Preventive Maintenance Schedule for Gear Manufacturing Shop Using Genetic Algorithm

by

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Abstract:

The Genetic Algorithm (GA) has been used widely to solve an array of combinatorial optimization problems such as the traveling salesman problem, the job-shop scheduling problem, the quadratic assignment problem, and production planning problems. On the other hand, solving the problem of Preventive Maintenance (PM) scheduling for a group of non-identical machines using a GA is a relatively new topic. Thus, in this paper a GA is used to optimize a particular PM schedule. The objective is to satisfy the maintenance requirements of various non-identical machines as closely as possible to their due dates, since there is a cost associated with undertaking the maintenance task either 'too early' or 'too late'. An approach, employing a penalty method is used for the non-confirmation of the observed PM frequency with the desired PM frequency for a given machine.

Key Words:

Preventive Maintenance, Breakdown Maintenance, Actual frequencies, Desired frequencies, Optimal feasible solution, Schedule.

Introduction:

As the name suggests "Preventive Maintenance" is a set of maintenance activities undertaken for a particular machine/piece of equipment/system before it actually fails or goes out of operation due to breakdowns. While "Breakdown Maintenance" is the maintenance carried out on the machine/equipment/system after it has failed. An approach similar to "prevention is better than cure" is applied for PM. Thus, PM is periodically carried out, based on the history of the machine/equipment, so as to allow it to be in a desired state or condition which in turn ensures the availability of the machines/equipment as and when needed.

It is considered that the cost of repairing the machine/equipment/system after the failure is greater than the cost of maintaining the system before its failure. Since the maintenance cost after failure not only includes the repair and/or replacement cost of each failed part but also the losses incurred due to the down time of the entire production line, due to non availability of the machine under breakdown maintenance. Sometimes the loss incurred can go as high as the production loss of the entire unit for four shifts. To avoid such heavy losses, regular PM has to be performed. For this we need to formulate an effective PM policy addressing issues such as frequency of PM, replacement and inspection, replacement rules, effect of technological changes on replacement decisions, the size of maintenance crew, optimum inventory levels of spare parts, sequencing and scheduling rules for maintenance jobs, number and type of machines available in the maintenance shop.

Of the above topics, this paper will address the important issue of sequencing and scheduling problems associated with the PM of non-identical gear manufacturing machines using GA. Since smart scheduling will not only reduce the overall maintenance budget but also valuable loss of resources occurring due to non-schedule breakdown maintenance. In addition, PM is required in a variety of industries including the automobile industry, the aircraft industry, the textile industry, the electrical industry and the transportation industry etc. Thus, a general method of optimizing PM schedules, one that could be used in variety of industries, has the potential of having a significant financial impact.

Bajaj Auto Ltd., one of the largest manufactures of two and three wheelers in the world is currently undergoing Total Preventive Maintenance (TPM) activities in their shop floors so as to achieve higher efficiency from their available resources. The area of concentration for this paper will be the gear manufacturing shop having 31 machines, categorized into 8 different groups based on the functions of each machine. [Based on the study and practical data collection for the reasons of failure (such as oil condition, filter choking, machine part breakdown, electrical breakdowns, vibrations of machines related to load, accuracy of parts manufactured, etc.) a set of activities to be performed and the PM frequencies for each group of machine were developed.]

Total Number of Machines = 31					
Maximum Number of Machines Per Week =6					
Group Number	**Type of Machine**	**Number of machines**	**PM frequencies in weeks**	**cumulative Machines**	**For all machine of this type desired occurrence**
1	Cooper-gear Shaping Machine	3	6	3	13.00
2	PMT Horizontal Grinding Machine	7	5	10	36.40
3	Press (light weight)	1	6	11	4.33
4	GCL 100 (Grinders)	1	3	12	8.67
5	Turning Centers (Automated)	8	6	20	34.67
6	Honning Machines	1	13	21	2.00
7	Gear Shaping machines(automated)	8	7	29	29.71
8	Other Machines	2	5	31	10.40

The existing system faced problems such as frequent online production breakdowns. The existing PM schedule was not working as planned due to a variety of reasons such as improper scheduling, manpower shortage, improper PM activities, non availability of machines for PM, etc. This resulted in a loss of valuable resources. Thus the goal here is to devise a PM schedule such that the available resources are properly utilized and the online breakdown is minimized. In fact almost all mass production companies commonly face the above deficiencies.

Many people including Barlow and Hunter(8), Nakagawa(9), etc have worked on the problem of determining the individual PM frequency of single machine using various approaches. The work by Paz and Leigh(4) reviewed the issue, results and research needs concerning maintenance scheduling. They also describe how the PM problem differs from a classical scheduling problem. In a deterministic maintenance problem the machines are not subjected to failure but their unit production cost increases with usage. Several research papers have been devoted to provide mathematical models of these types of problems in various manufacturing and service context.

Escudero(10) presented a large scale mixed integer-programming model to determine the optimal maintenance schedule of production units under the time allocations and labor assignment constraints. Hyunchul(3) presented an approach in which a GA combined with simulated annealing was used for maintenance scheduling of thermal units in electric power systems. Sule and Harman(6), Hariga (2)and Duffuaa and Ben-Daya(5) studied the maintenance-scheduling problem under a deterministic environment for several non-identical machines. Sriskandarajah, Jardine and Chan[1] have developed maintenance schedules for rolling stock (trains) for the Hong Kong transportation using a GA. Their scheduling is done for 27 trains for a period of one year without repetition of the trains. They have employed the penalty method to accommodate the different maintenance frequencies of different train units of a single train (as previously they used to do the PM for individual train units), when they employed the policy of total PM for the whole train.

This paper will deal with the problem of scheduling 31 non-identical machines (having different PM frequencies) for a period of one-half year (26weeks), with at most 6 machines taken in a week. There will be repetitions of machines; with the constraints such as no machine can occur in consecutive weeks, all machines under PM must occur within the first eight weeks, all machines must occur in the schedule etc.

The mechanics of a simple GA:

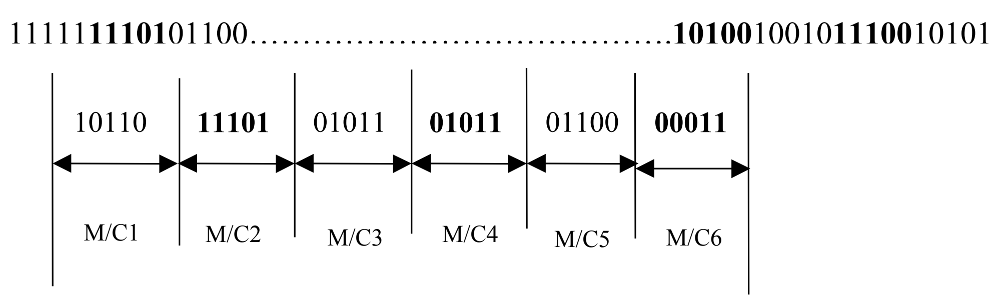
GA’s are powerful search algorithms based on the mechanics of natural genetics. They ensure the proliferation of quality solutions while investigating via a systematic information exchange that utilizes probabilistic decisions. It is this combination which allows GAs to exploit historical information to locate new points in the search space with expected improved performance. It is composed of three basic operators namely reproduction, crossover and mutation. These operators are implemented by performing the basic tasks of copying strings, exchanging portions of strings and generating random numbers.

Coding Scheme:

Thus for a GA to be effective, we must develop both coding scheme and the fitness function, as these will be the important aspects for the GA to perform well in yielding the desired results. For this problem we will choose a string of binary bits, which will represent the entire PM schedule for one-half year (26weeks). Each machine can be represented by 5 binary bits as there are in all 31 machines to be represented in the coding scheme. Thus the total string length will be:

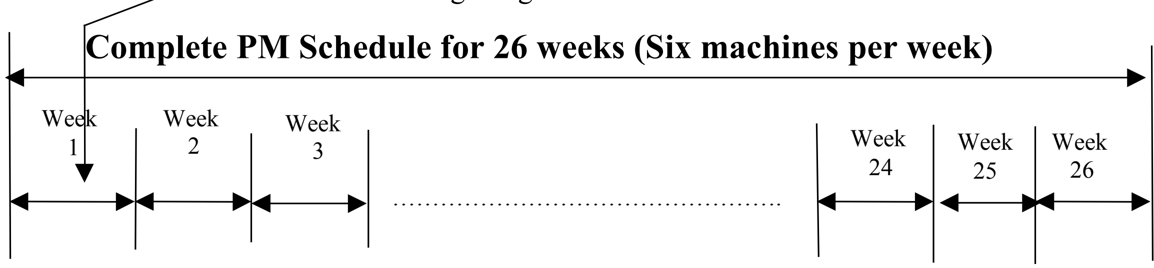
Total string length =(bits to represent a machine X max number of machines per week X number of weeks)

= 5 X 6 X 26 =780 bits



Six machines for PM for the First week

String Length = 5X6X26 = 780



Fitness Function:

After the decoding of the string is done, an array for each machine will be created. The array will store the information regarding the occurrence of that particular machine with respect to the week number. Thus by subtracting the $(x+1)^{th}$ element of the array from the x^{th} element we can deduce the observed frequencies for that machine. The fitness function will be evaluated as the sum of all the square of differences between the desired and actual PM frequencies (errors), for all the machines. Also we add some constraints to the fitness function to get a better and more accurate PM schedule. The constraints are as follows: no machine can occur in consecutive weeks (each such violation amounts to the addition of 225 points to fitness value), as far as possible, machines should not be repeated in the same week (each violation amounts to the addition of 225 points to fitness value) all machines under PM must occur within first eight weeks (each violation amounts to the addition of 100 points to fitness value), all machines must occur in the schedule etc (each violation amounts to the addition of 500 points to fitness value), all machines must occur more than ones (each such violation amounts to the addition of 500 points to fitness value).

Fitness Function =

$$\text{Min}\{\sum(f_d - f_a)^2 + 225\sum M_c + 225\sum M_s + 100\sum M_8 + 100\sum M_{81} + 500\sum M_o + 500\sum M_t + 150\sum M_v\}$$

where f_d : Desired PM frequency for a particular machine.

f_a : Actual PM frequency for a particular machine.

M_c : Number of times any machine has occurs in consecutive weeks.

M_s : Number of times any machine has occurs in same weeks.

M_8 : Number indicating how many machines have not occurred in the first 8 weeks.

M_{81} : Number indicating how many machines have not occurred in the first 8 weeks.

M_o : Number indicating how many machines have not at all occurred for PM.

M_t : Number indicating how many machines have occurs only once for PM.

M_v : Number of vacant positions,(counted only after first ten have occurred).

Reproduction is simply a process by which strings with smaller (for minimization problem) fitness values, good solutions to the problem at hand, receive correspondingly larger numbers of copies in the new population. In this case tournament selection is used. The participants in these competitions are selected based on the relative fitness of the strings, manifesting a “survival of the fittest” atmosphere. About 6.25% of the total population of 400 strings are considered for Tournament selection. Once the strings are reproduced, copied for possible use in the next generation, they are placed in a mating pool where they await the action of the other two operators. The second operator, crossover, implements a systematic information exchange utilizing probabilistic decisions. A single point crossover is used for the problem at hand. The Probability of crossover is 0.9. As the string length is very large a simple mutation operator is used with a very small probability of occurrence (0.002).

Conditions and parameters set for a GA run are:

Number of GA runs to be performed----> 1

Population Size ----------------------------> 400

Chromosome Length ---------------------> 780

Maximum number of generations --------> 5000

Crossover Probability(Pc) ----------------> 0.9

Mutation Probability(Pm) ----------------> 0.002

Field Size (must be less than 16) --------->5
Tournament size for selection -------------> 25
Random number seed, 0.0 to 1.0 ---------> 0.789

Results and Conclusion:

The objective of this paper is to find the optimal PM schedule for the gear manufacturing shop with 31 non-identical machines (having different PM frequencies) for a period of one-half year (26weeks), with at most 6 machines taken in a week. After analyzing the solution given by the GA, it is concluded that the PM Schedule is free of any penalties associated with non-conformance of the set constraints (stated below). The square error of the difference between actual and observed frequencies is 208, while only the difference of actual and observed frequencies is 124. This indicates that most of the machines (around 80% to 90%) are under PM within ± one week from the desired frequencies. The actual occurrences and the desired occurrences of machines for PM in the schedule are almost equal, which indicated that the schedule is giving proper representation for all machines as per their desired frequencies in the optimal PM schedule (refer figure 1 & 2). The machine frequencies are from 3 (machine 12) to 13 (machine 21) weeks for different machines (refer figure 1 & 2). Thus to take care of such extreme constraints, penalties for these machines were either tightened or relaxed respectively so as to yield the desired PM Schedule.

Penalty for not satisfying the set criteria's

Penalty per unit for not occur in the first 8 weeks	= 100
Penalty per unit for not occur in the last 8 weeks	= 100
Penalty per unit for occurring only once	= 500
Penalty per unit for not occurring	= 500
Penalty per unit for occurring in the same week more than once	= 225
Penalty per unit for occurring in the consecutive weeks	= 225
Penalty per unit for having more than 10 vacant positions	= 150

Actual Results

Penalty for not occur in the first 8 weeks	= 0
Penalty for not occur in the last 8 weeks	= 0
Penalty for occurring only once	= 0
Penalty for not occurring	= 0
Penalty for occurring in the same week more than once	= 0
Penalty for occurring in the consecutive weeks	= 0
Penalty for not following desired frequencies (in square)	= 208
Penalty for not following desired frequencies	= 124
Penalty for having more than 10 vacant positions	= 0
Total Penalty	**= 208**

The "On-line" and "Off-line" performance of GA reveals that off-line performance is better that the on-line performance for a period of 5000 generations. On-line performances start above the fitness value of 10000 and then decreases to fitness value of 1325, while the Off-line performances start above the fitness value of 7000 and then decreases to fitness value of 264 (refer figure 3). The best fitness schedule starts with fitness value of 7088 and converges towards fitness value of 208 (refer figure 4).

Thus the PM Schedule obtained is an optimal feasible solution.

Future Scope:

The above problem can be set as a integer programming one with the added constraint of precedence relations for a set of machines i.e. machine 2 must be under PM before machine 22 comes for PM. Optimal Manpower allocation can be combined with the optimal PM schedule.

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