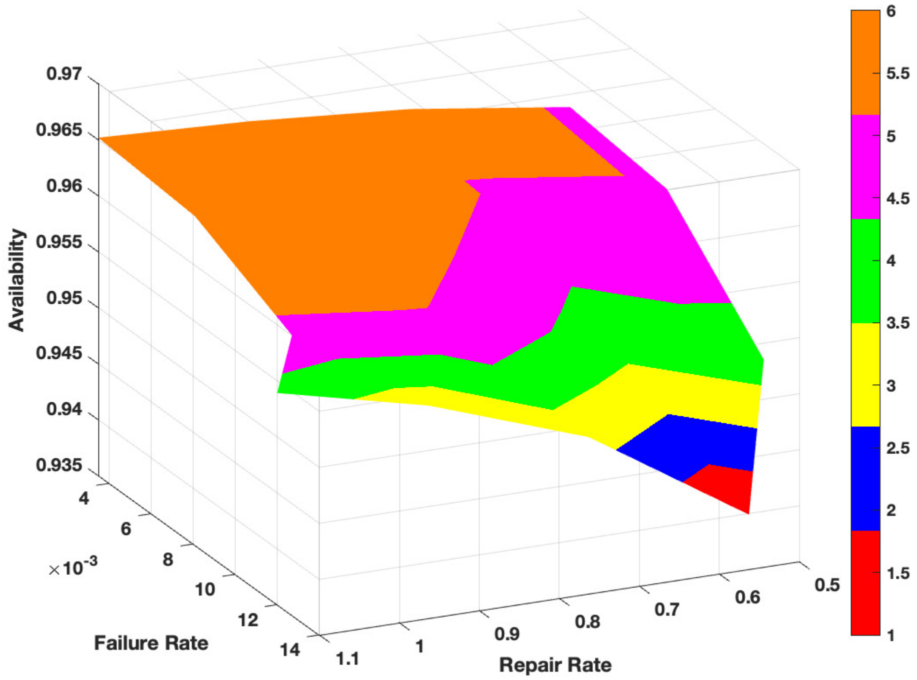


**Figure 3:** *Effect of Veneer Drying Variation in FRR on Plywood System Performance*

The impact of changes in the failure and repair rate parameter of the glue mixing subsystem on the system availability is demonstrated in Table 2.

**Table 2:** *The Effects of Glue Mixing Subsystem Repair and Failure Rates on System Availability*

| | Repair rate $\Psi_2$ | | | | |
|---|---|---|---|---|---|
| Failure rate $\Omega_2$ | 0.7 | 0.9 | 1.1 | 2 | Constant Parameters |
| 0.005 | 0.9615 | 0.9630 | 0.9639 | 0.9659 | $\Omega_1 = 0.0035, \Omega_3 = 0.0028$ |
| 0.008 | 09610 | 0.9626 | 0.9635 | 0.9655 | $\Omega_4 = 0.0059, \Omega_5 = 0.0071$ |
| 0.011 | 0.9602 | 0.9619 | 0.9630 | 0.9653 | $\Psi_1 = 0.51, \Psi_3 = 0.21$ |
| 0.0173 | 0.9535 | 0.9572 | 0.9595 | 0.9641 | $\Psi_4 = 0.57, \Psi_5 = 0.61$ |

Upon observation, it has been determined that when the failure rate of this subsystem increases from 0.005 to 0.0173, the system's availability reduces from 0.9615 to 0.9535. This corresponds to a decrease in system availability of 0.8% as a result of the fluctuation in the failure rate of this subsystem. The system's availability is enhanced from 0.9615 to 0.9659 as a result of the repair rate of this subsystem increasing from 0.7 to 2. This corresponds to a 0.44% gain in availability due to the higher repair rate of this subsystem. Figure 4 displays a graphical depiction of the relationship between the system's availability and changes in the parameter of the glue mixing subsystem.

The influence of variations in the Pressing subsystem on the failure and repair rate parameters has been demonstrated in Table 3, illustrating its effect on the system availability.

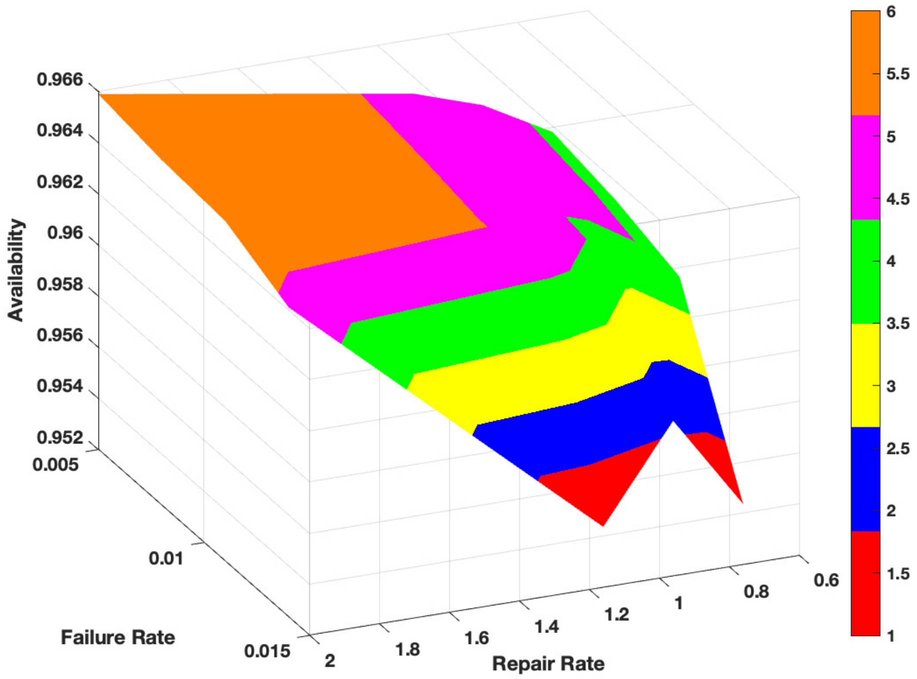


**Figure 4:** *Effect of Glue Mixing Variation in FRR on Plywood System Performance*

**Table 3:** *The Effects of Pressing Subsystem Repair and Failure Rates on System Availability*

| | Repair rate $\Psi_3$ | | | | |
|---|---|---|---|---|---|
| Failure rate $\Omega_3$ | 0.21 | 0.42 | 0.61 | 0.82 | Constant Parameters |
| 0.0028 | 0.9615 | 0.9696 | 0.9722 | 0.9736 | $\Omega_1 = 0.0035, \Omega_2 = 0.005$ |
| 0.0038 | 0.9587 | 0.9682 | 0.9712 | 0.9729 | $\Omega_4 = 0.0059, \Omega_5 = 0.0071$ |
| 0.0048 | 0.9587 | 0.9682 | 0.9712 | 0.9729 | $\Psi_1 = 0.51, \Psi_2 = 0.7$ |
| 0.0058 | 0.9570 | 0.9674 | 0.9706 | 0.9724 | $\Psi_4 = 0.57, \Psi_5 = 0.61$ |

The analysis of Table 3 reveals that when the repair rate of this subsystem is increased from 0.21 to 0.82, the system's availability increases from 0.9615 to 0.9736. Similarly, when the failure rate of this subsystem increases from 0.0028 to 0.0058, the availability of this subsystem decreases from 0.9615 to 0.9570.

The pressing subsystem's improved repair rate resulted in a 1.21% gain in system availability, while this subsystem's increased failure rate caused a 0.45% drop in system availability. Figure 5 provides a graphical depiction of how variations in the pressing subsystem parameter impact system availability.

Table 4 demonstrates that the system's availability is influenced by the fluctuation in the failure and repair rate parameter of the Quality Assurance and Evaluation subsystem.

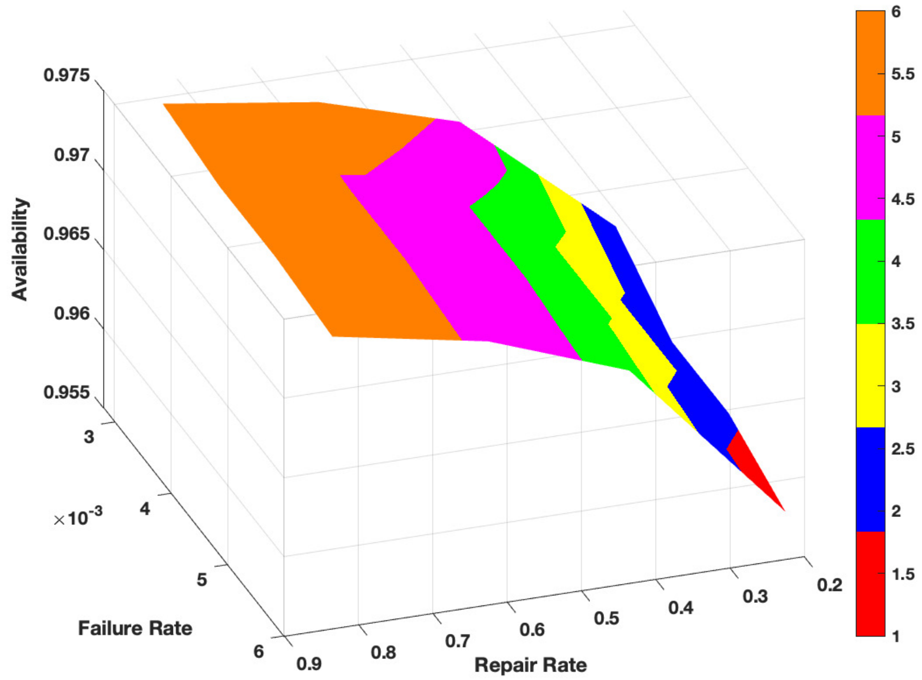


**Figure 5:** *Effect of Pressing Variation in FRR on Plywood System Performance*

**Table 4:** *The Effects of Quality Assurance and Evaluation Subsystem Repair and Failure Rates on System Availability*

| | Repair rate $\Psi_4$ | | | | |
|---|---|---|---|---|---|
| Failure rate $\Omega_4$ | 0.57 | 0.77 | 0.97 | 1.19 | Constant Parameters |
| 0.0059 | 0.9615 | 0.9638 | 0.9652 | 0.9661 | $\Omega_1 = 0.0035, \Omega_2 = 0.005$ |
| 0.0079 | 0.9591 | 0.9620 | 0.9638 | 0.9650 | $\Omega_3 = 0.0028, \Omega_5 = 0.0071$ |
| 0.0099 | 0.9541 | 0.9582 | 0.9607 | 0.9624 | $\Psi_1 = 0.51, \Psi_2 = 0.7$ |
| 0.0128 | 0.9514 | 0.9569 | 0.9601 | 0.9624 | $\Psi_3 = 0.21, \Psi_5 = 0.61$ |

Upon observation, it has been determined that when the failure rate of this subsystem grows from 0.0059 to 0.0128, the system availability reduces from 0.9615 to 0.9514, representing a 1.01% decrease. Similarly, when the repair rate of the subsystem grows from 0.57 to 1.19, the system availability improves from 0.9615 to 0.9661, representing a 0.46% increase. The graphical representation of this observation is depicted in Figure 6.
The finishing subsystem is a crucial component of the plywood system. The probability of failure for this subsystem is low due to its singular unit configuration. Table 5 displays the impact of system availability as a result of changes in subsystem E's failure and repair rate parameters.

Analysis is based on the finding that when the Finishing subsystem failure rate rises from 0.0071 to 0.01 the system's availability falls from 0.9944 to 0.9970; likewise, when this subsystem's repair rate rises from 0.61 to 1.2 the system's availability rises from 0.9944 to 0.9977. The availability of the system is lowered by 0.74% due to the variability in the failure rate of subsystem D, while the availability is increased by 0.27% due to the variability in its repair rate. Figure 7 depicts the graphical representation of the fluctuations in the failure and repair rate of this subsystem, and how these fluctuations impact the availability of the system.

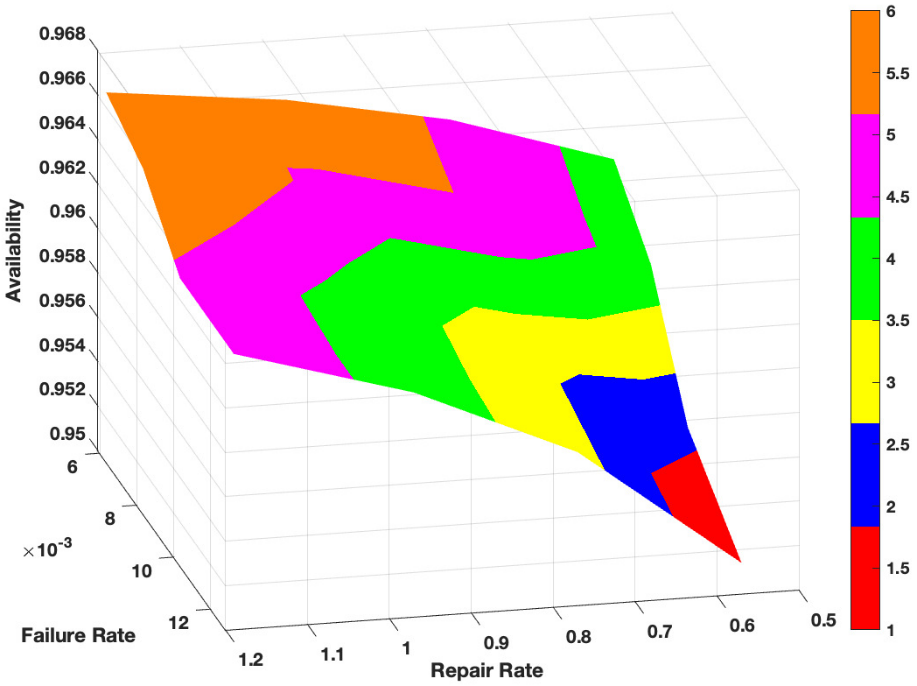


**Figure 6:** *Effect of Quality Assurance and Evaluation Variation in FRR on Plywood System Performance*

**Table 5:** *The Effects of Finishing Subsystem Repair and Failure Rates on System Availability*

| Failure rate $\Omega_5$ | Repair rate $\Psi_5$ 0.61 | 0.73 | 0.91 | 1.2 | Constant Parameters |
|---|---|---|---|---|---|
| 0.0071 | 0.9944 | 0.9953 | 0.9962 | 0.9971 | $\Omega_1 = 0.0035, \Omega_2 = 0.005$ |
| 0.0083 | 0.9935 | 0.9946 | 0.9956 | 0.9967 | $\Omega_3 = 0.0028, \Omega_4 = 0.0059$ |
| 0.0091 | 0.9870 | 0.9891 | 0.9913 | 0.9934 | $\Psi_1 = 0.51, \Psi_2 = 0.7$ |
| 0.01 | 0.9970 | 0.9891 | 0.9913 | 0.9934 | $\Psi_3 = 0.21, \Psi_4 = 0.57$ |

In the Petri nets simulations approach, the availability of the system is also influenced by the presence of a repairman or repair facility. System availability fluctuates with the presence of repair personnel, making it a critical factor. Based on this, we recommend that industries or engineers determine the required number of repair personnel. Table 6 illustrates the correlation or impact of system availability on the presence of a repair technician.

**Table 6:** *The Effects of Overall Performance of the System due to Repair Man*

| Repairman | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Availability | 0.9615 | 0.9631 | 0.9631 | 0.9631 | 0.9631 |

By examining the correlation between the availability of the system and the number of repairmen, it is observed that the initial availability of the system is 0.9615 when there is only one repairman. As the number of repairmen increases, the availability of the system also increases. However, after a certain threshold, the availability remains constant. The plywood manufacturing system's availability is now steady at 0.9631 after two repairmen. The impact of repairmen on the

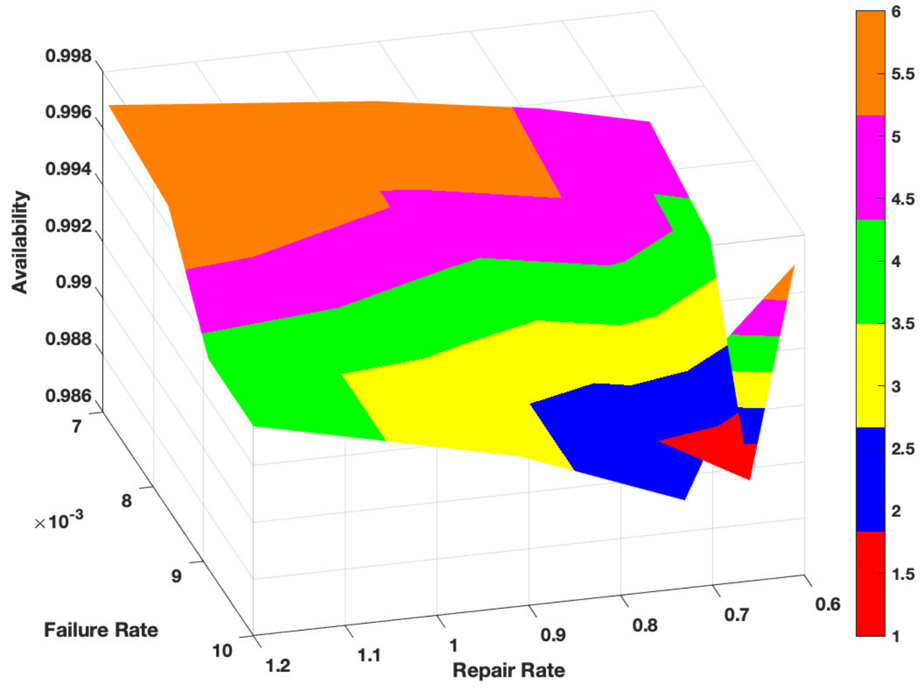


**Figure 7:** *Effect of Finishing Variation in FRR on Plywood System Performance*

system's availability is visually depicted in Figure 8.

Based on their observation, it is advised to the engineer that two repairmen are sufficient for repairing the plywood manufacturing system.

## 5. Conclusion

The current case study's findings indicate that the plywood manufacturing process is the most important component of the wood industry system and needs the highest maintenance level. Petri nets simulation modeling is utilized for this purpose in order to examine the system's performance behavior.
Performance matrices 1 through 4 present the findings about the impact of varying failure and repair periods on system availability throughout a range of system operating capacities. Based on the observation, it is determined that the veneer drying subsystem is the most crucial component of this system. This is because any fluctuations in the failure rate of this subsystem result in a reduction of the system's availability by 2.49%. This subsystem must give priority to maintenance with a greater level of importance. The order of maintenance priority of all the subsystems in this plywood system is listed in the following order:

1. Veneer Drying (VD) Subsystem.
2. Quality Assurance and Evaluation (QSE) Subsystem.
3. Glue Mixing (GM) Subsystem.
4. Finishing Subsystem.
5. Pressing Subsystem.

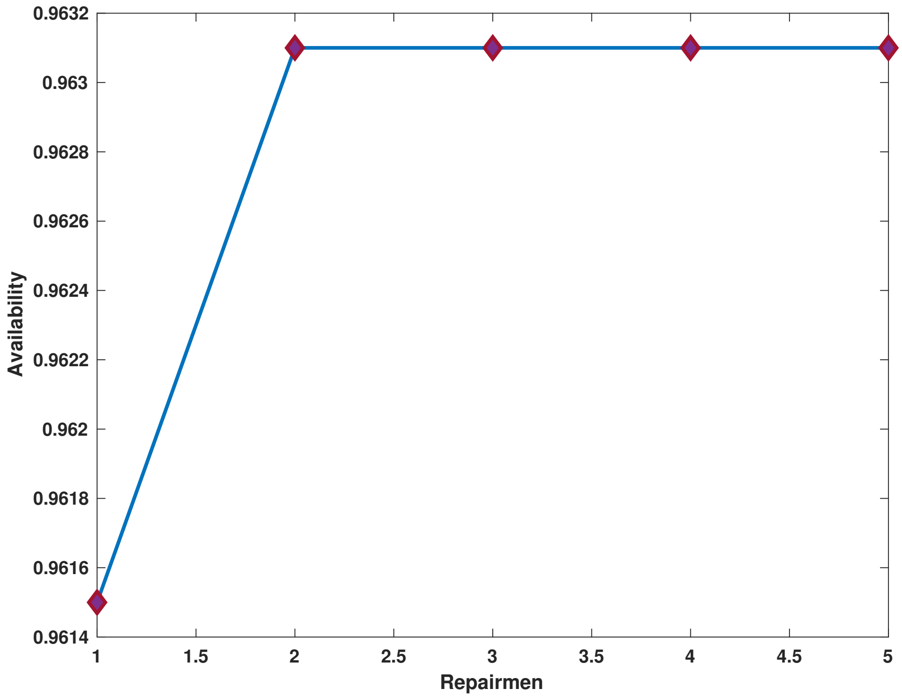


**Figure 8:** *Improving Availability with Additional Repair Capacity*

Repairmen impact the system's availability. An analysis reveals that the initial availability of the system grows as the number of repairmen increases. When there are two repairmen, the availability of the system is measured at 0.9631. If there is a rise in the number of repairs beyond two, the system availability remains at 0.9631. The premise of this study is that it is advisable for the engineer to employ a team of only two repairmen to address any issues with the plywood manufacturing system.

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