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Algorithm for Manufacturing Planning Under Unavailability Constraints

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ABSTRACT

Production scheduling is a major issue in industrial engineering because of its impact on optimization of profits the use of resources. This paper proposes an algorithm for optimizing a production scheduling model under production and maintenance constraints. This work is an extension of resources management algorithm developped by Ezzeddine et al. [6] to an industrial application purpose. A numerical example is illustrated in the last section of this paper.

Key words : Optimization, Production, Maintenance, management, Scheduling, Planning

1. INTRODUCTION

Decision support systems continue to be very popular in industrial engineering, because of their ability to help decision makers to better manage their resources in function of several manufacturing constraints. Manufacturing systems are complex systems that connecting a large number of technical and human resources. These systems are often looking for more efficiency. To satisfy this need, new strategies are developed, especially in production planning the management of production and maintenance planning using these new strategies differ greatly from management policies in traditional manufacturing. These strategies are more deterministic and more flexible since they could take into account different parameters impacting production and control activities performances.

Production scheduling is considered a determinant functionality in the production management whole system. To guarantee a good efficiency of operation scheduling and since production activities depend on several parameters, production scheduling may need to take into account the manufacturing system status and operational condition in the production layer. The importance of considering production management components linked to Manufacturing Execution Systems (MES) has hugely increased during the last years. The Figure 1 [9] illustrates the MES growth between 2006 and 2016.

This paper is organized as follows: the first section presents briefly the main contributions in production scheduling. In the second section, the production planning model is developed and then illustrated with a numerical example in the third part.

2. LITERATURE REVIEW

In literature, many proposals deal with manufacturing system allocation and production planning. Several research

Figure 1: Growth of MES systems

work ([1],[3],[4]) focused on mathematic modeling to express the production scheduling problem in terms of variables and constraints.

Giffler and Thompson [1] proposes a set of algorithms in order to minimize the length of production planning. Proposed algorithms are used to generate all possible optimal schedules grouped into subsets. The author proposes then computational algorithms in order to evaluate these susets performances and select the best ones in function of given performances parameters. [3] develops an hybrid policy to deal with the optimal production scheduling complexity due to various kinds of uncertain factors such as breakdowns, maintenance actions and production parameters. The author used the Genetic algorithm as a resolution tool to minimize the total completion time. [4] summarized the production planning computation complexity for various types of cost functions, maintenance costs and production capacity limits.

Many research works deal with several industrial constraints such as subcontracting, warranty, and quality in manufacturing and logistic fields. For more details about determination of production and maintenance control policies under different types of constraints, the reader may refer to Rezg et al. [5].

The main goal is to find a schedule that satisfies all resource constraints while minimizing the total cost. Other proposals integrate different parameters as subject of optimization in order to get the best decisions from which we cite tasks selection and sizing, assignment of tasks to manufacturing systems and jobs sequencing. The figure 2 [10] illustrates the major decisions that could be determined through production scheduling.

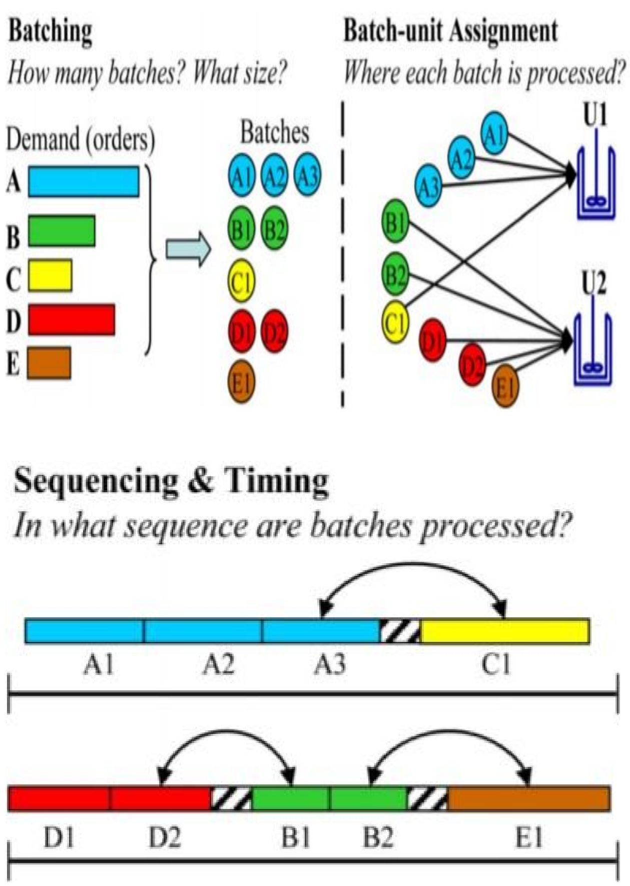

Figure 2: Major decision in production planning decisions

In other proposals [2], simulation and meth-heuristics tools are used to highlight operating issues and evaluate different decisions of resources management. In [6], the authors proposed an algorithm dealing with beds management issues in hospital centers.

Maintenance strategies currently used by decision makers are generally classified into two main classes: the corrective maintenance and the preventive one. Corrective maintenance actions is realized when a machine breaks down. The main task of such maintenance activities is to restore the machine to a desired condition. Preventive actions are performed regularly to increase the machine disponibility and to avoid as possible it's breaking down. In this paper, we will consider preventive maintenance actions which are already planified in the initial production planning.

The junction of maintenance and production scheduling was the subject of many proposals in the literature. In particular, [7] discusses the optimal joint production and maintenance plan in the case of a system consisting of several identical machines. [8] developed a new approach for joint production and maintenance scheduling in the case of multiple machines. Machines are subject to failures and an age-dependent preventive maintenance policy is used. In the case of this study, we consider that a preventive maintenance scheduling is given in the initial manufacturing systems availability plan.

The main contribution of this paper is to determine the optimal production scheduling in function of unavailability constraints of preventive maintenance actions and preprogrammed production tasks.

1. MODEL DESCRIPTION

In this part, a planning of manufacturing systems allocation is presented. Our proposition is to develop a production plan under production constraints. The mathematical model is based on model developed by Ezzeddine et al. [6].

The proposed model is based on following assumptions:

- The production duration is considered as known in advance.
- Products cannot be operated on more than one manufacturing system
- Each product is associated to two dates: earliest manufacturing date and latest manufacturing date. Real manufacturing date must be included between these two dates.
- Two type of workshops: workshops with two manufacturing systems and ones with only one manufacturing system
- Manufacturing of different types of products in the same workshop at the same time is forbidden.

Thus, the main objective consists to assign the maximum of products. Assignment has to respect constraints and not to disturb current planning. Availability (empty and occupied manufacturing systems) are determined and updated after each assignment.

A. Notations and Decision Variables

- NP : total number of products
- H: horizon of time
- NMS: total number of manufacturing systems
- EM_i: earliest manufacturing date for product i

- LM_i: latest manufacturing date for product *i*
- *Ti*: product type *i*
- *MC*: manufacturing cost per unit of time, the same for all type of products
- *MDi*: manufacturing duration of product *i*
- *M* : positive constant
- *NW* : number of workshops
- *t*: time elementary period
- *Bl,t* = 1 if manufacturing system *l* is free in the time *t*, 0 otherwise.
- $Main_{l,t}$ = 1 if there is a preventive maintenance action on the manufacturing system *l* in the time *t*, 0 otherwise
- *Mj,k,l* = 1 if manufacturing systems *j* and *k* are in the same workshop, 0 otherwise
- *Ti* = -1 if product *i* is type A, 1 if it is type B
- *SPl,t* = -1 if manufacturing system *l* is occupied by a product type A during *t*, 1 if it is occupied by a product type B and 0 if it is free.
- $Work_i$ = 0 if the workshop i has one manufacturing system, 1 if it has two.

The decision variables of this model are as follows:

- X*i,l,t* = 1 if product *i* is assigned in manufacturing system l during the period *t*, 0 otherwise.
- F*i* = 0 if product *i* is operated, 0 otherwise
- A*i,l* = 1 if product *i* is assigned in manufacturing system *l*, 0 otherwise
- J*i* indicates the real manufacturing date
- End_i indicates the end manufacturing date: (End_i = *Ji* +*MDi-1*)

Variables *i*, *l* and *t* have to be included respectively in [1,*NP*] , [1;*L*] and [1; *T*].

B. Algorithm for Production Scheduling

The objective function is expressed as following:

$$Min\left(MC\cdot\sum_{i=1}^{NP}[(J_i-EM_i)+(F_i\cdot MD_i)]\right) \quad (1)$$

The objective function aims to maximise the production profits and so minimize the non operated (rejected) products. This function is a bi-objetive function :

- The first part: $MC\cdot\sum_{i=1}^{NP}(J_i-EM_i)$ aims to reduce the manufacturing date of each product and thus reduce the total completion time.
- The second part: $\sum_{i=1}^{NP}(F_i\cdot MD_i)$ aims to reduce the number of non operated products. Each non operated product is expressed by a waste equal to the benefit if it has been operated.

The model constraints are given as following

$$\sum_{l=1}^{NMS} X_{i,l,t}\le 1 \quad (2)$$

(2): A product cannot be operated by more than one manufacturing system in a time unit *t*.

$$\sum_{i=1}^{NP} X_{i,l,t}\le 1 \quad (3)$$

(3): A manufacturing system operates at most one product in a time unit *t*.

$$\sum_{l=1}^{NMS}\sum_{t=EM_i}^{H} X_{i,l,t}+F_i\cdot MD_i=MD_i \quad (4)$$

(4): Non interrupted manufacturing. The model assumes that manufacturing operation is continuous. the length of stay of the product in the workshop is strictly equal to its manufacturing duration.

$$\sum_{l=1}^{NMS} A_{i,l}\le 1 \quad (5)$$

$$MD_i\cdot A_{i,l}=\sum_{t=EM_i}^{H} X_{i,l,t} \quad (6)$$

(5) and (6): A product can occupy at most one manufacturing system.

$$J_i\ge EM_i \quad (7)$$

$$J_i\le LM_i \quad (8)$$

(7) and (8): Upper and Lower bounds for manufacturing date.

$$\sum_{t=EM_i}^{H} X_{i,l,t}\cdot B_{l,t}=A_{i,l}\cdot MD_i \quad (9)$$

(9) : Availability of The manufacturing system to operate the product *i*

$$Work_i \cdot M_{j,k,l} \cdot \left(\sum_{i=1}^{NP} T_i \cdot (X_{i,j,t} - X_{i,k,t}) \right) \leq 1 \quad (10)$$

$$Work_i \cdot M_{j,k,l} \cdot \left(\sum_{i=1}^{NP} T_i \cdot (X_{i,j,t} - X_{i,k,t}) \right) \geq -1 \quad (11)$$

$$Work_i \cdot M_{j,k,l} \cdot \left(SP_{j,t} - \sum_{i=1}^{NP} (X_{i,j,t} \cdot T_i \right) \leq 1 \quad (12)$$

$$Work_i \cdot M_{j,k,l} \cdot \left(SP_{j,t} - \sum_{i=1}^{NP} (X_{i,j,t} \cdot T_i \right) \geq -1 \quad (13)$$

(10), (11), (12) and (13): Products of different types cannot be operated in the same workshop at a given unit of time.

$$\sum_{t=EM_i}^{H} X_{i,l,k} \cdot B_{l,t} \cdot Main_{l,t} = A_{i,l} \cdot MD_i \quad (14)$$

(14) Expresses the preventive maintenance constraints. Related to the maintenance planning, we take into account the fact that Manufacturing systems must be maintained after a given number of operated products. Preventive maintenance is not linked to duration but to a given quantity produced, after which the system has to be inspected and maintained. This quantity is mostly fixed on the basis of system characteristics such as the equipment life duration, its mechanic characteristics and the environmental and operational conditions in which the system operates.

Table 1 gives the initial unavailability dates of manufacturing system in the time horizon which will be subject of scheduling. As mentioned before, the unavailability, in this paper, corresponds to one of these two cases:

- Unavailability for preventive maintenance actions: on the basis of Table 1, in the studied time horizon, system 1 will be inspected and maintained in the 10^{th} and 11^{th} time units. System 3 will be inspected and maintained in the 6^{th} and 7^{th} time units
- Unavailability for preprogrammed production activities: on the basis of Table 1, as an example, preprogrammed procution actions in the studied time horizon for the system 1 are the manufacturing of product type B for 5^{th} and 6^{th} time units.

Table 3 illustrates the obtained results. The simulation results highlights the optimal production scheduling in the given time horizon and in function of model constraints. Results lead to conclude that production constraints consisting that two products of different types could not be in the same workshop at a given time t are respected. On the above of these results, product 2 is operated in the first workshop, on the first machine during the 2nd, 3rd and the 4th time units. Product 5 is operated on the 4th machine on the 10th, the 11th and 12th time units.

The optimal solution is obtained with the solver Lingo. From a total of 11 products, one product is not scheduled for operation. The product is rejected due to the earliest and latest manufacturing dates constraint

4. NUMERICAL EXAMPLES

For the numerical example, we consider 3 workshops having 4 manufacturing systems (2 double workshops and 1 single). The following database is considered (Table 1 and Table 2):

- The horizon time is fixed at 14 units of time.
- The average production cost per unit of time is 5 euro.
- The manufacturing duration MD is fixed at 3 units of time for product type A and 2 units of time for product type B.
- Initial unavailability is expressed by the preventive maintenance action plan by the letter M in the Table 1 and Table 3 and preprogrammed production actions expressed by Letter B for product type B and Letter A for product type A

5. CONCLUSOINS

Using planning models and tools, decision makers can anticipate the production plan permitting to optimize profits.
Resources allocation depends usually on production and maintenance constraints.
In this paper, we have discussed an algorithm for solving an optimal production planning under production and unavailability constraints. Unavailability is expressed in this contest by a preventive maintenance actions and preprogrammed production tasks.
The aim of future works is to integrate other production constraints in the manufacturing planning.

Table 1: Manufacturing Systems Initial Unavailability

	Manufacturing systems	Planning horizon													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Workshop 1	1					B	B	A	A		M	M			
	2											B			
Workshop 2	3						M	M							
Workshop 3	4							A	B	B				A	A

Table 2: Data for Operated Products

Product(i)	EM(i)	LM(i)	T(i)	J(i)	End(i)	Manufacturing system (i)	F(i)
1	1	2	B	1	4	4	accepted
2	2	3	A	2	4	1	accepted
3	3	4	A	3	6	2	accepted
4	3	6	B	3	8	3	accepted
5	9	10	A	10	12	4	accepted
6	8	12	A	8	9	2	accepted
7	12	12	A	12	14	2	accepted
8	9	9	B	9	12	3	accepted
9	12	13	A	12	14	1	accepted
10	13	13	B	13	19	3	accepted
11	13	13	A	14	17	4	rejected

Table 3: Manufacturing Planning

	Manufacturing systems	Planning horizon													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Workshop 1	1		2	2	2	B	B	A	A		M	M	7	7	7
	2			3	3	3			6	6	6	B	9	9	9
Workshop 2	3			4	4		M	M		8	8			10	10
Workshop 3	4	1	1					A	B	B	5	5	5	A	A

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