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Using a Genetic Algorithm, Integrated Preventive Maintenance Planning and Production Scheduling for a Single Machine

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ABSTRACT

Although preventive maintenance and production scheduling are closely related, most industrial units plan them independently. Preventive maintenance is typically scheduled to maximize machine availability, whereas production scheduling aims to optimize customer satisfaction, often measured by minimizing total weighted expected completion time. This study addresses this gap by proposing integrated and realistic approaches to merge production scheduling and maintenance planning models. The proposed framework is applied to Rafsanjan Arvand Wheel Co. to evaluate its practicality and effectiveness on an industrial scale. Implementation results demonstrate not only the successful synchronization of production and maintenance activities but also substantial performance improvements. Specifically, the integrated strategy leads to a 42% reduction in overall weighted completion time of client orders, significantly enhancing customer satisfaction. Detailed analyses highlight how aligning maintenance and production planning can optimize resource utilization, reduce operational conflicts, and improve service levels simultaneously. These findings suggest that industrial firms can achieve both operational efficiency and improved customer outcomes by adopting integrated scheduling approaches. The proposed model provides a robust decision-support tool for managers seeking to optimize complex production-maintenance interactions, offering a practical pathway toward more efficient and customer-focused industrial operations.

1. INTRODUCTION

In the real-world preventive maintenance planning and production scheduling are performed separately and this would cause disorderliness in activities and reduction in optimization. The first articles about production scheduling were published in 1950s and books about it were released in 1960 for the first time. Demands in government and industry inspired more study on this field, these models were mostly deterministic. In 1993, Morton and Pentico introduced Meta heuristic models. In 2001, Pinedo presented the first probabilistic model. Integrated preventive maintenance and production scheduling discussed by Graves and Lee [1]. In their model there was only one

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possibility for preventive maintenance. In 2005 a paper that was published by Kutanoglu and Cassady [2] a model was represented that integrates preventive maintenance and production scheduling. The objective function was minimizing the total weighted expected completion time. They consider considered this model for small problems (3, 4 and 5 jobs) and according to results they have proposed a heuristic method. In the same year Sortrakul, Natchmann, Cassady released another paper [3] in this paper they discussed solving the model by genetic algorithm.

In this paper the results of implementing the model proposed by Kutanoglu and Cassady in Arvand Wheel Co [2] Is presented. In mathematical model section, the integrated model is reviewed in a glance. Heuristic Section discusses the implementation of model in industrial scale and finally the results are analyzed.

2.1. MATHEMATICAL MODELWSPT sequencing model

Suppose that objective is minimizing total weighted jobs in process of manufacturing and the jobs don't have the same importance. The objective function is as following:

$$Fw = \sum_{j=1}^{n} wj\ Fj \tag{1}$$

This objective would be minimized by WSPT sequencing [4]:

$$\frac{p_{[1]}}{w_{[1]}} \leq \frac{p_{[2]}}{w_{[2]}]} \leq \frac{p_{[3]}}{w_{[3]}]} \leq \cdots \leq \frac{p_{[n]}}{w_{[n]}} \tag{2}$$

In other words, for optimizing objective function jobs should be in sequence from smallest to the largest according to their ratio of processing time on weight. Preventive Maintenance Planning Holland

It is supposed that failure probability distribution of the machine is Weibull and its scale and shape parameters are η and β (El-Damcese et al. 2014). Nearly almost in all machines by passing time the probability of failure increases, in statics words it means β>1. After performing preventive maintenance, the probability of failure decreases. With connivance it is supposed that by performing PM the machine becomes as new and its age returns to zero. So the expected number of failure between two PM operation is as following formula:

$$m(\tau) = \int_0^{\tau} Z(t)\ dt = \int_0^{\tau} \frac{\beta}{\eta^{\beta}}\ t^{\beta-1}\ dt = (\frac{\tau}{\eta})^{\beta} \tag{3}$$

Let t_p represent required time for PM operation and t_r represent required time for repairing the machine. The renewal period consists of useful operation time, PM operation time and repairing time. So the availability of machine would be:

$$A(\tau) = \frac{\tau}{\tau + m(\tau)t_r + t_p} \tag{4}$$

After differentiation with respect to $\boldsymbol{\tau}$ and setting the equation equal to zero and doing algebraic analysis the formula will show the $\boldsymbol{\tau}$ quantity to maximize the machine availability is:

$$\tau^* = \eta\ [\frac{t_p}{t_r\ (\beta-1)}]^{1/\beta} \tag{5}$$

2.2. Integrated preventive maintenance planning and production scheduling

All the assumption in the previous sections are true about this model. Another assumption is also added, it is supposed that job will continue after interruption and no additional time is needed. There are two variables in this model one of them represents the sequencing of jobs and the other one represents PM binary decision variable (Performing PM or not). Let n represents the number of jobs. So there are $n!$ possible sequencing conditions for jobs and 2^n possible PM decision making conditions. So there are $n! \times 2^n$ conditions for combination of them. Cos the nature of failure is probabilistic the model is also probabilistic.

Let the $p_{[i]}$ represents processing time of job i in sequence, $w_{[j]}$ represents weight of job j in sequence $\bar{a}_{i-1}$ represents age of machine prior to job$i$, a_i represents age of machine after performing job$i$, a_0 represents age of machine prior to planning and $y_{[i]}$ represents binary PM decision making variable that defined as relation (10). The integrated model would be as follow:

$$Min \;\; TWECT = \sum_{i=1}^{n} w_{[i]}\, E(C_{[i]}) \tag{6}$$

Subject to:

$$E(C_{[i]}) = \sum_{k=1}^{i} \{t_p \; y_{[k]} + \; p_{[k]} + \; t_r \; [m(a_{[k]}) - m(\; \bar{a}_{[k-1]})]\} \quad i = 1.2. \ldots . n \tag{7}$$

$$a_{[i]} = \; \bar{a}_{[i-1]} + \; p_{[i]} \qquad i = 1.2. \ldots . n \tag{8}$$

$$\bar{a}_{[i-1]} = \; a_{[i-1]}(1 - y_{[i]}) \qquad i = 1.2. \ldots . n \tag{9}$$

$$y_i = \begin{cases} 1. \text{ if PM is performed prior to the ith job} \\ 0. \text{ otherwise} \end{cases} \tag{10}$$

The total weighted expected completion time (TWECT) can be calculated by relation (6). This relation is objective function and should be minimized. Expected completion time job i obtained by constrain (7).

If before job i PM operation has being performed the age of machine prior to job i would be zero because by performing PM operation machine becomes as new. Otherwise the age of machine prior to job i would be equal to age of machine after performing job$i - 1$. This matter could be formulated as constrain (9). Constrain (8) shows that the age of machine after performing job i is the age of machine prior to doing it plus its processing time.

2.3. Heuristic

As discussed this model have $n! \times 2^n$ feasible solutions and this matter require a lot of time for solving large problems. Kutanoglu and Cassady studies shows that optimum solution often obeys WSPT sequence and in the case of contravention the WSPT sequence the diversion is not substantial. [2] They have supposed following heuristic:

- First of all, make WSPT sequence
- Determine binary PM decision making variables

2.4. Genetic algorithm

Genetic algorithms are exploratory search and optimization methods that were devised on the principles of Darwinian evolution and population genetics, which was first introduced by J. Holland [5] in cooperation of his coworker and students in University of Michigan in 1975 [6]. In solving the problems variables are considered as gens. A set of gens (variables) makes a chromosome. An index is defined as fitness function that evaluates how much the chromosomes is optimum. A set of chromosome is produced randomly as initial population. A number of these chromosomes are selected probabilistically according to their fitness and transferred to mating pool. Chromosome randomly reproduction a new generation. Some chromosome doesn't mate in mating pool that is called transfer. The probability that a chromosome mates in mating pool is represented by crossover probability. The contents of offspring gens is changed randomly, this probability is represented by mutation probability. The fitness of offspring chromosome is evaluated and the best one is determined, then again some of them are selected to go to mating pool, this cycle iterate till meats a predefined criterion.

3. COMPUTATIONAL RESULTS

It is the first time that the model is implemented in industrial scale. In this section has been tried to represent the method applied for implementation and lesson learned from implementing this model in Arvand Wheel Co. This factory is the greatest manufacturer of sport aluminum wheel for cars in Iran. In 2006, Arvand Wheel Co. established in an industrial complex, in Rafsanjan, Kerman. Its capacity is 750000 wheel per annual. Its units are including: melting and casting, machining, casting, painting, several labs, quality insurance, etc. Their key machine was a CNC machine machining unit that is selected for planning.

In this case study the heuristic method in section 3 has been applied. However, this heuristic decreases the computing but there are other justification to apply it. The job sequencing is determined by business preferences that is reflected in jobs' weighs. It is impractical to change the product until the finish of a batch. And a product batch is delivered to customer and producing a product in the middle of another batch absolutely will increase the TWECPT.

If we want consider PM variable for each product the computing volume will be huge and such exactness is not needed in real world. Product batches can be chosen to be the base of optimization but batches processing time may be long so it is proposed that set batches as base of optimization cost after finishing a batch it is delivered to customer and break the batches to sub batches to consider for PM decision making variable. According to condition batches can be broken to sub batches with one or eighth, etc. duration. Here 1one hour sub batches are selected.

3.1. Preventive maintenance and repairing data analysis

With statically analyzing of PM units the parameters of Webull distribution has been estimated. Results shows that β is 1.14 and τ is 130.52. Mean of Required time for repairing is 1.22 hours and mean time required for PM operation is 0.37 hours.

3.2. Production plan

Hierarchical additive weighing–Method is used for determining weights of batches [7] determinate factors are including: batch size, payment status, lag penalty, due date price. The weights of jobs are shown in following table:

Weekly batches that should be produced are shown in the following table. They are ordered in WSPT order.

Table1. Batches specification

WSPT order	Batch	w_j	Batch size	Unit processing time	Total Duration	t_j/w_j
1	AK	0.124	192	0.024	4.608	37.16
2	AB	0.124	192	0.031	5.952	48.00
3	AR	0.31	576	0.027	15.552	50.17
4	AS	0.182	960	0.021	20.160	110.77
5	IK	0.26	1258	0.027	33.966	130.64

It is tried to break the batches to sub batches with duration near to one hour and result are shown in table 2. The first column represents sub batches code (from-to). The second column shows the type of batch or product. As you seen 80 sub batches are produced that are coded by numbers from 1 to 80.

Table 2. Sub b6atches

No.	product	Batch Size	Unit Processing Time		Time
1-4	AK	48	0.024		1.152
5-10	AB	32	0.031		0.992
11-26	AR	36	0.027		0.972
27-46	AS	48	0.021		1.008
47-80	IK	37	0.027		0.999

3.3. Genetic algorithm options

For optimizing genetic algorithm is applied. Sortrakul, Natchmann, Cassady specified initial generation and crossover probability as 30 chromosomes and 1 percent [3]. Generally, it is recommended for all genetic algorithm crossover probability should be between 0.6 and 0.9 and mutation probability should be between 0.001 and 0.01.

In this case study chromosome is a matrix that its gens represents PM decision making variable prior to each sub batch. Initial population is 50 chromosomes, crossover probability specified as 0.9, mutation probability is 0.001 and 200 iterations is determined as stop criteria. Because the purpose is minimizing the TWECT the fitness function is defined as 1/TWECT.

$y_{[1]}$	$y_{[2]}$	$y_{[3]}$	…	$y_{[n]}$

Fig. 1. Problem chromosome

4. RESULTS

One outputs of genetic algorithm show that TWECT of a good solution could be 22.73. In this feasible solution PM operations are performed prior to following sub batches: 3, 18, 24, 25, 27, 28, 29, 31, 34, 35, 36, 44, 47, 48, 50, 54, 58, 64, 72, 76, and 79. Its gen is represented in figure 2. This gen fitness is 0.0442.

0010000000000000010000011011101001110000000100110100010001000001000000000100010010

Fig. 2. Gen of a good solution

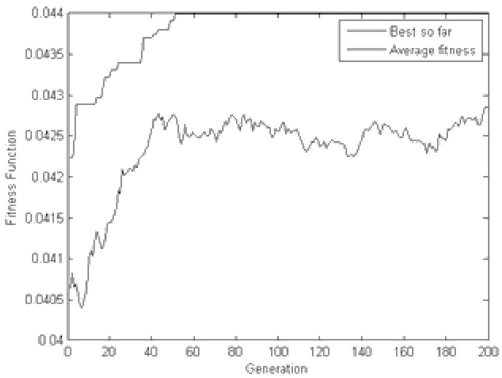

Fig. 3. Different Generations Fitness

For maximizing the availability of machine according to relation 5 interval between two PM operation should be 257.14 hours and if jobs performed in WSPT sequence the TWECT would be 39.68. It means this integrated model have 42.7% improved the objective function.

Table 3. Comparison of integrated model and old method

model	Description	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	TWECT
Integrated model	Expected Completion	5.01	11.01	27.77	51.00	88.50	22.73
	Weighted Expected Completion	0.62	1.36	3.44	6.32	10.97	
Old method	Expected Completion	4.66	10.67	26.38	46.76	81.10	39.68
	Weighted Expected Completion	0.58	1.32	8.18	8.51	21.09	

5. CONCLUSION

Integrated preventive maintenance planning and production scheduling implemented successfully in Arvand Wheel Co. Improvement was substantial. Total weighted expected completion time have diminished from 39.68 hours to 22.73 hours which means 42.7% improvement. In the other hand we have developed an integrated system of production and maintenance planning that solve controversy about the time of preventive maintenance operation and customers are more satisfied for delivering their orders sooner.

Future studies would be trying other heuristic Methods like ant colony to solve the problem or to develop a special heuristic to determine preventive maintenance variables. A specific heuristic with a fewer optimization is desirable to decrease the computing volume and to develop an easier approach for solving the problem.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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