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OPTIMIZATION OF INDUSTRIAL MACHINE MAINTENANCE SCHEDULING USING ANT COLONY METHOD

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Abstract. The importance of machine maintenance has been gradually recognized especially with the great attention in industrial sector. A company was named M is a manufacturing company which engaged in the industrial manufacturer of body pail cans. Previously, the process of machine maintenance at company M is to repair the machine when a problem occurs. This causes several machines to break down frequently and disrupt the production process. Furthermore, the purpose of this research is to determine the optimum and well-planned maintenance scheduling that can reduce the risk of- or prevent machine failures that may ruin the production process by doing the preventive maintenance in right time. Ant Colony Optimization (ACO) method was used in this research as maximizing the interval time between preventive maintenance periods before the trouble occurs based on previous breakdown data period as minimizing frequency of the task. In the principle of ACO, the required parameters are α, β, m, e, el. As a result of using ACO with the combination of parameters above, the optimal well-planned maintenance scheduling was obtained by using α=2, β=5, e=0.3, el=0.96, and a number of ants needed. Finally, the optimizing of schedule maintenance has proposed in daily for next year period.

Keywords: Ant Colony Optimization, Preventive Maintenance, Scheduling, Metaheuristic.

1 Introduction

The maintenance of machines is an essential process to support the production. Poor maintenance causes the decrease of economic life and leads to declining production capacity and loss for the company. Hence, it is a necessary process to keep the functional aspect of the machine as research from Sharma and Yadava [1]. We found from another researcher [2] explained that there are 3 types of maintenance: preventive, corrective and predictive. Preventive maintenance has selected in this research because it’s consists of a set of activities that aim at improving the overall reliability and availability of a system[3] are conducted in a routine, planned and scheduled manner. Predictive maintenance was chosen because it could detect failure accurately when the operation is undergoing. The aim of predictive maintenance scheduling is to determine the optimal frequency of maintenance based on Arab et al.[4] research.

The scheduling of maintenance is imperative for the company to maintain the lifespan of the machine and prevent further breakdown. As expressed by Liu and Lv [5] maintenance plays a very important role to utilize the machine effectively in the aspects of cost, safety, and product availability. In this research exposed that the scheduling in a

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manufacturing system is a very interesting and challenging, especially in the case of high complexity; it requires accurate alternatives as scheduling is a vital key to improve the productivity of the whole system. Thus, to plan the maintenance schedule accurately using ACO as in the research by Samrout et al. [6], this method showed a better result in term of stability. Due to its stability in searching for optimum result, ACO is widely used in solving real-world-engineering issues [7]. ACO has also perceived a result in optimum solution because the search result aims to the maximum of objective function needed [8]. Moreover, the scarce use of ACO method in real case reflected a huge interest in this choice of method.

The aim of this research is to determine the optimum schedule of preventive maintenance so that it may reduce the risk of- or prevent machine failure that will ruin the production process, as the objective function is maximize the maintenance interval time that obtained the lowest frequency for doing maintenance by the technician. Our method is based on a modified ACO algorithm that applied for maximizing, and we will show this algorithm has an efficient answer for this optimization problem [9].

2 Experimental Details

In this research, for the problem description on maintenance schedule as we described in introduction, we modelled the problem to find an optimal sequence for preventive maintenance using ACO algorithm. In our application, each node represents an interval time of machine before breakdown or trouble time. To find the optimum schedule of preventive maintenance must do, we used quantitative data. This research is perceived as quantitative since it based on measurable data to achieve a strong, valid quantitative interpretation. Based on the purpose, this research used a descriptive method that investigating the status of a group of population, objects, a set of condition, a systematic idea or a class of occasion in the present time from Vasko et al. [10]. From direct observation, we could see and understand the real-time condition of the subject. By interview method, we could gain the information of machine condition and history, the type of machines, the type of failures and particularly the data of machine failure in 2016. All this data was used to find the optimization of scheduled maintenance.

ACO method is based on ants' behaviour to find the most optimum route from the anthill to the source of food. In the principle of ACO, the required parameters are α, β, m, e, el. By using ACO with the combination of parameters above and execute it with Matlab 2013b licensed version from Mathworks leads the convergence towards an optimal solution of the problem [11] , doing the maintenance task with acceptable time and technician, and finally obtained the optimal well-planned maintenance scheduling for one year period.

This model has some assumptions as only those trouble listed that must and can be maintained, there are 2 or 3 technicians to do the preventive maintenance task, the task is not done simultaneously on one machine and the available working days are 5 days in Monday to Friday and the maximum of maintenance time was 1 hour.

3 Results and Discussion

In this company, there were 8 machines which were used to produce the body of pail cans are slitter, cutting, rolling, welder, expander, flanger, seamer and laspand machines. After we analysed all the machine problems in that company with Pareto diagram, we determined the main problems of maintenance schedule and defined on five matrices. In this research, the model of production scheduling based on the machine used was a flow shop model; in which each job had an identical flow pattern (linear) and each machine had a target of capacity as 2000 units/days.

3.1 Matrix

Here we present the matrix used as the input in MATLAB software, which is nodes in square-grid matrix forms of 17x17, 16x16, 4x4, 19x19 and 8x8. The history of trouble in each machine in interval time of operational hour was represented by matrix W1 (17x17) for trouble at welding roll in Table 1, matrix W2 (16x16) for breaking of copper line in Table 2, and matrix W3 (4x4) for trouble at calibration instrument in Table 3. The trouble of flanger was represented by matrix F1 (19x19) in Table 4 for unstable motor while unstable of flanger adjustment was represented by matrix F2 (8x8) in Table 5.

Table 1. The value matrices of W1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0	18	41	61	85	103	119	138	155	194	216	232	250	261	279	299	313
2	18	0	23	43	67	85	101	120	137	176	198	214	232	243	261	281	295
3	41	23	0	20	44	62	78	97	114	153	175	191	209	220	238	258	272
4	61	43	20	0	24	42	58	77	94	133	155	171	189	200	218	238	252
5	85	67	44	24	0	18	34	53	70	109	131	147	165	176	194	214	228
6	103	85	62	42	18	0	16	35	52	91	113	129	147	158	176	196	210
7	119	101	78	58	34	16	0	19	36	75	97	113	131	142	160	180	194
8	138	120	97	77	53	35	19	0	17	56	78	94	112	123	141	161	175
9	155	137	114	94	70	52	36	17	0	39	61	77	95	106	124	144	158
10	194	176	153	133	109	91	75	56	39	0	22	38	56	67	85	105	119
11	216	198	175	155	131	113	97	78	61	22	0	16	34	45	63	83	97
12	232	214	191	171	147	129	113	94	77	38	16	0	18	29	47	67	81
13	250	232	209	189	165	147	131	112	95	56	34	18	0	11	29	49	63
14	261	243	220	200	176	158	142	123	106	67	45	29	11	0	18	38	52
15	279	261	238	218	194	176	160	141	124	85	63	47	29	18	0	20	34
16	299	281	258	238	214	196	180	161	144	105	83	67	49	38	20	0	14
17	313	295	272	252	228	210	194	175	158	119	97	81	63	52	34	14	0

Table 2. The value matrices of W2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	18	38	56	84	99	122	134	156	178	207	218	238	259	273	290
2	18	0	20	38	66	81	104	116	138	160	189	200	220	241	255	272
3	38	20	0	18	46	61	84	96	118	140	169	180	200	221	235	252
4	56	38	18	0	28	43	66	78	100	122	151	162	182	203	217	234
5	84	66	46	28	0	15	38	50	72	94	123	134	154	175	189	206
6	99	81	61	43	15	0	23	35	57	79	108	119	139	160	174	191
7	122	104	84	66	38	23	0	12	34	56	85	96	116	137	151	168
8	134	116	96	78	50	35	12	0	22	44	73	84	104	125	139	156
9	156	138	118	100	72	57	34	22	0	22	51	62	82	103	117	134
10	178	160	140	122	94	79	56	44	22	0	29	40	60	81	95	112
11	207	189	169	151	123	108	85	73	51	29	0	11	31	52	66	83
12	218	200	180	162	134	119	96	84	62	40	11	0	20	41	55	72
13	238	220	200	182	154	139	116	104	82	60	31	20	0	21	35	52
14	259	241	221	203	175	160	137	125	103	81	52	41	21	0	14	31
15	273	255	235	217	189	174	151	139	117	95	66	55	35	14	0	17
16	290	272	252	234	206	191	168	156	134	112	83	72	52	31	17	0

Table 3. The value matrices of W3

	1	2	3	4
1	0	93	199	276
2	93	0	106	183
3	199	106	0	77
4	276	183	77	0

Table 4. The value matrices of F1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	0	21	36	53	77	93	107	126	143	162	190	214	228	247	252	266	288	308	326
2	21	0	15	32	56	72	86	105	122	141	169	193	207	226	231	245	267	287	305
3	36	15	0	17	41	57	71	90	107	126	154	178	192	211	216	230	252	272	290
4	53	32	17	0	24	40	54	73	90	109	137	161	175	194	199	213	235	255	273
5	77	56	41	24	0	16	30	49	66	85	113	137	151	170	175	189	211	231	249
6	93	72	57	40	16	0	14	33	50	69	97	121	135	154	159	173	195	215	233
7	107	86	71	54	30	14	0	19	36	55	83	107	121	140	145	159	181	201	219
8	126	105	90	73	49	33	19	0	17	36	64	88	102	121	126	140	162	182	200
9	143	122	107	90	66	50	36	17	0	19	47	71	85	104	109	123	145	165	183
10	162	141	126	109	85	69	55	36	19	0	28	52	66	85	90	104	126	146	164
11	190	169	154	137	113	97	83	64	47	28	0	24	38	57	62	76	98	118	136
12	214	193	178	161	137	121	107	88	71	52	24	0	14	33	38	52	74	94	112
13	228	207	192	175	151	135	121	102	85	66	38	14	0	19	24	38	60	80	98
14	247	226	211	194	170	154	140	121	104	85	57	33	19	0	5	19	41	61	79
15	252	231	216	199	175	159	145	126	109	90	62	38	24	5	0	14	36	56	74
16	266	245	230	213	189	173	159	140	123	104	76	52	38	19	14	0	22	42	60
17	288	267	252	235	211	195	181	162	145	126	98	74	60	41	36	22	0	20	38
18	308	287	272	255	231	215	201	182	165	146	118	94	80	61	56	42	20	0	18
19	326	305	290	273	249	233	219	200	183	164	136	112	98	79	74	60	38	18	0

Table 5. The value matrices of F2

	1	2	3	4	5	6	7	8
1	0	31	65	144	200	247	280	312
2	31	0	34	113	169	216	249	281
3	65	34	0	79	135	182	215	247
4	144	113	79	0	56	103	136	168
5	200	169	135	56	0	47	80	112
6	247	216	182	103	47	0	33	65
7	280	249	215	136	80	33	0	32
8	312	281	247	168	112	65	32	0

3.2 Parameter Testing

Several selections of parameters α, β, m was tested in this research to find the best computational time and result. All the parameters were listed in Table 6 for each case matrix

Table 6. Testing parameters for each matrix

<table>
<tr><th>Case Matrix</th><th>α</th><th>β</th><th>m</th></tr>
<tr><td>W3 (4x4)</td><td rowspan="5">0, 0.5, 0.8, 1, 2</td><td rowspan="5">0, 0.5, 0.8, 1, 2, 5</td><td rowspan="2">10, 50, 100</td></tr>
<tr><td>F2 (8x8)</td></tr>
<tr><td>W1 (17x17)</td><td rowspan="3">100, 200, 300</td></tr>
<tr><td>W2 (16x16)</td></tr>
<tr><td>F1 (19x19)</td></tr>
</table>

For case W3 and F2, we used the numbers of ants were 10, 50 and 100 as the cases were not complicated and if the number of ants used was excessive, it would result in a longer computation time. However, for W1, W2, and F1, the numbers of ants were 100, 200 and

300 as they were complicated cases and if we used fewer numbers of ants, it would require longer iteration time to achieve the optimum point and needed a longer computation time. Despite that, the number of ants did not significantly influence the optimum solution. The optimum solution was more to be influenced by α and β and in this case is was obtained with no others solution better with all identical constraints. Thus, it is important to find the combination closest to the optimum solution in each case. The maximum number of iteration was determined at 800 and the replication was 5 times for each optimum solution we obtained. In the parameter test, each case had a different number of the node so that the optimum value was also varying. Therefore, the parameter test was necessarily conducted for each matrix to obtain the combination closest to optimum solution and shows in Table 7.

Table 7. The best results of each parameter

Case	α	β	m	Iteration	Results	Computational Time
W3(4x4)	2	5	10	2	552	0.07
F2(8x8)	2	5	50	3	624	0.13
W1(17x17)	2	5	200	7	626	0.43
W2(16x16)	2	5	200	5	580	0.46
F1(19x19)	2	5	300	12	652	0.89

Moreover, to reduce the frequency of maintenance for W2 and F2 maintenance would be conducted on September 12 for 30 minutes while F1 maintenance would be still conducted on September 13 as it needed 1 hour maintenance time. Table 8 presents the proposed plan of maintenance schedule in each case based on the day in 2017 and shows that the scheduling satisfies all of the constraints.

By doing the implementation in the production line, as a result, this research showed more efficient task for the technician and avoided the disruption of production process compared to previously run maintenance plans without scheduled maintenance plan and successful to achieve the target of production as 2000 units/day.

Table 8. Optimized maintenance schedule planning in 2017

Case	January				February				March					April					May				June			
	9	10	27	30	10	14	19	20	2	8	13	15	27	5	6	12	20	25	12	15	28	31	1	2	19	20
W1	●		●					●			●				●			●	●			●			●	
W2		●		●			●			●				●			●			●	●				●	
W3		●														●										
F1	●			●		●			●				●			●		●		●			●			●
F2		●			●							●												●		

Case	July				August					September					October					November				December		
	11	18	27	28	9	11	21	22	25	6	12	13	18	25	2	6	12	16	24	2	13	17	27	4		
W1				●			●			●				●		●			●		●		●			
W2	●				●			●			●				●			●		●						
W3			●														●									
F1		●				●			●		●		●		●				●		●			●		
F2				●								●						●				●				

Keterangan:

● = *maintenance of welding roll (W1)*

● = maintenance of welder machine (W2)

● = maintenance of calibration tools (W3)

● = maintenance of motor welder (F1)

● = maintenance of adjusment (F2)

4 Conclusion

This work presents a first attempt to seek the optimal preventive maintenance scheduling using ACO algorithm by using the nodes as the interval of trouble time of each machine. Based on the data processing and analysis, this research obtained the best planned and optimum maintenance schedule for one year was obtained by using $\alpha=2$, $\beta=5$, $e=0.3$, $el=0.96$ with several variations of iteration. The maintenance is best conducted in the overtime during Monday-Friday with 2 or 3 technicians for each day and the maximum maintenance time is 1 hour. This result, as applied in production line using this optimum and well-planned maintenance scheduling is reduced the risk of- or prevents machine failures that may ruin the production process.

The result showed more efficient task for the maintenance operation by reducing the number of technician needed, allocating them by exactly date for each maintenance that must run and has avoided the disruption of production process to maintenance plans previously compared. This optimized schedule of maintenance also successful to achieve the target of production as 2000 units/day. As part of the future work in this research topics, the ant colony was recommended to develop for another application for more complex system and another kind of maintenance problems.

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