System Availability Assessment and Optimization of Repairable Cooling Module of HVAC System using PSO Algorithm

Rajneesh Chaudhary, P.C. Tewari, Vikas Modgil

Research Scholar, Department of Mechanical Engineering, NIT, Kurukshetra Haryana, India
Department of Mechanical Engineering, NIT, Kurukshetra, Haryana, India
Department of Mechanical Engineering, DCRUST, Haryana, India

Abstract. Availability is the main scope of system execution under the explicit states of working. Any mechanical system contains subsystems orchestrated in arrangement, parallel or half and half setup of the subsystems. Along these lines, the concern for achieving higher availability in manufacturing activities has a significant role. In the proposed research work deals with numerical and simulation modeling of condenser manufacturing system along with its subsystems. These numerical equations are solved by using the Markov Model (MM) with normalizing conditions. Also, the study has attempted to present an effective tool for improving the quality of condenser manifold assembly by executing a meta-heuristic algorithm i.e. Particle Swarm Optimization (PSO). The performances of each subsystem are analyzed by its Failure Rate (FR) and Repair Rate (RR), the optimal FR and RR is achieved by the proposed PSO algorithm and its efficiency is compared with the existing algorithm.

Keywords: Manifold Assembly, Condenser, Markov Model, PSO, Availability, FR and RR

1. Introduction

With the advancement in today’s competitive world, organizations are changed consistently. Such changes and dynamic conditions which are influenced by innovative, financial, political, and different issues make new and vulnerable opportunities for production units [1]. Among the production industries, the manufacturing industry is presented to more threats with higher coefficients in their procedures [2]. In the manufacturing industry, items from changing over raw materials until the point that the last packing might be influenced by different hazard factors that prompted delivering dangerous items which can influence customers' health and have unsalvable monetary ramifications for the material production industry [3-5]. Long-run accessibility, as well as reliability of the framework, causes the administration to comprehend the impacts of change in the failure or repair rates of the parts in a framework [6]. With the expansion in the unpredictability of the framework, high reliability can be acquired either by giving adequate excess parts or by expanding the capacity of the system [7]. In the present work, we embrace manufacturing of manifold assembly for Condenser which involves vast complex building units orchestrated in arrangement [8], parallel or a mix of both the setups. A portion of these units is fryer, seasoning machine, heat exchanger, infeed transport, x-ray machine and so forth [9]. These units are organized in series as well as parallel or blend of both. The focal point of research work is to create availability model dependent on failure and repair rate by utilizing numerical methodology.

In the present work an attempt has been made to evaluate, analyze and optimize availability of automobile HVAC manufacturing system of the plan situated in Bhiwari, Haryana, India. The cooling
module is made up of three parts: Radiator, Condenser and Cooling Fan, we have considered the condenser part.

The upcoming section is structured as follows: Subsequent to this introduction section, section 2 presents the review of existing literature related to the manufacturing industry and its failure rates. Section 3 depicts the methodology portion which briefly explains the system description, mathematical modeling of the system. Section 4 analyzes the result of the performance of the proposed system. Finally, section 5 concludes the proposed model along with its future scope.

2. Literature Review

With respect to developing populace and expanding urbanization, it is of high significance to address this issue. The expanding request, particularly for dairy and meat items, prompts the need of an ascent in production from 60 to 110% by 2050 Schneider, F., 2013 [10]. The decrease of production losses in the manufacturing industry can prompt a lower use of crude materials, lessen the processing of material and enhance the nature of the item, researched by Guiseppe et al., 2014 [11]. Rakesh, Jos, and Mathew, 2013 [12] presented FMEA as a steady instrument for originators; it has been broadly utilized in a wide scope of industries. A standout amongst the most imperative utilizations of this procedure is in the material manufacturing industry. In any case, because of the referenced constraints of FMEA in the past segment, a few specialists, in specific Rezaee et al., 2018 [13] have consolidated FMEA method with Multi-Criteria Decision Making (MCDM) strategies to enhance the way toward deciding, investigating and diminishing the failures in industries. Yang, J., et al. 2011 [14] embraced the altered Dempster–Shafer procedure to total the diverse assessment data by considering different specialists' assessment conclusions, failure modes, and three hazard factors individually. At long last, this technique is utilized to manage the risk priority assessment of the failed methods of rotor cutting edges of an aircraft turbine under various sources of unverifiable assessment data. The result of this technique is discerning and effective. Enitan, A.M. and, Adeyemo, J., 2011 [15] and Wari, E., and Zhu, [16] compared the exhibitions of various sorts of evolutionary algorithm systems and recommended further territories of utilization of the methods in material processing optimization. From the reviewed literature, it is evident that some researches on failure modes analysis of assembling industry have been done by previous researchers. For analyzing the performance such as system availability and reliability of the condenser manufacturing industry, a mathematical model is presented in this paper. Also, the failure rates are accurately examined by the inclusion of optimization techniques in the prediction process.

3. Methodology

The methodology deals with the performance modeling and availability analysis of manufacturing condenser system. This system consists of six sub-systems. By considering the exponential dissemination of FR and RR of sub-frameworks, the mathematical formulation of the model is produced with the utilization of mnemonic rule for these six sub-frameworks and Chapman-Kolmogorov differential conditions are gotten from the progress outline. The scientific model of assembly area has been produced based on probabilistic methodology utilizing Markov model. At long last, the execution of each sub-system of the framework has been enhanced and dissected for choosing the most optimal subsystems in the plant by utilizing simulation modeling. Here, PSO is utilized to choose the optimal availability of the framework.

3.1 System modeling

The process flow diagram of an assembly section of the condenser is shown in figure 1. It consists of six subsystems as described below:
In subsystem 1, failure of anyone does not affect the system, if both machines failed then the whole system completely failed. In subsystem 2, the furnace divided into 3 zones for fluxing and bracing. In subsystem 2 and 3, failures of this processing in machine cause complete failure of the system. In subsystem 4, TIG Welding (TW) is done after Air Leak Testing (ALT). The complete failure of this subsystem causes the failure of the system. In subsystem 5, the failure of any one causes reduced capacity state. If the failure of the system happens, both of machines are failed. In subsystem 6, failure of the processing cause complete system failure.

3.2 Modeling procedure
The production system is made out of production forms that convert a lot of contributions to some ideal output. Likewise, every production procedure is made out of sub-forms. In this examination, new modeling approach i.e. Markov model and simulation for determining the availability of a production framework is proposed by considering every component of the framework and their importance in the framework structure [19].

3.2.1 Markov Model. The methodology for deciding the availability of the framework depends on Markov Modeling. The FR of the distinctive subcomponents of the system is taken as consistent while their fix times are self-assertively disseminated. To examine Markov process, differential conditions are effectively gotten from the Transition Diagram (TD) as most extreme execution and in this way, for that, an optimization method is connected on the system availability model over scope of unknown factors. The relating TD of included states appears in Figure 1.
Figure 1. Transition diagram of a condenser manufacturing system

Notations and Declaration of variables used in TD

The notions associated with the TD shown in Figure 1 are as follows:

- Prescribes the full, reduced and failed state capacity of the system

Declaration of variables

- $C, B, L, T, H, F$: Subsystem in the operating state
- $c, b, l, t, h, f$: Failed state of $C, B, L, T, H, F$
- $\alpha_i, \mu_i$: Mean FR & RR of $C, B, L, T$ and $H, F$
- $C_0$: The probability of the system in working with full capacity at time $z$
- $\frac{d}{dz}$: Derivatives with respect to $z$

The MM considers states and transitions where states speak to the conceivable states of the system that can be depicted as failed or good by the disappointment of every segment. The differential conditions related with the TD, are inferred based on Markov birth-death process. Different probability contemplations create the accompanying arrangements of differential conditions:

\[
C_0'(z) + \sum_{i=1}^{N} \alpha_i C_0(z) = \mu_1 C_1(z) + \mu_2 C_8(z) + \mu_3 C_9(z) + \mu_4 C_2(z) + \mu_5 C_3(z) + \mu_6 C_{10}(z) \tag{1}
\]

\[
C_1'(z) + \sum_{i=2}^{N} \alpha_i C_1(z) = \mu_2 C_{12}(z) + \mu_3 C_{13}(z) + \mu_6 C_{14}(z) + \lambda_1 C_0(z) + \mu_4 C_4(z) + \mu_5 C_5(z) + \mu_7 C_{11}(z) \tag{2}
\]
These equations are settled for portraying the steady-state availability of the System. Different Chapman–Kolmogorov differential conditions are as per the following:

**Initial condition at time** \( z = 0 \)

\[
C_i(z) = \begin{cases} 
1 & \text{for } i = 0 \\
0 & \text{for } i \neq 0 
\end{cases}
\]

**Availability** \( (Av) \Rightarrow \sum_{i=0}^{7} C_i \)

\[
A_v = C_0(1 + [M_0 + M_{10} + M_{11} + M_{12} + M_{13} + M_{14} + M_{15}])
\]

The final equation (15) indicates the availability of the manifold assembly of the condenser system in the Markov model. Since the quantity of failures does not consider the distinctions in downtime of each failure, we recommend that amplifying availability additionally be viewed as production system of a condenser utilizing simulation modeling.

**3.2.2 Optimizing the Parameters Using PSO Model**

Simulation is entirely adaptable and can be utilized freely of the model size and the utilized disseminations. There are different methodologies, for example, heuristic or meta-heuristic algorithms to decide the optimal parameters of segments. By upgrading FR and RR for each subsystem gives an
optimal value to create an optimal availability of the system. Contrasted with GA, the merits of PSO are that PSO is easy to actualize and there are couples of parameters to modify. PSO has been effectively connected in numerous regions: function optimization, network training, system control, and different regions

Particle Swarm Optimization (PSO): PSO is a meta-heuristic global optimization technique and it is inspired by the behavior of swarm intelligence, depends on the research of bird as well as fish flock movement behavior. Every particle flies in the search space with a velocity adjusted by its own flying recognition and the flying knowledge of its accompanying person in the PSO. Every particle possesses a key function value which is evaluated by a fitness function.

The Implementation Procedure of PSO Algorithm

Particle Swarm Optimization (PSO): PSO is an evolutionary computation technique initially created by Kennedy and Eberhart (1995). PSO is a meta-heuristic global optimization technique and it is inspired by the behavior of swarm intelligence, depends on the research of bird as well as fish flock movement behavior. The algorithm keeps up a population of particles, where every particle speaks to a potential solution for an optimization problem. Every particle flies in the search space with a velocity adjusted by its own flying recognition and the flying knowledge of its accompanying person in the PSO. Every particle possesses a key function value which is evaluated by a fitness function. Every particle monitors its directions in the problem space, which are related with the best solution (fitness) it has accomplished up until this point. This esteem is called particle best. Another best esteem that is followed by the global rendition of the swarm is the general best esteem, and its location acquired so far by any particle in the population. This location is called global best.

The implementation process involves five stages, namely initialization, fitness evaluation, Position_best and Global_best calculation, position and velocity updating and termination criteria. The overall process is shown in below flowchart (figure 2)

![Flowchart for PSO](image)

**Figure 2.** Flowchart for PSO

**Initialization of PSO Algorithm:** Initialize the particles with random positions and their corresponding velocities. Here, the purpose of proposed PSO is to optimize the Failure Rate (FR) and Repair Rate (RR) of every subsystem of the condenser.

\[
FR_1, FR_2, \ldots, FR_n
\]

\[
RR_1, RR_2, \ldots, RR_n
\]

Where, the value of \(i\) ranges from 1, 2, 3…n.

**Fitness function:** The fitness function of the PSO algorithm is calculated based on the objective function of the research work. Here, the contribution of optimization is to attain an optimal value of both FR and RR from the given set of values.

**Fitness Function** = \(\text{Opt}_{\text{Rates}}(FR, RR)\)

\[
(18)
\]
Calculate $\text{Position}_\text{best}$ and $\text{Global}_\text{best}$: At the beginning, the fitness value is approximately determined for each and every particle. The optimal one is elected as $\text{Global}_\text{best}$ and $\text{Position}_\text{best}$ value among the fitness value. Subsequent to that iteration, the current optimal fitness value is selected as $\text{Position}_\text{best}$ and the overall best fitness value chosen as the $\text{Global}_\text{best}$. Compare fitness value of particle with its $\text{Position}_\text{best}$, if the current value is better then set $\text{Position}_\text{best}$ equal to the current value. The particles change its condition as indicated by the accompanying three standards: (i) To keep its latency. (ii) To change the condition as per its most confident optimist position. (iii) To change the condition as per the swarm’s most self assured optimist.

Update the velocity and position: The formulation for updating the velocity and position of the particles in the original PSO is given as:

$$v_i(t+1) = v_i(t) + b_1 \text{rand} (\text{Position}_\text{best}(t) - r_i(t)) + b_2 \text{rand}(\text{Global}_\text{best} - r_i(t)) \tag{19}$$

$$r_i(t+1) = r_i(t) + v_i(t+1) \tag{20}$$

Where, $v_i$ is the particle velocity, $r_i$ is the current position of a particle, rand is a random number between (0, 1), $b_1, b_2$ are learning factor, usually $b_1 = b_2 = 2$. According to the update procedure on (41), the $i^{th}$ particle position is directed by the position of the global best solution and position best solution. Then, find the fitness for a new updated solution.

Termination Criteria: Check the new optimal value solution. If the desired optimum value is reached, then stop the procedure of PSO; otherwise repeat the process from fitness evaluation.

Case study: In this case study, we gathered data from Hanon Climate Systems India Private Limited; it is a Private consolidated on 06 December 1991. It is involved in the manufacture of parts & accessories for engine vehicles and their motors [brakes, outfit boxes, axles, street wheels, suspension safeguards, radiators, silencers, fumes channels, directing wheels, guiding sections and controlling boxes and different parts and extras].

4. Result and Discussion

The numerical modeling is carried out in the working platform of MATLAB 2016a with the system configuration, i5 processors with 4GB RAM. The modeling for the condenser manufacturing process is prepared by MM Process using probabilistic approach and differential equations related to transition diagram. The optimization of the proposed system (MM-PSO) is highly influenced by the FR and RR of each subsystem. The validating result is shown below:
Validation results

| FF & RR   | No. of population |
|-----------|-------------------|
|           | 10                | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| a1        | 0.096291          | 0.039363 | 0.078018 | 0.109213 | 0.114775 | 0.0983374 | 0.058905 | 0.039171 | 0.086207 |
| a2        | 0.048767          | 0.060239 | 0.043649 | 0.041738 | 0.045381 | 0.0433645 | 0.047538 | 0.102104 | 0.073222 |
| a3        | 0.006048          | 0.005521 | 0.005018 | 0.005117 | 0.008616 | 0.0052532 | 0.005323 | 0.008419 | 0.006632 |
| a4        | 0.003115          | 0.003111 | 0.003111 | 0.002614 | 0.002859 | 0.0026887 | 0.004775 | 0.003536 | 0.005975 |
| a5        | 0.013423          | 0.008338 | 0.008151 | 0.007167 | 0.022659 | 0.0179384 | 0.026815 | 0.13849  | 0.066215 |
| a6        | 0.013527          | 0.015655 | 0.016659 | 0.011525 | 0.012703 | 0.0827337 | 0.080465 | 0.041189 | 0.119117 |
| a7        | 0.028036          | 0.025625 | 0.03102  | 0.026484 | 0.054808 | 0.0356543 | 0.024279 | 0.028355 | 0.069488 |
| b1        | 0.147281          | 0.79179  | 0.209084 | 1.049958 | 0.152667 | 0.7032798 | 0.591533 | 0.578047 | 1.001541 |
| b2        | 1.043134          | 0.920768 | 1.03618  | 0.770136 | 0.959382 | 0.9187018 | 0.608829 | 0.401272 | 0.948072 |
| b3        | 0.909108          | 0.710968 | 0.728489 | 0.883571 | 0.878037 | 0.8984738 | 0.690198 | 0.768358 | 0.552648 |
| b4        | 0.57301           | 0.59351  | 0.595376 | 0.662613 | 0.478829 | 0.5685256 | 0.658627 | 0.426831 | 0.63982 |
| b5        | 1.035059          | 1.300157 | 1.006014 | 0.705602 | 0.895535 | 1.3132066 | 1.180926 | 1.125744 | 1.146251 |
| b6        | 1.023342          | 1.127592 | 1.035164 | 1.233847 | 1.135325 | 1.0784481 | 0.614932 | 0.877931 | 0.899373 |
| b7        | 0.764651          | 0.668805 | 0.813832 | 0.760902 | 0.682938 | 0.7496739 | 0.636036 | 0.774403 | 0.594341 |
| Availability | 0.76664          | 0.70088  | 0.95276  | 0.96612  | 0.91544  | 0.86183  | 0.73732  | 0.55099  | 0.93951  |

Table 1 presents the results of simulation modeling, which is implemented in MATLAB software. Table 8 shows the proposed results i.e. the availability of using PSO algorithm. The availability is performed based on a number of iterations.

![Figure 3](https://example.com/f3.png)

**Figure 3.** Fitness evaluation by varying iteration a) Subsystem 1 (b) Subsystem 2 (c) Subsystem 3 (d) Subsystem 4 (e) Subsystem 5 (f) Subsystem 6 (g) Subsystem 7
Figure 3 presents the fitness evaluation graph that is implemented in MATLAB programming. The main objective of our optimization technique is finding the optimal FR and RR. The optimal FR and RR produces optimal fitness function. In simulation, modeling fitness is evaluated for increasing iterations. Availability is analyzed by varying iterations like 20 to 200, here, we compare the proposed PSO into existing Genetic Algorithm (GA). Similarly, our manufacturing MAC model reaches optimal availability in 180th to 200th iterations. It receives the availability of above 0.756 to 0.996 in PSO, but in GA perceives the range of 0.654 to 0.864. Compared to the result of each iteration, PSO performs maximum fitness value than GA.

Figure 4 represents the availability comparison for all the subsystem based on various techniques.

Figure 4. Availability comparison for all the subsystem based on various techniques

Figure 4 represents the comparison chart for availability which compares the proposed model (MM with PSO) into existing models (MM, and MM with GA). For every subsystem (subsystem 1 to subsystem 7) the proposed MM with PSO reaches the optimal FR and RR which enables maximum availability in MAC.

5. Conclusion

In the proposed novel study, we analyze the availability of manifold assembly of condenser manufacture in manufacturing plant using MM approach and PSO. The result revealed that increase in FR minimized the availability (fitness function) and increased the RR maximizing the fitness function. Thus, the FR and RR of condenser subsystems have an enormous effect on system availability of the manufacturing system. The optimal value of FR and RR had chosen using PSO algorithm that enables the optimal result by comparing with GA. The maximum availability perceived in subsystem 7 that is 0.9923 by reducing FR. The constant parameters of FR are 0.128, 0.008, 0.017, 0.021, 0.20, 0.0038, and 0.118, and the RR as 0.44, 0.65, 0.61, 0.16, 0.02, and 0.42 in condenser manufacturing. The outcome demonstrated that MM with PSO gives most extreme availability contrasted with MM and GA. Further, these outcomes help in settling on the choices identified with support, to be performed in manufacturing enterprises. In this way, a hybrid algorithm will be utilized to speed up the calculation of the modeling.
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