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Multi-Objective Optimization Research on Multi Parallel Machine with Different Preventive Maintenance Planning and Scheduling with Genetic Algorithm

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Abstract

Maintaining the reliability of a system is one of the most critical and challenging tasks for factories during production. Researchers have begun to investigate the integrated optimization problem of preventive maintenance (PM) and production scheduling with a single objective. In this paper, our objective function includes five parts; minimizing maintenance cost, make span, total weighted completion time of jobs, total weighted tardiness, and maximizing machine availability are simultaneously considered to optimize the integrated problem of PM and production scheduling. We solve the problem with two different types of PM on multi-parallel-machine. Each of them includes multi jobs. First: When a part needs to be repaired and the second type considers when a part needs to be changed. Genetic algorithms help us to solve this model for finding a Local Optimum solution for this problem.

Keywords: Preventive Maintenance, Reliability, Multi-machine, Multi-objective, Genetic Algorithm

Introduction

One of the critical issues in determining the key to success of a factory is to maintain high equipment reliability. Higher equipment efficiency results in improved productivity and profitability, which relies heavily on a reliable maintenance planning. Preventive maintenance is a broad term that encompasses a set of activities aimed at improving the overall reliability and availability of a system. All types of systems, from conveyors to cars to overhead cranes, have prescribed maintenance schedules set forth by the manufacturer that aim to reduce the risk of system failure. The advantage of preventive maintenance to avoid failure and severe damage and analysis system, time and level of maintenance equipment are identified.

Sadfi et al. (2005) developed a modified algorithm MSPT for a single-machine scheduling problem with the aim of minimizing the total completion time. Using their algorithm, the worst-case ratio was 20/17[5]. Bris et al. (2003) consider cost and availability as the systems criteria in their research. They optimize a model including cost in the objective function and availability as the constraint by using a genetic algorithm to find the best preventive maintenance schedule. Shalaby et al. (2004) develop an optimization model for preventive maintenance scheduling of multi-component and multi-state systems. They define sequence of preventive maintenance activities as the decision variables and the summation of preventive maintenance, minimal repair, and downtime costs as the objective function. In addition, they consider system reliability, minimum intervals between maintenance actions, and crew availability as the constraints of their model. Later Yao et al. (2004) extend their previous model to be more general, apply this extended model in a production line of a semiconductor manufacturing system, and show the application of it via numerical examples. Cassady and Kutanoglu (2005) also developed a similar integrated model for minimizing the total expected weighted completion time of jobs. Duarte et al. (2006) present a model and algorithm to maintain optimization of a system with series components. Chelbi and Ait-Kadi (2008) considered a mathematical model for a repairable production unit supplying input to a subsequent assembly line operating according to a JIT configuration. The decision variables, the buffer stock size, and the PM period length, were obtained by minimizing the sum of the maintenance cost, the inventory holding cost, and the shortage cost. Nakagawa and Nakamura (2007) studied an Entoropy model with the application of a maintenance policy in which machine's failure time satisfied Weibull distribution. Another excellent study in this area is by Tam et al. (2006). They developed three nonlinear optimization models: one that minimizes total cost subject to satisfying a required reliability, one that maximizes reliability at a given budget, and one that minimizes the expected total cost including expected breakdown outages cost and maintenance cost.

Prasad et al. (2006) used a genetic algorithmic approach to solve the multi-objective scheduling problems in a Kanban controlled flow shop with intermediate buffer and transport constraints.

Alardhi et al. (2007) present a binary integer linear programming model in order to find the best preventive maintenance schedule in separated and linked cogeneration plants. Kenne et al (2007) formulated an analytical model for the joint determination of age dependent production planning and age-preventive maintenance with the objective to minimize an overall cost function, including inventory holdings, lost sales, preventive, and corrective maintenance cost. However, the production decisions are safety stock levels instead of scheduling job orders although most of the relevant research considers preventive maintenance planning into the scheduling model, they usually take production scheduling and preventive maintenance planning as two independent problems, which makes the scheduling model not a real integrated model. So the result may be not optimal. Hence, this study explicitly integrates production scheduling and preventive maintenance planning into an improved scheduling model [6]. Zhou et al. (2007) tried to integrate sequential imperfect maintenance policy into condition-based predictive maintenance (CBPM) in their article. They assumed that the system hybrid hazard rate recursion rule is based on the concept of age reduction factor and they assumed a known function of the system condition and that can be derived directly through CBPM. Whenever the system reliability reaches the threshold R, an imperfect preventive maintenance (PM) is performed on the system. In another paper [11] writer proposes a preventive maintenance (PM) scheduling model to improve performance of cellular manufacturing systems (CMS) according to machine reliability, and resource utilization. They considered weibull distribution for machine failure times and proposed a PM model that determines a schedule for performing PM actions on each machine in each cell by minimizing the total maintenance cost and probability of machine failures. Their model uses an integrated cost and reliability based approach, and optimizes maintenance costs. Lapa et al. (2006) presented a model for preventive maintenance planning based on reliability and cost. Two main objectives are important in this paper: first they presented a novel methodology for PM policy evaluation based on a cost-reliability model and second goal is to automatically optimize the preventive maintenance policies, considering the proposed methodology for systems evaluation. In order to evaluate the proposed methodology, the High Pressure Injection System (HPIS) of a typical 4-loop PWR was used as a case study. Moradi et al. (2010) integrated flexible job shop problem (FJSP) with preventive maintenance (PM) activities under the multi-objective optimization approaches. In this paper authors attempted to simultaneously optimize two objectives including: minimization of the production part and makespan and minimization of the system unavailability for the maintenance part. At the end writer presented four multi-objective optimization methods that they compared together for finding the Pareto-optimal front in the flexible job-shop problem case. Promising the obtained results, a benchmark with a large number of test instances and meticulous care is employed. In the other paper Liu et al. (2010) presented a preventive maintenance policy that is formulated using a fuzzy reliability framework which proposed a novel method for determining the membership functions of parameter and estimates the reliability functions of multi-parameter lifetime distributions. They used an artificial neural network for estimation of parameter, reliability prediction, and evaluation of the expected maintenance cost. They used two-parameter Weibull distribution for effectiveness of the proposed method. Xing et al. (2011) presented model based on analysis of the reliability of weapons system under the conditions of variable maintenance period, the number of maintenance and failure under the conditions of the minimum acceptable reliability. In this paper an optimization model is established on the basis of relationship between the preventive maintenance cost and the corrective maintenance cost, of equipment maintenance period.

In this paper, we propose multi-objective model including minimizing makespan, replacement parts and maintenance costs (inspection and slight services) with maximizing reliability in single machine. Also in each period planning, system reliability must be over a certain amount. Considering the failure rate of each segment, the distance between service components (maintenance interval) can be different. Let us consider a single machine in a manufacturing system that is required to sequentially process a set of n jobs, In contrast, life changing piece of new pieces is calculated. In this paper we consider two types of PM (for repairing and changing components), in multi-machines by considering some constraints (reliability, cost and ECT). One of the main goals is to minimize time and some types of cost according to reliability. We obtain local optimum solution by using GA.

Methodology

Let us consider multi-machine in a manufacturing system that is required to sequentially process a set of n jobs, and suppose that preempting one job for another is not permitted. let p[i] be the processing time, d[i] be the due time, w[i] be the weight (or priority), C[i] be the actual completion time and T[i] be the tardiness. To choose the optimal sequence for the jobs, three different objectives representing the general performance of the machine are considered in this work. Makespan is equivalent to the completion time of the last job in the job sequence.

Considering the development of this improved production scheduling model discussed before, the completion time for each job as a random variable should be influenced by:

1. The completion time of the previous jobs;
2. The processing time of this job;
3. The possibility of machine failures while processing this job;
4. Time for minimal repair;
5. The effective age of the machine prior to this job;
6. Decision variable for preventive maintenance activity;
7. Time for performing preventive maintenance activity.

In this paper two types of PM is presented:
1) When a part needs to be repaired, that in this type, reliability is reduced
2) A part needs to be changed that in this type, pieces are quite kind and reliability is also the primary mode returns.

PM And Age Of Machine Definition

While scheduling PM plan, maintenance cost (MC) and machine availability must be considered. Maintenance cost includes PM cost and minimal repair and replacement cost, Decisions about the type of PM according to the amount of reliability is determined. At first, reliability is calculated, time and cost of system in repair mode, if reliability is low and time is high we change component. We assume that the 2nd type of PM restores the machine to "as good as new" condition and first type is improving condition. To calculate the initial age of part in PM:

$$a_{s[0]} = ή \times \exp\left[\frac{ln(-ln(1-R_0))}{\beta}\right] \qquad (1)$$

That β and ή are fix amount of Weibull distribution, and Suppose R0 (R0∈ [0, 1]) is the initial reliability of the machine prior to performing all the jobs.

At first we calculate the amount of R in first type of PM (When a part needs to be repaired); if amount of R is lower than a fix number we calculate the reliability in the second type of PM (A part needs to be changed in this type) and compute age of machine by new reliability.

For first type of PM, we assume m_1 and $m_2 \in [0\ 1]$, and in second type m1 and m2 is 1.R0 the initial reliability, r is the reliability for first job at end of first interval r $\in [0\ 1]$, tp time of PM, and R (i,k) the amount of reliability for each k (number job done in the machine) and I (number of machine). For the first job we use nom (2) and the rest nom (3). At last calculate reliability by nom (4):

R =r + $m_2 \times (R_0 - r)$ (2)
R =R (I,k-1) + $m_2 \times (R_0 - R(i,k-1))$ (3)
R(i,k) = R $\times \exp(-\frac{1}{\acute{\eta} \times (m_1 * tp)})^{\beta}$ (4)

After calculating the reliability, we compute the age of machine components. Age of machine in both types is:

$ae(I,k-1) = \acute{\eta} \times \exp(\frac{ln(-ln(R(I,k)))}{\beta})$ (5)

ae(I,k)=ae(i,k-1) + P(i,k) (6)

That ae (i,k) age of ith population and kth job. For k=1 we use (3) constraint and for k greater than 1 and compute age of machine parts with (4) constraint; which p (i,k) is processing time of the kth job and ith population in the job sequence. Due to different values that m1 and m2 are, reliability in second kind of PM (when component is changed) is more than in first type (when component is repaired) therefore life of parts is increased.

Suppose that the machine used to process the jobs is subject to random failure, and the time to failure of the machine follows a Weibull probability distribution having scale parameter η and shape parameter b (b>1). When b>1, the hazard function is an increasing function and it may be practical and important to take preventive maintenance for the machine in order to reduce the increasing risk of machine failure.

$N(k) = \int_0^k h(t)\, dt = (\frac{k}{n})^{\beta}$

Whereh (t) is the hazard function [2].

Makespan And Multi-Objective Computation

The completion time of the ith job in the job sequence is expressed as

$C(i,k) = P(i,k) + tp + tr \times ((\frac{ae(i,k)}{\acute{\eta}})^{\beta} - (\frac{ae(i,k-1)}{\acute{\eta}})^{\beta})$;

That tr is time of repair component. If component is changed:

$C'(i,k) = P(i,k) + tp + tc \times ((\frac{ae(i,k)}{\acute{\eta}})^{\beta} - (\frac{ae(i,k-1)}{\acute{\eta}})^{\beta})$;

That tc is time of change component. Actually C'(i,k).

For the ith job in the job sequence, let p[I,k] be the processing time, d[I,k] be the due time, w[I,k] be the weight (or priority), C[I,k] be the actual completion time and T[I,k] be the tardiness, i=1,2,..., n(number of job).k=1,2,….,n(number of machines) [3]

$P(i,k) = \sum_i \sum_j p(i,j) \times x(i,j)$

$W(i,k) = \sum_i \sum_j w(i,j) \times x(i,j)$

$D(i,k) = \sum_i \sum_j d(i,j) \times x(i,j)$

T(i,k) = max(0, C (i,j)-D(i,j))   i , j = 1,2,3,…,n

To choose the optimal sequence for the jobs, three different objectives representing the general performance of the each machine are considered in this work. Makespan is equivalent to the completion time of the last job in the job sequence. Total weighted completion time (TWC) gives a measure of total holding cost, specifically the inventory costs incurred by the schedule. Total weighted tardiness (TWT) represents the general case of on-time delivery.

Makspan = C(n,j)

TWC = $\sum_i \sum_j W(i,j) \times C(i,j)$

TWT = $\sum_i \sum_j W(i,j) \times T(i,j)$ i, j = 1,2,3,…,n

That TWC and TWT are sum of all completion time and tardiness respectively and MC is total maintenance cost and cost of repaired or changed machine parts.

Maintenance cost is defined as follows: [1]

$MC(i,k)=cp+cr\times((\frac{ae(i,k)}{\eta})^{\beta} -(\frac{ae(i,k-1)}{\eta})^{\beta});$

and

$MC(i,k) = cp+cc\times((\frac{ae(i,k)}{\eta})^{\beta} -(\frac{ae(i,k-1)}{\eta})^{\beta});$

That cr is cost of repair when the component is repaired and cc is cost of change when component is changed and cp cost of PM when PM is performed for each machine. [3]

$X_{i[j]} = \begin{cases} 1 & \text{if the ith job sequentially performed is job j} \\ 0 & \text{O.w for } i,j = 1,2,\ldots,n \end{cases}$ (8)

Main Objective Definition

In this work we have considered specific weight, or we could consider randomly that weighted sum of multiple-objective functions that is used to combine them into a scalar fitness function. The weights relating to the multiple-objective functions are random for each selection operation and therefore the search direction can vary. we assign a random number to each weight. In this problem we assume MC is the most important objective and suppose wMC = w_1,wTWT = w_2, wTWC = w_3 and wmak (makespan) = w_4.

M = $w_1 \times$MC + $w_2 \times$TWT + $w_3 \times$TWC + $w_4 \times$ mak

Or we could consider the following:

$W_k = \frac{random\,k(.)}{\sum random\,k(.)}$ k=1,…,4

Where random k (.) is a non-negative random real number in the closed interval [0, 1] or according to our priority is given tow weight. Because all the objectives in this work are expected to be minimized, the weighted-sum objective can be written as follows so M is minimized:

M =$w_1 \times$MC + $w_2 \times$TWT + $w_3 \times$TWC + $w_4 \times$mak

Constraints

Two main constraints are important in this paper, reliability and time. This is the core of this article and due to this matter we introduce one lower bound for reliability. Reliability is increased according to type of PM; hence when a part needs to be repaired (in first type of PM) reliability increase more than second type of PM (a part needs to be changed) until achieve to above lower bound. In other hand, we want minimize sum of repaired and changed parts time. Because of components disruption and failure occur suddenly; in this paper PM is performed randomly.

Multi-Objective Genetic Algorithm (MOGA)

The objectives of the multi-objective optimization problem are always in conflict, so the problem rarely converges to one solution that optimizes all the objectives simultaneously .GA is well suitable to solve multi-objective optimization problems because it works with a population of solutions and thus generates a representation of many solutions. The chromosome represented using a numerical string can be separated into two different parts, one describing the binary PM decisions and the other depicting the job sequence. we define one array (pop (npop,numj) number of machine in row and number of job in column) of 0 and 1 by randomly.

$$Pop\ (i,j)=\begin{cases}1 & if\ PM\ is\ done \\ 0 & O.W\end{cases}$$

i = ith machine, j = jth job

Crossover

The chromosome represented using a numerical string can be separated into two different parts, one describing the binary PM decisions and the other depicting the job sequence. we use from rollet-wheel method for crossover this model (produced for the parents and the selected genes).

For this, we select one random number between 1 to *nc* (nc = crossover probability×initial population) then if the number of genes selected cost less than the previously estimated cost, it was to be replaced:

nc = round (Pc×npop)

xovsp performs single-point crossover between pairs of individuals contained in the current population, *OldChrom*, according to the crossover probability, XOVR, and returns a new population after mating, *NewChrom. OldChrom* contains the chromosomes of the current population; each row corresponds to one individual. For the chromosomes any representation can be used.

New Chrom = xovsp (Old Chrom, XOVR)

For example consider the following two binary strings of the same length:

A1 = [1 1 0 1 0 1]

A2 = [1 0 1 0 1 0]

Single-point crossover involves selecting uniformly at random an integer position, *k*, between 1 and (length (A1)-1), and swapping the variables in positions *k+1* to length (A1) between A1 and A2. Thus if the crossover position *k* = 3, then A1 and A2 would become:

A1' = [1 1 0 0 1 0]

A2' = [1 0 1 1 0 1]

Mutation

The one-point mutation, where the value of the gene at the mutation point is changed from 0 to 1 or vice versa, is applied for the PM decisions part of the chromosome when the random mutation point is in the closed interval [1, n]. In this paper, we define one variable (r_2), If mutation is performed with probability *mu* (mutation probability):

r_2 = round (1+ (numj-1)×rand);

$$pop(i,r_2)=\begin{cases}1 & if\ pop(i,r_2) is\ 0\\ 0 & O.W\end{cases}$$

Results

For a case study, we have implemented the above MOGA and procedures related to integrating optimization of PM planning and production scheduling. Some acronyms and their amounts are shown as follow;

1. cr=200; % cost of repair
2. cc=350; % cost of change
3. cp=1000; % time of PM
4. tp=5; % time of PM
5. tr=15; % time of repair
6. tc=10; % time of change
7. numj=5; % number of job
8. npop=20; % number of machine
9. maxit=100; % number of iteration
10. β =2 and ή =150 %parameters of age function

Table 1 shows the best PM process for 5 jobs and 5machines, and then optimization pop is:

Job No. / Machine No.	1	2	3	4	5
1	0	1	0	0	0
2	1	1	1	1	1
3	0	0	1	0	1
4	0	0	1	1	1
5	1	0	0	0	0

Table 1: Final Population

For each machine and objective we assume weight that determines degree important of them. Weight of each can be seen in Table 2:

Machine No.	Weight of machine	Objective	Weight of objective
1	0.35	Mc(cost)	0.5
2	0.1	TWT(waiting time)	0.2
3	0.2	TWC(total time)	0.2
4	0.1	Makespan	0.1
5	0.25		

Table 2:Weight of System

At first we calculate R (reliability) and MC (total cost) and c (total time) in repair mood. In this paper we are 3 of conditions. Each of them is established, changed pieces are done:

1. c (i,j)are more or equal 24
2. R (i,j)are less or equal 0.6
3. R (i,j) is less than0.75 and c(i,j) is more or equal than19

Best amount multi-objective = 0.1640

Rate changes and the original objective functions' final value can be seen in Figure1:

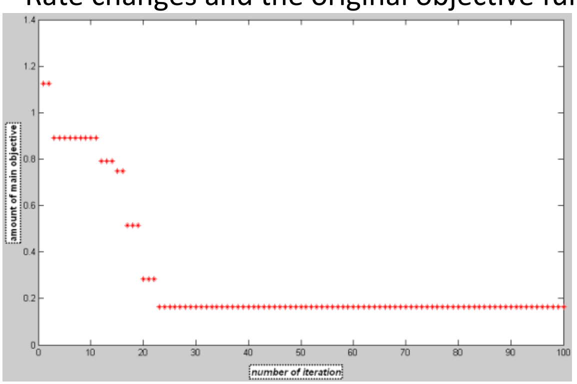

Figure 1:The Amount of Goal Continued

Conclusions And Future Work

Preventive maintenance (PM) planning and production scheduling are the most important problems in the manufacturing industries. In order to optimize the overall performance of the manufacturing system, it is necessary to integrate PM planning and production scheduling together.

This paper studied the joint determination of problem of PM planning and production scheduling for a single machine. We tried focusing on reliability amount for doing PM in planning and scheduling.

Multi-objective genetic algorithm was used to solve the joint optimization problem. The total weighted percent deviation, which represents the preferences of the objectives and the deviations of the solutions, was proposed to help decision-makers select the best solution among the near-Pareto optimal solutions obtained by the MOGA.

Original worked one in this study, considering two types of maintenance (repair and replacement parts), and assuming they were different according to the reliability, were separated in multi-parallel machine. At the first type, (when a part needs to be repaired) reliability is increased slightly. In the second type reliability is increased and time of PM is decrease because it is assumed that PM is perfect and repair after failure is minimal, PM restores the machine to "as good as new" condition, which implies the maintenance is perfect.
In this study, we discussed a single-machine scheduling problem and preventive maintenance. Future research can be:

1. Extensions of multiple machines with series form
2. Considering different types of machine (warm, hot, cold) for example by considering the possibility of any system functions and reliability, calculate total reliability
3. With approach k-out-of-N that work to be done at least k systems (jobs) work properly and PM is performed so that at least k systems are safe.

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