

Date of publication xxxx 00, 0000, date of current version xxxx 00, 0000.

Digital Object Identifier 10.1109/ACCESS.2017.Doi Number

Model for Integrating Production Scheduling and Maintenance Planning of Flow Shop Production system

Adel AL-Shayea¹, Emad Fararah¹, Emad Abouel Nasr^{1,2}, and Haitham A. Mahmoud^{1,2}

¹Industrial Engineering Department, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia

²Faculty of Engineering, Mechanical Engineering Department, Helwan University, Cairo 11732, Egypt

Corresponding author: Emad Abouel Nasr (e-mail: eabdelghany@ksu.edu.sa).

ABSTRACT In this paper, a model for integrating production scheduling and maintenance planning is proposed for flow shop production system. The suggested model in this paper is based on the optimal jobs sequence for jobs that will be processed in multiple machines connected in series. The objective of this study is to find the optimal sequence for jobs while reducing the total production and maintenance costs. The model works by generating an initial solution using longest processing time (LPT) dispatching rule. Then, tabu search algorithm is established to obtain the optimal sequence for jobs. Computational experiments are performed on problems with five serially machines which are assigned to process eight diverse jobs from the same product family. The result is compared with the genetic algorithm optimization technique under individual PM scheme for obtaining superior solutions that has been proved in the literature to be one of the best approach. The computational results show that the recommended approach is qualified over the simulation based genetic algorithm optimization technique.

INDEX TERMS Integrated model, Job scheduling, Maintenance planning, Tabu search algorithm.

1. INTRODUCTION

Production scheduling and maintenance planning are essential activities in all production systems. Maintenance of any machine of a production system has a direct influence on the performance of the system during its actual operation. If the machine in production system is not well maintained, the other machines would become more deteriorated, whereas excessive maintenance can lead to unnecessary costs. Implementing an appropriate maintenance policy and satisfying production function requirements is therefore necessary, as they reduce machine failures and fulfil the delivery schedule in a timely manner [1]. As an axiom

considered, the machine production function requires the utilization of its full capacity with a view to run into the delivery schedule in a timely manner. However, when the machine is disrupted, it delays the completion of the tasks and may impact the planned operations of any departments embroiled in the process.

Numerous machine scheduling problems that deal with maintenance planning have been presented in the literature. A previous study [2] shows that production scheduling and machine maintenance are correlated functions that affect the total costs of production and maintenance simultaneously. This integration of the two functions makes the problem of satisfying their requirements to be challenging and interesting.

In particular, performing maintenance activities may require the task being processed in the production system to be interrupted, and carrying out maintenance correction actions of unintended breakdown will lead to machines unavailability. Based on this configuration, a more realistic production scheduling model should reflect maintenance planning [3].

The motivation for this research is based on the aforementioned observations that show a lack of models that integrate production jobs scheduling and maintenance activities planning for multi-machines in a flow shop production system. Therefore, the review of literature delivers motivation to develop and demonstrate a joint optimization methodology for maintenance planning and job scheduling on multi-machines. This modeling process takes into account the initial age, the level of preventive maintenance (PM), and the degree of restorations of each machine.

The rest of this paper is organized as follows. Section 2 is devoted to the literature review. Section 3 presents the proposed methodology. Section 4 gives detail of the cost models. Section 5 shows the problem description. Section 6 illustrates the problem with an example. Section 7 concludes the paper and recognizes the future scope of work.

2. RELATED WORK

Production scheduling and maintenance planning problem has attracted many researchers, and it has been studied many times in order to find an optimum solution. Many previous studies have tried to model the problem using exact modeling methods, such as mixed integer linear programming (MILP). The benefit of this approach is that it gives the optimal solution depending on the designed constraints. In contrast, one of the most weaknesses of this approach is that it may solve the integrated problem as several separate sub-problems and uses the results of one sub-problem as an input for the next sub-problem. This, in turn, leads to some limitations in the solution area.

The difficulty of finding solution to such integrated problem is associated with the existing of too many conflicting constraints needed to be fulfilled, and with achieving all the objectives as well as considering and satisfying both hard and soft constraints in order to fully solve the problem. Many difficulties will show up during the solution of this problem as well such as; number of jobs which should be processed on a single machine, due date for each job and the total maintenance cost. In short, it is an absolutely complicated combinatorial problem.

The preferred solution methodology to this problem ranged from the heuristic approach to ones that are more complicated. Heuristic approach in its own is most likely not the best one, since an optimal solution is hard to guarantee due to the nature

of this problem. However, the inclusion of genetic algorithms (GA), tabu search (TS), simulated annealing, and scatter methods, as a parts of the heuristic approach, may help in solving the problem by reaching its optimal solution. This type of approach for solving problems has been adopted to optimize Multi-Criteria Model Sequencing Problem (MC-MSP) of Mixed-Model Assembly Lines (MMALs) using a modified simulation integrated Smart Multi-Criteria Nawaz, Enscore, and Ham (SMC-NEH) algorithm [4]. Also, it has been applied to integrate planning and scheduling problem of multiple projects with different release dates and execution modes while considering the renewable and non-renewable resource constraints using raccoon family optimization (RFO) algorithm [5]. This approach has wide usage in the industry such as the unified representation model, and a simulated annealing-based approach used to facilitate the integration and optimization of process planning and scheduling modules of job shop to increase the flexibility and responsiveness [6].

Production scheduling and maintenance planning problem can be modeled by applying constructive or improvement heuristics that build a solution from scratch or improve an existing solution. The studies that utilize this approach have a lot of innovation and capability to solve such complicated problems. However, they require the use of several assumptions with this approach, which leads to unrealistic models for the studied problem. Naderi et al. [7] used four constructive heuristics to consider (PM) and production activities simultaneously for different policies to minimize makespan.

Furthermore, lots of recent researches suggested metaheuristics that can be adapted to any optimization problem. The advantage of this approach is that it seeks the near to optimal solution or try to touch the optimality while consider the different boundaries of the realistic problem's model. The model by Pan et al. [3] applied an integrated approach that deals with the PM planning and production scheduling for single machine. The established model showed that a maintenance time variable is affected by machine degradation. The computational results of their study demonstrate an improvement on production scheduling. Also, Moghaddam et al. [8] developed a non-linear mixed-integer optimization model to minimize the total cost while maximize the total reliability of a system. They proposed a method based on heuristic and metaheuristic solution procedures to solve large problems with several machines and/or periods.

In another model, Hadidi et al. [9] studied the practical effects of management decisions to integrate the maintenance operations with scheduling of production. Their objective is minimizing holding costs of the selected product while optimizing the maintenance costs. They proposed a sequential inadequate model of PM and modified it to deal with multiple units. The aim of the developed model was to improve the

maintenance management manner for the production systems with multiple-units.

Another metaheuristic model developed by Angelo-Bello et al. [10] has been formulated to find solution to the job scheduling problem that has been applied on a single machine with planned PM activities and extended with sequence-dependent setup times. The authors found that a similar problem has been publicized in operations research literature. So, they came up with a solution using metaheuristic procedures to deliver a high quality solution in applicable computational times. Using the same approach, Liu et al. [11] recommended an integrated model that can deal with the maintenance planning and the production planning problems on a single machine. They consider complete scheduling in a maintenance plan, in which job scheduling, predictive maintenance and other maintenance tasks are included. The model compares two strategies, the strategy of production scheduling and the optimization strategy of predictive maintenance. The results illustrate that the proposed model is capable and operational in solving the problem. In another study, Kumar et al. [12] have suggested integrated model for job scheduling and multi-components maintenance planning in a production system. Their recommended approach is aimed to minimize the total maintenance costs as well as reach the optimal sequence of jobs. They solved their problem using a simulation-based GA.

Moreover, the meta-heuristics approach has been used to solve the problem of production scheduling and maintenance planning in flow shop system. Zandieh et al. [13] applied a two meta-heuristics approach to solve such problem. Two decisions were resulted using the developed approach simultaneously: a) finding the best sequence of jobs on machines in order to minimize the makespan, and b) deciding on how often to perform preventive maintenance actions in order to minimize the system unavailability. Also, in another study, Cassady et al. [14] recommended an integrated model that simultaneously solve the problem of production scheduling and preventive maintenance planning in order to minimize the total weighted tardiness of jobs. They compared the integrated solution and its performance with the solutions gained from solving the production scheduling and preventive maintenance planning problems independently. Moreover, Cui et al. [15] proposed a proactive joint model of production scheduling and maintenance planning in flow shops considering both quality and solution robustness. They applied a two-loop algorithm to optimize the jobs sequence, positions of preventive maintenances and idle times simultaneously. However, the model introduces unnecessary idle times to take care of performing corrective maintenance activities when unexpected failures of the machines have taken place. In addition to all of these studies, Xiao et al. proposed a joint optimization model to minimize the total cost including production cost, preventive maintenance cost, minimal repair

cost for unexpected failures and tardiness cost. They targeted the problem of production scheduling and machine group preventive maintenance planning. They considered the problem as non-deterministic polynomial-time problem, and they used random keys genetic algorithms to solve it. Although, the model has neglected the time for minimal repair, machine setup and job transition; it is still considered as the most comprehensive model compared with the other models in the literature that solve such a problem.

All presented approaches in this literature review were carried out to study specific cases, where each case needs different specifications. They focus on scheduling the maintenance activities that are necessary to keep items in the best operational condition, while ensuring an appropriate production performance of equipment or device. These suggested approaches consider maintenance activities as either perfect or minimal, which means there is partial or no consideration of the corrective maintenance (CM) cost or time. Also, they did not consider the effects of the failures of the machine on the whole system and they were verified with many cases that are classified as small size. On the contrary, most problems in real world are considered as much more complicated, which require a suitable beneficial algorithm to deliver useful solutions in an acceptable time. This paper will deal with such complicated cases by proposing a model for jobs scheduling on multi-machines of flow shop production system while planning for the maintenance of these machines. The aim of this paper is to minimize the total production and maintenance costs as well as reach the optimal sequence for jobs. The paper will use tabu search algorithm and (LPT) dispatching rule to obtain the optimal solution for the problem. The main contributions of this paper are as follows:

- Finding the best jobs sequence on multi-machines in flow shop production system with the consideration of PM and CM activities schedule.
- Reaching the optimal PM planning for the machines in the flow shop.
- Verifying the proposed model with large-scale cases.

3. PROPOSED METHODOLOGY

The proposed model in this paper is based on using the longest processing time (LPT) dispatching rule to find the completion date of the job sequence without any maintenance consideration for machines. Then, tabu search algorithm is applied to find the completion date of the job sequence, while taking in consideration the maintenance schedule and unexpected flurries, as shown in [Figure 1](#).

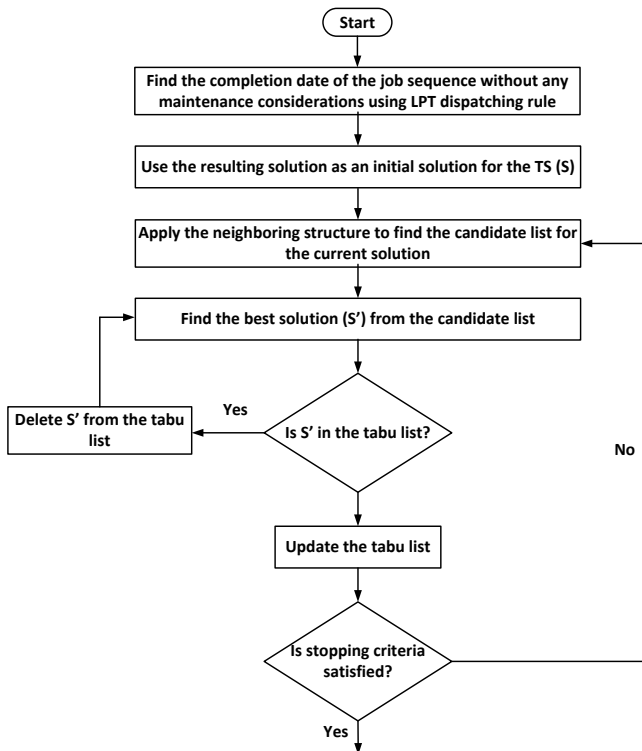


Figure 1. A flow chart for the proposed methodology.

The TS algorithm is used, since it produces better timetables than those of some algorithms such as the GA [16-18]. Further, the search time spent in TS is less than that of some algorithms such as GA [19]. The main features of the TS are initial solution, neighboring structure, tabu list, aspiration criteria, and stopping criteria [20]. In this model, the initial solution for TS is fixed using the LPT rule, in which jobs are sequenced in non-increasing order of the manufacturing time. Moreover, the solution and neighborhood structure is based on local search procedures by which attempts in terms of iterations are performed to find a schedule that is better than the current one in the neighborhood. At each iteration, a local search procedure performs a search within the neighborhood and evaluates the various neighboring solutions. Two schedules are neighbors, if one can be obtained through a well-defined modification of the other. The procedure either accepts or rejects a candidate solution as the next schedule to move to, based on a given acceptance-rejection criterion. The search process within a neighborhood was done by considering insertion technique. This technique is based on the concept of inserting a new batch within the cycle of exchanging neighbors, which means that the batch number of the optimal solution may be different from that of the initial solution. In addition, the value of the parameters of TS will affect its execution. For this purpose, pilot runs to tune the parameters for the algorithm with different settings and instances were executed for a wide range of parameters values of the TS algorithm. After pilot runs, the total production cost was calculated for each combination of parameters values and relative percentage deviation (RPD) is determined. Then,

values that minimize RPD will be selected. The best settings used in the proposed method are as follows:

1. The number of generated candidates was set to 70 candidates based on pilot experiments.
2. The size of the tabu list was fixed to be three elements and the First-In-First-Out (FIFO) strategy was applied to update the tabu list.
3. The number of iterations was assigned to be 5000.
4. The aspiration criteria were selected as previously pointed out (if a move results in a solution that is better than the best solution reached so far; then continue on that structure).

In the proposed method, the common TS algorithm for the minimization problem was built as follows:

Algorithm 1: TS algorithm template.

```

Select an initial solution  $s_0$ ;
Initialize memory structures;
Repeat
    Generate a set "A" of non-tabu solutions  $\in N(s_0)$ ;
     $s = \text{best solution of } A$ ;
    Update memory structures;
    if  $f(s) < f(s_0)$  then  $s_0 = s$ ;
Until stopping criterion = true.
 $s_0$  is the approximation to the optimal solution.
    
```

The assessing of the execution of the suggested TS algorithm is accompanied by computational experiments. The proposed algorithm has been coded using the MATLAB® programming toolbox, whereas the computational experiments for all cases have been run on an identical computer that has the following specifications: Processor: Intel (R) Core™ i7- 4702MQ CPU at 2.2 GHz; RAM: 16 GB. In addition, an analysis was carried-out to compare the computational results from the proposed LPT/TS with those of the genetic algorithm optimization technique under individual PM scheme.

4. DEVELOPED INTEGRATED COST MODEL

The following notations are used to develop the model.

INDICES:

- i index of jobs; $= \{1, \dots, n\}$
- j index of machines; $j = \{1, \dots, m\}$

PARAMETERS:

- $C_{p i}$ Penalty cost for job i
- $C_{h i}$ Holding cost for job i
- DD_i Due date for job i
- $FTR_{pm j}$ PM fixed repair time of machine j
- $VTR_{pm j}$ PM variable repair time of machine j
- $T_{m ij}$ Manufacturing time for i^{th} job on machine j
- TS_{ij} Setup time for processing i^{th} job on j^{th}

	machine
a_{ij}	Initial age of j^{th} machine before processing i^{th} job
η_j	Scale parameter of j^{th} machine
β_j	Shape parameter of j^{th} machine
R_j	PM restoration factor for j^{th} machine
FC_{pmj}	Fixed costs of PM for j^{th} machine
FC_{cmj}	Fixed costs of CM for j^{th} machine
$C_{production,i}$	Production cost of the i^{th} job
C	Labor hour rate for performing PM and CM activities

VARIABLES:

ATC	Average total cost
PMC	Preventive maintenance costs
CMC	Corrective maintenance costs
ETPC	Expected total production cost
ETMC	Expected total maintenance cost
$TC_{Manufacturing}$	Total manufacturing cost
$TC_{Penalty}$	Total penalty cost
$TC_{Holding}$	Total holding cost
CT_i	Actual completion time for job i
TTR_{pmj}	Time to repair for PM of machine j
$(N_{pmi-})_j$	The PM factor for of j^{th} machine; $(N_{pmi-})_j = 1$ if PM is performed before processing i^{th} job in j^{th} machine; otherwise, $(N_{pmi-})_j = 0$
$NF_{i,j}$	Number of failures of j^{th} machine during processing i^{th} job
$T_{operation i,j}$	Operation time of i^{th} job on machine j

Several assumptions were associated with the model to facilitate its procedures. These assumptions are as follows:

- Each job is available at the beginning of production period.
- Failure of machines is independent.
- Machine is available at the start of production.
- The time to failures (TTF) for each machine follows a two-parameters Weibull distribution (η, β) since it can be applied in all three phases of the whole-life of the machine (burn-in phase, useful life phase and wear-out phase).
- The time to repairs (TTR) for each machine follows a normal distribution (μ, σ) as it represents the common distribution of most repair cases [21 -23].

4.1. EXPECTED TOTAL PRODUCTION COST MODEL (ETPCM)

The developed integrated cost model (DICM) is the summation of expected total production cost model (ETPCM) and expected total maintenance cost model (ETMCM) for the scheduling horizon. It is mainly concerned with the minimization of the integrated average total cost (ATC) that is stated as follows:

$$\text{Minimize } ATC = ETPC + ETMC \quad (1)$$

Expected total production cost (ETPC) is the sum of manufacturing cost, penalty cost and holding cost.

$$ETPC = TC_{Manufacturing} + TC_{Penalty} + TC_{Holding} \quad (2)$$

$TC_{Manufacturing}$ is the sum of production cost for each job and it is represented mathematically as follows:

$$TC_{Manufacturing} = \sum_{i=1}^{i=n} \sum_{j=1}^{j=m} C_{Production,i} \times T_{m,i,j} \quad (3)$$

$TC_{Penalty}$ and $TC_{Holding}$ are the respective sum of penalty cost (C_{P_i}) and holding cost (C_{H_i}) for all the jobs. These costs are different in relation to the difference between actual completion date and due delivery date. They are represented mathematically as follows:

$$TC_{Penalty} = \sum_{i=1}^{i=n} C_{P_i} (CT_i - DD_i), \text{ for all } CT_i \geq DD_i \quad (4)$$

$$TC_{Holding} = \sum_{i=1}^{i=n} C_{H_i} (DD_i - CT_i), \text{ for all } CT_i < DD_i \quad (5)$$

The actual completion time is calculated as follows:

$$CT_i = T_{Operation_{i,m}} \quad (6)$$

Where $T_{Operation_{i,m}}$ is the operation time of the i^{th} job at the last machine (m) in sequence.

Operation time ($T_{Operation}$) for each job depends on the time needed to execute the PM before processing the job, machine setup time needed for processing the job, processing time of the job and corrective maintenance (CM) time acquired if any failure happens during the processing of the job. $T_{Operation}$ is calculated as follows:

$$T_{Operation_{1,1}} = [(N_{pm1-})_1 \times TTR_{pm1}] + T_{M_{1,1}} + T_{S_{1,1}} + [NF_{1,1} \times TTR_{cm1}] \quad (7)$$

$$T_{Operation_{i,1}} = T_{Operation_{i-1,1}} + T_{S_{i,1}} + T_{M_{i,1}} + [(N_{pmi-})_1 \times TTR_{pm1}] + [NF_{i,1} \times TTR_{cm1}]; \quad i=2, \dots, n \quad (8)$$

$$T_{Operation_{1,j}} = \max[T_{S_{1,j}}, T_{Operation_{1,j-1}}] + T_{M_{1,j}} + [(N_{pm1-})_j \times TTR_{pmj}] + [NF_{1,j} \times TTR_{cmj}]; \quad j=2, \dots, m \quad (9)$$

$$T_{Operation_{i,j}} = \max [T_{Operation_{i-1,j}} + T_{S_{ij}}, T_{Operation_{i,j-1}}] + T_{M_{i,j}} + [(N_{pm_{i-}})_j \times TTR_{pm_j}] + [NF_{i,j} \times TTR_{cm_j}]$$

$$i=2\dots, n \quad j=2\dots, m \quad (10)$$

$$TTR_{pm_j} = FTR_{pm_j} + VTR_{pm_j} \quad (11)$$

Equations (7) and (8) are used to determine the operation time of the first job and the other jobs on the first machine, while equations (9) and (10) are used to find the operation time of the first job and the other jobs on the other machines, respectively.

PM factor $(N_{pm_{i-}})_j$ in the above equations can take a value either '1' or '0' depending on machine drives for PM or not. Performing PM maintenance depends on the percentage of consumption of the initial age of the j^{th} machine. If this percentage reached seventy-five percent or more before starting i^{th} job, then PM for j^{th} machine is due [8,10,11]. TTR_{pm_j} is the time to repair for preventive maintenance which is sum of the fixed repair time of machine j (FTR_{pm_j}) and the variable repair time of machine j (VTR_{pm_j}) where VTR_{pm_j} is normally distributed. TTR_{cm_j} in the above equations is normally distributed time to repair for CM of j^{th} machine. The number of failures $NF_{i,j}$ can be calculated using the following formula, which based on the initial age of the j^{th} machine before processing i^{th} job, manufacturing time, and the shape and scale parameters of j^{th} machine time to failure [24]:

$$NF_{i,j} = \left[\frac{(T_{m_{i,j}} + a_{ij})}{\eta_j} \right]^{\beta_j} - \left[\frac{a_{ij}}{\eta_j} \right]^{\beta_j} \quad (12)$$

Where a_{ij} is represented mathematically as follows:

$$a_{ij} = [(a_{i-})_j + T_{m_{i-},j}] \times [1 - (R_j \times (N_{pm_{i-}})_j)] \quad (13)$$

4.2. EXPECTED TOTAL MAINTENANCE COST MODEL (ETMCM)

Expected total maintenance cost (ETMC) is the summation of the corrective and preventive maintenance costs.

$$ETMC = PMC + CMC \quad (14)$$

Where, PMC and CMC are calculated as follows.

$$PMC = \sum_{i=1}^{i=n} \sum_{j=1}^{j=m} (N_{pm_{i-}})_j \times [TTR_{pm_j} \times C + FC_{pm_j}] \quad (15)$$

$$CMC = \sum_{i=1}^{i=n} \sum_{j=1}^{j=m} NF_{i,j} \times [TTR_{cm_j} \times C + FC_{cm_j}] \quad (16)$$

Downtime cost is not included in equation (15) and equation (16) as it is included in terms of penalty cost in equation (2).

5. APPLICATION CASE

The minimizing of the total production and maintenance costs has an important effect on the factory/facility design since these costs have a significant contribution on the total budget of the facility. As result, reaching the optimal sequence for jobs and minimize the total production and maintenance costs are important factors that should be consider by the production manager. The proposed model has been applied on a factory that consists of different flow shop production areas. The production manager of the factory wants to study the effect of maintenance planning on the job scheduling and wants to know which type of maintenance (preventive or corrective maintenance) should be performed on the machines used in one of flow shop areas of the manufacturing system. The chosen production area has five serially machines MC1, MC2, MC3, MC4 and MC5. The time to failures (TTF) for each machine follows a two parameters Weibull distribution (η, β). Whenever, a failure happens in one of the machines, minimal repair is implemented in order to restore it back to the working conditions. The time to repairs (TTR) for each machine follows a normal distribution. Additionally, preventive maintenance may be done to reduce the unexpected downtime loses; this is clearly shown as a binary variable $(N_{pm_{i-}})$ takes a value of (1) for the j^{th} machine before processing i^{th} job. Commonly, the restoration success in preventive maintenance is greater than that in corrective maintenance [25]. Consequently, comparatively higher fixed cost is convoluted in preventive maintenance. In the current case, a twenty-five percent of the preventive maintenance fixed cost is the machine corrective maintenance fixed cost; this assumption has been used in many previous studies [26- 28]. Also, the labor cost is SAR 300 per hour for both corrective and preventive maintenance.

The machines in the flow shop area are assigned to process eight diverse jobs (J1, J2, J3, J4, J5, J6, J7 & J8). All the jobs belong to same product family and have singular processing times on each machine as shown in Table 1. Also, each job has due date associated with customer prerequisite. All production job parameters are given and provided in Table 2. Setup time for each job on each machine are considered to be equal to (0) for the purpose of the comparison with the results of genetic algorithm optimization technique of the individual PM scheme by L. Xiao et al, [2].

In case of late delivery, each job acquires a penalty cost. Likewise, if a job is processed early, manufacturing operator

will have to hold the job up to due date, which results in committed holding cost. Moreover, each machine has a different Weibull parameters and preventive maintenance cost as shown in Table 3 and all time values are given in time unit and all cost values are in dollars \$. Production manager desires to select the best sequence in which these jobs can be performed on the machines of the flow shop area so that total production cost is minimized. He seeks to determine if it is beneficial to perform PM activities for one or more of the multi-machines before the start of each production run. Therefore, the current model’s objective is to optimize the production sequence and maintenance plan simultaneously, such that overall operations and maintenance costs are minimized.

6. COMPUTATIONAL RESULTS AND DISCUSSION

The application case has been solved by both simulations based genetic algorithm optimization technique coupled with the individual PM scheme by L. Xiao [2] for obtaining superior solutions and the proposed tabu search (TS) method. The way to solve the problem of the case by using simulations based genetic algorithm optimization technique was explained in the paper of Xiao et. al. [2], while the way to solve the case problem by the proposed tabu search (TS) method is explained in this section.

The application of the proposed model to solve the problem of the case starts with using the longest processing time

(LPT) dispatching rule to find the completion date of the job sequence without any maintenance consideration for machines as shown in Figure 2. Then, the resultant sequence from the LPT is used by TS as lower bound from which the building of the neighborhood structure is started. The way to build the neighborhood is based on insertion technique of a new batch within the cycle of exchanging neighbors, which means that the batch number of the optimal solution may be different from that of the initial solution. At each step the TS algorithm calculated the total cost and compared it with the previous result in order to check if there is an improvement or the stopping criteria was satisfied. Once TS reached, the stopping criteria by either reached the selected number of iterations or there was no improvement in the final results; the TS fixed the last sequence as the optimal solution for the studied problem. After modeling, the final results are summarized in Table 4 and are shown in Figure 3. The results illustrate the optimal sequence of the eight jobs obtained by GA and TS&LPT algorithms. Also, the total cost, preventive maintenance cost, delay cost and expected corrective maintenance cost for each technique. Furthermore, a clear comparison between the tabu search (TS) and genetic algorithm optimization technique coupled with the individual PM scheme is shown in Figure 4. This comparison is based on the different types of costs, which are resulted from the both methodologies.

Table 1. Job operation times on each machine (Time unit)

	J1	J2	J3	J4	J5	J6	J7	J8
MC1	25	17	41	74	37	72	11	31
MC2	15	41	155	12	95	34	77	39
MC3	12	22	83	24	72	62	31	141
MC4	40	36	121	48	52	32	26	56
MC5	60	58	160	78	153	162	32	79

Table 2. Job delivery time, production cost and delay cost

	J1	J2	J3	J4	J5	J6	J7	J8
Due date	222	186	850	545	621	477	346	788
Production cost	27	40	39	23	21	34	49	29
Penalty cost	121	184	193	127	127	128	190	168
Holding cost	24	32	27	20	18	35	15	19

Table 3. Machine information about degradation and cost

	M1	M2	M3	M4	M5
Weibull scale parameter (η)	275	225	284	236	318
Weibull shape parameter (β)	2	2.2	1.8	1.8	1.6
Normal scale parameter (σ)	0.30	0.35	0.40	0.45	0.50
Normal shape parameter (μ)	2.5	3.0	3.6	2.7	4.5
Initial age	1500	2200	1500	2700	2500

Restoration factor	0.85	0.83	0.75	0.65	0.67
PM fixed time	15	22	20	18	23
PM cost	180	230	170	200	500

Table 4. Final results for the three different techniques

GA under individual PM.	Job Sequence	J2	J1	J7	J6	J4	J5	J8	J3	
	Total Cost (ATC)	\$ 1.593*10 ⁵								
	Delay Cost	\$ 52003								
	PM cost	\$ 4460								
	Expected Minimal Repair Cost	\$ 2.488*10 ⁴								
TS algorithm based on LPT	Job Sequence	J4	J6	J3	J5	J8	J1	J2	J7	
	Total Cost (ATC)	\$ 1.213*10 ⁵								
	Delay Cost	\$ 32655								
	PM Cost	\$ 3687								
	Corrective Maintenance Cost	\$ 1.726*10 ⁴								

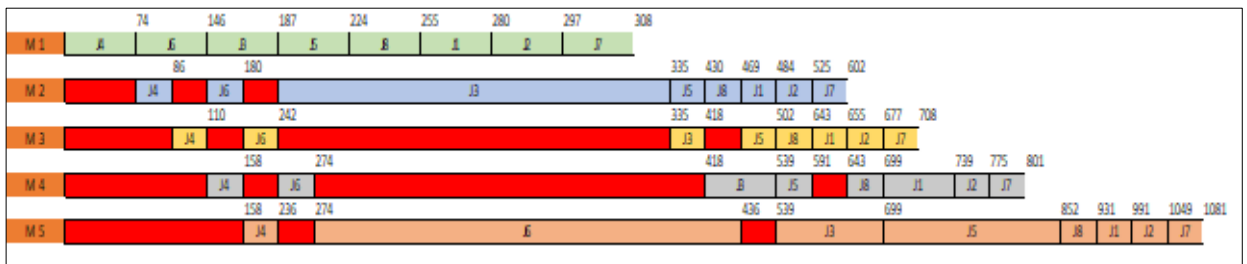


Figure 2. Initial solution using longest processing time (LPT) dispatching rule.

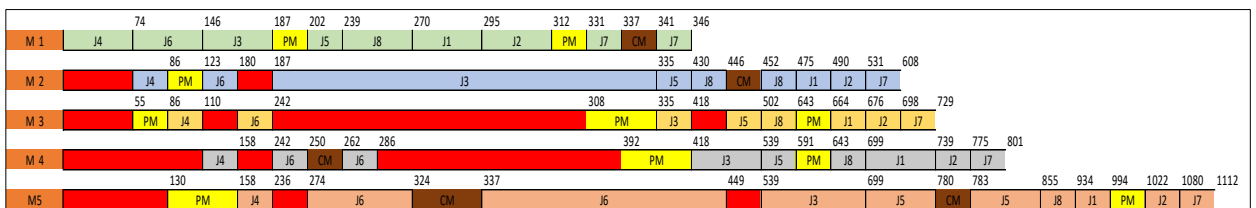


Figure 3. Final sequence resulted from TS algorithm under preventive and corrective Maintenance

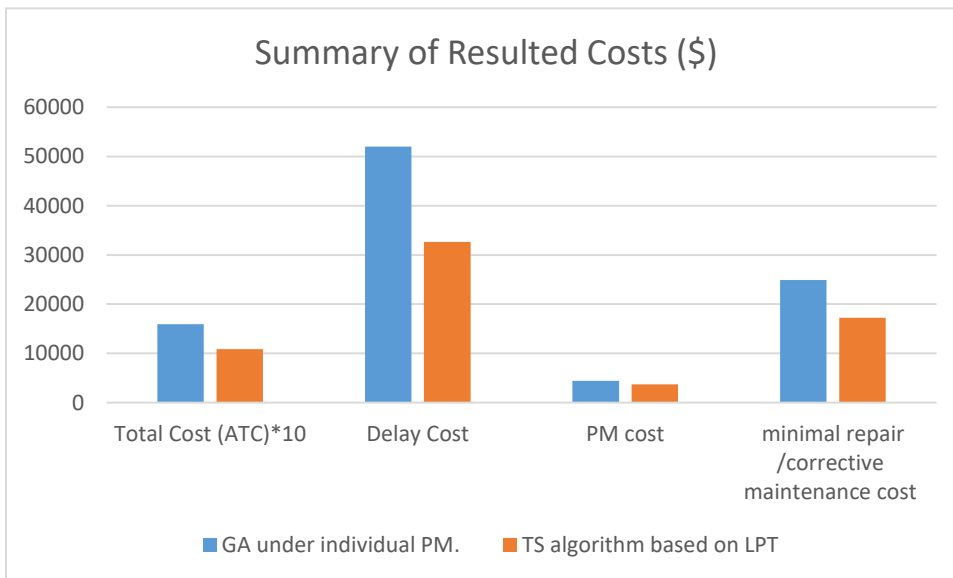


Figure 4. Comparison between TS based on LPT and GA based on individual PM.

The results show that the TS algorithm gives an accepted performance with total cost equals to $\$ 1.213 \times 10^5$, while the GA algorithm with individual PM scheme ended with a solution of total costs of $\$ 1.593 \times 10^5$. In addition, TS algorithm saves the delay cost by more than $\$ 20000$ compared to the delay cost provided by GA algorithm with individual PM scheme. Furthermore, TS algorithm required about $\$ 3687$ to perform the preventive maintenance for the different five machines, whereas, GA algorithm with individual PM scheme required $\$ 4460$. Moreover, Table 5 summarized a clear comparison among the actual completion time and the delivery time for each job after applying the tabu search (TS) algorithm. The results in this table showed that J1, J2, J5, J7 and J8 were responsible for the delay and its incorporated cost, whereas, J3, J4 and J6 were responsible for the holding cost.

Additionally, due to the nature of the series system in the example, a single machine downtime can cause the entire system to be unavailable. In this respect, GA under individual PM scheme that has been used by Xiao et.al. [2] and others has much more unavailability than the TS technique, and more tardiness is incurred. This because TS technique was designed to give a priority for those jobs with the longest processing time, as well as, it helps several preventive maintenance tasks to be performed at the idle time of the different machines and that saved a lot of time and made these machines more available.

The risk of unplanned failure is also higher in the GA under individual PM scheme than that in TS technique. This is due to the deference in the selection criteria of preventive maintenance tasks in the two techniques, and the consideration of the setup times on the different machines by TS algorithm, which works as inspection criteria to avoid the

upcoming failures. Therefore, the selection criteria of PM tasks should be taken into consideration when making maintenance decision in the series system. Finally, the proposed methodology can be applied on large instance with many jobs ($i = n$) and several machines ($j = m$).

Table 5. Comparison between completion and delivery time.

	Completion time	Delivery time
J1	994	222
J2	1080	186
J3	699	850
J4	236	545
J5	855	621
J6	436	477
J7	1112	346
J8	934	788

7. CONCLUSION

This paper dealt with the difficulties of modelling combined optimization of production scheduling and maintenance planning for machines in flow-shop production system. Reducing the total production and maintenance costs was the objective function for the targeted problem to deal with joint improvement in the two cost sources. TS algorithm optimization procedure has been recommended to reach the best solution. Firstly, an initial jobs sequence has been obtained using LPT dispatching rule. Then, tabu search has

been utilized to influence a near optimal solution. The best setting for the parameter values of the TS algorithm is premeditated on the using of simulation run for a wide range of parameters values. Computational experiments are implemented on problems with five functions and four different cases. The proposed algorithm showed reasonably good results in reducing the average total cost of maintenance and production. Therefore, the TS policy delivers a better solution compared with other computational approaches such as the GA technique. Furthermore, the developed model by TS showed better average total cost than the GA under individual PM scheme.

For future work, the current proposed model can be extended to handle other uncertainties such as variations of number of jobs, arrival of new jobs, and job cancellations. It is interesting to find out how such assumptions relaxing affect the operational decisions.

ACKNOWLEDGMENT

The authors extend their appreciation to the Deanship of Scientific Research at King Saud University for funding this work through research group No (RG-1439-009). The authors would like to thank the Deanship of Scientific Research and RSSU at King Saud University for their technical support.

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Dr. Adel Al-Shayea is a consultant industrial engineer (CE-SCE). He is a member of the Saudi Council of Engineers (SCE) Saudi Arabia as well as a member of several committees such as the national committee for the codification and standardization of operation and maintenance works. He is currently the assistant vice president for academic and educational affairs at King Saud University. Previously, he was a consultant at King Saud University Rector's Office and worked for SABIC Marketing Ltd. in Riyadh and

at the Institute of Public Administration (IPA). In addition, he is a consultant in King Abdullah Institute of Research and Consulting Studies. He participated and conducted several consultative works for governmental and private organizations. He also refereed several engineering works in Saudi Arabia. Email: alshayea@ksu.edu.sa



EMAD ABOUEL NASR received the Ph.D. degree in industrial engineering from the University of Houston, Houston, TX, USA, in 2005. He is currently an Associate Professor with the Department of Industrial Engineering, College of Engineering, King Saud University, Riyadh, Saudi Arabia, and the Mechanical Engineering Department, Faculty of Engineering, Helwan University, Egypt. His current research interests

include CAD, CAM, rapid prototyping, advanced manufacturing systems, and collaborative engineering. Email: abdelghany@ksu.edu.sa



EMAD FARARAH received the B.C degree in industrial engineering from the University of King Saud, Riyadh, Saudi Arabia in 2016. He is currently an MSc. Student in the Department of Industrial Engineering, College of Engineering, King Saud University, Riyadh, Saudi Arabia. His current research interests include industrial systems and operation research. Email: emad.fararah@gmail.com



Haitham A. Mahmoud received the Ph.D. degree in industrial engineering from the University of Helwan, Egypt, in 2012. He is currently an Assistant Professor in the Department of Industrial Engineering, College of Engineering, King Saud University, Riyadh, Saudi Arabia, and the Mechanical Engineering Department, Faculty of Engineering, Helwan University, Egypt. He worked as an engineering consultant for several industrial organizations in Egypt. His current research interests include optimization modeling, theory, and algorithm design with applications in waste management and energy management, financial engineering, and big data. Email: hmahmoud@ksu.edu.sa