PERFORMABILITY OPTIMISATION OF MULTISTATE COAL HANDLING SYSTEM OF A THERMAL POWER PLANT HAVING SUBSYSTEMS DEPENDENCIES USING PSO AND COMPARATIVE STUDY BY PETRI NETS

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Abstract

This paper deals with an analysis methodology for evaluating the performance of a coal handling system utilized in a coal based thermal power plant. To simulate the interactions between the subsystems, a stochastic Petri nets technique is used. A licensed software package named Petri module of GRIF were used for computations. This work addresses the performability and cost multi-objective optimization problem for a series-parallel coal handling system of a thermal power plant having subsystem failure dependencies. Performability of subsystems has been examined in relation to variations in failure and repair rates. The Particle Swarm Optimization Technique, which is based on an algorithm discussed, has been used to optimize the results. Based upon the observation and criticality of failure, the subsystems of the coal handling system were given maintenance order priority. A decision support provided at last which will the maintenance personnel™s to take better and informed decision while forming the maintenance policies. It has been observed that the Crusher and Tippler are crucial components that demand the full attention of plant manager.

Keywords: Petri Nets, Particle Swarm Optimization, Performability, Decision Support System

1. Introduction

Electricity consumption has significantly increased in India as a result of the country's fast development. The Thermal Power Plant (TPP) is one of the primary sources of power generating. The high availability of key components of equipment is necessary for continuous electricity generation. Reliability and maintainability of the used equipment, subsystem, and system are factors that affect thermal power plant availability to the utmost extent[1]. Keeping the systems of thermal power plant in operational state is a big challenge for the maintenance personnels. Unfortunately, system failure cannot be completely avoided, but it can be reduced to the absolute minimum[2]. To increase plant efficiency, the performability of subsystems TPP's must be evaluated. In this study, Stochastic Petri Nets (SPN) approach is used to examine the performance evaluation of TPP. The design of any system in the context of performability presents numerous challenges, and the objectives may be conflicting at a time. System reliability, availability, maintainability, safety, and cost are all prime aspects of system performability[3, 4, 5, 6]. To keep systems in a working state over the course of several decades, maintenance scheduling was crucial. The best maintenance plan takes care of TPP's maintenance requirements for the least cost[7]. The maintenance cost is influenced by both scheduled and unscheduled maintenance tasks. Due to this, research have been done in the past to decrease system downtime, which has improved plant availability. The field has slowly expanded to include more systems that schedule system maintenance using condition-based maintenance strategies. Various attempts have been undertaken in the past to identify and prioritise the TPP's important subsystems[8]. Furthermore, the field of power generation has widely embraced condition monitoring tools. It makes it easier to identify and fix major equipment flaws so that working equipment can be restored as soon as possible[9, 10, 11]. For a coal-fired thermal power plant, earlier scholars attempted a number of different attempts at RAM analysis. It's important to assess TPP's performance under actual circumstances. He [12] has proposed a method using the Petri Net approach for reliability evaluation and safety assessment of an industrial manufacturing system. Using Petri nets, Sachdeva et al. [13, 14, 15, 16, 17] assessed the pulping system's availability in the paper sector. The study's main aim was to determine the overall coast of operation and repair. In their investigations, it was explored how different parameters affected the system's availability. Based on the Petri Nets model's Mante Carlo simulation, the various reliability parameters were calculated. The uses of the Petri nets model and its capacity to simulate the real world were presented by Schneeweiss [18]. It has also been demonstrated how PN models can be used to analyse non-repairable systems. .

2. System Description

Coal handling system is a crucial element of a coal-based thermal power plant. The continuous operation of the thermal power plant and consequently the production of power will be ensured by the system's smooth operation. Tipplers are used to unload the coal and send it to the storage yard after it has been transported to the plant via a variety of routes, including rail, road, and water. The following description applies to the numerous subsystems of the coal handling system also represented by fig. 1, which is configured in a hybrid mode.

- Wagon Tippler: Tipplers are used to tip laden waggons to empty them of their contents. Tippler secures the waggon from the side and the top using gripping devices that are built into the waggon. In addition, waggon tippler features include wheel grippers, limit switches of various types, and track stops.
- Crusher: The bigger coal rocks are broken down into smaller coal rocks, gravel, and rock dust using a crusher. The coal is crushed or compressed in coal crushers using metallic surfaces.
- Bunker: Bunkers are utilised as a depot to guarantee a steady and smooth supply of coal to the mill.
- Feeder: Feeders are used to feed coal to coal mills, primarily ensuring a smooth and constant supply of coal in accordance with boiler demand.
- Coal Mills: For further combustion in the furnace, the coarse coal is ground into a fine powder in a coal mill

The above-mentioned subsystems are conned in the hybrid mode of configuration i.e., the combination of series and parallel configuration. The systems become more complex as it has the dependencies on the performance of all subsystems mentioned. The overall performance thus depends upon the failure and repair rate of all subsystems. Thus, it is necessary to optimize these failure and rapier rates so that the overall performance can be enhanced in terms of performability. Based upon the severity of failure and performance, the critical subsystems can be identified, which will be further provided with better maintenance policies and procedures. It will the maintenance engineers to make better strategies for repairs for the overall system.

3. Petri Nets Modelling

Petri Nets Modelling of Coal Handling System: The performability and long-term availability, of the various subsystems of the Coal Handling System of a coal-operated thermal power plant, has been assessed in this section. The numerous input values, including FRR for different subsystems, were taken from repair and maintenance manuals with the help of maintenance

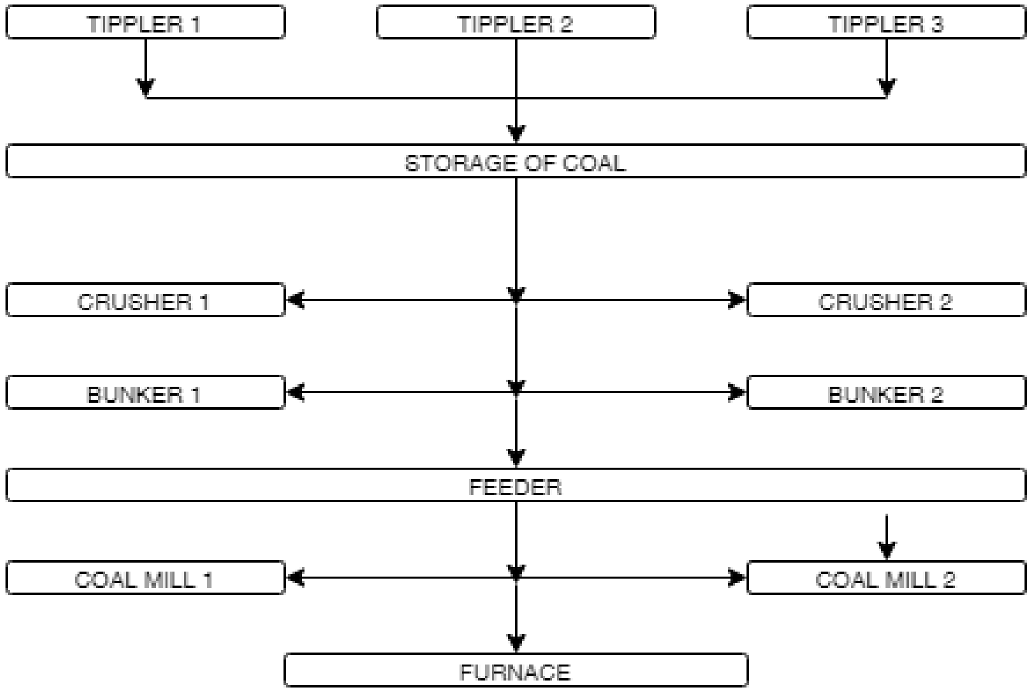

Figure 1: *Illustrative Diagram of Coal Handling System of Thermal Power Plant*

staff and supervisors. The Weibull distribution pattern was intended to be followed by the Failure and Repair Rates. The performance modelling of the coal handling system, which utilised the MOCA-Computation engine based on the Monte Carlo Simulation Approach, was done using the stochastic Petri nets technique (SPN) shown in fig.2. Using simulation for 10000 hours with 21000 replications and a 95 confidence level, the characteristics of plant behaviour were determined. By adjusting Failure and Repair Rates (FRR) within acceptable ranges while doing performance modelling of the plant, it is possible to determine the long-term availability of the various subsystems. the MATLAB program-generated charts for the performability matrices of the Coal Handling System's subsystems. Figures 3 to 7 display the performability w.r.t. FRR for different Coal Handling System subsystems, and tables 1 to 5 display the performability matrices.

Assumptions Notations: The Petri Nets were used for performability analysis, with the following notations and presumptions:

- The failure and repair rates of different subsystems of thermal power plant are exponentially dispersed.
- Single subsystem failures happened one at a time.
- Repaired devices work just as well as brand-new ones.
- Repair includes both component replacement and repair.
- There won't be any instances of two or more subsystems failing simultaneously.
- Standby systems are similar in nature comparable to active systems.
- Over time, the failure rate and repair rate patterns will be stable and statistically independent.

Places: in the petri nets are represented by the circles P = {P1 P2 P3 P4 P5. . . . . . Pn} is a non-empty finite set of places. Each place could be vacant or only store a certain number of tokens. A Petri net's state can be determined via the number of tokens it hold, often known as marking the net.

sys_available: indicates the upstate of the entire system, meaning that it is ready for use.

sys.works_full cap.: depicts the state of the entire system when it is operating at maximum efficiency.

sys.works_red.cap: indicates a system that is operating at a decreased capacity.

sys_failed: depicts the system's downstate

rep.facilities_available: indicates a facility for quick repairs.

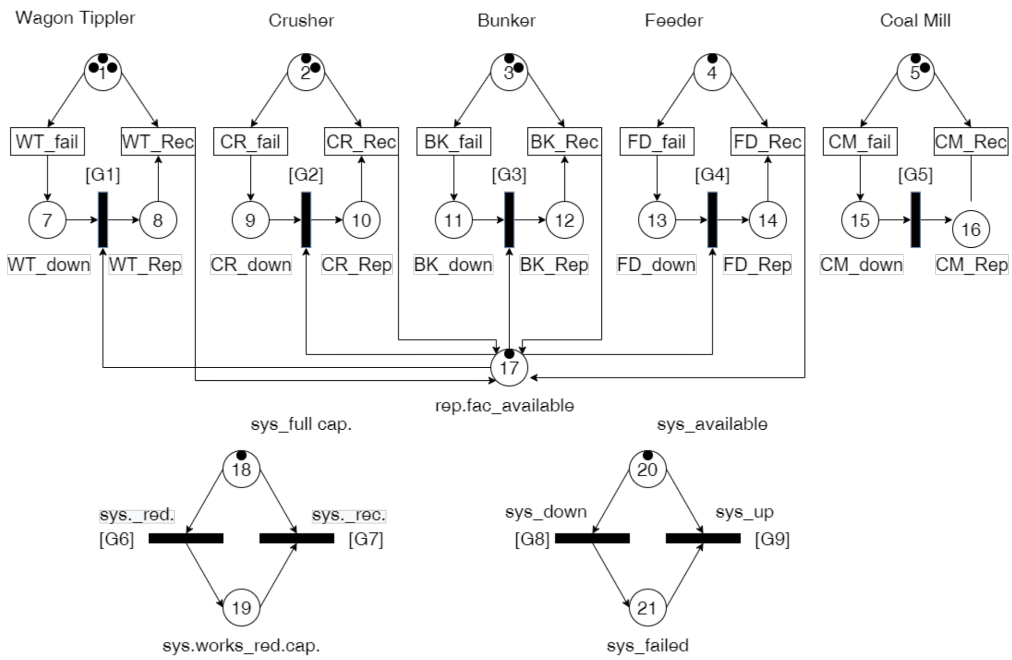

Figure 2: *Modelling of Coal Handling System of Thermal Power Plant Using Petri Nets*

WT_up, CR_up, BK_up, FD_up, CM_up: reflect the operational condition i.e., working state of Wagon Tipplers, Crushers, Bunkers, Feeders and Coal Mills.

WT_down, CR_down, BK_down, FD_down, CM_down: symbolises a state of inefficiency i.e., non-working state of Wagon Tipplers, Crushers, Bunkers, Feeders and Coal Mills.

WT_Rep, CR_Rep, BK_Rep, FD_Rep, CM_Rep: indicates restored conditions of Wagon Tipplers, Crushers, Bunkers, Feeders and Coal Mills.

Transitions: Firing of transitions means occurring of events. Transition fired only if it has at least one token in every location connected to it as an input. These are represented by black or white bars transition T = {T1 T2 T3 T4 T5. . . . Tn,} is a non-empty finite set of transitions. These transitions fired according some predefined sets of rules are known as guard functions. when a transition fires it removes one token from each of its input places and produces a single token on each of its output places. These are of two types timed and direct transitions. Timid transitions fired with some predefined delay. Similarly, the direct transitions fired at once without any kind of time delay. The various transitions used during the performance modelling of coal handling system are as follows:

WT_fail, CR_fail, BK_fail, FD_fail, CM_fail: depict timid transitions linked to failure patterns of Wagon Tipplers, Crushers, Bunkers, Feeders and Coal Mills.

WT_OK, CR_OK, BK_OK, FD_OK, CM_OK: indicates timid transitions that are linked to the failure pattern of waggon tippers., Crushers, Bunkers, Feeders and Coal Mills.

rep. avail_ WT, rep. avail_ CR, rep. avail_ BK rep. avail_ FD, rep. avail_CM: are the immediate transitions indicative of the presence of facilities for repair Wagon Tipplers, Crushers, Bunkers, Feeders and Coal Mills respectively.

sys_ red, sys_ recovered, sys_ fail, and sys_ ok: are immediate transitions which fired immediately without any delay.

Guard Functions: The guard functions, often referred to as enabling functions, are Boolean expressions built using PN primitives (places, transitions, tokens). In addition to the usual requirements, the enabling function must evaluate to true, which modifies the enabling rule. Below is a description of the guard functions related to various transitions.:

[G1]: = (#7>0 and #17>0) **rep. avail_ WT** transition was started via this guard function.

[G2]: = (#9>0 and #17>0) **rep. avail_ CR** transition was started via this guard function.

[G3]: = (#11>0 and #17>0) **rep. avail_ BK** transition was started via this guard function.
[G4]: = (#13>0 and #17>0) **rep. avail_ FD** transition was started via this guard function.
[G5]: = (#15>0 and #17>0) **rep. avail_ CM** transition was started via this guard function.
[G6]: = #2<3 and #2>0 or #3<3 and #3>0 or #5<3 and #5>0) **sys_ red** transition was started via this guard function.
[G7]: =(#2>2and#3>2and#5>2) blocks transition from firing **sys_ recovered.**
[G8]: = (#1>0 or #2>0, or #2>3, or #4>0, or #5>0) **sys_ fail** transition was started via this guard function.
[G9]: = (#1>0 and #2>0, and #2>3, and #4>0, and #5>0) blocks transition from firing **sys_ ok.**

4. Results and Discussion

Table 1: *Performability-Matrix for Wagon Tippler of Coal Handling System*

	Performability Matrix						
$\Phi 1$ $\rho 1$	0.02	0.03	0.04	0.05	0.06	Const. Parameters	
0.0045	0.8133	0.8613	0.8848	0.8932	0.8999		
0.0065	0.7534	0.8342	0.8662	0.8794	0.8839	$\rho 2 = 0.0075$	$\Phi 2 = 0.12$
0.0085	0.6854	0.7968	0.8532	0.8669	0.8794	$\rho 3 = 0.0125$	$\Phi 3 = 0.26$
0.0105	0.6320	0.7623	0.8301	0.8526	0.8734	$\rho 4 = 0.00025$	$\Phi 4 = 0.0075$
0.0125	0.5573	0.7285	0.8030	0.8412	0.8634	$\rho 5 = 0.0004$	$\Phi 5 = 0.005$

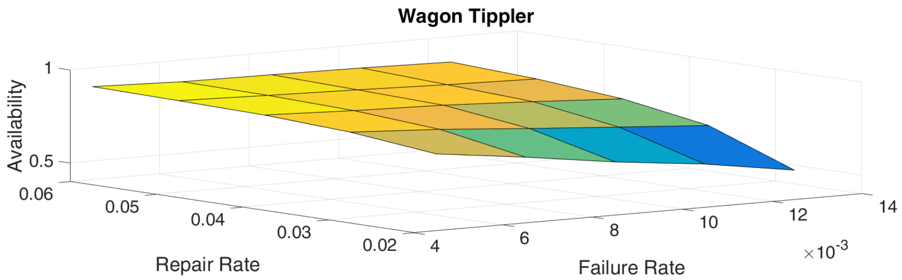

Figure 3: *Impact of varying FRR of Wagon Tippler on the Performability of Coal Handling System*

The effects of variations in the FRR on the performance levels of the waggon tipper (WT) of the coal handling system are shown in Table 1 and Figure 3. Maintaining the repair rate at 0.02, as the failure rate ($\phi 1$) of the WT grows from 0.0045 to 0.0125, and the system's performance severely declines from 0.8133 to 0.5573, or 25.06 %. Similar to this, by maintaining the Failure Rate at 0.0125 while the Repair Rate ($\rho 1$) rises from 0.02 to 0.06, the System's Performability increases immediately from 0.5573 to 0.8634, or by 30.61 %. With variations in FRR combinations, the overall availability of a subsystem can vary by up to 34.26 %.

Table 2: *Performability-Matrix for Crushers of Coal Handling System*

	Performability Matrix						
Φ2 ρ2	0.02	0.07	0.12	0.17	0.22	Const. Parameters	
0.0035	0.7626	0.8532	0.8643	0.8673	0.8707		
0.0055	0.7050	0.8375	0.8555	0.8556	0.8581	$\rho 1 = 0.0085$	$\Phi 1 = 0.040$
0.0075	0.6461	0.8270	0.8532	0.8489	0.8565	$\rho 3 = 0.0125$	$\Phi 3 = 0.26$
0.0095	0.5661	0.8229	0.8388	0.8449	0.8527	$\rho 4 = 0.00025$	$\Phi 4 = 0.0075$
0.0115	0.5140	0.7993	0.8310	0.8377	0.8456	$\rho 5 = 0.0004$	$\Phi 5 = 0.005$

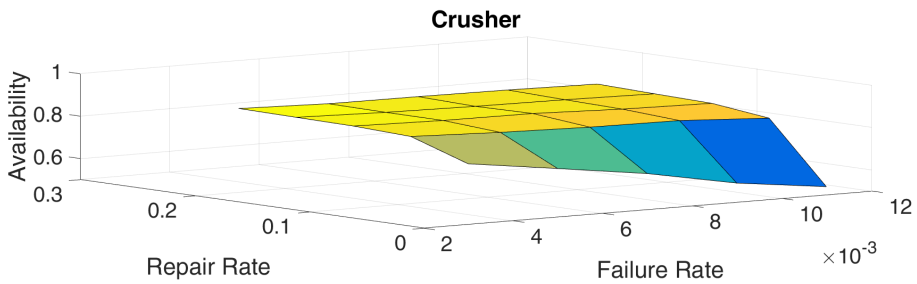

Figure 4: *Impact of varying FRR of Crushers on the Performability of Coal Handling System*

The performance of the Crusher (subsystem) of the coal handling system is affected by variations in the FRR, as shown in Table 2 and Figure 4. The performability levels obtained show that there is a significant impact of FRR fluctuation on the subsystem's performability. The Crusher's failure rate ($\phi 2$) ranges from 0.0035 to 0.0115, keeping Repair Rate of 0.02 causes the Crusher's performability levels to drop significantly, from 0.7626 to 0.5140, or 24.86 %. Additionally, the performability levels increase abruptly from 0.5140 to 0.8456, or 33.16 %, when the repair rate ($\rho 2$) varies from 0.02 to 0.22. By using various combinations of FRR, it is possible to identify the total variation of 35.67 % in the subsystem's performability.

Table 3: *Performability-Matrix for Bunkers of Coal Handling System*

	Performability Matrix						
Φ3 ρ3	0.16	0.21	0.26	0.31	0.36	Const. Parameters	
0.0085	0.8591	0.8595	0.8610	0.8630	0.8642		
0.0105	0.8480	0.8545	0.8573	0.8523	0.8594	$\rho 1 = 0.0085$	$\Phi 1 = 0.040$
0.0125	0.8354	0.8467	0.8532	0.8546	0.8517	$\rho 2 = 0.0075$	$\Phi 2 = 0.12$
0.0145	0.8350	0.8390	0.8416	0.8453	0.8431	$\rho 4 = 0.00025$	$\Phi 4 = 0.0075$
0.0165	0.8274	0.8332	0.8413	0.8336	0.8401	$\rho 5 = 0.0004$	$\Phi 5 = 0.005$

Table 3 and Figure 5 indicate the variations in the performability levels of the bunkers (a component of the coal handling system) at various combinations of FRR. According to the performability matrix and plot, the performability dramatically declines from 0.8591 to 0.8274, or 3.17 %, when the failure rate ($\phi 3$) of the Bunker rises from 0.0085 to 0.0165. The performability only rises from 0.8274 to 0.8401, or 1.27 %, with an increase in repair rate ($\rho 3$) from 0.16 to 0.25. Performability with combinations of FRR has been reported to vary by an average of 3.68 %.

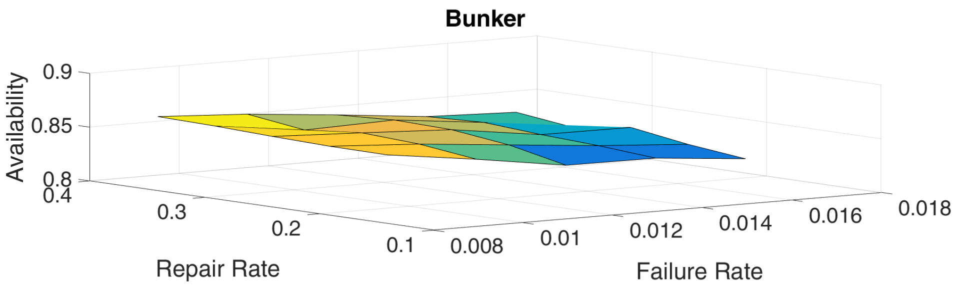

Figure 5: *Impact of varying FRR of Bunkers on the Performability of Coal Handling System*

Table 4: *Performability-Matrix for Feeders of Coal Handling System*

	Performability Matrix					
Φ4 ρ4	0.0015	0.0045	0.0075	0.0105	0.0135	Const. Parameters
0.00005	0.8528	0.8744	0.8808	0.8835	0.8819	
0.00015	0.7971	0.8548	0.8664	0.8740	0.8805	$\rho1 = 0.0085$ $\Phi1 = 0.040$
0.00025	0.7332	0.8243	0.8532	0.8626	0.8686	$\rho2 = 0.0075$ $\Phi2 = 0.12$
0.00035	0.6804	0.8067	0.8332	0.8493	0.8529	$\rho3 = 0.0125$ $\Phi3 = 0.26$
0.00045	0.6418	0.7861	0.8188	0.8445	0.8495	$\rho5 = 0.0004$ $\Phi5 = 0.005$

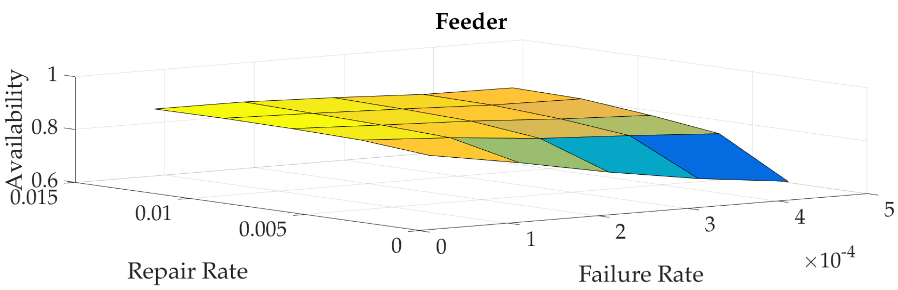

Figure 6: *Impact of varying FRR of Feeders on the Performability of Coal Handling System*

The effects of variations in FRR on the Feeder (subsystem) of the coal handling system are shown in Table 4 and Figure 6. It shows that the performability drops from 0.8528 to 0.6418, or 21.10 %, when the failure rate ($\phi4$) rises from 0.00005 to 0.00045. Similar to this, the performability increases from 0.6418 to 0.8495, or 20.77 %, with variation in repair rate ($\rho4$) from 0.0015 to 0.0135. The entire subsystem performability changes by an outrageous 24.01 %, as observed.

Table 5: *Performability-Matrix for Coal Mills of Coal Handling System*

	Performability Matrix					
Φ5 ρ5	0.0040	0.0045	0.0050	0.0055	0.0060	Const. Parameters
0.00030	0.8464	0.8578	0.8623	0.8665	0.8774	
0.00035	0.8418	0.8490	0.8522	0.8639	0.8635	$\rho1 = 0.010$ $\Phi1 = 0.24$
0.00040	0.8255	0.8409	0.8532	0.8602	0.8640	$\rho2 = 0.00020$ $\Phi2 = 0.0035$
0.00045	0.8150	0.8317	0.8345	0.8493	0.8524	$\rho3 = 0.0011$ $\Phi3 = 0.5$
0.00050	0.8097	0.8208	0.8294	0.8409	0.8427	$\rho4 = 0.075$ $\Phi4 = 0.10$

According to Table 5 and Figure 7, the performability levels of the coal mill (subsystem) of the coal handling system vary significantly. The performability levels considerably drop from 0.8464

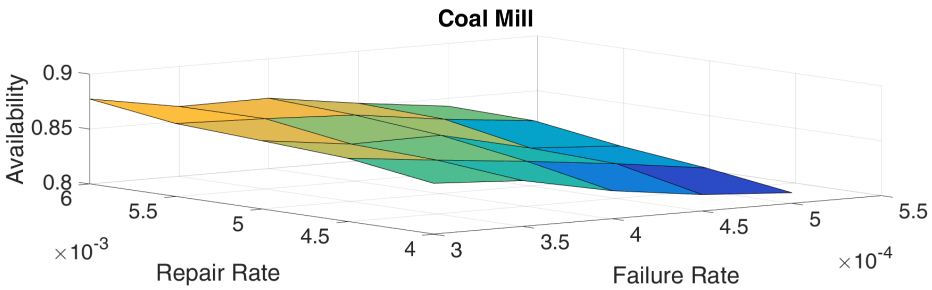

Figure 7: *Impact of varying FRR of Coal Mill on the Performability of Coal Handling System*

to 0.8097, or 3.67 %, when the failure rate of the coal mill ($\phi 5$) rises from 0.00030 to 0.00050. The performability also rises from 0.8097 to 0.8427, or 3.00 %, with an increase in repair rate ($\rho 5$) from 0.0040 to 0.0060. The performability of coal mills has changed by a total of 6.77%.

Table 6: *Variation in the Overall Performability with increase in Repair Facilities*

Availability Matrix					
No. of Repair Facilities	1	2	3	4	5
Availability	0.8532	0.9383	0.9515	0.9446	0.9441

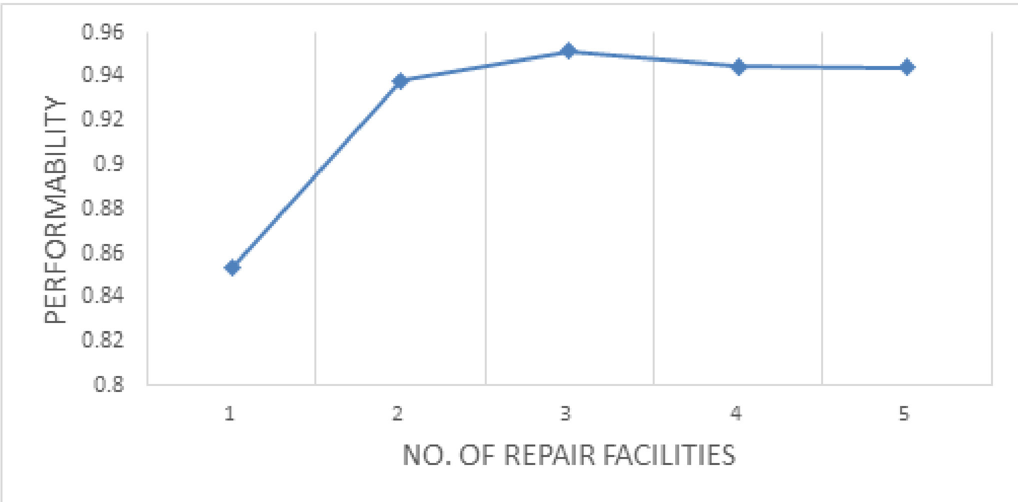

Figure 8: *Impact of variation in Repair Facilities on the Performability of System*

The effect of more repair facilities on the system's overall availability is seen in Table 6 and Fig. 8. The total performability of the coal handling system is seen to dramatically enhance from 0.8532 to 0.9383 as the repair facility grows from 1 to 2. The performability increases noticeably from 0.9383 to 0.9515 when the repair facility is increased from 2 to 3. As the availability goes from three to four and beyond, the performance becomes practically consistent.

5. Optimization Using PSO

The goal of optimization is to identify the best possible solution to a given issue while taking into consideration all of its constraints. In the current study, a population-based global optimisation method known as PSO was used to evaluate the performance of the coal handling system. A stochastic global optimization technique called particle swarm optimization (PSO), proposed by

Eberhart and Kennedy in 1995, was motivated by the social behaviour of fish schools and flocks of birds. The PSO is motivated by swarm behaviour in nature[19, 20, 21, 22]. The movement patterns of several fish and birds served as inspiration for this optimization process. A particle in the swarm is referred to as a bird or a fish. PSO consists of several particles, each of which consists of its current objective value, velocity, and position. Its personal best position, which is the position at which the personal best value has been attained, contrasts with its personal best value, which is the best objective value the particle has ever experienced. The following relations are used by the global best PSO, a common variant of classical PSO, to calculate the ith particle's velocity and position[24].

$$Vi(n+1) = w * Vi(n) + C1(n) * R1i(n) * p - besti - Xi(n) + C2(n) * R2i(n) * g - best - Xi(n) \quad (1)$$

N=0,1,....., N-1

$$Xi(n+1) = Xi(n) + Vi(n+1); n = 0, 1, ..., N-1 \quad (2)$$

where Xi is the position of the ith particle, Vi is its velocity, and n in parentheses is the number of iterations; n = 0 refers to the initialization. N stands for the overall number of iterations, C1 and C2 stand for the personal weight and the global weight, respectively, and they range from 0 to 2 (ideally, C1 = C2 = 2). The random numbers, which are dispersed between 0 and 1, are R1i and R2i. The inertia weight, or w, is a number between 0.4 and 1.4.

Algorithm 1 provides the major steps of the PSO that was implemented also represented in Fig. 9
Steps of the implemented PSO [23]
Repeat
Evaluate z(n, r);
For all particles y Do
Update velocities;
Move to the new position;
If z(n, r) < z(pbesty) then pbesty= (n, r);
If z(n, r) < z(gbest) then gbest= z(n, r);
Update position and velocity;

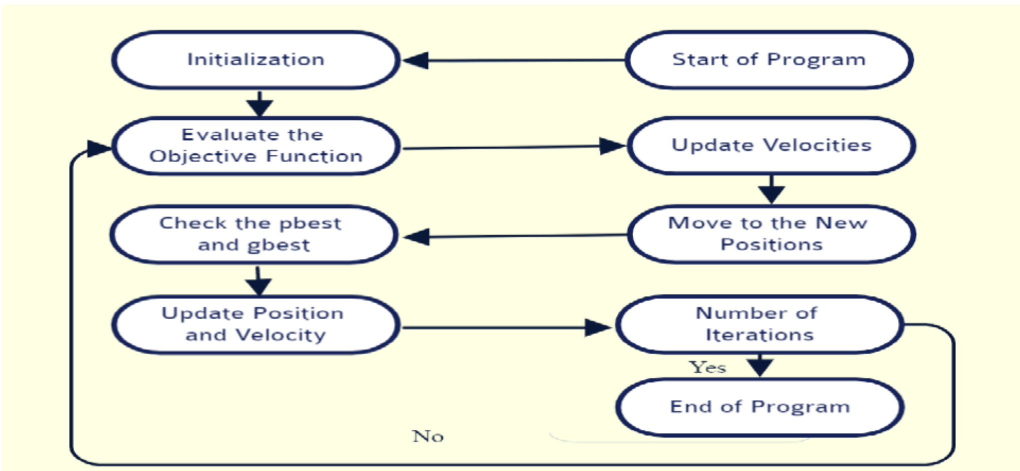

Figure 9: *Flowchart of PSO Implemented*

The following subsection gives more specific results on performance optimization.

Table 7: *Numerous PSO Parameters for Various System*

PSO Parameters			
Sr. No.	Parameter	Range/ Value	Remarks
1	Particle or Population Size	10-100	for optimum Performability
2	Number of Generations	5-50	optimum Performability
3	Inertia Weight (w)	0-1	Its value lies between 0-1
4	Cognitive Factor (c1)	1.49	Selected Arbitrarily
5	Social Factor (c2)	1.49	Selected Arbitrarily
6	Random Number (R1)	0-1	Selected Arbitrarily
7	Random Number (R2)	0-1	Selected Arbitrarily

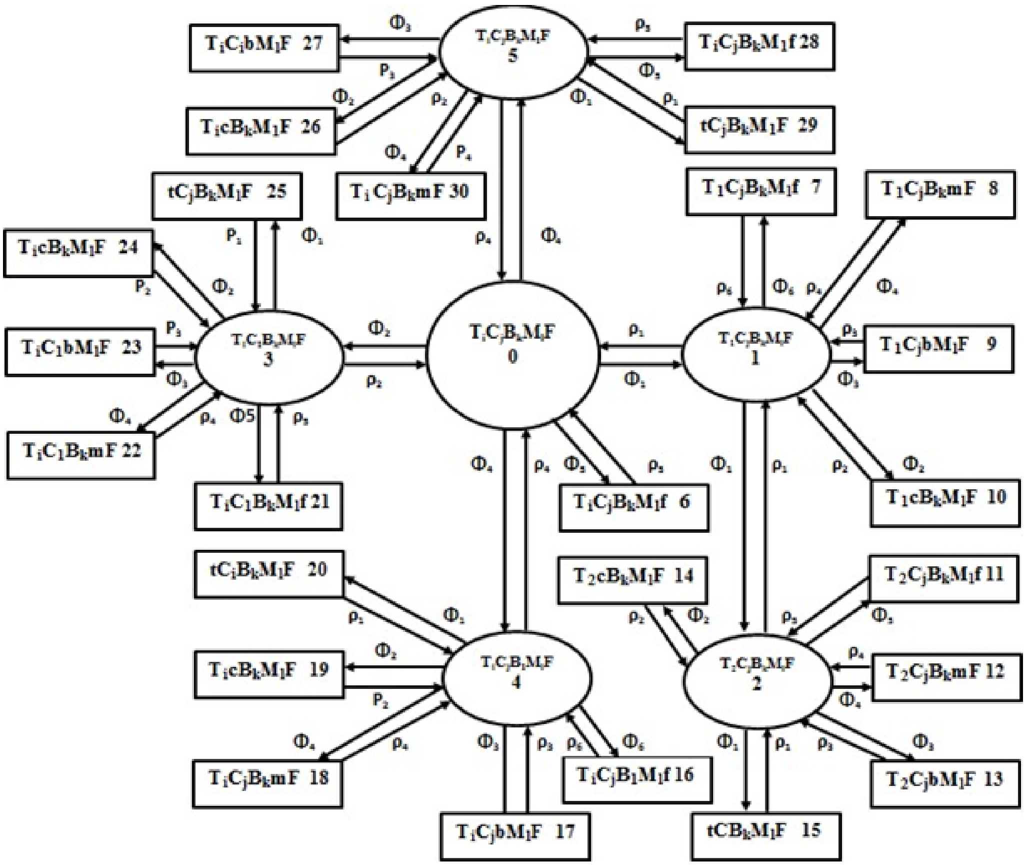

Figure 10: *Transition Diagram for Coal Handling System*

The transition diagram of the coal handling system were obtained as shown in fig. 10. After solving the transition diagram of coal handling system using the Markovian approach the following equation has been obtained for the performance measurement.

$$P0 = 1/[1 + (K1 + K2 + K3 + K4 + K5)(1 + K1 + K1K1 + K2 + K3 + K4)] \quad (3)$$

Where,

Ki = ϕi/ρi

i = 1, 2, 3, 4, 5

By adjusting two factors, PS and the number of generations, the performance was optimised using the aforementioned approach. The following chart illustrates the designed ranges for the failure (ϕ) and repair rate (ρ) parameters of the various subsystems of :

$\phi1$ (0.0045 - 0.0125), $\rho1$ (0.02 - 0.06)- Tippler
$\phi2$ (0.0035-0.0115), $\rho2$(0.02 - 0.22) Crushers
$\phi3$ (0.0085-0.0165), $\rho3$ (0.16-0.36) Bunkers
$\phi4$ (0.00005-0.00045), $\rho4$ (0.0015-0.0135) Feeders
$\phi5$ (0.00030-0.00050), $\rho5$ (0.0040-0.0060) Coal Mill

The optimum performability of the coal handling system achieved is 93.34 % by using the PSO algorithm at a PS of 40 and by taking constant GS i.e. 100. Table 8 gives the appropriate combinations of FRR as $\phi1$ = 0.006, $\phi2$ = 0.007, $\phi3$ = 0.011, $\phi4$ = 0.0002, $\phi5$ = 0.0003, $\rho1$ = 0.07, $\rho2$ = 0.21, $\rho3$ = 0.36, $\rho4$ = 0.006 and $\rho5$ = 0.005. The effect of common parameters like PS at constant GS on the performability of the system is described in Figure 11. The performability levels for coal handling system at PS varied from 5 to 50 in a step of 5 taking constant GS are mentioned in Table 8.

Table 8: *Effect of PS on System Performability at constant GS (100)*

Performability Matrix										
FRR	PS5	PS10	PS15	PS20	PS25	PS30	PS35	PS40	PS45	PS50
$\phi1$ 1	0.008	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
$\phi1$ 2	0.007	0.006	0.006	0.006	0.005	0.006	0.007	0.007	0.007	0.007
$\phi1$ 3	0.012	0.009	0.009	0.009	0.010	0.010	0.011	0.011	0.011	0.011
$\phi1$ 4	0.0003	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
$\phi1$ 5	0.0004	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
$\rho1$	0.06	0.07	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07
$\rho2$	0.10	0.15	0.15	0.15	0.15	0.15	0.20	0.21	0.20	0.20
$\rho3$	0.33	0.25	0.25	0.25	0.25	0.26	0.35	0.36	0.36	0.36
$\rho4$	0.007	0.009	0.009	0.009	0.009	0.009	0.006	0.006	0.006	0.006
$\rho5$	0.006	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
PA	90.19	92.40	92.41	92.40	92.42	92.46	93.10	93.34	93.22	93.21

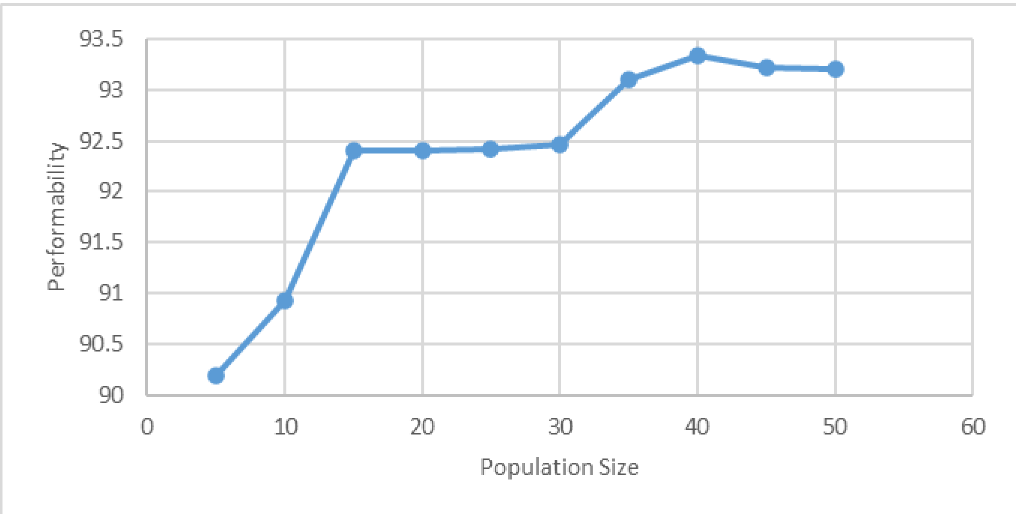

Figure 11: *Effect of PS on System Performability*

The optimum performability of coal ash handling attained is 93.32 % by using the PSO algorithm at a GS of 70 and by taking constant PS i.e. 40. Table 9 offers the appropriate combinations of FRR as ϕ 1 = 0.006, $\phi2$ = 0.007, $\phi3$ = 0.011, $\phi4$ = 0.0002, $\phi5$ = 0.0003, $\rho1$ = 0.07, $\rho2$ = 0.21, $\rho3$ = 0.36, $\rho4$ = 0.006 and $\rho5$ = 0.005. The effect of common parameters like PS at constant

GS is indicated in Figure 12. The performability levels for power generation system at GS varied from 10 to 100 in a step of 10 taking constant PS are given in Table 9.

Table 9: *Effect of GS on System Performability at constant PS (40)*

Performability Matrix										
FRR	GS10	GS20	GS30	GS40	GS50	GS60	GS70	GS80	GS90	GS100
$\phi 1$ 1	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
$\phi 1$ 2	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
$\phi 1$ 3	0.012	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
$\phi 1$ 4	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
$\phi 1$ 5	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
$\rho 1$	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
$\rho 2$	0.20	0.20	0.21	0.20	0.21	0.21	0.21	0.21	0.21	0.21
$\rho 3$	0.34	0.35	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
$\rho 4$	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
$\rho 5$	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
PA	91.70	93.03	93.09	93.16	93.20	93.26	93.32	93.23	93.21	93.13

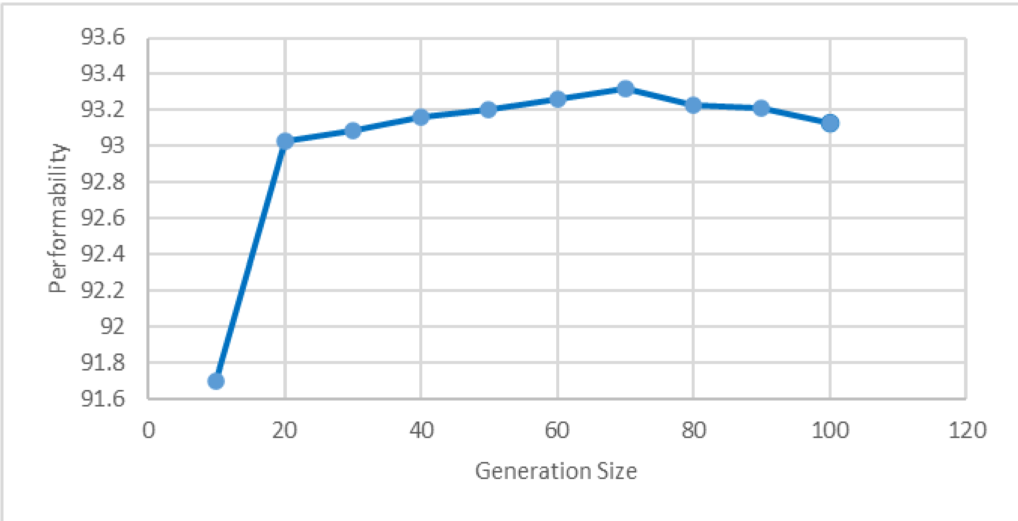

Figure 12: *Effect of GS on System Performability*

Table 10: *Effect of PS on System Performability at constant GS (100)*

Decision Support System				
Subsystem	Variation in FR (ϕ)	Variation in RR (ρ)	Change in Availability	Priority
Tippler	0.0045- 0.0125	0.02- 0.06	55.7 to 89.99	2
Crusher	0.0035- 0.0115	0.02 -0.22	51.40 to 87.07	1
Bunker	0.0085- 0.0165	0.16 -0.36	82.7 to 86.42	5
Feeder	0.00005- 0.00045	0.0015 -0.0135	64.1 to 88.19	3
Coal Mill	0.00030- 0.00050	0.0040 -0.0060	80.97 to 87.74	4

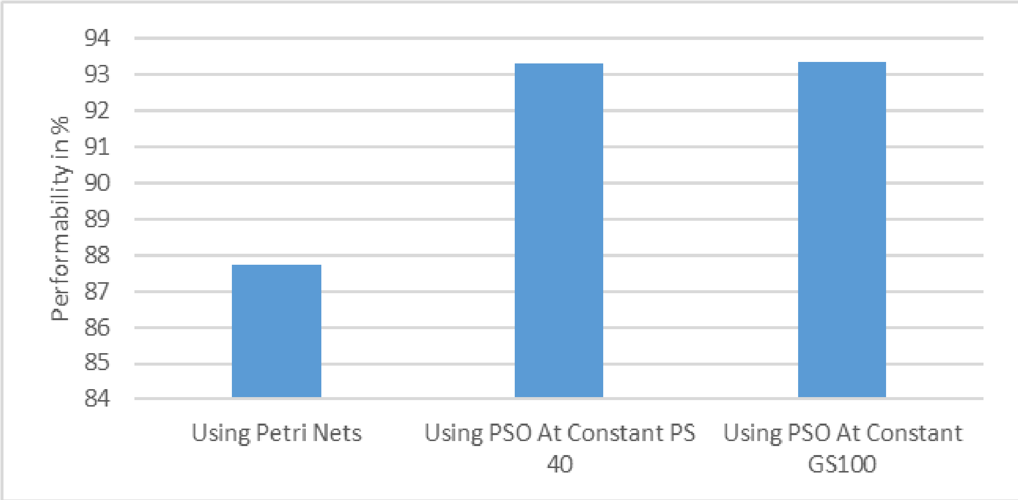

Figure 13: *Comparative Analysis of Performability Levels using Petri Nets and PSO*

6. Conclusion

The analytical identification of the most important subsystems is one of the key conclusions of present case study's . Due to the high risk of failure, these subsystems should be given top priority during maintenance. It is observed that the Crusher and Tippler are crucial components that demand the plant manager's full attention. As a result, the concerned plant authorities can develop and implement suitable maintenance plans to enhance system functionality. A DSS has been suggested (in Table 10) to help the plant managers, based on a thorough analysis, and is likely to increase efficiency even more. Due to the resources available and the maintenance planning techniques being used, managing the maintenance of industrial systems that can be repaired is a very difficult task. This approach also establishes a trade-off between financial investments and benefits earned in terms of revenue, reputation, safety, etc. The best value of the system performability obtained by PSO as shown in fig. 13 reveal that the PSO has outperformed the Petri Nets.

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