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Review Article

Scheduling with Maintenance Technique in Dynamic Job Shop System including Machine Breakdowns

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Abstract

Machine scheduling is concerned with the problem of optimally scheduling available machines. However, scheduling literature review has been focused on common assumptions that machines are available at all times. The availability constraint is may not frequency occurred because a machine may become unavailable during a certain periods of time. This paper is addressed to study the problem of job shop in dynamic environment with the risk of random machine breakdown. It is considered a NP Hard optimization problem. Predictive maintenance is an answer to prevent the system from risk of machine breakdown. The objective function is to minimize the completion time of the last job being executed. Hence, we propose a met heuristic approach based on GA approach to solve the issue. Experimentation results assume that the used approach based on maintenance function is required to produce, for each machine, the adequate scheduling plan.

Keywords: dynamic job shop scheduling problem; genetic algorithm; makespan; preventive maintenance; operating schedule; optimization problem

Introduction

Production scheduling is the process of sequencing a given set of jobs on a certain number of machines with the objective to satisfy some performance measures. All jobs are processed through each machine according to a pre-determined sequence. Up today, many papers with a variety of practical and impractical assumptions have been published; however, there always exists in the literature for this special field. One of the most thoroughly studied scheduling problems is the job shop problem (JSP). In the classical JSP, we have a set of n jobs J1, J2, etc. Jn and a set of m machines M1, M2, etc. Mm. Each job i has a set of operations and each operation can be executed by one machine j. All jobs have different processing routes. Scheduling jobs one by one on each assigned machine. Each job has a fixed processing time Pij for operating job i on machine j. Most of the classical scheduling studies assume that all data and parameters of the problem are fully known. However, in practice, manufacturing systems are not so deterministic. During the execution of the offline generated schedule, many disturbances may occur. There are many dynamic events as new job arrivals, machine breakdowns, changes in due dates, order cancellations, arrival of urgent.

Manufacturing systems may not be available because of periodical repair, preventive maintenance (PM), or unforeseen breakdowns. For the above reasons the maintenance needs to be integrated with the scheduling in order to react rapidly to changes and improve the manufacturing system performance. To prevent risks of breakdown, preventive maintenance policy can be carried out. Generally, preventive tasks are realized periodically. These tasks are planned for each machine. They required that a specific machine should be stopped. Maintenance tasks have to be done on time, that is why it is always considered as a constraint for the production scheduling problem. Through this motivation, we propose a proper preventive maintenance for solving the dynamic job shop scheduling problem

(DJSSP), known as one of the most complexe scheduling shop system, from unforeseen machines failures. Then, to improve the system performance.

The present paper is organized as follows. Literature review of maintenance in dynamic JSSP is presented in Section 2. Both scheduling and preventive maintenance are introduced in Section 3. A proposed strategy of integrating the preventive maintenance is presented in Section 4. Computational studies and results are discussed in Section 5, while Section 6 is followed with a conclusion and future aims.

Literature Review

Production scheduling is one of the most significant activities in the planning and scheduling of the manufacturing systems since it aims at planning orders on machines to ensure customer satisfaction and system profitability. One of the most complicated scheduling system is the JSS problem which is the process of allocating and timing resource usage in manufacturing system to complete jobs over time according to some criteria. An extension of the Job Shop is called a Dynamic JSSP which is a well known NP-hard combinatorial optimisation problem. To deal with dynamic events, especially machine breakdowns, scheduling system should be notified with preventive maintenance methods before unconditionally failures occur.

In [6], authors addressed production scheduling and preventive maintenance planning for a single machine. The purpose of the scheduling problem is to choose an optimal sequence for jobs as well as an optimal preventive maintenance planning which minimizes the total weighted expected completion time of the jobs. They used the Genetic Algorithm (GA) approach to search for the optimal flexible interval preventive maintenance planning and job scheduling. Authors in [13] propose revised techniques to schedule operations with maintenance activities in a manufacturing system using a high level of prediction to perform the degradation of manufacturing equipments. In [11], authors investigated the job shop scheduling with sequence-dependent setup times and preventive maintenance in order to minimize makespan. Well known metaheuristics in the literature are employed to solve the problem. The performances of the proposed algorithms based GA are evaluated by comparing their solutions through two benchmarks based on Taillards instances. In recent years, some studies concern the cost and manufacturing performance analysis of maintenance policies. The analysis of the DJSSP is discussed in few papers in literature. As far as we reviewed, there is much less literature on integrating job shops scheduling as well as dynamic job shops with preventive maintenance.

In fact, the maintenance task is related to production scheduling in industrial settings. However, both activities conflicts incetheyact on the same resources. In addition to that, maintenance operations consume production time where as delaying maintenance activities because of production demands may increase the probability of machine breakdown. In this paper, we propose the joint of DJSS issue of scheduling new jobs and preventive maintenance for solving unexpected machine failures. The machine ready time and job release times are all zeros. The pre-emption is allowed to speed task scheduling. The developed objective function through the paper is the minimization of C_{max} (makespan).

Furthermore, the adopted hypotheses in this problem are:

- All the machines are available at time zero.
- One random machine could be in failure state.
- The order of operations are linked with a precedence relationship.
- The processing time of operations is defined in advance.
- Each machine can process only one operation at a time.
- The preemption is allowed.
- New jobs are entering the scheduling process; only when the current task is terminated.

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The main issue of the Dynamic JSSP is described in [3]. Up to now, real world environments are usually changing dynamically as unpredictable real time events that take place during the process of production, e.g., machine breakdowns suddenly and gets repaired after some time. Such occurrences of real time events are known as dynamic issues. For the dynamic job shop model, suppose there are n jobs to be processed on m machines. Each job j contains a sequence of n operation. Each operation k should be processed on a predefined i machine within a given processing time Pijk. Each operation of each job should be processed one by one in the given order with pre-emption if needed, and at most one operation can be processed on each machine at one time. The goal of the DJSSP is to schedule new jobs n' once they appear at the system during its execution. Most used metaheuristics adopted to solve this issue are mainly based on the evolutionary algorithms. Among them, the GA is used to handle upcoming events due to its flexibility that has been deeply involved in literature as studied in [8, 10, 3] and [5]. In our study, we aim to integrate the principle of preventive maintenance for enhancing machine breakdown and to optimize the DJSS process for makespan minimization as performance criterion.

Given a set I= 1,...,n of n independent jobs of varying sizes needs to be scheduled on a set M=1,...,m of m machines. Each job iϵI consists of ni ordered operations Oi,1,...,Oi,ni , each of which must be processed on one of the m machines. Let O = 0, 1<, o, o + 1 denote the set of all operations to be scheduled. Each operation kϵO is associated with a fixed processing time Pij. Each machine j can process at most one operation at a time and once an operation begins processing on a given machine, it must complete processing on that machine without interruption until terminated. Furthermore, let pk be the predecessor operation of other operation kϵO. Operations are interrelated by two kinds of constraints. First, operation kϵOcan only be scheduled if the machine on which it is processed is idle. Second, precedence constraints require each operation kϵO to be scheduled after its predecessor operation pk has been completed.

$$\text{Minimize } C_{max}=F_{o+1} \quad (1)$$

Subject to:

$$F_{pk}+P_{ij}\leq F_k;\ k=1,...,o+1, \quad (2)$$

$$F_{i1}-F_{i2}\geq P_{ij} \text{ or } F_i-F_{i2}\geq P;\ (i1,i2)\epsilon O_k \quad (3)$$

$$F_i\geq 0;\ k=1...o+1. \quad (4)$$

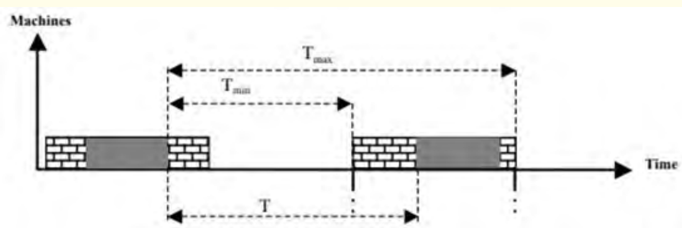

Figure 1: Interval of a preventive maintenance operation.

The objective function Eq. 1 minimizes the makespan, i.e., the finishing time of operation o + 1. Constraint Eq. 2 imposes the precedence relations between operations of the same job, while constraint eq. 3 imposes the precedence relations between operations on the same machine. Finally, constraint eq. 4 requires the finishing times of all the operations to be non- negative.

Scheduling and Preventive Maintenance

The interaction between maintenance and production, particularly their joint scheduling, is relatively little studied. There are many studies that have determined the best moment to plan maintenance operations according to a compromise between the maintenance cost and the risk of machines unavailability such in [4] and [5]. Other works are elaborated in the context of industrie 4.0 using machine learning techniques as seen in [14, 16] and which recently is mentioned in [15]. Some authors propose to solve the single-machine scheduling problem while others propose to solve it on m machines. In [7], they formulate the single-machine problem with total weighted completion time as the objective function, but they schedule only one maintenance operation during the planning horizon.. Authors in [17] consider a joint scheduling of jobs and preventive maintenance operations on a single machine with an objective to minimize the total earliness.

Integrated Strategy

The objective of this paper is modeling and proposing an effective solution for handling a dynamic job scheduling problem considering maintenance constraint. The problem includes dynamism in production because of new job arrivals in a no zero time and random machine breakdown. Flexibility of operations that comes from parallel machines using the GA approach. Maintenance is defined as any activity carried out on a system to maintain it or to restore it to a specific state. Maintenance operations can be classified into two large groups according to the intervention time: Corrective Maintenance (CM) and Preventive Maintenance (PM). The CM is carried out when the failure has already taken place. The PM consists in carrying out the operations in machines and equipment before the failure or the breakdown takes place, and at fixed time intervals previously established. The objective of PM is to prevent failures before they happen and therefore to minimize the probability of failure. The importance of PM is well established in a manufacturing environment. Recently, in [13], the PM is pointed out to solve the job shop by regarding its importance in solving shop floor problems.

Each machine is maintained periodically at known intervals of time. The PM operations are periodic interventions occurring every T periods. The processing time of PM operation j on machine i is pij. The processing times are fixed, nonnegative and evaluated with more or less certainty. Moreover, the periodicity T of these operations can vary in a tolerance interval noted [Tmin, Tmax]. This interval gives some flexibility to plan PM operation while respecting the production constraint, disturbing the least possible the production schedule, and respecting the maintenance equipment periodicity. Ideally a PM operation is planed inside the interval [Tmin, Tmax] as showed in Fig.1. Moreover, if some PM operations are programmed after Tmax in Fig.2.

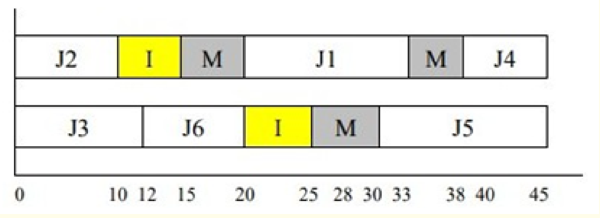

Figure 2 Part 1: Including Preventive maintenance with scheduling production.

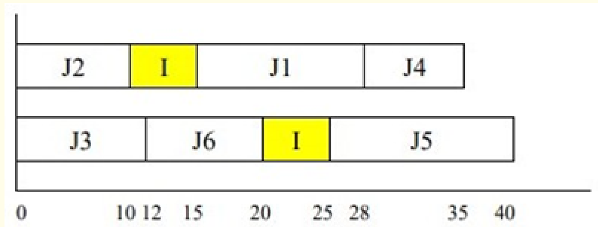

Figure 3 Part 2: Including Preventive maintenance with scheduling production.

As a result, the machine would be unavailable, and also induces a maintenance cost increase. A machine i can be subject to several different PM operations which will be repeated periodically. Let:

- Mij: the PM operation j on machine i.
- Tij: periodicity of the PM operation Mij.
- Tminij: earliest time separating two consecutives occurrences of Mij.
- Tmaxij: latest time separating two consecutives occurrences of Mij.
- Pij: processing time of PM operation Mij. It is supposed to be known and constant.

Ideally a PM operation is programmed inside the interval [Tmin, Tmax].

The constraints imposed by the customers to their suppliers are often expressed in term of time, which lead us naturally to the minimization of the makespan. One will note the production objective function in Eq. 5 as:

$$Cmax = Max(Cij) \quad (5)$$

Where C is the completion time of the last time the best case is the one minimizing the Eq. 5. If a PM operation is inserted before Tmin (maintenance useless) or after Tmax (risk of breakdown) provided that the evaluation of the resulting scheduling is better.

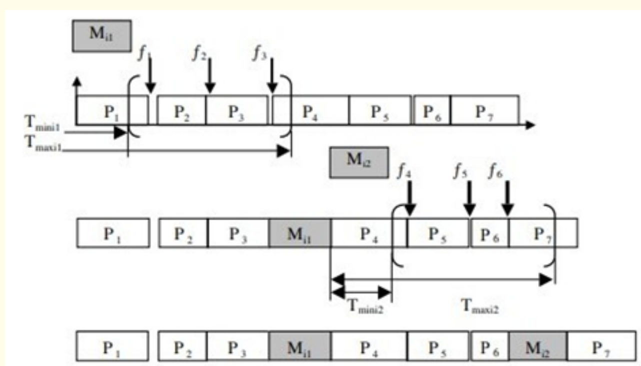

Figure 4: Possible cases of inserted operation in PMmodel.

Joint the DJSSP with preventive maintenance

In the sequential strategy, the objective function is mainly the minimization of the makespan. The aim is to optimize a global objective function which takes into accounts both production and maintenance criterion. Therefore, the resolution strategy is based on a

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joint representation of production and maintenance actions. In the following, we present a scheduling solution to solve the DJSSP using GA approach. Each chromosome represents an individual configuration as well as a solution to a given problem. Each one is composed of two parts: production scheduling and preventive maintenance. All tasks are assigned to specific chromosome that will be evaluated and modified to minimize the makespan (completion time of the last task on scheduling system). To understand that, we give a short example in Table I where we give 6 jobs scheduled on 2 machines. We fixed the preventive maintenance for each machine (M1, M2) in the last part of the table at (15, 20) respectively for each intervention. PM values (LB, UB) are generated randomly where LB is the maximum between the minimum of current execution time and the arrival of new job; UB is the minimum between the execution time of the last job minus the minimum execution time.

J1	J2	J3	J4	J5	J6	PM	
1	1	2	1	2	2	15	20

Table 1: TS Parameters.

An integrated genetic algorithm for the DJSSP

In this section, we focus on giving some details about the used parameters for the implemented research methodology based on GA. All details are given in Table I. The used GA operators are described as follows:

Crossover

It is applied on the production sequence for intensification purpose. Amongmany production crossover operators defined for GA; Goldberg(1989) and Portmann(1996) are frequently applied. In our study, we use the well known two-point crossover operator.

Mutation

It is applied on production sequence for diversification purpose. We apply the swapping moves only to the production sequence while keeping the maintenance values unchanged. The goal of this strategy is to create new individuals by changing the execution order of the production jobs. At each iteration, in order to diversify the generated population, we apply randomly the genetic operators. Authors in [2] and [3] give more details about GA operators for solving the DJSSP. Fig 5 presents the used approach based preventive maintenance (PM) where the process is starting by a random initial solution.

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We generate a set of benchmarks instances represented by the number of jobs, the number of machines and the number of new jobs arrivals to evaluate the proposed methodology based preventive maintenance to keep the system away from unforeseen machine breakdown, therefore, to solve the Dynamic JSSP without delaying the scheduling time. The studied performance criterion is the makespan minimization Cmax which is one of the most used criterion to evaluate the system's performance. These instances are generated with a range from 10x3x5 to 200x45x70 problems sizes showed in Tables III and IV where instances sizes represent n jobs, m machines and n' new jobs. The used method for solving the dynamic JSP based GA and PM is compared with some common dispatching rules that have widely been used in the literature and the TS metaheuristic algorithm. A list of the used dispatching rules is ad follow: (1) The shortest processing time (SPT).

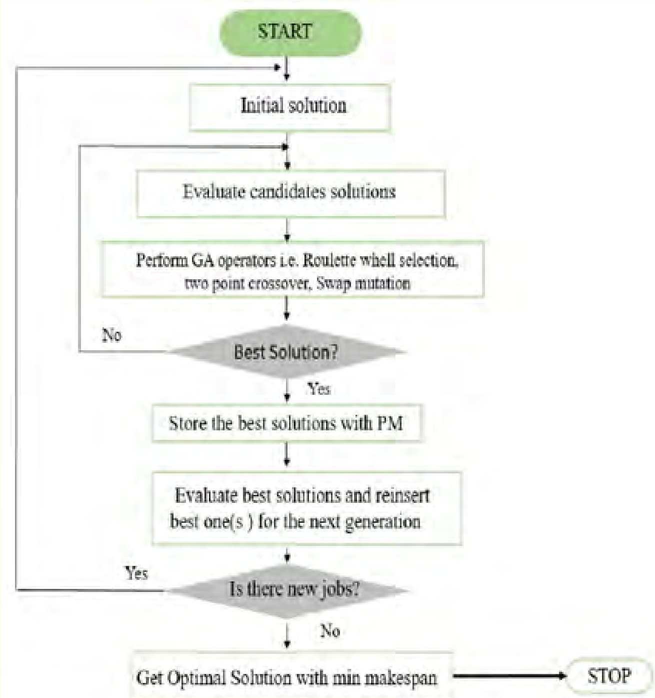

Figure 5: Flowchart of the used GA with Preventive maintenance for solving the DJSSP.

Parameters	values
Chromosome size	n*m*n’
Crossover probability	0.9
Mutation probability	0.1
Number of iteration	50
Population size	100
Termination criterion	Min C_{max}

Table 2: GA Parameters.

Instance size nxmxn'	Metaheuristics TS	GA+PM	Dispatching rules SPT	LPT	MWKR
(10x3x5)	1334	**1228**	2411	2234	1984
(20x3x10)	1446	1354	2591	2412	2256
(30x5x5)	1532	1428	2694	2518	2437
(30x5x10)	1622	1496	2895	2610	2591
(40x10x5)	1786	1694	2989	2912	2824
(40x10x10)	2089	1933	3389	3290	3187
(50x20x10)	2242	2114	3479	3516	3446
(50x20x20)	2486	2394	3699	3631	3597
(60x25x20)	2682	2632	3895	3814	3787
(60x30x40)	2889	2691	4420	4386	4110
(80x35x50)	3327	2979	4692	4329	3945
(100x45x70)	3786	3682	4635	4592	4565
(200x45x70)	4741	**4598**	6324	6220	6179

Table 3: The Performance Measure of all Methods with preventive maintenance for solving the DJSSP.

(2) The longest processing time (LPT) dispatching rule. The most work remaining time (MWKR) dispatching rule.Table III reveals that the proposed method based GA approach outperform the TS metaheuristic and all used dispatching rules in terms of makespan minimization without integrating the principle of preventive maintenance. The pro- posed method is capable of achieving the optimal solutions for the most case studies. It can be found that makespan of the proposed method is shortest or nearly shortest among these methods from Table IV. These results illustrate that the proposed method performs better with preventive maintenance for machine breakdown. With the increase number of the job arrivals, the proposed method with PM as given in Table IV is effective for solving the DJSSP.

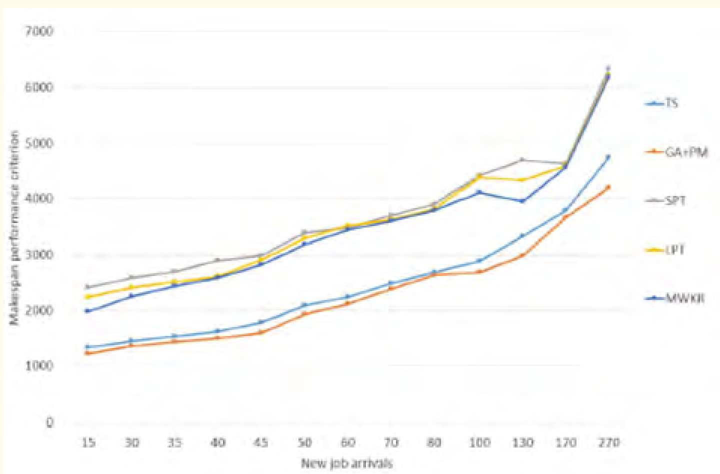

Figure 6: Comparison between all methods in terms of makespan minimization and new job arrivals.

Fig.6 shows the main impact of using the principle of preventive maintenance for solving the DJSSP with machine breakdown and, therefore, optimising the performance measure makespan under different number of the job arrivals. The x-axis represents the job arrivals with PM for machines, and the y-axis represents the performance measure. As indicated in Fig.6, the performance measure changes sharply for little, small and large job arrivals number with PM have greater impact on the schedule performance, especially in large job arrivals as indicating the GA approach gives minimum Cmax compared to all methods. The minimum value reaches 1228 for 10x3x5 problem size by using the GA to solve the DJSSP without preventive maintenance. Moreover, for all calculated cases, the minimum makespanis obtained when we apply the GA with preventive maintenance. Especially, for 200x45x70, the Cmax is equal to 4598 and still the shortest among all obtained values. As a conclusion, we can say that GA for DJSSP is effective to solve the problem.

Conclusion

This paper addresses the problem of dynamic job shop including preventive maintenance to deal with new job arrivals and machine breakdowns. The machine suffers unexpected breakdowns. Hence, we propose integrating preventive maintenance into the production-scheduling problem, in which the completion time is minimized. With the aim to optimize the dynamic job shop system, a genetic algorithm based on the properties of the optimal schedule is proposed. The experimental results demonstrate that the proposed algorithm is efficient and effective under practical problem sizes com- pared to well known dispatching rules. For future directions, we aim to explore more research methodology with the principle of preventive maintenance to solve new extension of the DJSSP. For future research methods, we focus on using exact methods like branch and bound to improve our results.

Acknowledgements

Kaouther Ben Ali received the M.Sc degree in computer science from the Higher Institute of Management of Tunisia in 2015. Currently, she is a PhD student in computer science at the same institute. Her research interets include almost the fields of Operation Reasearch, Combinatorial Optimization problems and Artificial Intelligence for real world applications. She is an IEEE fellow student and since 2017 she started working as a researcher student at the SMART Laboratory of computer science department at the Higher Institute of Management of Tunisia. The aim of her recent publications is to discuss new trends, review industrial needs and present innovative solutions in production scheduling fields. A lot of attractive work is still needed her at modeling and solving hard combinatorial optimization problems.

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well-known conferences around the world. His main areas of research are the performance assessment and the analysis in management in general using Data Envelopment Analysis (DEA) and its derived approaches.

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