A new strategy to the joint production scheduling and maintenance planning under unconventional constraints

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***Abstract*-Since jobs scheduling becomes subject to both renewable and non-renewable resources at the same time and the production systems are characterised by random machine failures, multiple production criteria and the presence of uncertain events, selecting the most appropriate jobs to be executed and the optimal intervention date of maintenance actions becomes a critical issue and has a high impact on the system performance. In this context, this paper deals with the joint consideration of production scheduling and maintenance planning, in parallel machine environment under the resources constraints. We propose a new resolution strategy which allows the decision maker to find compromise solutions between the two services. The integrated strategy consists to establish an optimal number of preventive maintenance interventions in order to maximize the productivity of the system and to minimize the system unavailability. The simulation results show that the proposed integrated strategy improve the profitability and the performances of the system.**

***Keywords*-**Production scheduling, maintenance planning, integrated model optimization, genetic algorithm

I. INTRODUCTION

Production and maintenance strategies are two major issues in manufacturing companies in order to ensure optimal availability of production system; so it is necessary to determine the production strategy taking into account the planning of maintenance actions intervention dates. Indeed, despite the interrelationship between manufacturing strategy and maintenance, both activities are usually planned and executed separately which leads to a conflict in the decisions. In these environments, the production and maintenance decisions are required to be highly reactive to cope with unanticipated circumstances. Therefore it is essential to coordinate between the two services in order to satisfy different objectives. Moreover, the consumable resources are considered as one of the main strategic tools because it provides many benefits, such as improving production rate and enhancing the system performances. But, achieving all these objectives and benefits is conditioned by a good cooperation between human and machine to control system the human intervention remains necessary to exercise intelligent decisions and supervisory management.
In this direction, this study which consist to accomplish and to improve precedent works, focuses on production scheduling and maintenance planning with the consideration of consumables resources constraint using metaheuristics. This paper firstly, extends the results obtained in [8] and secondly provides a methodology, which takes into account the machines reliability, to join the production scheduling and maintenance planning in parallel machines environment to minimize makespan, machine unavailability and maintenance cost.

II. CONTEXT AND MOTIVATION

The practical relevance of parallel machines scheduling problems with non-renewable resources has lead to a major research project, comprising development of an important range of resolution approaches, nevertheless research works concerned the production aspect ignore generally the maintenance service or assume that the maintenance periods are already planned. Recently, some studies have been devoted to the optimization of the two functions relating to the maintenance and production, but separately. Lee [1] tackles this problem by considering various unavailability periods like maintenance activities. They consider problems in which the maintenance intervention dates are not fixed in advance. In this approach, maintenance is often favored to the detriment of the production. Kaabi et al. [2] propose four heuristics for maintenance and scheduling on a single machine to minimize total tardiness of jobs. The authors assume that the intervals of maintenance activities are fixed in advance. Kaabi et al. [3] consider production and maintenance a problem of a flow shop system and assume that the maintenance interventions dates must be carried out in advance, within a predefined period. They present a genetic algorithm for solving the problem studied. Cassady and Kutanoglu [4] propose an integrated model that simultaneously determines production scheduling and preventive maintenance planning decisions to minimize the total weighted tardiness of jobs on a single machine. They propose an exact procedure which is ineffective for the problems of industrial size. Gharbi and Kenne [5] consider the production and preventive maintenance control problem for a multi-machine manufacturing system. They present a two-level hierarchical control to find the production and preventive maintenance rates for the machines so as to minimize the total cost of inventory/backlog, repair and preventive maintenance. Ruiz et al. [6] introduce an integrated model to solve a permutation flow shop where maintenance periods are fixed to maintain a minimum level of reliability for each machine. The reliability level is considered a constraint. Their objective is to minimize the makespan. Xu et al. [7] consider an integrated environment of parallel machines problem in which maintenance activities are quasi-periodic in order to minimize the makespan. The production aspect is still disadvantaged in their research. Berrichi et al. [8] propose an integrated model of preventive maintenance and production scheduling on parallel machines. They use a reliability model to take into account the maintenance aspect. They propose two genetic algorithms to optimize two criteria which are: the minimization of the makespan for the production side and the minimization of the system unavailability for the maintenance part. Berrichi et al. [9] deal with the same problem described above, they suggest, a metaheuristic based ant colonies to improve the results obtained in [8]. Moradi et al. [10] propose a genetic algorithm to treat an integrated problem of a flexible job shop with a preventive maintenance activity. The performance criteria considered for production and maintenance are respectively, the makespan and the unavailability of the production system. Berrichi et al. [11] consider the same problem studied in [8], they propose an ant colonies approach to minimize the total tardiness for the production part and to optimize the system unavailability for the maintenance side.

III. THE INTEGRATED MODEL

This section describes separately the problem definition of production scheduling problem, the planning of preventive maintenance and the proposed integrated model.

For the production part, the problem can be stated as follows: There are *n* independent jobs to be scheduled on *m* parallel machines subject to consumables resources constraints. Each job j has a processing time pj and a quantity of component k that consumes; and it can be processed on a machine i, when all necessary components are available. All machines can process only one job at a time. The preemption is not allowed in jobs processing. The objective is:

$$Min\ Cmax \quad (1)$$

The decisions variables are:

$$Xjip = 1 \text{ if the job j is scheduled in position p on machine i } 0\ otherwise \quad (2)$$

$$Yipt = 1\ if\ dip \geq t \text{ (start date of job processing on machine i in position p} \geq t) \ 0\ otherwise \quad (3)$$

For the maintenance part, we aim to provide a systematic preventive maintenance plan; we manipulate the rational strategy introduced in [8] to insert preventive maintenance activities. But the difficulty of this maintenance strategy resides in determining the intervention dates of operators to achieve the maintenance action for each machine.

: failure rate of machine i
: repair rate of machine i
(t') : the availability of machine i at time t'
(t') : the system availability at time t'
(t') : the system unavailability at time t'

The availability expression of a machine i depends on it failure rate λi and repair rate μi. In the remainder of this work, we consider that these two parameters are constant. We also assume that each maintenance action restore the system to "as good as new." We apply a rational strategy to insert preventive maintenance action.

Therefore, the availability $A_i(t')$ of a machine i, is given by the following expression [12]:

$$A_i(t') = \frac{\mu_i}{\lambda_i+\mu_i} + \frac{\lambda_i}{\lambda_i+\mu_i} exp[-(\lambda_i + \mu_i)t] \quad \textbf{(4)}$$

The unavailability $\overline{A_i}(t')$ of a machine *i*, from the time *t'=0,* until the time *t'* can be computed as follows:

$$\overline{A_i}(t') = 1 - A_i(t') \quad \textbf{(5)}$$

Since the studied system has a parallel structure, with m identical parallel machines, each having a fu

availability $A_i(t')$, this implies that the system availability $A_s(t')$ at instant *t'* is given by the following expr

$$A_s(t') = 1 - \prod_{i=1}^{m}[1 - A_i(t')] \quad \textbf{(6)}$$

So, the system unavailability $\overline{A_s}(t')$, during the maintenance operations can be illustrated as follows:

$$\overline{A_s}(t') = 1 - A_s(t') = \prod_{i=1}^{m}[1 - A_i(t')] \quad \textbf{(7)}$$

The purpose is to integrate the maintenance and production part under the consumable resources constraints in the same model, these two services must cooperate with the operator anticipation to determine the preventive maintenance interventions dates to minimize the system unavailability and to maximize the system productivity.

VI. GENETIC ALGORITHM (GA)

GAs are a stochastic search methods designed to explore spaces of complex problems and to guide the research process in order to find optimal solutions using the minimum information about the problem. Unlike other optimization techniques, GAs are characterized by the utilization of a population of individuals to establish research on different regions of the solutions space in order to optimize a predetermined function.

TABLE I
SOLUTION ENCODING

j_1	j_2	j_3	j_4	Preventive Maintenance p	
1	1	2	1	10	15

The six first alleles determine the assignment of jobs to machines and the last two alleles (10, 15) means that a maintenance action must be performed every 10 time units and on the second machine every 15 time units.

Solution evaluation

The solution evaluation steps can be summarized as follows:

- Affect jobs to machines
- Calculate the makespan of the system.
- Insert the preventive maintenance actions in the scheduling according to a rational strategy. The intervention of preventive maintenance date can be advanced or delayed by the decision maker depending on the assignment of jobs
- Update the jobs scheduling dates.
- Update the makespan after insertion of preventive maintenance actions and calculate the unavailability of the system and preventive maintenance cost

Therefore, the simplified structure of the genetic algorithm can be presented as follows:

If there are a set of jobs not scheduled **then**
Generate the initial population
For each chromosome
Evaluate the solution
End for
While the number of iterations without improvement is not satisfied
Apply the selection, crossover and mutation operators
For each chromosome
Evaluation the solution
End for
Constitute the next generation.
End while
End if

V. Computational results

In this section, extensive computational experiments were conducted in order to analyze the effect of the proposed integrated strategy on system behavior. We apply some performance measures which can be illustrated as follows:
- the average resolution time (CPU_{time}) for optimally solved instances.
- the maximum completion time (C_{max}) value of each approaches to calculate the reported GAP

$GAP = (C_{maxcur} - C_{maxbest}) / C_{maxbest}$, where:
- $C_{maxbest}$ is the solution obtained by GA without preventive maintenance actions
- C_{maxcur} is the current solution
- The machine unavailability and maintenance cost

Tables 2 show the average results obtained by the GA for different size problems. The test protocol is composed of a set of computational experiments to evaluate the performance of each strategy.
- The results obtained by the GA without Preventive Maintenance is denoted "GA-WPM".
- The results obtained by the GA of production scheduling integrated with the Preventive Maintenance actions is denoted "GA-PM".
- The results obtained by the GA of production scheduling integrated with the Preventive Maintenance actions and Resources unavailability periods is denoted "GA-PMR".

TABLE II
COMPARISON BETWEEN DIFFERENT STRATEGIES FOR DIFFERENT SIZE PROBLEMS

	GAP (%)		
Strategies	**GA-WPM**	**GA-PM**	**GA-PMR**
Small size problems	0,00%	8,23%	2,44%
Medium size problems	0,00%	6,07%	1,23%
Large size problems	0,00%	6,14%	0,93%

In the results obtained in Tables 2, it can be noticed that the strategy which integrates preventive maintenance with production scheduling and unavailability resources periods provides the best results for different sizes problems. The GA provides better results for the joint production scheduling and maintenance planning problem in a parallel machine environment under consumable resources constraints. This is due to good exploitation of resources unavailability periods, trying to combine between intervention dates for preventive maintenance and unavailability periods of resources.

TABLE III
PERFORMANCE IMPROVEMENT BY THE PROPOSED STRATEGY

Problems	Performance improvement by the proposed strategy (PMR)
Small size problems	5,78%
Medium size problems	6,04%
Large size problems	6,50%

We can notice in table 3 that there is a significant improvement in the results of the integrated approach, when preventive maintenance actions are inserted with 'unavailability periods of consumables resources. Furthermore, we can remark that the performance of the proposed strategy continue to give better results when the problem size increases.

TABLE VI
IMPACT OF THE TWO STRATEGIES ON THE PREVENTIVE MAINTENANCE COST

Strategies	Preventive maintenance cost
PM	42600
PMR	10500

According to table 4, we notice that the model that integrates production, maintenance and management of resources improves the obtained results, the profitability and the performances of the system. The strategy PMR surpasses the strategy PM for all instances. Based on these results, the proposed met heuristic remained the most effective for PMR comparing to PM and can find good solutions for different test problems.

TABLE V
IMPACT OF THE TWO STRATEGIES ON MACHINES UNAVAILABILITY

Strategies	Machines unavailability
PM	4.89%
PMR	4.51%

According to table 5, we can note that the better results are obtained by strategy which take into consideration the joint production scheduling and maintenance planning problem under consumable resources constraints. So the proposed integrated strategy, which, leads to an acceleration of the scheduling, allows an improvement in system performance by minimizing the system unavailability.

CONCLUSION

In this paper, we have proposed a strategy to solve the joint production scheduling and maintenance planning problem, in parallel machine environment under the resources constraints. We propose a new integrated model which allows the decision maker to find compromise solutions between the two services. We have proposed a genetic algorithm to validate the proposed strategy, to maximize the productivity of the system, to minimize the system unavailability and maintenance cost. The integrated strategy which promotes the cooperation between human and machine consists to establish an optimal number of preventive maintenance interventions. The simulation results show that the proposed integrated strategy improve the profitability and the performances of the system.

In this study, we apply a rational strategy to insert preventive maintenance actions, so as perspectives, it would be interesting to apply other maintenance policies for this problem. Moreover, it appears interesting to develop a local search procedure in order to improve the behavior of the genetic algorithm.

ACKNOWLEDGMENT

The author would like to thank the Erasmus Mundus EU-METALIC project team Coordinated by Cardiff Metropolitan University. "*This project has been funded with support of the European Commission. This paper reflects the view only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.*"

REFERENCES

[1] C.-Y. Lee, Machine scheduling with an availability constraint. *Journal of Global Optimization, 9*, pp. 395–416, 1996.

[2] J.Kaabi, C. Varnier, and N. Zerhouni, "Heuristics for scheduling maintenance and production on a single machine". IEEE Conference on Systems, *Man and Cybernetics*. October 6–9, Hammamet, Tunisia, 2002.

[3] J.Kaabi, C. Varnier, and N. Zerhouni, "Genetic algorithm for scheduling production and maintenance in a Flow Shop". *Laboratory of automatic of Besançon*, France, 2003.

[4] C.R.Cassady, E. Kutanoglu. "Minimizing job tardiness using integrated preventive maintenance planning and production scheduling". *IIE Trans*, pp. 35:503– 513, 2003.

[5] A. Gharbi, And J. P. Kenne, "Maintenance scheduling and production control of multiple-machine manufacturing systems". *Computer and Industrial Engineering*, 48(4), pp. 693–707, 2005.

[6] R.Ruiz, J.C. García-Diaz, and C. Maroto, "Considering scheduling and preventive maintenance in the flow shop-sequencing problem". *Computers & Operations Research*, 34(11), pp. 3314–3330; 2007.

[7] D.Xu,K. Sun, and H. Li, "Parallel machine scheduling with almost periodic non-preemptive maintenance and jobs to minimize makespan". *Computers and Operations Research*, 35, pp. 1344-1349, 2008.

[8] A. Berrichi, L.Amodeo, F.Yalaoui, E. Châtelet, and M. Mezghiche, "Bi-objective optimization algorithms for joint production and maintenance scheduling: application to the parallel machine problem". *Journal of Intelligent Manufacturing*, *20*(4), pp. 389-400, 2009.

[9] A. Berrichi, L.Amodeo, F. Yalaoui, and M.Mezghiche, "Bi-Objective Ant Colony Optimization approach to optimize production and maintenance scheduling", *Computers & Operations Research*, Vol. 37, pp. 1584–1596, 2010.

[10] E. Moradi, S.M.T. FatemiGhomi, and M.Zandieh, "Bi-objective optimization research on integrated fixed time interval preventive maintenance and production for scheduling flexible job-shop problem". *Expert systems with applications*, 38(6), pp. 7169-7178, 2011.

[11] A. Berrichi, and F. Yalaoui, "Efficient bi-objective ant colony approach to minimize total tardiness and system unavailability for a parallel machine scheduling problem". *The International Journal of Advanced Manufacturing Technology*, 68(9-12), pp. 2295-2310, 2013.

[12] C.E. Ebeling, "An introduction to reliability and maintainability engineering". McGraw-Hill, USA, 1997.