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A Scheduling Model of Flexible Manufacturing System to Reduce Waste and Earliness/Tardiness Penalties

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ABSTRACT

Nowadays, flexible manufacturing system (FMS) is introduced as a response to the competitive environment. Scheduling of FMS is more complex and more difficult than the other scheduling production systems. One of the main factors in scheduling of FMS is variable time of taking orders from customers, which leads to a sudden change in the manufacturing process. Also, some problems are created in production system such as waste, earliness and tardiness costs, and increase inventory. In this paper, a part of flexible manufacturing system where products are produced in two stages and in multiple repositories, is known as a bottleneck. In this study, a mathematical model for scheduling of this problem considering the limitations of the production system such as flow rate and output reservoirs, variable time order entry, waste resulting from the cessation of production, and the storage capacity of reservoirs is developed. Then, the proposed model has been solved by GAMS software. Results confirm the validity of the proposed model.

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1. INTRODUCTION

Production planning in multi-product industry where production is exposed to operational constraints, is extremely complex and difficult [1]. This issue is important, because the optimal computed production volume should be compatible with scheduling constraints [2, 3]. Determining production scheduling as one of the key success factors has an effective role in any manufacturing organization. Production scheduling prevents the accumulation of capital, reduces wastes, brings about timely response to customer orders and better supply of raw material at the right time [4-6]. One of the important questions that must be answered in production systems is “How the required output based on external factors such as changes in demand, and internal factors such as the time needed to produce must be met?” Cessation of production may occurs based on several reasons including equipment failure and limitations, production bottlenecks, and changes in customer orders.

Flexible manufacturing systems (FMSs) are considered as one of the most important production technologies to efficiently handle current changes in market requirements. An FMS is a network of workstations interconnected by material-handling devices, where a low or medium volume of parts can be manufactured. In the context of FMSs, the current literature offers several competing definitions and classifications of flexibility types. In recent years, scheduling problems related to earliness and tardiness costs have been highly regarded. Some researchers consider scheduling with a set of start time-dependent jobs that makespan has been minimized [7]. Some others have considered concepts such as lean manufacturing and JIT production. According to the concept of JIT production, earliness and tardiness are harmful to profitability and should be minimized [8]. Therefore, earliness and tardiness penalties are intended to respond the demand. In fact, problems with earliness penalties are very useful to demonstrate the practical issues. So, we should consider two items: Deterioration

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or storage costs of goods delivered early. Earliness and tardiness are calculated as follows:

$T_i = \max(0. C_i - D_i)$, $E_i = \max(0. D_i - C_i)$

where C_i is completion time and D_i delivery time of product i. It is obvious that a job cannot have a positive earliness and tardiness, simultaneously. In addition, earliness and tardiness mostly are the same in terms of costs resulting from delivery. So, these two formulas can be converted into a single one:

$f_i(C_i) = a_i E_i + b_i T_i$

The above deviation function can be generalized to more complex combinations.

Allahverdi et al. [9] presented a two-stage assembly scheduling problem for minimizing total tardiness with setup times. This problem has received much attention from researchers because it is applicable to many real-life environments. In this literature, the objective of minimizing total tardiness is important because the fulfillment of due dates for customers must be considered when making scheduling decisions. Mejia and Montoya [10] presented an algorithm for minimizing total tardiness in flexible manufacturing systems. In this paper, they focus on the total tardiness criterion and extended the beam search algorithm presented in a previous work with capability to handle the total tardiness criterion. Tthe total tardiness can only be determined when a full schedule is calculated. Computational tests were conducted on Petri Net models of both flexible job shop and flexible manufacturing systems. Also, Tardiness minimization in a flexible job shop problem has been presented by Scrich et al. [11]. A PSO algorithm for optimising tardiness of job and tool in a flexible manufacturing system has been presented by Udhayakumar and Kumanan. [12]. The PSO algorithm provides the minimum tardiness with reasonable computational time. This research work leads to a conclusion that the procedures developed in this work can be suitably modified to any kind of FMS.

In another research, Kumar et al. [13] solved a scheduling of flexible manufacturing system with a heuristic approach. They believe that earliness of the job can be handled in the same way as tardiness, where a penalty is assigned for completing the jobs before its due date. Kashfi and Javadi [14] presented a model for selecting suitable dispatching rule in flexible manufacturing systems that all decision criteria and prevents system considered tardiness and idle time. Also, Pang and Le [15] proposed a reactive scheduling for flexible manufacturing system that minimizes the sum of energy cost and tardiness penalty under power consumption uncertainties. The effectiveness of the proposed model was evaluated in terms of deviation from global optimality and mean interrupted time based on an industrial stamping system. Fazlollahtabar et al. [16] presented a mathematical optimization to minimize the penalized earliness and tardiness in a flexible manufacturing system. Low et al. [17] developed a multi objective model for solving FMS scheduling problems considering three performance measures, namely minimum mean job flow time, mean job tardiness, and minimum mean machine idle time, simultaneously. So far, many different ways are developed to solve the FMS, but selecting the suitable method is still a challenge for decision-makers and planners. This process should be done according to the comparing system conditions, performance measures, and the selected values of the system criteria such as mean flow time, mean tardiness, work-in-process inventory, production rate and other performance criteria [18]. For some researches on this issue, we can refer to [19-24].

In this paper, we consider a bottleneck that has an important role in production systems. This bottleneck is a part of production system that has two stages with multiple repositories. Also, a mathematical model for scheduling of this problem considering the limitations of the production system such as flow rate and output reservoirs, the storage capacity of reservoirs, variable time order entry, waste resulting from the cessation of production, and reduce the time to complete the task has been developed. Figure 1 shows the general process of oil production in one of Iranian oil companies.

2. PROBLEM DESCRIPTION

A Blending unit and its stages considered as the case study subject. The complexity of this subject makes it as a bottleneck. Then a continuous two-stage multi-product model has been selected to solve the problem, resulted to reduce costs. Solving scheduling problem included reducing waste and earliness and tardiness penalties. The objective function is minimizing the earliness and tardiness costs and some costs resulting from the cessation of work and completion time of last work. In this model, limitations and assumptions have been considered. As can be seen in Figure 2, the final product is produced in two stages. In the first stage, the raw material (all types of oils) combines with additives in storage reservoirs. When enough products that has been produced in first stage is combined, it enters the second stage and blending process starts. Final product of production reservoirs enter the filling unit which is in the form of a barrel, metal or plastic container with specific volume.

3. PROBLEM DEFINITION

3. 1. Problem Assumptions

In this section, a non-linear programming model of a two-stage multiproductscheduling will be provided to minimize earliness and tardiness penalties, costs caused by cessation of work, and complete the order range in each reservoir. In this problem we assume that the processing time, the time of completion and delivery time are integers. Other assumptions are as follows:

1. The quantity of demand and time of raw material preparation for production of each product varies.
2. Production program changing from one product to another product in reservoirs is possible.
3. In any situation, only one product in each reservoir at each stage can be processed.

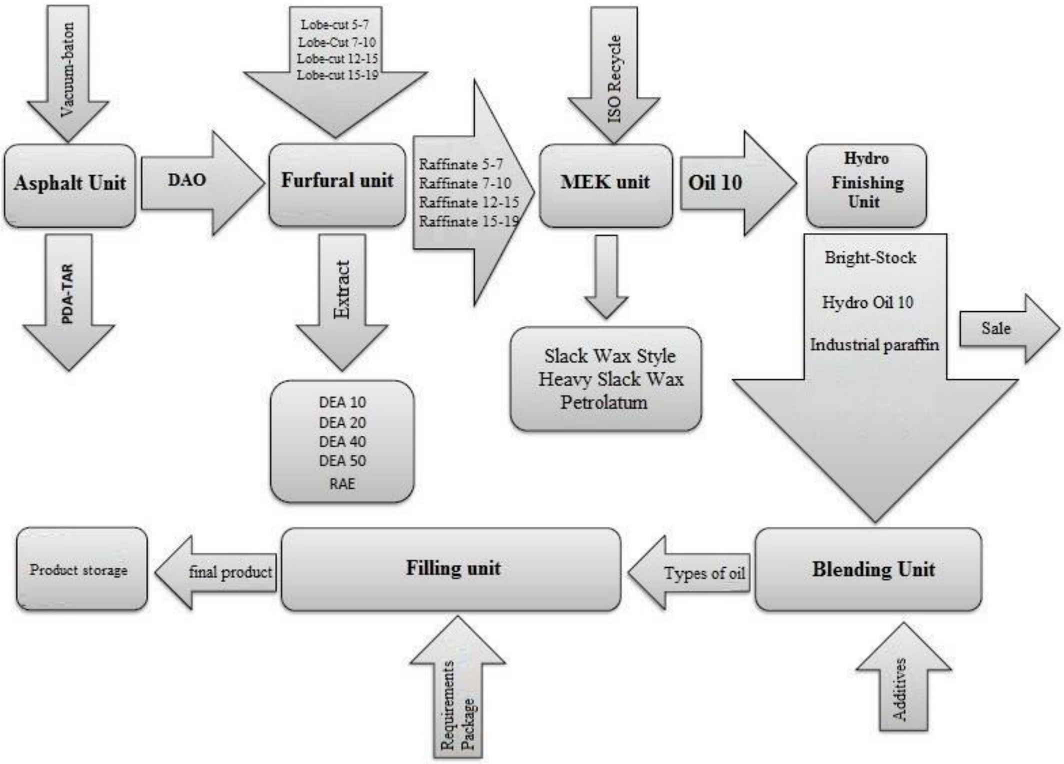

Figure 1. The general process of oil production in one of Iranian oil companies

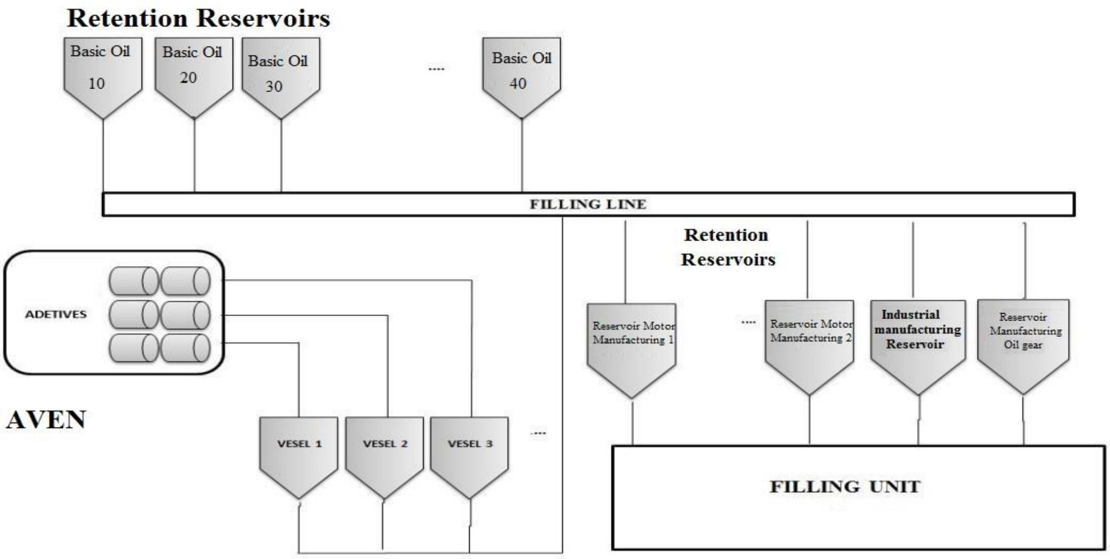

Figure 2. Blending Unit in one of Iranian oil companies

4. The time duration is identified and is the same.
5. A work cessation cost depends on occurrence time.
6. Manufacturing process for the product is done in two stages. Interruption is allowed in each reservoir.
7. Each order has a pre-determined delivery date.
8. By changing the processed product in a reservoir from one group to another, some loss of time and money incurs.
9. Login the order of different products based on the availability of raw materials is variable.

The nonlinear mathematical model of the production planning in the case study is as follows:

Indices and Sets:

I	Sets of products
i, i′	Indices of products
J	Sets of production stages
j	Indices of production stages
K	Sets of reservoirs
k	Indices of reservoirs
T	Sets of time periods
t	Indices of time periods
M	A large positive number
ϑ	Coefficient cost per working day

Parameters:

PT_{ij}	The number of product i (based on barrels considering the capacity of reservoirs) that can be processed in step j at a time period.
TPT_{ij}	The total processing time of product i in step j based on total demand.
α_i	Amount of production tardiness penalty for each unit of production i after due date (Du_i).
β_i	Amount of production earliness penalty for each unit of production i before due date (Du_i).
γ_i	The costs of waste in production planning (based on type of product i) for a reservoir at each time of change
DU_i	Deadline of product delivery
D_i	Total demand in planning (based on type of product i)
RT_i	Order entry time of product i to start the program
Cap_{ik}	Product processing of type i in reservoir k (if reservoir have capability)

Variables:

C_i	The completion time of product i
C_m	The completion time of all orders
T_i	Duration of tardiness product i
E_i	Duration of earliness product i
Y_{ijk}	$\begin{cases} 1 & If\ product\ i\ on\ the\ stage\ j\ in\ period\ t\ is\ processed \\ 0 & Otherwise \end{cases}$
YY_i	$\begin{cases} 1 & If\ product\ i\ \ in\ period\ t\ on\ the\ second\ stage\ is\ process \\ 0 & Otherwise \end{cases}$

3. 2. Mathematical Model

Objective Function The purpose of this model is minimizing earliness and tardiness penalties and reducing the changes of production plan in each reservoir and reducing the time of work completion.

$$Min\ Z =$$

$$\sum_{i\in I} \alpha_i \cdot TT_i \quad (1\text{-}1)$$

$$+\sum_{i\in I} \beta_i \cdot E_i \quad (1\text{-}2)$$

$$+\frac{1}{2}\sum_{i\epsilon I}\sum_{j\epsilon J}\sum_{k\epsilon K}\gamma_i \cdot \left[\left(\sum_{t=1}^{T-1}\left|y_{ijkt} - y_{ijkt+1}\right|\right) + y_{ijkT} + y_{ijk1} - 2\right] \quad (1\text{-}3)$$

$$+\vartheta \cdot C_{max} \quad (1\text{-}4)$$

Constraints:

$$TT_i = \max(0. C_i - DU_i) \qquad \forall i \in I \quad (2)$$

$$E_i = \max(0. DU_i - C_i) \qquad \forall i \in I \quad (3)$$

$$\frac{\sum_{t=1}^{cur}\sum_{k\in K} y_{ij=1kt}}{TPT_{ij=1}} \geq \frac{\sum_{t=1}^{cur}\sum_{k\in K} y_{ij=2kt}}{TPT_{ij=2}} \ \forall i \in I. \forall j \in J. cur = 1.2. \dots . T \quad (4)$$

$$C_i = max_t(t \cdot yy_{it}) \qquad \forall i \in I. \forall t \in T \quad (5)$$

$$\sum_{t=1}^{T}\sum_{k\in K} y_{ijkt} = TPT_{ij} \qquad \forall i \in I. \forall j \in J \quad (6)$$

$$\sum_{i\in I} y_{ijkt} \leq 1 \qquad \forall j \in J. \forall k \in K. \forall t \in T \quad (7)$$

$$y_{ijkt} \leq 0 \quad \forall j \in J. \forall i \in I. \forall k \in K. \forall t = 1.2. \dots . RT_i \quad (8)$$

$$\sum_{k\in K} y_{ijkt} \leq M \cdot YY_{it} \qquad \forall i \in I. \forall j = 2. \forall t \in T \quad (9)$$

$$\sum_{k\in K} y_{ijkt} \geq YY_{it} \qquad \forall i \in I. \forall j = 2. \forall t \in T \quad (10)$$

$$C_{max} = maxC_i \qquad \forall i \in I \quad (11)$$

$y_{ijkt} \leq Cap_{ijk}\ \forall j \in J. \forall i \in I. \forall k \in K. \forall t \in T$ (12)

$y_{ijkt}. YY_{it} \in \{0.1\}\ \ \forall j \in J. \forall i \in I. \forall k \in K. \forall t \in T$ (13)

$TT_i. E_i. C_i. C_{max}\ is\ integer \qquad \forall i \in I$ (14)

3. 3. Description of the Model The objective function is composed of 4 types of costs, including: earliness costs, tardiness costs, costs resulting from the cessation of work, and the cost of work completed.

Constraints 2 and 3, respectively calculate tardiness and earliness time. Constraint 4 ensures first and second stage parallel production progress in producting one product. Constraint 5 calculates the time required to complete each task. Equation 6 shows the process duration time for product i in stage j and reservoir k equals to process total time of product i. Equation 7 ensures that at any time situation in a reservoir, utmost one product can be processed. Constraint 8 makes certain that raw materials are not ready before the time of order entry or order has not been received from the client. This constraint ensures that the respective product is not produced in the production order program. Constraints 9 and 10 indicate that in the second stage, in any time situation, whether a product (regardless of reservoir) is processed or not. Equation 11 calculates the completion time of all the works in the reservoirs. Equation 12 guarantees the processing of a product in a reservoir (depends on reservoir capability).

3. 4. Calculating the Number of Changes in the Production Program in Each Reservoir In the third part of the objective function formula (Equation (1)-(3)), for calculating the number of work cessation times, a mathematical equation has been used wherein y_{ijkt} values as a binary variable, presents the following conditions for equation $|y_{ijkt}-y_{ijkt+1}|$:

- If $y_{ijkt}=1$ and $y_{ijkt+1}=1$, then $|y_{ijkt}-y_{ijkt+1}|=0$. So, this result estimates that product i is proceeds in time periods of t and t+1. Therefore, cessation of work does not occur between t and t+1.
- If $y_{ijkt}=1$ and $y_{ijkt+1}=0$, then $|y_{ijkt}-y_{ijkt+1}|=1$. So, this result is estimated that product i proceeds in time period of t and does not proceed in time period of t+1. Therefore, cessation of work occurs between t and t+1.
- If $y_{ijkt}=0$ and $y_{ijkt+1}=1$, then $|y_{ijkt}-y_{ijkt+1}|=1$. So, the result will be similar to the previous item.
- If $y_{ijkt}=0$ and $y_{ijkt+1}=0$, then $|y_{ijkt}-y_{ijkt+1}|=0$. So, this result estimates that product i does not proceed in time periods of t and t+1. Therefore, cessation of work does not occur between t and t+1.
- If the starting situation of product i is in any situation other than its first situation, amount $\sum_{t=1}^{T-1}|y_{ijkt} - y_{ijkt+1}|$ is calculated as cessation work times that is not adopted to reality situation.

Similarly, if the product i would complete in any situation except T situation, $\sum_{t=1}^{T-1}|y_{ijkt} - y_{ijkt+1}|$ work cessation is accounted that is not adopted to really situation.

To fix the error in calculating the number of cessation of work, subtract 2 units from $\sum_{t=1}^{T-1}|y_{ijkt} - y_{ijkt+1}|$. When variables y_{ijk1} and y_{ijkT} are equal to 1, this means that at the beginning and end time, product i is processed. So, it is necessary to subtract 2 units from $\sum_{t=1}^{T-1}|y_{ijkt} - y_{ijkt+1}|$. Also, to eliminate this effect, we should add 2 units to function $y_{ijkT} + y_{ijk1}$.

On the other hand:

$$\sum_{i\epsilon I}\sum_{j\epsilon J}\sum_{k\epsilon K}\gamma_i\left[\left(\sum_{t=1}^{T-1}|y_{ijkt}-y_{ijkt+1}|\right)+y_{ijkT}+y_{ijk1}-2\right]$$

which calculates the number of work cessation is twice than real value. Therefore, it must be divided by 2.

This model is a non-linear model. Because solving of most non-linear models need to spend more time than linear models, and also these models have not accurate answers, therefore, to calculate the exact answer, efforts should be spent on converting this model into linear and mixed with integer numbers model. That is done in this paper.

Linearization method of equations is as follows:

The objective function is nonlinear that with deformation of formula $|y_{ijkt} - y_{ijkt+1}|$ to $|y_{ijkt}^P - y_{ijkt}^M|$ and adding the following set of constraints make became linear.

$$y_{ijkt} - y_{ijkt+1} = y_{ijkt}^P - y_{ijkt}^M\ \ \forall i. \forall j. \forall k. \forall t = 1.2 \ldots . T - 1$$

Constraints 2 and 3 are non-linear that instead of them, two linear inequalities follow have been added. These linear inequalitiesgive us the same answer.

$$TT_i \geq (C_i - DU_i) \qquad \forall i\epsilon I. j = 1$$

$$E_i \geq (DU_i - C_i) \qquad \forall i\epsilon I. j = 1$$

constraint 5 is non-linear that can be turned into the following linear equation:

$$C_i \geq t \cdot YY_{it} \qquad \forall i \in I. j = 2. \forall t \in T$$

4. CASE STUDY

In this section the data derived from one of Iranian oil companies for scheduling of flexible manufacturing system have been presented. This data includes the scheduling of 20 types of product in a period of 30-day. Table 1 shown the parameters of tardiness penalty, earliness penalty, cessation of work penalty, delivery deadline, order entry time. Processing time of products in stages 1 and 2 is shown in Table 2. Also, processing time of products based on demand in stages 1 and 2 is shown in Table 3. Processing capability of reservoir matrix in stage 1 and 2 are presented in Tables 4 and 5.

TABLE 1. Tardiness Penalty, Earliness Penalty, Cessation of Work Penalty, Delivery Deadline, Order Entry Time Parameters

Product	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	l_{13}	l_{14}	l_{15}	l_{16}	l_{17}	l_{18}	l_{19}	l_{20}
Demand	96	71	37	53	24	68	72	18	47	28	60	28	25	18	20	48	36	27	14	16
Tardiness Penalty	10	12	17	20	20	13	19	12	18	11	13	16	15	14	10	16	19	20	12	15
Earliness Penalty	17	11	20	19	10	12	13	15	17	10	14	16	18	20	19	8	13	12	16	15
Cessation of Work Penalty	14	10	9	11	17	13	8	20	12	15	9	14	16	11	18	13	9	20	15	12
Delivery Deadline	10	8	14	28	4	10	40	25	14	40	22	8	5	8	1	3	14	9	21	17
Order Entry Time	0	2	1	1	0	5	2	3	1	2	1	1	0	2	5	4	6	7	4	6

TABLE 2 Processing Time of Products in Stages 1 and 2

Product	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	l_{13}	l_{14}	l_{15}	l_{16}	l_{17}	l_{18}	l_{19}	l_{20}
Stage 1	3	4	7	3	3	5	5	9	6	7	4	4	10	3	5	5	9	9	5	4
Stage 2	2	3	2	2	2	3	4	5	3	5	2	4	5	2	4	4	6	3	2	2

TABLE 3. Processing Time of Products Based on Demand in Stages 1 and 2

Product	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	l_{13}	l_{14}	l_{15}	l_{16}	l_{17}	l_{18}	l_{19}	l_{20}
Stage 1	8	5	4	5	2	5	4	1	3	4	3	2	1	2	3	2	1	1	2	1
Stage 2	8	9	7	6	3	7	9	3	8	5	4	2	4	8	7	4	3	2	3	3

TABLE 4. Processing Capability of Reservoir Matrix in Stage 1

	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	l_{13}	l_{14}	l_{15}	l_{16}	l_{17}	l_{18}	l_{19}	l_{20}
K_1	√	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	√	√	√
K_2	√	√	-	-	-	-	-	-	-	-	-	-	-	-	-	-	√	√	-	-
K_3	-	√	√	-	-	-	-	-	-	-	-	-	-	-	-	√	√	-	-	-
K_4	-	-	√	√	-	-	-	-	-	-	-	-	-	-	√	√	-	-	-	-
K_5	-	-	-	√	√	-	-	-	-	-	-	-	-	√	√	-	-	-	-	-
K_6	-	-	-	-	√	√	-	-	-	-	-	-	√	√	-	-	-	-	-	-
K_7	-	-	-	-	-	√	√	-	-	-	-	√	√	-	-	-	-	-	-	-
K_8	-	-	-	-	-	-	√	√	-	-	√	√	-	-	-	-	-	-	-	-
K_9	-	-	-	-	-	-	-	√	√	√	√	-	-	-	-	-	-	-	-	-
K_{10}	-	-	-	-	-	-	-	-	√	√	-	-	-	-	-	-	-	-	-	-

TABLE 5. Processing Capability of Reservoir Matrix in Stage 2

	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	l_{13}	l_{14}	l_{15}	l_{16}	l_{17}	l_{18}	l_{19}	l_{20}
K_{11}	√	-	-	-	√	-	-	-	√	-	-	-	√	-	-	-	√	-	-	-
K_{12}	√	√	-	-	√	√	-	-	√	√	-	-	√	√	-	-	√	√	-	-
K_{13}	-	√	√	-	-	√	√	-	-	√	√	-	-	√	√	-	-	√	√	-
K_{14}	-	-	√	√	-	-	√	√	-	-	√	√	-	-	√	√	-	-	√	√
K_{15}	-	-	-	√	-	-	-	√	-	-	-	√	-	-	-	√	-	-	-	√

The proposed flexible manufacturing system, examines the constraints of blending unit in one of Iranian oil companies. The results of solving this model are presented in this section. These results mentioned, according to the data presented in the previous section. These data are calculated for production of 20 types of product in a period of 30 days. As described in section 4, complete time of productions for each product is calculated by mathematical models and GAMS software. If the product is produced earlier than expected delivery time, earliness time is calculated. If the product is produced later than expected delivery time, tardiness time is calculated. These results are shown in Table 6. Finally, the objective function and component costs are presented in Table 7.

Gantt Chart Gantt chart of activities based on the progress time period is presented. This Gantt chart for scheduling orders in the case study is calculated.

For example, the number of cessation of work in reservoir K_1 is 4. So that in position 7, the product i_1 is processed. It means the product l_1 is not processed in position 8. Therefore, a cessation of work is created. Then, no products could not be processed in position 1_3. But the product l_{20} is processed in position 14. So, another cessation of work is created. Also, the product l_{20} is processed in position 14. It means the product l_{20} is not processed in position 15. Therefore, another cessation of work is created. Finally, in position 16, no products could not be processed. But the product l_{19} is processed in position 17. Therefore, another cessation of work is created. In general, these process show that 4 cessation of work is created in reservoir K_1.

5. CONCLUSION

Scheduling is the method by which work specified by some means is assigned to resources that complete the work considering to constraints and specific objectives. Because time is always limited resources, therefore, activities must be scheduled so that the consumption of resources, have been optimized. In recent decades, flexible manufacturing systems have emerged as a response to market demands of high product diversity.

TABLE 6. Completion Time, The duration of Tardiness / Earliness of Orders

Product	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	l_{11}	l_{12}	l_{13}	l_{14}	l_{15}	l_{16}	l_{17}	l_{18}	l_{19}	l_{20}
Completion Time	10	20	26	26	22	11	26	25	25	26	22	8	16	21	21	6	14	9	21	17
The duration of Tardiness	-	12	12	-	18	1	11	-	11	-	-	-	11	13	20	3	-	-	-	-
The duration of Earliness	-	-	-	2	-	-	14	-	-	14	-	-	-	-	-	-	-	-	-	-

TABLE 7. The Objective Function and Component Costs

Tardiness Cost	Earliness Cost	Cessation of Work Cost	Number of Cessation in Work	Completion Time Cost	Total Cost	The Time of Solve
1514	360	979	79	7800	10653	18 minutes

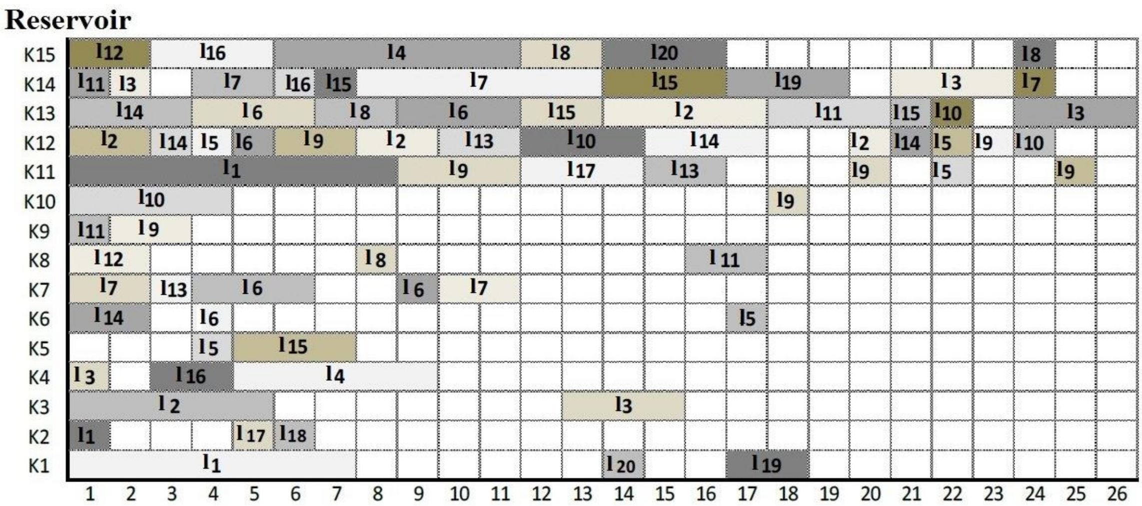

Figure 3. Gantt chart for scheduling orders in one of Iranian oil companies

Scheduling is one important phase in production planning in all manufacturing systems. Although scheduling in classical manufacturing systems, such as flow and job shops, is well studied. Rarely, any paper studies, scheduling of the more recent flexible manufacturing system. In this paper, a part of production system where products are produced in two stages and in multiple repositories, is known as a bottleneck. Then, the two-step mathematical model presented in this paper is provided for scheduling 15 single-purpose reservoirs to minimize earliness costs, tardiness costs, and cessation of work costs. This model was presented as a case study in one of Iranian oil companies. Finally, the proposed model has been solved by GAMS software. Results confirm the validity of the proposed model.

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A Scheduling Model of Flexible Manufacturing System to Reduce Waste and Earliness/Tardiness Penalties

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چکیده

امروزه سیستم های تولید انعطاف پذیر به عنوان پاسخی برای محیط رقابتی معرفی شده است. زمانبندی سیستم های تولید انعطاف پذیر (FMS) بسیار پیچیده تر و سخت تر از سایر برنامه های زمانبندی تولید می باشد. یکی از عوامل اصلی در زمانبندی FMS، تغییرات زمان گرفتن سفارشات از مشتری است که منجر به یک تغییر ناگهانی در فرایند تولید می شود. همچنین، برخی مسائل همچون اتلاف ها، هزینه های زودکرد و دیرکرد، و هزینه های افزایش موجودی در سیستم تولید بوجود می آید. در این مقاله، بخشی از سیستم تولید انعطاف پذیر که در آن محصولات در دو مرحله و در مخازن مختلف تولید می شود، به عنوان یک گلوگاه شناخته شده است. در این مطالعه، یک مدل ریاضی برای زمانبندی این مساله با توجه به محدودیت های سیستم تولید مانند سرعت جریان ورودی و خروجی مخازن، زمان متغیر ثبت سفارش، ضایعات ناشی از توقف تولید، و ظرفیت ذخیره سازی مخازن، توسعه داده شده است. سپس مدل پیشنهادی با نرم افزار GAMS حل شده است. نتایج ارائه شده نشان می دهد که مدل پیشنهادی دارای اعتبار بالایی می باشد.

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