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ORIGINAL PAPER

An Integrated Multi-Criteria Computer Simulation-AHP-TOPSIS Approach for Optimum Maintenance Planning by Incorporating Operator Error and Learning Effects

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Abstract The objective of this study is to optimize maintenance activities in a production system by incorporating cost and reliability. An integrated multi-criteria approach is presented to optimize maintenance planning and also define its policies. Modelling maintenance activities is usually nonlinear and complex since it includes various parameters. Therefore, a simulation optimization approach is presented to handle such complexities. Production and maintenance functions are estimated by means of historical data. In this study, maintenance activities with different scenarios along with probability of human error and learning effects are discussed. The scenarios are generated from a combination of inputs such as time between preventive maintenance, number of operators and skills. Different outputs such as reliability, machine availability, human errors and cost are obtained from these scenarios. The outputs are analysed to reach the optimized scenario by using an integrated analytical hierarchy process (AHP) and techniques for order preference by similarity to ideal solution (TOPSIS) method. The applicability of this approach is shown in an actual production line with four series machines. The results of this study can be helpful for decision makers to choose the best policy of maintenance planning. This is one of the first studies that optimize reliability and human cost by considering human error and learning effects through an integrated simulation, AHP and TOPSIS approach.

Keywords Maintenance planning · Reliability optimization · Human error · Learning effect · Integrated simulation · Analytical hierarchy process (AHP) · Technique for order preference by similarity to ideal solution (TOPSIS)

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Introduction

Maintenance planning is one of the main factors for production with the purpose of reducing machine downtime and total cost. It would result in increased manufacturing speed and quality of products. Different maintenance planning models have been studied in the literature review [7,8,11,18,24,26,30,31,33,34].

In fact, maintenance activities are not perfect. One of the main reasons for the imperfection of maintenance activities is human error incidence during work [19]. Maintenance operator's error is unavoidable. The occurrence of human error in maintenance may have an effect on safety and system efficiency. For example, poor maintenance can play an important role in increasing the number of equipment failures. Dhillon and Liu [9] explained the important role of humans in reliability of equipment. They published a literature review on human errors maintenance. Yang and Dhillon [37] provided an approach to analyse the level of availability in human-machine system. In the proposed method, different types of distribution functions such as Gamma, Weibull and Exponential are considered for repair time. Kumar and Gandhi [20] presented quantification of human error in maintenance by using graph theory and matrix approach. The approach played a significant role in identifying sources of human errors and predicting their impact. In this study, it is assumed that the operator's performance will improve over time and maintenance time will decrease consequently. This is called learning effect.

In the past decades, the problem of maintenance and production has been investigated from several perspectives.

Several models have been proposed in this research area and recent researches have tried to integrate the models. Budai et al. [4] reviewed the studies that have integrated production and maintenance models.

In this study, maintenance is performed by two main strategies: corrective and preventive maintenance. Corrective maintenance is due to occurrence of equipment failure while preventive maintenance is done in periodic time intervals.

Computer simulation is the process of designing a mathematical-logical model of a real system and experimenting with this model on a computer [27]. The optimization of maintenance strategies is difficult. All the parameters having a significant effect on the equipment and its performance lead to complex analytical models. It is not an easy task to create a maintenance planning model by mathematical methods; therefore, simulation is used in such cases [28]. In this study, an optimization problem of maintenance in an automated series manufacturing system is considered by simulating the manufacturing operation. Different scenarios are generated using different level of inputs in simulation approach.

AHP and TOPSIS methods have proven success in maintenance strategy selection, as it has been the case for many other decision-making problems. AHP method helps analysts organize the critical aspects of a problem into a hierarchical structure likea family tree. By reducing complex decisions to a series of simple comparisons and rankings, then synthesizing the results, the AHP not only helps analysts arrive at the best decision, but also provides a clear rationale for their choices [6]. Also, the basic principle of TOPSIS is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [17]. In this regard, some studies have been done on maintenance using AHP or TOPSIS to select the best maintenance policy [1–3,16,32,35].

The literature review shows that the impact of maintenance parameters such as reliability and availability has been investigated in a few researches [5,12–14,23,36]. While former studies considered only a few features, this study investigates the influence of more parameters on improving decision making process in maintenance problems. The parameters which are considered in this study are reliability, availability, operator error and learning effect. Another advantage of this study is that the inputs are considered in a multiple form and the ranking of scenarios is exact. In this study, a multi-criteria model is presented that simulates different scenarios with maintenance parameters mentioned earlier. Since the effect of each criterion is not the same as others, assigning weights to criteria is important from decision makers' point of view. In fact, weights allocation approach by means of AHP is flexible and the weights of the criteria can be different. Then, the rank of each scenario by considering weights of the criteria will be determined using TOPSIS method and the best policy is selected accordingly. The proposed algorithm of this study is suitable for small and medium-sized problems with different dimensions and can examine various options to find the best solution. As the matter of fact, the proposed algorithm can handle problems which are different in scenarios number. However, an increase in the number of machines causes testing different options for each machine to take much more time.

This study is comprised of the following structure: The first section expressed the introduction and relevant literature of maintenance, human error, simulation and AHP-TOPSIS. "Methodology" section presents methodology concepts including simulation and AHP-TOPSIS in more details. Then, the case study is introduced in "Experiment" section. In "Results and Discussion" section, the results are reported. Last but not least is the conclusion of this study in "Conclusion" section.

Methodology

This study is aimed at modelling and scheduling maintenance activities for an operating unit. It can be met by exact analytical methods and mathematical models or simulation. Due to the effect of complex nature of the various parameters, the exact mathematical model for this problem is so complicated and even might not exist. Hence, in this case, simulation for modelling maintenance activities would be a better option. In this method, required data are collected from a production line of household appliances. Based on the data, failure and production functions are obtained. The more accurate the data are, the more accurate the estimate of function will appear to be. Significant parameters in maintenance planning optimization are estimated from the actual process and random behaviour of the system. In this study, Visual Simulation Language for Analogue Modelling has been used to design simulation network. Maintenance activities of the system are simulated, considering human errors and their learning effect. Production and maintenance functions are estimated according to the historical data of a production line of household appliances and by means of EASYFIT software. Input parameters are set to time to preventive maintenance, number of maintenance operators and operators' skill. The combination of these parameters consists of several scenarios. The simulation network is executed for these scenarios and, as a result, several outputs are obtained.

Since, this problem is multi-criteria and the outputs have different natures with different units, an integrated AHP and TOPSIS method are used to find the optimal solution which is the combination of all parameters. Since usually in decision makers' sight of views, the importance of criteria is not the same, aassigning different weights to the criteria based on experts' opinions is mentioned in this study.

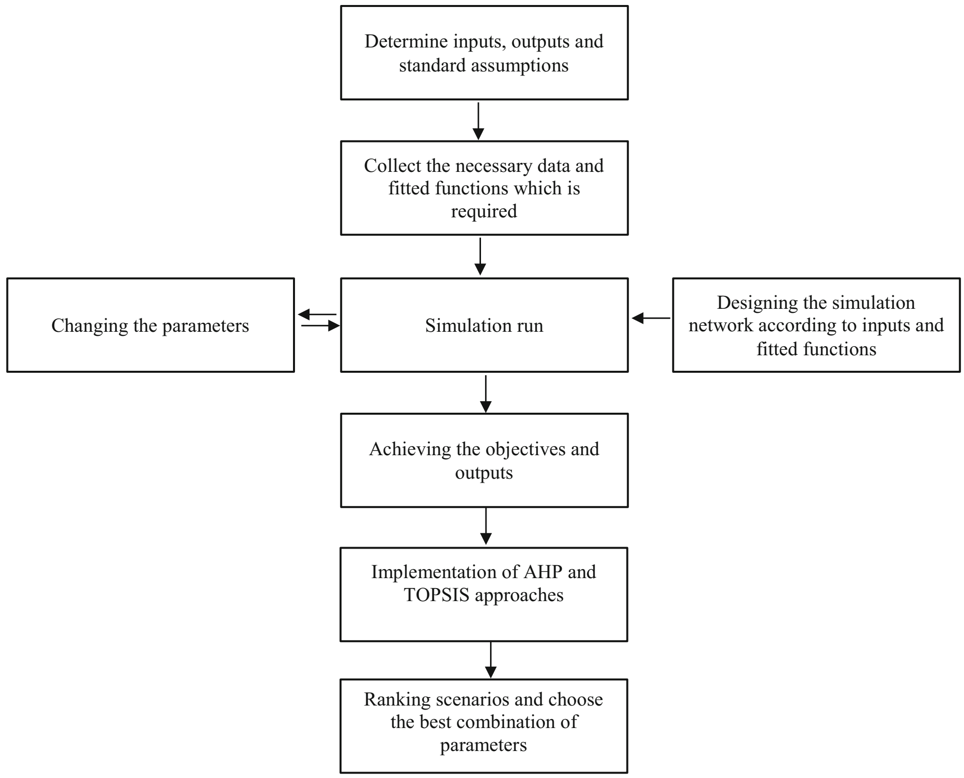

Fig. 1 Integrated simulation-AHP-TOPSIS approach

In Fig. 1, the approach is explained. The designed simulation network was run for several times with different inputs and different scenarios. Based on the nature of the problem, AHP-TOPSIS are identified as appropriate methods to rate the scenarios. In the following section; simulation, AHP and TOPSIS methods are described.

Simulation

Simulation is the process of modelling the real-world and conducting experiments by using the model. It is a powerful tool for understanding the behaviour of systems and analysing scenarios [27]. Computer simulation has been used in various engineering fields [10,15,21,22]. One of the useful features of this study is to develop a simulation network for modelling maintenance activities that allow decision makers to adjust and change the parameters of the problem and make the best decision. The simulation is done by Visual Analogue Modelling as a fully object-oriented simulation language. The structure of Visual Analogue Modelling network will be described later.

The Integrated AHP-TOPSIS Approach

The analytic hierarchy process (AHP) methodology is a powerful tool in solving complex decision problems [29]. In AHP approach, the decision problem is structured hierarchically at different levels with each level consisting of a finite number of decision elements. The upper level of the hierarchy represents the overall goal, while the lower level consists of all possible alternatives. One or more intermediate level embodies the decision criteria and sub-criteria [25]. For pairwise comparisons, the 1–9 scale of [29] was used to determine the degree of importance of activities.

TOPSIS defines an index called similarity to the positive-ideal solution and the remoteness from the negative-ideal solution. TOPSIS is a multiple criteria method to identify solutions from a finite set of alternatives. One of the advantages of TOPSIS is that it is easy to compute and understand because the method directly receives a definite value from experts to calculate their final results.

The steps of TOPSIS approach are as follows:

Step 1 Creation of a decision matrix to rank, including m alternatives and n criteria, where $A_1, A_2, \ldots, A_m$ are different scenarios. $C_1, C_2, \ldots, C_n$ are different criteria. In this study, there are 128 scenarios (alternatives) and 9 criteria. In all following steps of TOPSIS approach, the parameters have been replaced with their values (m = 128 and n = 9).

Step 2 The decision matrix is normalized as follows:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{128} x_{ij}^2}}, \quad j = 1, 2, \ldots, \tag{1}$$

The value of each cell in the column is divided by the square of the sum of squares of the numbers.

Step 3 Assign weights to the normalized decision matrix, the matrix V is calculated as follows:

$$V_{ij} = n_{ij} \times w_j \quad i = 1, 2, \ldots, 128, \; j = 1, 2, \ldots, 9 \qquad (2)$$

Step 4 Determine the ideal and non-ideal solution, according to the following relations:

$$\begin{aligned} &A^+ = \left(v_1^+, v_2^+, \ldots, v_{128}^+\right) \\ &\quad v_i^+ = max_i \left\{v_{ij}\right\}, \\ &\quad i = 1, 2, \ldots, 128, \, j = 1, 2, \ldots, 9 \end{aligned} \qquad (3)$$

$$\begin{aligned} &A^- = \left(v_1^-, v_2^-, \ldots, v_9^-\right) \\ &\quad v_i^- = min_i \left\{v_{ij}\right\} \\ &\quad i = 1, 2, \ldots, 128, \, j = 1, 2, \ldots, 9 \end{aligned} \qquad (4)$$

Step 5 Determine the distance of each alternative from the ideal solution as follows:

$$\mathrm{d}_\mathrm{i}^+ = \sqrt{\sum_{\mathrm{j}=1}^{9} \left(\mathrm{v}_\mathrm{j}^+ - \mathrm{v}_\mathrm{ij}\right)^2} \quad \mathrm{i} = 1, 2, \ldots, 128 \qquad (5)$$

And from the non-ideal solution as follows:

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_j^- - v_{ij}\right)^2} \quad i = 1, 2, \ldots, m \qquad (6)$$

Step 6 Calculate the relative closeness to the ideal solution; relative proximity switch is determined as follows:

$$cl_i^+ = \frac{D_i^-}{D_i^- + D_i^+} \quad i = 1, 2, \ldots, 128 \qquad (7)$$

Step 7 Rating options. The higher value indicates a better option. The best option is an option that holds more relative closeness to the ideal solution for men.

Experiment

In this section, the proposed approach is applied to a case study. A system consisting of four machines in a series production line of household appliances is considered. These machines periodically require maintenance. Each of these machines is prone to failure based on specific distribution functions. With growth of time to periodic maintenance, the probability of failure increases and this adds to the cost of the system. Because more time the system is halted, unforeseen expenses can be entered into the system and the production program might be interrupted. Also when the machine is halted, the process will be stopped.

Since the problem is a complex combination of optimization problem, some hypotheses are considered as follows to simplify it:

- The machines can suddenly fail.
- Production System is an automated system and the human error in this sector plays no role.
- Operators may accidentally commit human error in any position, and the errors reduce the usual time between failures.

For running a simulation, data are needed as functions or numbers, so at first we have to define production functions and failure functions. By using EASYFIT software, different functions were tested and the functions were fitted to the input data (Table 1).

After determining the inputs, network simulations have been plotted. Four machines in the network are in a row and output of each machine is input for the next one (Fig. 2).

In simulation network, there is an AWAIT section before each machine and if the machine is working or it is under maintenance operating, the entity waits at this section.

If the machine is not under maintenance or malfunction, the process starts on the entity that is in AWAIT section. After the completion of the process, the machine is set free by the free node and gets ready to serve the next entity or initiate maintenance and preventive repairs. Finally, COLCT and TERMINATE nodes collect such information as frequency of failures, frequency of preventive maintenance and time of entity in system and, then, the entity will be logged out.

Periodic maintenance of four separate networks, one for each machine is designed and displayed. In this network, the entity is generated by CREAT node. After the passage of machine maintenance, the entity will enter the ASSIGN node, which is the index for the number of maintenance and periodic upgrade, and, then, it enters to the ALTER nodes and uses capacity of the machine. Then, it enters to AWAIT node and waits for the operator's maintenance. After that, periodic maintenance is performed with specific distribution and the capacity of the machine and the operator's maintenance will change by ALTER and FREE nodes. Professional and normal maintenance operators may commit errors with defined probability during the operation. In this experiment, error rates of 5 and 10 % are attributed to expert and normal maintenance operators, respectively. It should be noted that these error rates have been obtained from past experiences and information. But, the highest human error rate is assigned to normal operators and the lowest one is assigned to expert ones. If the operator commits an error, ASSIGN node adds one number to operator error counters and simultaneously reduces the gap between machine failures. Then, during the interval, the next periodic maintenance re-enters the ASSIGN nodes and the number maintenance frequency

Table 1 The best fitted distribution functions using EASYFIT

Items	Machine 1	Machine 2	Machine 3	Machine 4
Duration of process	NORMAL (11.2,1.6)	NORMAL (10.3,1.7)	NORMAL (11.14,1.8)	NORMAL (9.8,1.2)
Interval between failure	EXPON (80)	EXPON (75)	EXPON (75)	EXPON (67)
Downtime	NORMAL (16,3)	NORMAL (15,4)	NORMAL (16,4)	NORMAL (15,3)
Preventive maintenance time	NORMAL (14,1)	NORMAL (14,1)	NORMAL (13,2)	NORMAL (14,1.5)

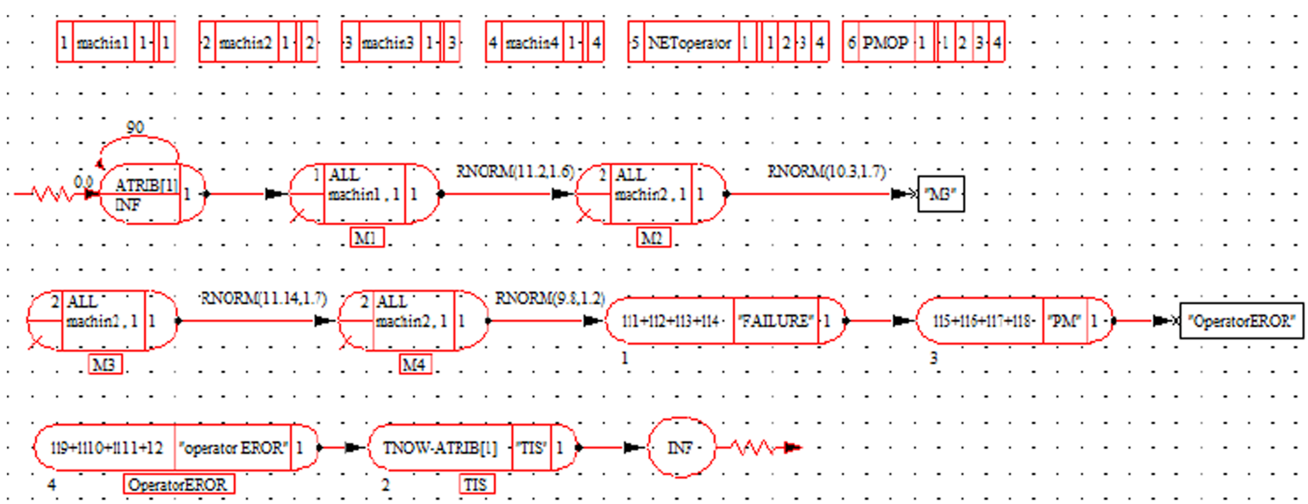

Fig. 2 Visual Simulation Language for Analogue Modelling consisting of four machines

is added periodically. Also operator learning effect is considered as a time-dependent function where operating time will decrease by the passage of time. This function is showed in Fig. 3. The network will be continuing until the end of simulation is repeated for each of the machines.

There is a network of random failures and a network is separately plotted for each machine. The network started with a CREAT node which inserts an entity into the network. The entity enters GOON node and the condition will be examined. If the length of time after the completion of the last check is longer than the expected length of time for failure, the unit will enter the network and resultant failures will occur. However, when it is less than the expected time for system failure, the unit will await another period and the above condition will be checked again.

If the mentioned condition is satisfied, and failure occurs, the entity immediately enters PREEMPT node and the machine enters to the service and repair section. Then, the entity enters the AWAIT node and waits for the operator to maintain and repair. When the machine maintenance operator is allocated to specified machine, service is performed according to the distribution of specified time. Then, the entity enters the FREE node and the capacity of the machine and the operator will be released. Finally, the entity enters the ASSIGN node which counts the number of unplanned downtime.

Periodic Maintenance and failure service operator of the network is separately considered and each varies between one and two. The performance and availability of the operator are involved in making the final decision of the maintenance personnel's needs (Fig. 4).

The network runs for 128 times for different combinations of periodic maintenance and has been analysed. The values are obtained by mean and lower limit machine downtime based on the records. Different duration of maintenance for each machine and also different number of maintenance operators (1 or 2) and their skills lead to different scenarios as shown in Table 2. It is noted that there are no redundant rules and all rules of this study are active. The operators are active and there is no redundant allocation.

The results of the simulation are shown in Table 3. The outputs in the table are as follows:

1. Number of random machine failures (unanticipated failure of system represents the system reliability).
2. Number of PM activities.
3. Number of human errors (PM).
4. Average waiting time of machines (for service).
5. Percentage of machine usage (the greater percentage represents more smooth production and more accurate planning system).

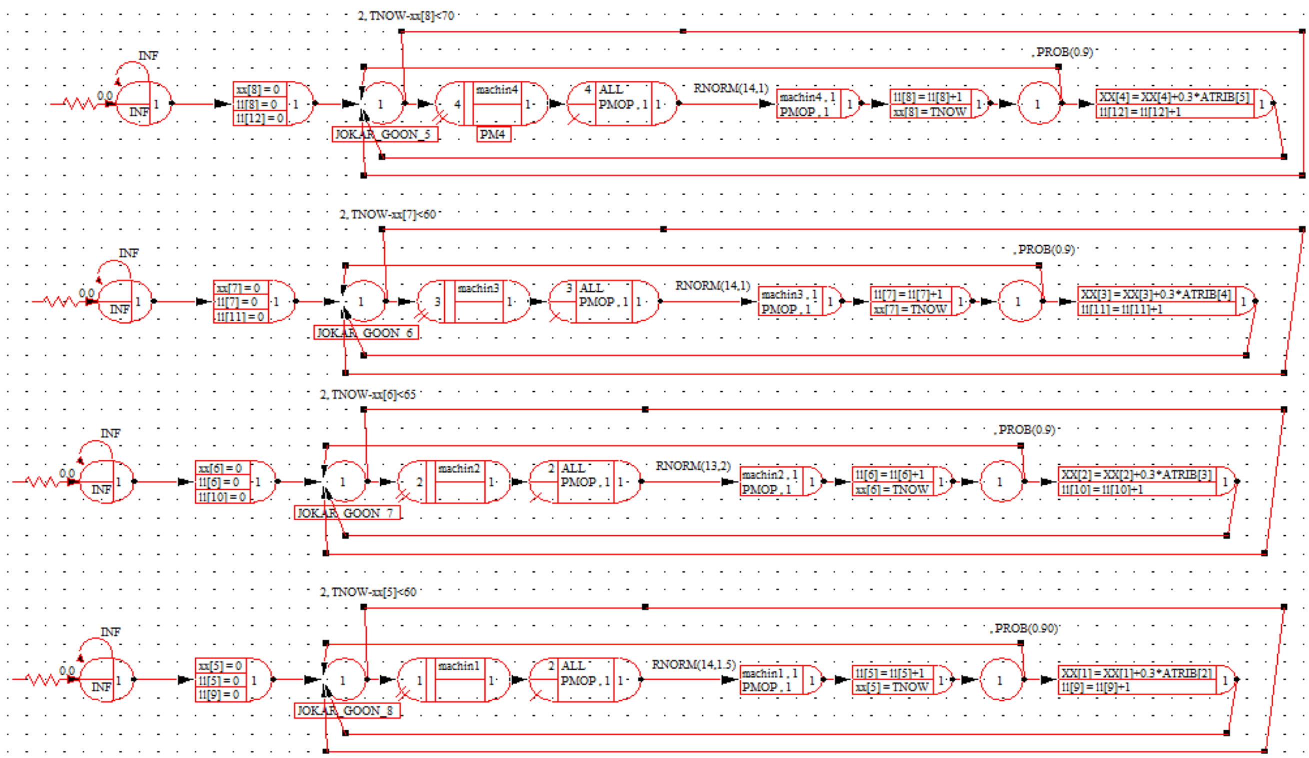

Fig. 3 Simulation network of preventive maintenance activities considering human error

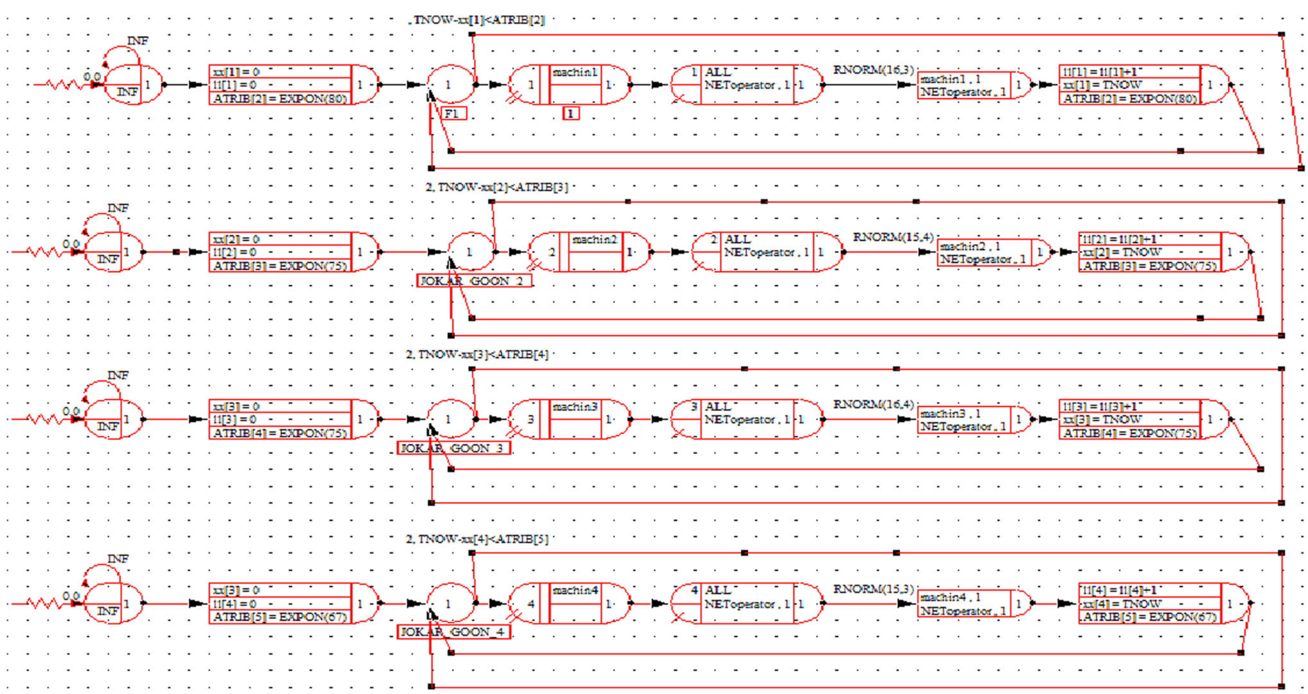

Fig. 4 Random failure simulation network

Table 2 Levels of variables for different scenarios

Scenario no.	Preventive maintenance Intervals formachine 1	Preventive maintenance Intervals formachine 2	Preventive maintenance Intervals formachine 3	Preventive maintenance Intervals formachine 4	Number of preventive maintenance operator	Number of corrective maintenance operator	Preventive maintenance operator type
1	70	60	65	60	1	1	EXPERT
2	70	60	65	60	1	1	NORM
3	70	60	65	60	1	2	EXPERT
4	70	60	65	60	1	2	NORM
5	70	60	65	60	2	1	EXPERT
6	70	60	65	60	2	1	NORM
7	70	60	65	60	2	2	EXPERT
8	70	60	65	60	2	2	NORM
9	70	60	65	67	1	1	EXPERT
10	70	60	65	67	1	1	NORM
11	70	60	65	67	1	2	EXPERT
12	70	60	65	67	1	2	NORM
13	70	60	65	67	2	1	EXPERT
14	70	60	65	67	2	1	NORM
15	70	60	65	67	2	2	EXPERT
16	70	60	65	67	2	2	NORM
17	70	60	75	60	1	1	EXPERT
18	70	60	75	60	1	1	NORM
19	70	60	75	60	1	2	EXPERT
20	70	60	75	60	1	2	NORM
21	70	60	75	60	2	1	EXPERT
22	70	60	75	60	2	1	NORM
23	70	60	75	60	2	2	EXPERT
24	70	60	75	60	2	2	NORM
25	70	60	75	67	1	1	EXPERT
26	70	60	75	67	1	2	NORM
27	70	60	75	67	1	2	EXPERT
28	70	60	75	67	1	2	NORM
29	70	60	75	67	2	1	EXPERT
30	70	60	75	67	2	1	NORM
31	70	60	75	67	2	2	EXPERT
32	70	60	75	67	2	2	NORM
33	70	75	65	60	1	1	EXPERT
34	70	75	65	60	1	1	NORM
35	70	75	65	60	1	2	EXPERT
36	70	75	65	60	1	−2	NORM
37	70	75	65	60	2	1	EXPERT
38	70	75	65	60	2	1	NORM
39	70	75	65	60	2	2	EXPERT
40	70	75	65	60	2	2	NORM
41	70	75	65	67	1	1	EXPERT
42	70	75	65	67	1	1	NORM
43	70	75	65	67	1	2	EXPERT
44	70	75	65	67	1	2	NORM
45	70	75	65	67	2	1	EXPERT

Table 2 continued

Scenario no.	Preventive maintenance Intervals formachine 1	Preventive maintenance Intervals formachine 2	Preventive maintenance Intervals formachine 3	Preventive maintenance Intervals formachine 4	Number of preventive maintenance operator	Number of corrective maintenance operator	Preventive maintenance operator type
46	70	75	65	67	2	1	NORM
47	70	75	65	67	2	2	EXPERT
48	70	75	65	67	2	2	NORM
49	70	75	75	60	1	1	EXPERT
50	70	75	75	60	1	1	NORM
51	70	75	75	60	1	2	EXPERT
52	70	75	75	60	1	2	NORM
53	70	75	75	60	2	1	EXPERT
54	70	75	75	60	2	1	NORM
55	70	75	75	60	2	2	EXPERT
56	70	75	75	60	2	2	NORM
57	70	75	75	67	1	1	EXPERT
58	70	75	75	67	1	1	NORM
59	70	75	75	67	1	2	EXPERT
60	70	75	75	67	1	2	NORM
61	70	75	75	67	2	1	EXPERT
62	70	75	75	67	2	1	NORM
63	70	75	75	67	2	2	EXPERT
64	70	75	75	67	2	2	NORM
65	80	60	65	60	1	1	EXPERT
66	80	60	65	60	1	1	NORM
67	80	60	65	60	1	2	EXPERT
68	80	60	65	60	1	2	NORM
69	80	60	65	60	2	1	EXPERT
70	80	60	65	60	2	1	NORM
71	80	60	65	60	2	2	EXPERT
72	80	60	65	60	2	2	NORM
73	80	60	65	67	1	1	EXPERT
74	80	60	65	67	1	1	NORM
75	80	60	65	67	1	2	EXPERT
76	80	60	65	67	1	2	NORM
77	80	60	65	67	2	1	EXPERT
78	80	60	65	67	2	1	NORM
79	80	60	65	67	2	2	EXPERT
80	80	60	65	67	2	2	NORM
81	80	60	75	60	1	1	EXPERT
82	80	60	75	60	1	1	NORM
83	80	60	75	60	1	2	EXPERT
84	80	60	75	60	1	2	NORM
85	80	60	75	60	2	1	EXPERT
86	80	60	75	60	2	1	NORM
87	80	60	75	60	2	2	EXPERT
88	80	60	75	60	2	2	NORM
89	80	60	75	67	1	1	EXPERT
90	80	60	75	67	1	1	NORM

Table 2 continued

Scenario no.	Preventive maintenance Intervals formachine 1	Preventive maintenance Intervals formachine 2	Preventive maintenance Intervals formachine 3	Preventive maintenance Intervals formachine 4	Number of preventive maintenance operator	Number of corrective maintenance operator	Preventive maintenance operator type
91	80	60	75	67	1	2	EXPERT
92	80	60	75	67	1	2	NORM
93	80	60	75	67	2	1	EXPERT
94	80	60	75	67	2	1	NORM
95	80	60	75	67	2	2	EXPERT
96	80	60	75	67	2	2	NORM
97	80	75	65	60	1	1	EXPERT
98	80	75	65	60	1	1	NORM
99	80	75	65	60	1	2	EXPERT
100	80	75	65	60	1	2	NORM
101	80	75	65	60	2	1	EXPERT
102	80	75	65	60	2	1	NORM
103	80	75	65	60	2	2	EXPERT
104	80	75	65	60	2	2	NORM
105	80	75	65	67	1	1	EXPERT
106	80	75	65	67	1	1	NORM
107	80	75	65	67	1	2	EXPERT
108	80	75	65	67	1	2	NORM
109	80	75	65	67	2	1	EXPERT
110	80	75	65	67	2	1	NORM
111	80	75	65	67	2	2	EXPERT
112	80	75	65	67	2	2	NORM
113	80	75	75	60	1	1	EXPERT
114	80	75	75	60	1	1	NORM
115	80	75	75	60	1	2	EXPERT
116	80	75	75	60	1	2	NORM
117	80	75	75	60	2	1	EXPERT
118	80	75	75	60	2	1	NORM
119	80	75	75	60	2	2	EXPERT
120	80	75	75	60	2	2	NORM
121	80	75	75	67	1	1	EXPERT
122	80	75	75	67	1	1	NORM
123	80	75	75	67	1	2	EXPERT
124	80	75	75	67	1	2	NORM
125	80	75	75	67	2	1	EXPERT
126	80	75	75	67	2	1	NORM
127	80	75	75	67	2	2	EXPERT
128	80	75	75	67	2	2	NORM

6. Percentage of utilizing corrective maintenance operators (the time they do not wait to service).
7. Percentage of utilizing preventive maintenance operator (the time they do not wait to service).
8. Human cost (PM).
9. Average cycle time (products).

Results and Discussion

In order to rank the weighted scenarios, the integrated AHP and TOPSIS are used. By collecting comments from experts, developing paired comparison matrices, and using the geo-

Table 3 Results of computer simulation

Scenario no.	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6	Output 7	Output 8	Output 9
1	3.000	13.000	35.990	18.990	0.680	0.540	0.610	0.550	177.000
2	5.000	11.000	36.310	19.310	0.680	0.550	0.620	0.400	171.000
3	1.000	6.000	82.230	65.230	0.730	0.560	0.630	0.800	222.000
4	2.000	10.000	39.570	22.570	0.700	0.550	0.620	0.650	264.000
5	1.000	9.000	40.780	23.780	0.690	0.530	0.600	0.850	157.000
6	4.000	5.000	37.440	20.440	0.680	0.610	0.690	0.550	200.000
7	1.000	7.000	32.870	15.870	0.670	0.620	0.700	1.100	193.000
8	3.000	15.000	35.830	18.830	0.680	0.520	0.580	0.800	164.000
9	1.000	11.000	56.680	39.680	0.710	0.550	0.620	0.550	100.000
10	2.000	11.000	39.650	22.650	0.680	0.560	0.630	0.400	140.000
11	1.000	13.000	33.740	16.740	0.700	0.580	0.650	0.800	290.000
12	1.000	6.000	57.820	40.820	0.700	0.580	0.650	0.650	198.000
13	1.000	10.000	34.540	17.540	0.680	0.590	0.660	0.850	92.000
14	2.000	9.000	36.990	19.990	0.670	0.600	0.670	0.550	148.000
15	3.000	11.000	39.540	22.540	0.680	0.560	0.630	1.100	185.000
16	4.000	10.000	33.500	16.500	0.680	0.590	0.660	0.800	110.000
17	1.000	7.000	32.940	15.940	0.670	0.600	0.670	0.550	166.000
18	1.000	5.000	35.120	18.120	0.670	0.580	0.650	0.400	132.000
19	1.000	4.000	43.800	26.800	0.680	0.570	0.640	0.800	198.000
20	9.000	7.000	32.790	15.790	0.670	0.590	0.660	0.650	95.000
21	4.000	3.000	34.140	17.140	0.650	0.610	0.690	0.850	186.000
22	2.000	15.000	29.410	12.410	0.670	0.770	0.860	0.550	185.000
23	1.000	13.000	37.860	20.860	0.680	0.740	0.830	1.100	154.000
24	1.000	10.000	29.560	12.560	0.650	0.790	0.880	0.800	294.000
25	9.000	13.000	33.010	16.010	0.670	0.790	0.880	0.550	142.000
26	1.000	10.000	37.390	20.390	0.680	0.770	0.860	0.400	161.000
27	3.000	5.000	39.000	22.000	0.690	0.810	0.900	0.800	97.000
28	4.000	5.000	32.030	15.030	0.650	0.800	0.890	0.650	147.000
29	4.000	18.000	31.040	14.040	0.680	0.750	0.840	0.850	116.000
30	1.000	15.000	30.640	13.640	0.660	0.770	0.870	0.550	128.000
31	2.000	15.000	34.910	17.910	0.680	0.750	0.840	1.100	156.000
32	1.000	13.000	31.190	14.190	0.660	0.770	0.870	0.800	113.000
33	1.000	11.000	29.140	12.140	0.660	0.790	0.880	0.550	167.000
34	1.000	13.000	36.430	19.430	0.670	0.760	0.850	0.400	151.000
35	4.000	10.000	28.300	11.300	0.650	0.080	0.090	0.800	161.000
36	1.000	9.000	27.490	10.490	0.650	0.800	0.890	0.650	134.000
37	2.000	14.000	32.450	15.450	0.670	0.760	0.850	0.850	194.000
38	3.000	9.000	61.870	44.870	0.690	0.760	0.850	0.550	111.000
39	4.000	11.000	27.520	10.520	0.610	0.790	0.880	1.100	129.000
40	3.000	9.000	29.440	12.440	0.660	0.530	0.590	0.800	391.000
41	1.000	5.000	31.830	14.830	0.660	0.540	0.600	0.550	120.000
42	1.000	9.000	25.320	8.320	0.710	0.550	0.620	0.400	130.000
43	9.000	5.000	35.720	18.720	0.680	0.540	0.600	0.800	169.000
44	1.000	6.000	32.950	15.950	0.670	0.520	0.580	0.650	144.000
45	3.000	11.000	38.100	21.100	0.660	0.600	0.670	0.850	127.000
46	4.000	3.000	34.920	17.920	0.650	0.610	0.680	0.550	158.000

Table 3 continued

Scenario no.	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6	Output 7	Output 8	Output 9
47	4.000	5.000	35.240	18.240	0.660	0.510	0.570	1.100	175.000
48	4.000	5.000	37.570	20.570	0.690	0.540	0.600	0.800	102.000
49	1.000	6.000	32.100	15.100	0.660	0.550	0.620	0.550	124.000
50	1.000	8.000	32.560	15.560	0.680	0.570	0.640	0.400	167.000
51	3.000	25.000	43.120	26.120	0.680	0.570	0.640	0.800	120.000
52	1.000	21.000	59.320	42.320	0.660	0.580	0.650	0.650	139.000
53	1.000	4.000	29.070	12.070	0.650	0.590	0.660	0.850	176.000
54	4.000	5.000	30.840	13.840	0.660	0.550	0.620	0.550	127.000
55	2.000	7.000	27.680	10.680	0.660	0.580	0.650	1.100	182.000
56	1.000	6.000	29.300	12.300	0.650	0.590	0.660	0.800	170.000
57	4.000	7.000	28.370	11.370	0.650	0.570	0.640	0.550	145.000
58	7.000	13.000	59.610	42.610	0.660	0.560	0.630	0.400	153.000
59	4.000	8.000	63.430	46.430	0.650	0.580	0.650	0.800	120.000
60	3.000	9.000	31.790	14.790	0.630	0.600	0.670	0.650	89.000
61	7.000	15.000	38.100	21.100	0.650	0.750	0.840	0.850	136.000
62	3.000	11.000	38.460	21.460	0.660	0.720	0.810	0.550	129.000
63	1.000	11.000	89.480	72.480	0.630	0.770	0.860	1.100	159.000
64	1.000	13.000	42.080	25.080	0.650	0.770	0.860	0.800	134.000
65	5.000	6.000	43.420	26.420	0.660	0.750	0.840	0.550	177.000
66	2.000	10.000	39.710	22.710	0.670	0.790	0.880	0.400	126.000
67	1.000	9.000	34.630	17.630	0.630	0.780	0.870	0.800	115.000
68	1.000	11.000	37.920	20.920	0.660	0.730	0.820	0.650	126.000
69	4.000	10.000	61.090	44.090	0.640	0.750	0.850	0.850	180.000
70	1.000	7.000	42.170	25.170	0.660	0.730	0.820	0.550	162.000
71	2.000	5.000	35.600	18.600	0.640	0.750	0.850	1.100	133.000
72	1.000	3.000	62.360	45.360	0.640	0.770	0.860	0.800	197.000
73	1.000	7.000	36.490	19.490	0.650	0.740	0.840	0.550	161.000
74	1.000	4.000	39.210	22.210	0.630	0.080	0.090	0.400	150.000
75	3.000	15.000	42.040	25.040	0.630	0.780	0.870	0.800	150.000
76	1.000	13.000	35.330	18.330	0.650	0.740	0.840	0.650	115.000
77	2.000	9.000	34.710	17.710	0.670	0.740	0.840	0.850	117.000
78	3.000	14.000	37.130	20.130	0.590	0.770	0.860	0.550	166.000
79	4.000	9.000	46.780	29.780	0.640	0.520	0.580	1.100	138.000
80	2.000	11.000	34.540	17.540	0.640	0.530	0.590	0.800	288.000
81	1.000	9.000	36.040	19.040	0.690	0.540	0.600	0.550	135.000
82	1.000	5.000	30.790	13.790	0.660	0.530	0.590	0.400	120.000
83	9.000	9.000	40.180	23.180	0.650	0.510	0.570	0.800	164.000
84	1.000	5.000	30.960	13.960	0.640	0.580	0.660	0.650	135.000
85	3.000	8.000	34.790	17.790	0.630	0.590	0.670	0.850	101.000
86	4.000	11.000	39.660	22.660	0.640	0.500	0.560	0.550	296.000
87	4.000	3.000	41.440	24.440	0.670	0.530	0.590	1.100	147.000
88	4.000	5.000	33.700	16.700	0.640	0.540	0.600	0.800	114.000
89	1.000	7.000	32.600	15.600	0.660	0.550	0.620	0.550	86.000
90	0.000	5.000	32.160	15.160	0.660	0.550	0.620	0.400	199.000
91	3.000	8.000	36.900	19.900	0.640	0.560	0.630	0.800	107.000
92	1.000	25.000	32.770	15.770	0.630	0.570	0.640	0.650	169.000

Table 3 continued

Scenario no.	Output 1	Output 2	Output 3	Output 4	Output 5	Output 6	Output 7	Output 8	Output 9
93	1.000	21.000	30.490	13.490	0.640	0.540	0.600	0.850	185.000
94	4.000	7.000	38.590	21.590	0.640	0.560	0.630	0.550	169.000
95	2.000	5.000	29.560	12.560	0.630	0.570	0.640	1.100	167.000
96	1.000	1.000	28.660	11.660	0.630	0.550	0.620	0.800	130.000
97	4.000	5.000	34.170	17.170	0.640	0.550	0.610	0.550	164.000
98	7.000	11.000	66.860	49.860	0.630	0.560	0.630	0.400	129.000
99	1.000	6.000	28.690	11.690	0.610	0.580	0.660	0.800	159.000
100	3.000	8.000	30.820	13.820	0.630	0.730	0.820	0.650	138.000
101	7.000	5.000	33.480	16.480	0.640	0.700	0.790	0.850	163.000
102	2.000	15.000	26.240	9.240	0.610	0.750	0.840	0.550	114.000
103	1.000	11.000	37.800	20.800	0.630	0.750	0.840	1.100	141.000
104	1.000	11.000	34.720	17.720	0.640	0.730	0.820	0.800	120.000
105	2.000	13.000	40.440	23.440	0.650	0.770	0.870	0.550	85.000
106	1.000	6.000	36.910	19.910	0.610	0.760	0.850	0.400	93.000
107	3.000	10.000	37.270	20.270	0.640	0.720	0.810	0.800	137.000
108	4.000	9.000	39.860	22.860	0.620	0.740	0.830	0.650	88.000
109	3.000	6.000	33.780	16.780	0.640	0.720	0.810	0.850	92.000
110	4.000	8.000	34.290	17.290	0.620	0.740	0.830	0.550	192.000
111	8.000	9.000	46.020	29.020	0.620	0.750	0.840	1.100	173.000
112	1.000	5.000	64.020	47.020	0.630	0.730	0.820	0.800	197.000
113	1.000	9.000	30.410	13.410	0.610	0.080	0.080	0.550	200.000
114	3.000	8.000	32.380	15.380	0.610	0.760	0.850	0.400	117.000
115	1.000	15.000	28.870	11.870	0.630	0.730	0.820	0.800	102.000
116	3.000	11.000	30.670	13.670	0.650	0.730	0.820	0.650	108.000
117	1.000	11.000	29.630	12.630	0.570	0.750	0.840	0.850	198.000
118	3.000	13.000	64.340	47.340	0.620	0.510	0.570	0.550	108.000
119	3.000	6.000	68.590	51.590	0.620	0.510	0.580	1.100	86.000
120	5.000	5.000	33.430	16.430	0.670	0.520	0.590	0.800	124.000
121	7.000	7.000	40.440	23.440	0.640	0.510	0.580	0.550	106.000
122	1.000	9.000	40.840	23.840	0.630	0.500	0.560	0.400	112.000
123	3.000	7.000	97.530	80.530	0.620	0.570	0.640	0.800	120.000
124	7.000	2.000	44.860	27.860	0.610	0.580	0.650	0.650	188.000
125	1.000	15.000	46.360	29.360	0.620	0.490	0.550	0.850	200.000
126	1.000	11.000	42.230	25.230	0.650	0.510	0.580	0.550	180.000
127	1.000	11.000	36.590	19.590	0.620	0.520	0.590	1.100	139.000
128	1.000	13.000	40.250	23.250	0.640	0.540	0.610	0.800	158.000

metric mean for each element in matrices, the final matrix of comments is provided (Table 4).

This final matrix of AHP is incompatible; therefore, the approximate total row is used to obtain weights (vector W). To this end, the sum of each row and column corresponding normalizing the result is obtained. At first, the sum of each row is calculated. For instance, the sum of row related to C2 is equal to 28.28. Then, the greatest value is determined among the calculated values and this value is associated with C1 (57.955). Finally, the weight of each item is obtained by dividing the sum of each row by 57.955. For example, w2 is equal to 28.28 divided by 57.955 and its value is 0.487. The vector of weights is as follows:

$$W = (w_1, w_2, w_3, w_4, w_5, w_6, w_7, w_8, w_9) \\ = (1, 0.487, 0.554, 0.112, 0.296, 0.550, \\ 0.074, 0.226, 0.499)$$

Then, the matrix V, the result of multiplying the normalized matrix and weight vector is shown in Table 5.

Table 4 The final matrix of AHP method

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1.000	7.937	5.916	7.937	7.937	9.000	9.000	7.937	1.291
C2	0.130	1.000	0.330	3.870	2.650	7.000	7.000	5.920	0.380
C3	0.169	3.000	1.000	5.916	5.000	6.708	5.916	3.873	0.577
C4	0.130	0.260	0.170	1.000	0.220	1.730	2.240	0.580	0.190
C5	0.126	0.378	0.200	4.583	1.000	4.583	3.873	2.236	0.218
C6	0.110	0.140	0.150	0.580	0.220	1.000	0.570	0.220	0.220
C7	0.111	0.143	0.169	0.447	0.258	1.732	1.000	0.216	0.218
C8	0.130	0.170	0.260	1.730	0.450	4.580	4.580	1.000	0.260
C9	0.775	2.646	1.732	5.196	4.583	4.583	4.583	3.873	1.000

Table 5 Normalized weighted matrix (V)

	−	−	−	−	+	+	+	−	−
	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	0.080	0.054	0.043	0.007	0.027	0.004	0.005	0.014	0.048
A2	0.133	0.046	0.043	0.008	0.027	0.004	0.005	0.010	0.047
A3	0.027	0.025	0.098	0.025	0.029	0.004	0.005	0.021	0.060
A4	0.053	0.042	0.047	0.009	0.027	0.004	0.005	0.017	0.072
A5	0.027	0.037	0.049	0.009	0.027	0.004	0.005	0.022	0.043
A6	0.106	0.021	0.045	0.008	0.027	0.004	0.006	0.014	0.054
A7	0.027	0.029	0.039	0.006	0.026	0.004	0.006	0.029	0.053
A8	0.080	0.062	0.043	0.007	0.027	0.004	0.005	0.021	0.045
A9	0.027	0.046	0.068	0.015	0.028	0.004	0.005	0.014	0.027
A10	0.053	0.046	0.047	0.009	0.027	0.004	0.005	0.010	0.038
A11	0.027	0.054	0.040	0.007	0.027	0.004	0.006	0.021	0.079
A12	0.027	0.025	0.069	0.016	0.027	0.004	0.006	0.017	0.054
A13	0.027	0.042	0.041	0.007	0.027	0.004	0.006	0.022	0.025
A14	0.053	0.037	0.044	0.008	0.026	0.004	0.006	0.014	0.040
A15	0.080	0.046	0.047	0.009	0.027	0.004	0.005	0.029	0.050
A16	0.106	0.042	0.040	0.006	0.027	0.004	0.006	0.021	0.030
A17	0.027	0.029	0.039	0.006	0.026	0.004	0.006	0.014	0.045
A18	0.027	0.021	0.042	0.007	0.026	0.004	0.006	0.010	0.036
A19	0.027	0.017	0.052	0.010	0.027	0.004	0.006	0.021	0.054
A20	0.239	0.029	0.039	0.006	0.026	0.004	0.006	0.017	0.026
A21	0.106	0.012	0.041	0.007	0.026	0.004	0.006	0.022	0.051
A22	0.053	0.062	0.035	0.005	0.026	0.005	0.007	0.014	0.050
A23	0.027	0.054	0.045	0.008	0.027	0.005	0.007	0.029	0.042
A24	0.027	0.042	0.035	0.005	0.026	0.005	0.008	0.021	0.080
A25	0.239	0.054	0.039	0.006	0.026	0.005	0.008	0.014	0.039
A26	0.027	0.042	0.045	0.008	0.027	0.005	0.007	0.010	0.044
A27	0.080	0.021	0.047	0.009	0.027	0.006	0.008	0.021	0.026
A28	0.106	0.021	0.038	0.006	0.026	0.006	0.008	0.017	0.040
A29	0.106	0.075	0.037	0.005	0.027	0.005	0.007	0.022	0.032
A30	0.027	0.062	0.037	0.005	0.026	0.005	0.008	0.014	0.035
A31	0.053	0.062	0.042	0.007	0.027	0.005	0.007	0.029	0.042
A32	0.027	0.054	0.037	0.006	0.026	0.005	0.008	0.021	0.031
A33	0.027	0.046	0.035	0.005	0.026	0.005	0.008	0.014	0.045
A34	0.027	0.054	0.043	0.008	0.026	0.005	0.007	0.010	0.041
A35	0.106	0.042	0.034	0.004	0.026	0.001	0.001	0.021	0.044

Table 5 continued

	− C1	− C2	− C3	− C4	+ C5	+ C6	+ C7	− C8	− C9
A36	0.027	0.037	0.033	0.004	0.026	0.006	0.008	0.017	0.036
A37	0.053	0.058	0.039	0.006	0.026	0.005	0.007	0.022	0.053
A38	0.080	0.037	0.074	0.017	0.027	0.005	0.007	0.014	0.030
A39	0.106	0.046	0.033	0.004	0.024	0.005	0.008	0.029	0.035
A40	0.080	0.037	0.035	0.005	0.026	0.004	0.005	0.021	0.106
A41	0.027	0.021	0.038	0.006	0.026	0.004	0.005	0.014	0.033
A42	0.027	0.037	0.030	0.003	0.028	0.004	0.005	0.010	0.035
A43	0.239	0.021	0.043	0.007	0.027	0.004	0.005	0.021	0.046
A44	0.027	0.025	0.039	0.006	0.026	0.004	0.005	0.017	0.039
A45	0.080	0.046	0.045	0.008	0.026	0.004	0.006	0.022	0.035
A46	0.106	0.012	0.042	0.007	0.026	0.004	0.006	0.014	0.043
A47	0.106	0.021	0.042	0.007	0.026	0.004	0.005	0.029	0.048
A48	0.106	0.021	0.045	0.008	0.027	0.004	0.005	0.021	0.028
A49	0.027	0.025	0.038	0.006	0.026	0.004	0.005	0.014	0.034
A50	0.027	0.033	0.039	0.006	0.027	0.004	0.006	0.010	0.045
A51	0.080	0.104	0.051	0.010	0.027	0.004	0.006	0.021	0.033
A52	0.027	0.087	0.071	0.016	0.026	0.004	0.006	0.017	0.038
A53	0.027	0.017	0.035	0.005	0.026	0.004	0.006	0.022	0.048
A54	0.106	0.021	0.037	0.005	0.026	0.004	0.005	0.014	0.035
A55	0.053	0.029	0.033	0.004	0.026	0.004	0.006	0.029	0.050
A56	0.027	0.025	0.035	0.005	0.026	0.004	0.006	0.021	0.046
A57	0.106	0.029	0.034	0.004	0.026	0.004	0.006	0.014	0.039
A58	0.186	0.054	0.071	0.017	0.026	0.004	0.005	0.010	0.042
A59	0.106	0.033	0.076	0.018	0.026	0.004	0.006	0.021	0.033
A60	0.080	0.037	0.038	0.006	0.025	0.004	0.006	0.017	0.024
A61	0.186	0.062	0.045	0.008	0.026	0.005	0.007	0.022	0.037
A62	0.080	0.046	0.046	0.008	0.026	0.005	0.007	0.014	0.035
A63	0.027	0.046	0.107	0.028	0.025	0.005	0.007	0.029	0.043
A64	0.027	0.054	0.050	0.010	0.026	0.005	0.007	0.021	0.036
A65	0.133	0.025	0.052	0.010	0.026	0.005	0.007	0.014	0.048
A66	0.053	0.042	0.047	0.009	0.026	0.005	0.008	0.010	0.034
A67	0.027	0.037	0.041	0.007	0.025	0.005	0.008	0.021	0.031
A68	0.027	0.046	0.045	0.008	0.026	0.005	0.007	0.017	0.034
A69	0.106	0.042	0.073	0.017	0.025	0.005	0.007	0.022	0.049
A70	0.027	0.029	0.050	0.010	0.026	0.005	0.007	0.014	0.044
A71	0.053	0.021	0.042	0.007	0.025	0.005	0.007	0.029	0.036
A72	0.027	0.012	0.074	0.018	0.025	0.005	0.007	0.021	0.054
A73	0.027	0.029	0.044	0.008	0.026	0.005	0.007	0.014	0.044
A74	0.027	0.017	0.047	0.009	0.025	0.001	0.001	0.010	0.041
A75	0.080	0.062	0.050	0.010	0.025	0.005	0.008	0.021	0.041
A76	0.027	0.054	0.042	0.007	0.026	0.005	0.007	0.017	0.031
A77	0.053	0.037	0.041	0.007	0.026	0.005	0.007	0.022	0.032
A78	0.080	0.058	0.044	0.008	0.023	0.005	0.007	0.014	0.045
A79	0.106	0.037	0.056	0.012	0.025	0.004	0.005	0.029	0.038
A80	0.053	0.046	0.041	0.007	0.025	0.004	0.005	0.021	0.078
A81	0.027	0.037	0.043	0.007	0.027	0.004	0.005	0.014	0.037
A82	0.027	0.021	0.037	0.005	0.026	0.004	0.005	0.010	0.033

Table 5 continued

	− C1	− C2	− C3	− C4	+ C5	+ C6	+ C7	− C8	− C9
A83	0.239	0.037	0.048	0.009	0.026	0.004	0.005	0.021	0.045
A84	0.027	0.021	0.037	0.005	0.025	0.004	0.006	0.017	0.037
A85	0.080	0.033	0.041	0.007	0.025	0.004	0.006	0.022	0.027
A86	0.106	0.046	0.047	0.009	0.025	0.003	0.005	0.014	0.081
A87	0.106	0.012	0.049	0.009	0.026	0.004	0.005	0.029	0.040
A88	0.106	0.021	0.040	0.006	0.025	0.004	0.005	0.021	0.031
A89	0.027	0.029	0.039	0.006	0.026	0.004	0.005	0.014	0.023
A90	0.000	0.021	0.038	0.006	0.026	0.004	0.005	0.010	0.054
A91	0.080	0.033	0.044	0.008	0.025	0.004	0.005	0.021	0.029
A92	0.027	0.104	0.039	0.006	0.025	0.004	0.006	0.017	0.046
A93	0.027	0.087	0.036	0.005	0.025	0.004	0.005	0.022	0.050
A94	0.106	0.029	0.046	0.008	0.025	0.004	0.005	0.014	0.046
A95	0.053	0.021	0.035	0.005	0.025	0.004	0.006	0.029	0.045
A96	0.027	0.004	0.034	0.005	0.025	0.004	0.005	0.021	0.035
A97	0.106	0.021	0.041	0.007	0.025	0.004	0.005	0.014	0.045
A98	0.186	0.046	0.080	0.019	0.025	0.004	0.005	0.010	0.035
A99	0.027	0.025	0.034	0.005	0.024	0.004	0.006	0.021	0.043
A100	0.080	0.033	0.037	0.005	0.025	0.005	0.007	0.017	0.038
A101	0.186	0.021	0.040	0.006	0.025	0.005	0.007	0.022	0.044
A102	0.053	0.062	0.031	0.004	0.024	0.005	0.007	0.014	0.031
A103	0.027	0.046	0.045	0.008	0.025	0.005	0.007	0.029	0.038
A104	0.027	0.046	0.041	0.007	0.025	0.005	0.007	0.021	0.033
A105	0.053	0.054	0.048	0.009	0.026	0.005	0.008	0.014	0.023
A106	0.027	0.025	0.044	0.008	0.024	0.005	0.007	0.010	0.025
A107	0.080	0.042	0.044	0.008	0.025	0.005	0.007	0.021	0.037
A108	0.106	0.037	0.048	0.009	0.024	0.005	0.007	0.017	0.024
A109	0.080	0.025	0.040	0.007	0.025	0.005	0.007	0.022	0.025
A110	0.106	0.033	0.041	0.007	0.024	0.005	0.007	0.014	0.052
A111	0.212	0.037	0.055	0.011	0.024	0.005	0.007	0.029	0.047
A112	0.027	0.021	0.076	0.018	0.025	0.005	0.007	0.021	0.054
A113	0.027	0.037	0.036	0.005	0.024	0.001	0.001	0.014	0.054
A114	0.080	0.033	0.039	0.006	0.024	0.005	0.007	0.010	0.032
A115	0.027	0.062	0.034	0.005	0.025	0.005	0.007	0.021	0.028
A116	0.080	0.046	0.037	0.005	0.026	0.005	0.007	0.017	0.029
A117	0.027	0.046	0.035	0.005	0.022	0.005	0.007	0.022	0.054
A118	0.080	0.054	0.077	0.018	0.024	0.004	0.005	0.014	0.029
A119	0.080	0.025	0.082	0.020	0.024	0.004	0.005	0.029	0.023
A120	0.133	0.021	0.040	0.006	0.026	0.004	0.005	0.021	0.034
A121	0.186	0.029	0.048	0.009	0.025	0.004	0.005	0.014	0.029
A122	0.027	0.037	0.049	0.009	0.025	0.003	0.005	0.010	0.030
A123	0.080	0.029	0.116	0.031	0.024	0.004	0.006	0.021	0.033
A124	0.186	0.008	0.054	0.011	0.024	0.004	0.006	0.017	0.051
A125	0.027	0.062	0.055	0.011	0.024	0.003	0.005	0.022	0.054
A126	0.027	0.046	0.050	0.010	0.026	0.004	0.005	0.014	0.049
A127	0.027	0.046	0.044	0.008	0.024	0.004	0.005	0.029	0.038
A128	0.027	0.054	0.048	0.009	0.025	0.004	0.005	0.021	0.043

Table 6 Distance between the ideal and each scenario

d1	0.098	d44	0.039	d87	0.111
d2	0.142	d45	0.093	d88	0.109
d3	0.088	d46	0.109	d89	0.038
d4	0.083	d47	0.113	d90	0.036
d5	0.052	d48	0.109	d91	0.087
d6	0.113	d49	0.037	d92	0.107
d7	0.051	d50	0.046	d93	0.093
d8	0.102	d51	0.130	d94	0.113
d9	0.063	d52	0.099	d95	0.063
d10	0.071	d53	0.041	d96	0.032
d11	0.081	d54	0.108	d97	0.110
d12	0.062	d55	0.067	d98	0.198
d13	0.049	d56	0.043	d99	0.041
d14	0.067	d57	0.111	d100	0.087
d15	0.097	d58	0.198	d101	0.189
d16	0.114	d59	0.121	d102	0.079
d17	0.044	d60	0.087	d103	0.057
d18	0.036	d61	0.196	d104	0.053
d19	0.050	d62	0.092	d105	0.075
d20	0.241	d63	0.098	d106	0.037
d21	0.111	d64	0.063	d107	0.091
d22	0.084	d65	0.139	d108	0.113
d23	0.064	d66	0.068	d109	0.084
d24	0.074	d67	0.046	d110	0.115
d25	0.245	d68	0.053	d111	0.219
d26	0.053	d69	0.125	d112	0.066
d27	0.084	d70	0.047	d113	0.054
d28	0.109	d71	0.062	d114	0.086
d29	0.129	d72	0.063	d115	0.065
d30	0.066	d73	0.044	d116	0.091
d31	0.084	d74	0.040	d117	0.060
d32	0.059	d75	0.103	d118	0.106
d33	0.055	d76	0.059	d119	0.100
d34	0.061	d77	0.065	d120	0.135
d35	0.115	d78	0.100	d121	0.189
d36	0.045	d79	0.117	d122	0.048
d37	0.083	d80	0.089	d123	0.124
d38	0.098	d81	0.047	d124	0.190
d39	0.116	d82	0.034	d125	0.077
d40	0.121	d83	0.243	d126	0.060
d41	0.034	d84	0.036	d127	0.057
d42	0.044	d85	0.087	d128	0.064
d43	0.241	d86	0.129		

Table 7 Distance between the non-ideal and each scenario

d1	0.194	d44	0.250	d87	0.188
d2	0.157	d45	0.199	d88	0.192
d3	0.232	d46	0.191	d89	0.254
d4	0.212	d47	0.185	d90	0.272
d5	0.242	d48	0.191	d91	0.206
d6	0.182	d49	0.252	d92	0.236
d7	0.246	d50	0.247	d93	0.236
d8	0.192	d51	0.189	d94	0.181
d9	0.240	d52	0.229	d95	0.229
d10	0.220	d53	0.252	d96	0.260
d11	0.234	d54	0.192	d97	0.187
d12	0.238	d55	0.226	d98	0.115
d13	0.249	d56	0.250	d99	0.251
d14	0.222	d57	0.188	d100	0.206
d15	0.193	d58	0.110	d101	0.142
d16	0.184	d59	0.173	d102	0.224
d17	0.248	d60	0.209	d103	0.243
d18	0.252	d61	0.123	d104	0.246
d19	0.245	d62	0.199	d105	0.222
d20	0.137	d63	0.230	d106	0.253
d21	0.189	d64	0.240	d107	0.200
d22	0.217	d65	0.161	d108	0.185
d23	0.240	d66	0.222	d109	0.212
d24	0.239	d67	0.248	d110	0.179
d25	0.118	d68	0.244	d111	0.114
d26	0.243	d69	0.164	d112	0.238
d27	0.210	d70	0.244	d113	0.244
d28	0.190	d71	0.229	d114	0.207
d29	0.177	d72	0.242	d115	0.246
d30	0.244	d73	0.247	d116	0.205
d31	0.216	d74	0.251	d117	0.242
d32	0.246	d75	0.191	d118	0.189
d33	0.245	d76	0.244	d119	0.200
d34	0.241	d77	0.226	d120	0.173
d35	0.182	d78	0.193	d121	0.141
d36	0.250	d79	0.176	d122	0.246
d37	0.215	d80	0.212	d123	0.191
d38	0.195	d81	0.246	d124	0.140
d39	0.184	d82	0.255	d125	0.232
d40	0.193	d83	0.116	d126	0.238
d41	0.254	d84	0.253	d127	0.243
d42	0.251	d85	0.207	d128	0.239
d43	0.129	d86	0.165		

The distance between the ideal and also the non-ideal of each scenario is shown in Tables 6 and 7, respectively.

As mentioned earlier, the method used in this study consisted of simulation, AHP and TOPSIS that assign different weights to the criteria based on expert judgments. Numbers of random failures of machines and operators' errors are used to model reliability in this study. Number of preventive maintenance activities must be optimized to enhance down time.

Table 8 Scenarios ranking based on AHP-TOPSIS approach

Scenario	Relative closeness	Rank	Scenario	Relative closeness	Rank	Scenario	Relative closeness	Rank
1	0.663	85	44	0.864	10	87	0.628	98
2	0.525	117	45	0.682	81	88	0.638	91
3	0.725	61	46	0.636	93	89	0.870	9
4	0.718	66	47	0.621	99	90	0.882	3
5	0.823	28	48	0.636	92	91	0.703	74
6	0.617	102	49	0.873	7	92	0.689	78
7	0.827	26	50	0.842	20	93	0.718	65
8	0.653	87	51	0.591	110	94	0.615	104
9	0.791	43	52	0.699	76	95	0.784	49
10	0.754	56	53	0.861	12	96	0.891	1
11	0.743	59	54	0.639	90	97	0.629	97
12	0.795	40	55	0.771	52	98	0.367	122
13	0.836	24	56	0.854	14	99	0.859	13
14	0.769	53	57	0.630	95	100	0.704	73
15	0.665	84	58	0.358	124	101	0.430	118
16	0.618	101	59	0.589	111	102	0.738	60
17	0.849	16	60	0.706	70	103	0.809	34
18	0.874	6	61	0.385	121	104	0.823	27
19	0.832	25	62	0.683	80	105	0.746	58
20	0.364	123	63	0.700	75	106	0.872	8
21	0.629	96	64	0.793	42	107	0.687	79
22	0.722	63	65	0.537	116	108	0.621	100
23	0.788	46	66	0.765	54	109	0.716	67
24	0.763	55	67	0.843	19	110	0.610	107
25	0.325	127	68	0.820	30	111	0.342	126
26	0.822	29	69	0.569	113	112	0.782	50
27	0.715	68	70	0.838	23	113	0.818	31
28	0.634	94	71	0.788	47	114	0.707	69
29	0.578	112	72	0.793	41	115	0.790	44
30	0.788	48	73	0.847	17	116	0.693	77
31	0.720	64	74	0.864	11	117	0.802	37
32	0.808	35	75	0.649	88	118	0.640	89
33	0.818	32	76	0.805	36	119	0.665	82
34	0.798	39	77	0.775	51	120	0.562	114
35	0.612	106	78	0.658	86	121	0.427	119
36	0.847	18	79	0.600	109	122	0.838	22
37	0.722	62	80	0.705	71	123	0.606	108
38	0.665	83	81	0.840	21	124	0.424	120
39	0.613	105	82	0.883	2	125	0.750	57
40	0.615	103	83	0.323	128	126	0.799	38
41	0.881	4	84	0.876	5	127	0.811	33
42	0.850	15	85	0.705	72	128	0.789	45
43	0.349	125	86	0.561	115			

This study optimizes operator utilization, cost and average time entities (products) spent in system. Regarding the above parameters, the best case scenarios in terms of a clear trend is identified. Optimum scenarios are 96, 82 and 90 as shown in Table 8. They lead to the best possible maintenance planning. In the mentioned scenarios, the normal operator that leads to lower cost was chosen. Probably, the number of five pieces has received more appropriate scheduled preventive maintenance, and the average time of entities' presence in system is considerably low. It indicates a higher production rate compared to other scenarios.

Conclusion

In this study, a unique and integrated approach was proposed for planning maintenance activities in an actual manufacturing system. Maintenance planning problems were discussed from various aspects and solved by various methods. However, integration of computer simulation and AHP-TOPSIS methods for maintenance planning problems incorporating human error and learning effects have not been considered in recent studies. Hence, incorporation of human error and learning effects in parallel to reliability and availability indicators in the integrated approach of this study makes it a quite unique approach for maintenance planning problems. Optimum maintenance planning is obtained from the best scenarios retrieved from AHP and TOPSIS. Considering the same weights for all criteria is usually far from reality, and is not feasible for decision making process. Thus, AHP-TOPSIS is used to consider weighting criteria based on experts' judgements. The results of this study indicated that that there is no failure and operators are identified as normal skilled workers in the best scenarios. The numbers of five scheduled preventive maintenance pieces seem to be appropriate and the average wait time is reasonably low. An advantage of the proposed method is the ability to add and change various parameters for sensitivity analysis. Changing the input of each parameter can change the result for each output. The results of this study are helpful for managers and other decision makers to select the best policy for maintenance planning.

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