PERFORMABILITY ANALYSIS OF MULTISTATE ASH HANDLING SYSTEM OF THERMAL POWER PLANT WITH HOT REDUNDANCY USING STOCHASTIC PETRINETS

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Abstract

This work seeks to propose a Petri nets-based technique for evaluating the performability features of ash handling system of a coal-based thermal power plant. The impact of failure and repair parameters on system performance has been determined. For the modelling of the system Stochastic Petri Nets (SPN) an extended version of Petri nets is applied. The recommended methodology used in this study allows for a better understanding of the system's performance behavior under various operating situations. The study provides Decision Support System which will assist managers in making informed decisions about inventory and spare parts for plant operations.

Keywords: Availability, Performability, Petri Nets, Ash Handling System

I. Introduction

In the present era, integrated automation in the industries has evolved a tendency to design and construct the systems with higher flexibility, complexity, and production capacity as a result of rapid technological breakthroughs. Power generation units are also facing a number of obstacles in meeting the rising demand for electricity in both industrial and domestic applications. High productivity, as well as high payback ratios, have become critical for these units' survival. The desire for improved availability has arisen as a result of the dynamic behavior of industrial equipment and systems. As a result, such industrial systems are expected to operate for as long as feasible in order to meet the appropriate level of output requirements. Performability practitioners' jobs have become more difficult as a result of having to investigate, characterize, measure, and analyse system behavior. Industrial systems, on the other hand, are practically impossible to operate without failure. Output losses, on the other hand, could be reduced by using enough redundant parts or expanding the system's production capacity [1].

II. Literature Review

A large number of research papers have sought to use reliability principles to examine the performance of real-world industrial systems. These are largely concerned with the modelling and analysis of multi-component complex systems. Cherry et al. [2] evaluated the plant's long-run availability assuming constant failure rate and repair for its various subsystems in a chemical industry. Dhillon and Rayapati [3] discussed the application of reliability engineering principles to chemical associated industries, as the risk associated with these industries is extremely significant. Singh [4] discussed the use of reliability approaches in a biogas plant was considered. Kumar et al. [5–8] In his research work for studying and evaluating the performance of paper, sugar, and fertilizer industries, Markov approach modelling was applied. Arora and Kumar [9] offered a stochastic study of a thermal power plant's ash handling system to aid plant personnel's in predicting the behavior of running units. Michelson [10] discussed the current state of reliability technology in the process industry and offered recommendations for the future. Singh and Mahajan [11] studied the reliability behavior of a utensil manufacturing plant. Sarkar and Sarkar [12] have addressed strategies for determining the availability and restricting the average availability of a system that is inspected on a regular basis, has a spare unit, and is well-maintained. Dai et al. [13] analyzed the service reliability and availability for a distribution system. Madu [14] in order to achieve competitiveness and customer happiness, the strategic importance of reliability and maintainability management was investigated. Singh and Garg [15] under the premise of constant failure and repair rates did an availability analysis of the core veneer manufacturing system in a plywood manufacturing system. Gupta et al. [16] used exponentially distributed failure rates of various components while evaluating the reliability metrics of a butter producing system in a dairy factory. Singh et al. [17] analyzed the reliability of ash-handling system with ash water pumps in which two units are operational at the same time and the third is a cold standby. More recently, Kumar et al [18, 19, and 20] for modeling and analysis of performability of various complex industrial systems, Petri nets were used.

III. System Description

After coal is burned, ash is continuously produced in the plant, necessitating an efficient ash handling system to dispose of this waste material. Figure 1 depicts the flow diagram of a thermal power plant's coal ash handling system. The following subsystems are arranged in a sequence in this system:

i) Furnace (F): A boiler furnace is used to produce high-temperature heating by combusting coal with the least amount of smoke possible. The outside half of these furnaces is made of cast iron, while the interior is made of a brick shell and glass wool. There is no hot redundancy available for furnace, hence the failure of furnace will shift the whole system into completely down state.

ii) Electrostatic Preceptor (Ei): It is a device that is extensively used to remove fly ash from flowing gas (boiler emissions) with the help of an electric charge. There are two Electrostatic Preceptor provides hot redundancy to the system. Failure of any one of these will brings the system into the state of working in reduced capacity.

iii) Vessel (V): These Vessels are positioned just below the ESP hoppers with the dome valve arrangement. These are supposed to hold the fly ash for a period of time before being transported to the fly ash silos. There is no hot redundancy available for vessel also, hence the failure this will shift the whole system into completely down state.

iv) Compressor Transportation Line (C): In the plant, there is a compressed air station. The compressed air station supplies air to the pneumatic conveying system and the fabric filter purging system. Similarly, there is no redundant unit available for Compressor Transportation Line. The failure of this will cause complete failure of system.

v) Ash Silo (Ai): It keeps the fly ash generated by the boiler at the highest possible level of continuous operation. There are three number of Ash Silo connected parallelly available in the system.

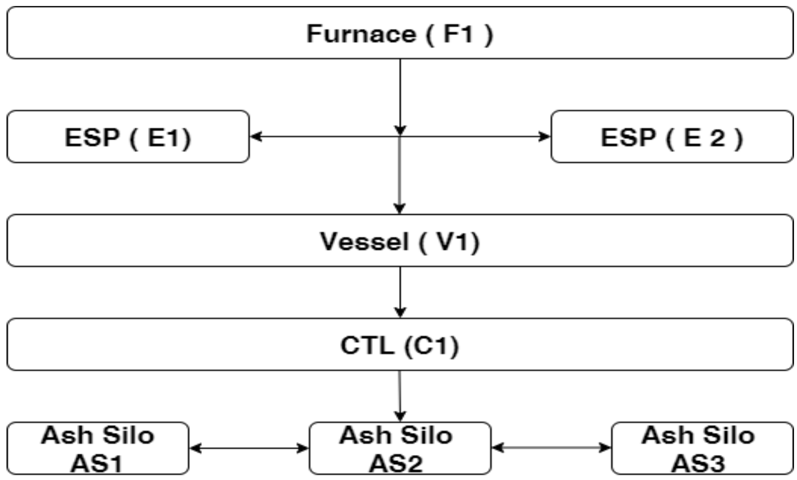

Figure 1: *Flow Diagram of Ash Handling System*

IV. Performance Modeling

The Petri Nets approach was used to create the performance model. It depicts the interactions between the many subsystems of system. When a number of repair facilities aren't up to snuff, all of the failures can't be handled at once, and the failed units have to wait in line to be repaired. In Fig.2, the PN model of the plant's ash handling system is illustrated as follows:

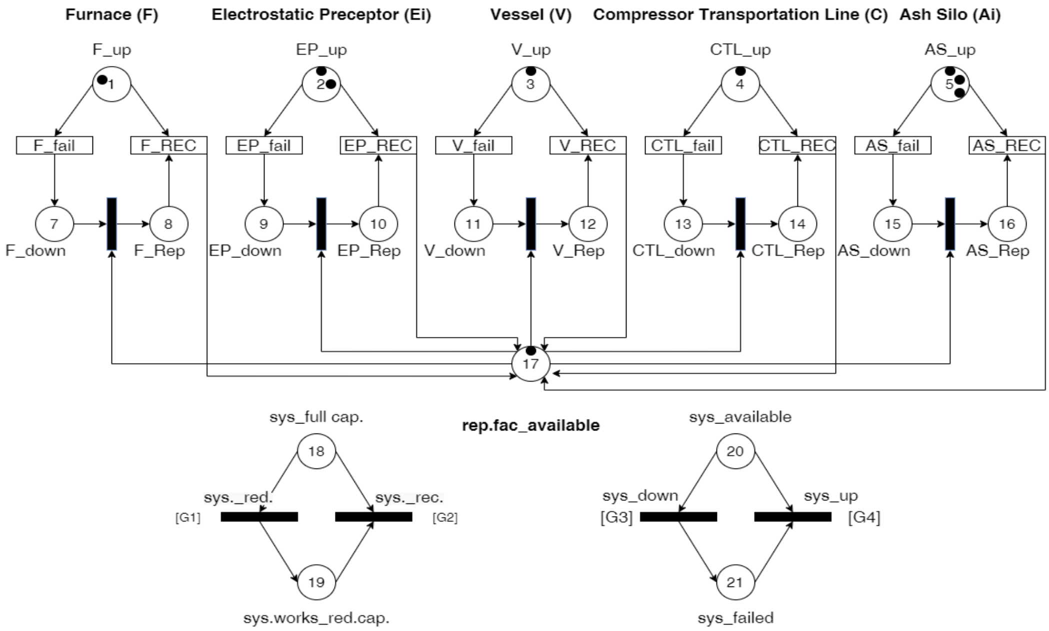

Figure: 2 *Petri Nets Modelling of Ash Handling System*

V. Performance Analysis

The system's dynamic behavior was analyzed utilizing a set of variables to determine the performability parameters. In consultation with the plant's maintenance engineers, the permissible value pair of failure and repair rates for the subsystems (Table 1) was determined. The impact of repairman availability on these factors is also explored. The results are shown in the tables below (Tables 2 to 11) and discussed further below.

Table 1: *Failure and Repair Rated of various subsystems of Ash Handling System*

Name of Subsystem	Failure Rate (per hour)	Repair Rate (per hour)
Furnace	0.0045	0.20
Electrostatic Preceptor	0.014	0.20
Vessel	0.0025	0.125
Compressor Transportation Line	0.014	0.065
Ash Silo	0.00006	0.015

Table 2: *Performability Matrix for Furnace of Ash Handling System in Full Capacity*

μ1 \ ρ1	0.10	0.15	0.20	0.25	0.30	Constant Parameters
0.0025	0.7437	0.7690	0.7710	0.7793	0.7810	
0.0035	0.7389	0.7650	0.7700	0.7714	0.7790	μ2= 0.014 ρ 2= 0.20
0.0045	0.7353	0.7614	0.7680	0.7700	0.7757	μ3= 0.0025 ρ 3=0.125 μ4= 0.014 ρ 4=0.065
0.0055	0.7344	0.7564	0.7610	0.7681	0.7750	μ5= 0.00006 ρ 5=0.015
0.0065	0.7278	0.7530	0.7592	0.7633	0.7677	

Table 3: *Performability Matrix for Furnace of Ash Handling System in Reduced Capacity*

μ1 \ ρ1	0.10	0.15	0.20	0.25	0.30	Constant Parameters
0.0025	8700.42	8731.13	8745.91	8749.65	8757.19	
0.0035	8666.48	8713.40	8732.40	8744.18	8748.26	μ2= 0.014 ρ 2= 0.20
0.0045	8647.71	8702.28	8726.70	8737.67	8746.96	μ3= 0.0025 ρ 3=0.125 μ4= 0.014 ρ 4=0.065
0.0055	8627.91	8689.00	8714.44	8731.01	8740.47	μ5= 0.00006 ρ 5=0.015
0.0065	8599.39	8678.57	8705.44	8720.97	8735.03	

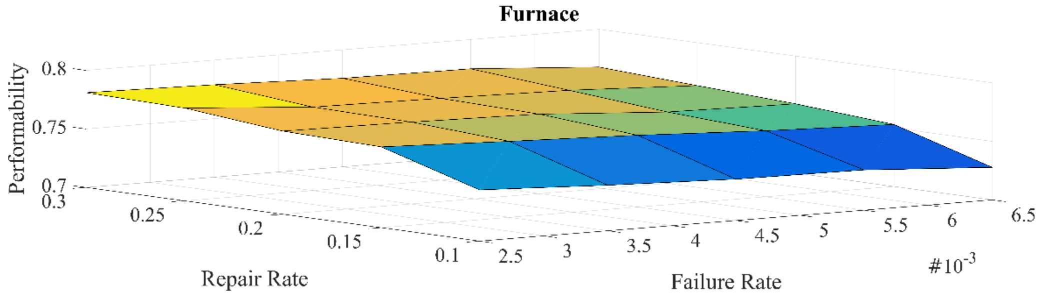

Figure: 3 *Impact of Variation in FRR of Furnace on the Performability of Ash Handling System*

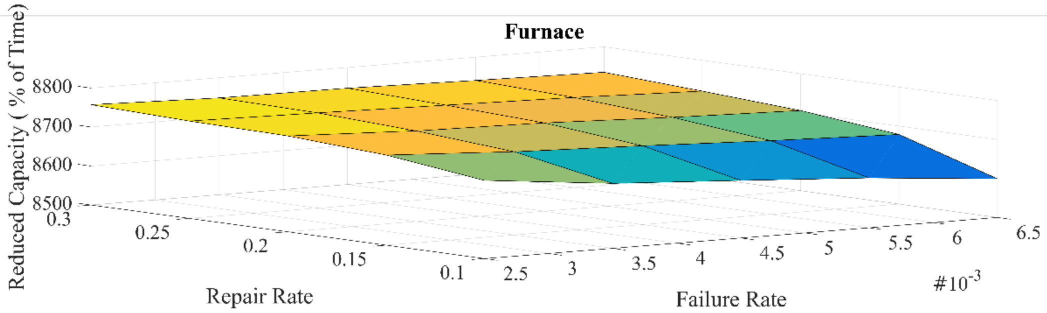

Figure: 4 *Impact of Variation in FRR of Furnace on the Performability of Ash Handling System (Reduced Capacity)*

The change in the failure and repair rates has a moderate impact on the system's availability, as shown in Fig. 3. The system availability is reduced by 5.32 percent due to an increase in furnace failure rates from 0.0025 to 0.0065 and a fall in repair rates from 0.3 to 0.1. However, changes in furnace failure and repair rates have a substantial impact on the system's ability in reduced capacity; variation up to 15.78 percent is observed. Figure 4 depicts the situation.

Table 4: *Performability Matrix for Crusher of ESP Handling System in Full Capacity*

μ2 \ ρ2	0.10	0.15	0.20	0.25	0.30	Constant Parameters	
0.012	0.7624	0.7941	0.8043	0.8291	0.8421	μ1=0.0045	ρ 1=0.20
0.013	0.7310	0.7628	0.7871	0.8055	0.8145	μ3= 0.0025	ρ 3=0.125
0.014	0.7121	0.7417	0.7680	0.7776	0.8043	μ4= 0.014	ρ 4=0.065
0.015	0.6790	0.7126	0.7528	0.7660	0.7821	μ5= 0.00006	ρ 5=0.015
0.016	0.6541	0.6990	0.7208	0.7504	0.7638		

Table 5: *Performability Matrix for Crusher of ESP Handling System in Reduced Capacity*

μ2 \ ρ2	0.10	0.15	0.20	0.25	0.30	Constant Parameters	
0.012	8621.50	8756.70	8846.73	8909.32	8954.51	μ1=0.0045	ρ 1=0.20
0.013	8520.06	8682.05	8782.05	8856.89	8907.44	μ3= 0.0025	ρ 3=0.125
0.014	8434.72	8610.48	8726.70	8810.61	8869.15	μ4= 0.014	ρ 4=0.065
0.015	8347.87	8544.23	8661.92	8758.54	8829.18	μ5= 0.00006	ρ 5=0.015
0.016	8278.33	8477.67	8626.18	8722.35	8789.41		

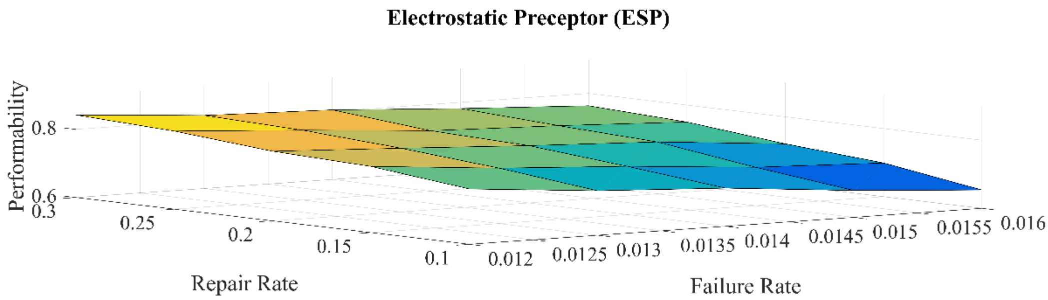

Figure: 5 *Impact of Variation in FRR of ESP on the Performability of Ash Handling System*

The variance in the ESP's failure and repair rates has a major impact on the system's availability, as shown in Figure 5. An increase in ESP failure rate from 0.012 to 0.016, as well as a fall in repair rates from 0.3 to 0.1, reduces system availability by up to 18.80%. The same changes in ESP failure and repair rates, on the other hand, have a moderate impact on the system's performability at reduced capacity varies up to 6.76 percent. Figure 6 depicts the situation.

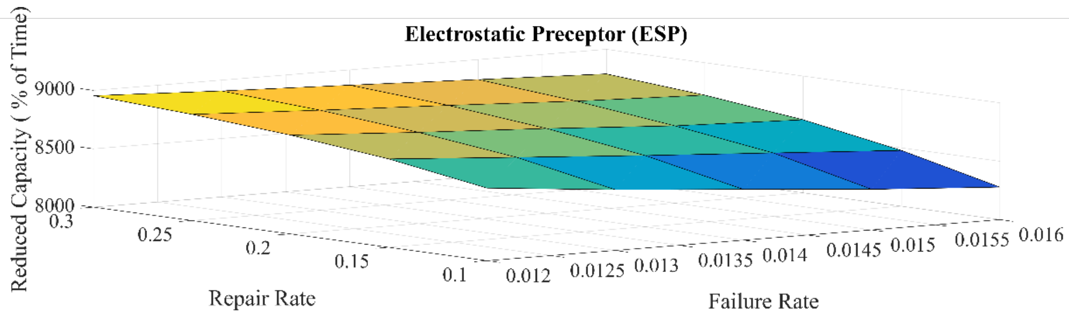

Figure: 6 *Impact of Variation in FRR of ESP on the Performability of Ash Handling System (Reduced Capacity)*

Table 6: *Performability Matrix for Vessel of Ash Handling System in Full Capacity*

μ3 \ ρ3	0.025	0.075	0.125	0.175	0.225	Constant Parameters	
0.0021	0.7618	0.7736	0.7742	0.7772	0.7814	μ1=0.0045	ρ 1=0.20
0.0023	0.7550	0.7603	0.7723	0.7760	0.7809	μ2= 0.014	ρ 2= 0.20
0.0025	0.7430	0.7617	0.7680	0.7752	0.7765	μ4= 0.014	ρ 4=0.065
0.0027	0.7354	0.7562	0.7592	0.7616	0.7700	μ5= 0.00006	ρ 5=0.015
0.0029	0.7275	0.7451	0.7544	0.7609	0.7690		

Table 7: *Performability Matrix for Vessel of Ash Handling System in Reduced Capacity*

μ3 \ ρ3	0.025	0.075	0.125	0.175	0.225	Constant Parameters	
0.0021	8196.63	8644.88	8877.38	9022.68	9118.56	μ1=0.0045	ρ 1=0.20
0.0023	8061.35	8551.31	8804.98	8962.56	9067.80	μ2= 0.014	ρ 2= 0.20
0.0025	7946.32	8454.31	8726.70	8890.41	9005.73	μ4= 0.014	ρ 4=0.065
0.0027	7796.23	8359.00	8648.22	8824.13	8943.50	μ5= 0.00006	ρ 5=0.015
0.0029	7691.22	8264.24	8566.09	8756.02	8884.35		

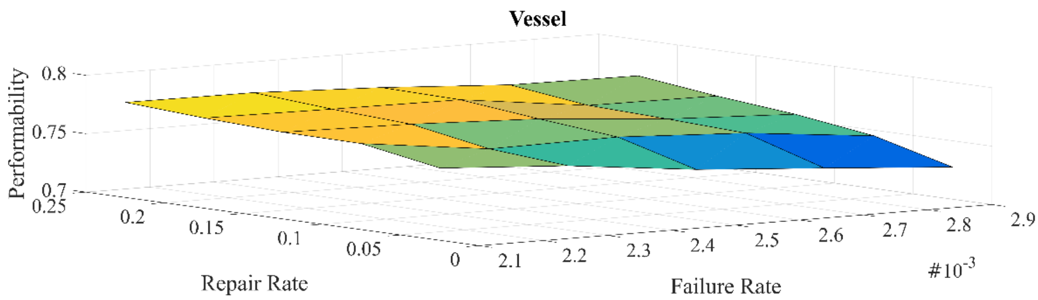

Figure : 7 *Impact of Variation in FRR of Vessel on the Performability of Ash Handling System*

The change in the Vessel's failure and repair rates has a lesser impact on the system's availability, as shown in Fig. 7. The system availability is reduced by 5.39 percent due to an increase in Vessel failure rates from 0.0021 to 0.0029 and a fall in repair rates from 0.225 to 0.025.

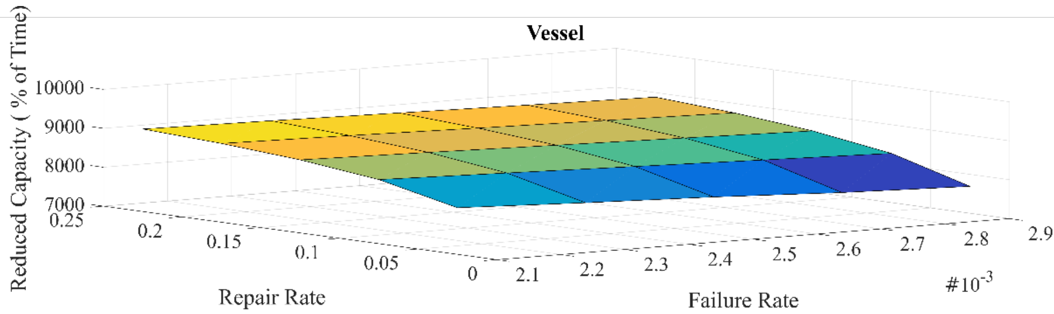

Figure : 8 *Impact of Variation in FRR of Vessel on the Performability of Ash Handling System (Reduced Capacity)*

However, the same fluctuations in the Vessel's failure and repair rates have a significant impact on the system's performability at reduced capacity, up to 14.27 percent change observed. Figure 8 depicts the situation.

Table 8: *Performability Matrix for CTL of Ash Handling System in Full Capacity*

μ4 \ ρ4	0.045	0.055	0.065	0.075	0.085	Constant Parameters	
0.010	0.7166	0.7597	0.7742	0.7781	0.7793	μ1=0.0045	ρ 1=0.20
0.012	0.7012	0.7568	0.7692	0.7713	0.7763	μ2= 0.014	ρ 2= 0.20
0.014	0.6930	0.7552	0.7680	0.7687	0.7754	μ3= 0.0025	ρ 3=0.125
0.016	0.6894	0.7483	0.7655	0.7685	0.7733	μ5= 0.00006	ρ 5=0.015
0.018	0.6849	0.7422	0.7586	0.7658	0.7656		

Table 9: *Performability Matrix for CTL of Ash Handling System in Reduced capacity*

μ4 \ ρ4	0.045	0.055	0.065	0.075	0.085	Constant Parameters	
0.010	8401.68	8690.45	8738.07	8750.19	8762.42	μ1=0.0045	ρ 1=0.20
0.012	8364.56	8682.63	8735.64	8748.93	8756.41	μ2= 0.014	ρ 2= 0.20
0.014	8318.63	8671.83	8726.70	8746.05	8751.93	μ3= 0.0025	ρ 3=0.125
0.016	8291.45	8665.80	8719.08	8744.20	8747.90	μ5= 0.00006	ρ 5=0.015
0.018	8271.02	8655.22	8718.37	8735.35	8745.78		

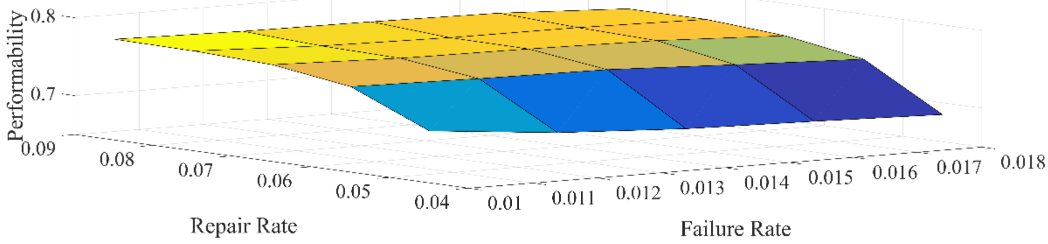

Figure : 9 *Impact of Variation in FRR of CTL on the Performability of Ash Handling System*

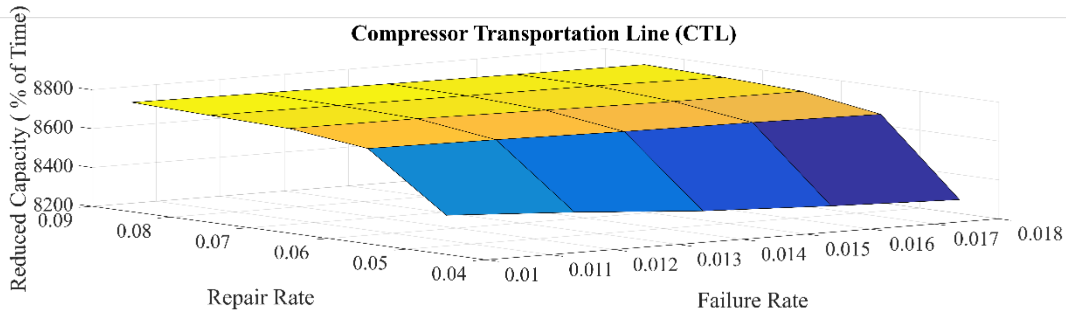

Figure : 10 *Impact of Variation in FRR of CTL on the Performability of Ash Handling System (Reduced Capacity)*

Table 10: *Performability Matrix for Ash Silo of Ash Handling System in Full Capacity*

μ5 \ ρ5	0.005	0.010	0.015	0.020	0.025	Constant Parameters	
0.00004	0.7679	0.7674	0.7698	0.7707	0.7740	μ1=0.0045	ρ 1=0.20
0.00005	0.7599	0.7634	0.7685	0.7701	0.7730	μ2= 0.014	ρ 2= 0.20
0.00006	0.7576	0.7630	0.7680	0.7661	0.7712	μ3= 0.0025	ρ 3=0.125
0.00007	0.7571	0.7621	0.7646	0.7660	0.7703	μ4= 0.014	ρ 4=0.065
0.00008	0.7555	0.7576	0.7574	0.7607	0.7616		

Table 11: *Performability Matrix for Ash Silo of Ash Handling System in reduced Capacity*

μ5 \ ρ5	0.005	0.010	0.015	0.020	0.025	Constant Parameters	
0.00004	8694.94	8729.57	8742.85	8750.96	8753.96	μ1=0.0045	ρ1=0.20
0.00005	8674.05	8717.78	8736.01	8743.07	8749.00	μ2= 0.014	ρ 2= 0.20
0.00006	8653.00	8707.61	8726.70	8736.81	8744.16	μ3= 0.0025	ρ 3=0.125
0.00007	8635.81	8700.05	8721.50	8732.69	8740.76	μ4= 0.014	ρ 4=0.065
0.00008	8615.26	8687.43	8713.46	8727.31	8736.70		

The change in failure and repair rates of the CTL has a significant impact on the system's availability, as shown in Fig. 9. The system availability is reduced by 9.44 percent due to an increase in CTL failure rates from 0.010 to 0.018 and a fall in repair rates from 0.085 to 0.045. The same changes in CTL failure and repair rates, on the other hand, have the least impact on the system's ability to operate at a reduced capacity of up to 4.91 percent. Figure 10 depicts it.

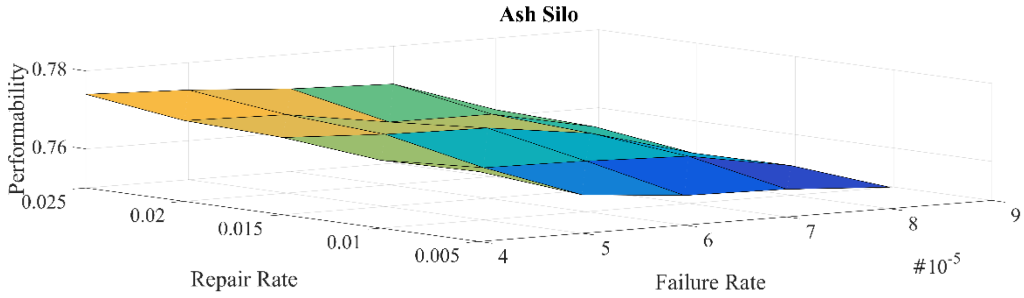

Figure : 11 *Impact of Variation in FRR of Ash Silo on the Performability of Ash Handling System*

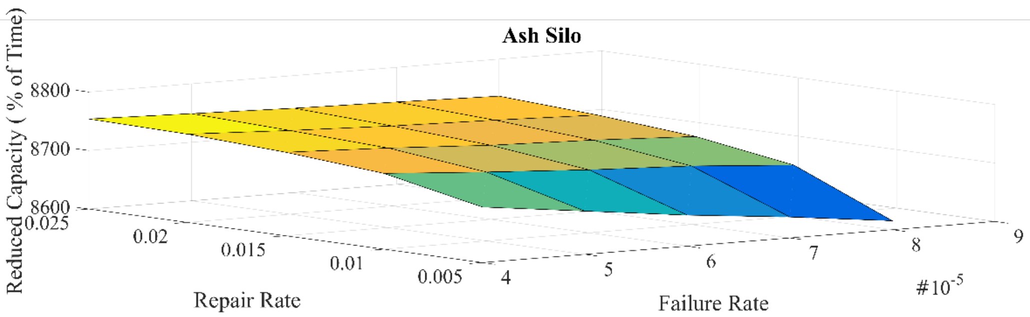

Figure : 12 *Impact of Variation in FRR of Ash Silo on the Performability of Ash Handling System (Reduced Capacity)*

The variance in failure and repair rates of the Ash Silo has a small impact on the system's availability, as shown in Fig. 11. The system availability is reduced by 1.85 percent due to an increase in Ash Silo failure rates from 0.010 to 0.018 and a fall in repair rates from 0.085 to 0.045. However, the same changes in the Ash Silo's failure and repair rates have had the least impact on the system's ability to perform in decreased capacity by up to 1.38 percent. Figure 12 depicts it.

Table 12: *Impact of Variation in the Repair Facilities on Performability of Ash Handling System*

No. of Repair Facilities	1	2	3	4	5
Availability	0.7680	0.7872	0.7877	0.7883	0.7882
Reduced Capacity	8726.70	8918.72	8922.80	8922.86	8922.80

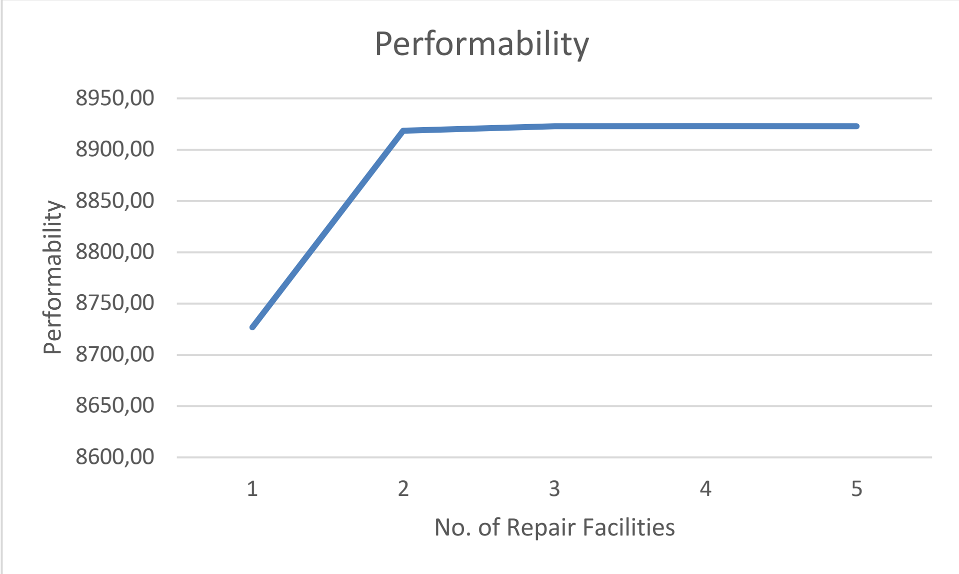

Figure : 13 *Impact of Variation in Repair Facilities on the Performability of Ash Handling System*

The influence of the number of repair facilities on system performance is depicted in Figure 13. When there are two or more repairmen in the system, the performance metrics stabilize. It leads to the conclusion that two separate repair facilities are required to obtain the best system performance.

VI. Conclusions

The Electrostatic Precipitator is the most vital part of the Ash Handling System, and it requires the most meticulous maintenance, according to the results of the current case study. The management will be aided in choosing the product mix by an examination of systems operating at decreased capacity and with degraded quality. The impact of repairmen availability on system performance will aid in resource allocation decisions. This will assist in lowering operation and maintenance expenses while also increasing output volume. It will also assist in raising the product's quality requirements.

Petri Nets can aid in the reduction of the time-consuming computational efforts required by Markov and other similar modelling methods. Choosing an appropriate technique, in fact, has a direct impact on operational and maintenance costs.
Decision Support System was developed based on the analysis as illustrated in Table 13. This will assist managers in making informed decisions about inventory and spare parts for plant operations.

Table 13: *Decision Support System*

Name of Subsystem	Impact of Variations in FRR on Performability at full capacity (percent)	Impact of Variations in FRR on Performability with reduced capacity(%)	Maintenance Priorities Suggestions
Furnace	5.32	15.78	IV
Electrostatic Preceptor	18.80	6.76	I
Vessel	5.39	14.27	III
Compressor Transportation Line	9.44	4.91	II
Ash Silo	1.85	1.38	V

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