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Multi-product sequencing and lot-sizing under uncertainties: A memetic algorithm

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The paper deals with a stochastic multi-product sequencing and lot-sizing problem for a line that produces items in lots. Two types of uncertainties are considered: random lead time induced by machine breakdowns and random yield to take into account part rejects. In addition, sequence dependent setup times are also included. This study focuses on maximizing the probability of producing a required quantity of items of each type for a given finite planning horizon. A decomposition approach is used to separate sequencing and lot-sizing algorithms. Previous works have shown that the sequencing sub-problem can be solved efficiently, but the lot-sizing sub-problem remains difficult. In this paper, a memetic algorithm is proposed for this second sub-problem. Computational results show that the algorithms developed can be efficiently used for large scale industrial instances.

1. Introduction

In this paper, a multi-product lot-sizing and sequencing problem under uncertainties is studied. The source of the problem is derived from an automated semiconductor manufacturing plant where there are non-negligible percentages of rejects and breakdowns. However, this situation can concern any automatic production line working under uncertainties and the proposed approach could be easily extended to different types of production lines.

The example given here is from our experience of designing a paced line to produce several types of conductor patterns. These parts are used to obtain electronic modules (printed circuits). Since the considered semi-conductor factory is greatly automated, there is no staff other than maintenance for almost the whole day. The facility functions with three shifts. Specifically, the main task for the day shift is to define the production plan for the next 24 h and start the manufacturing process. The evening and night shifts, which consist of maintenance personnel only, insure the production line continue to function, but cannot change the production plan. As a consequence, the production plan is set for 24 h and will not be adjusted to take into account rejects or breakdowns that may occur in the later shifts.

After processing, parts (conductor patterns) are placed in an automatic storage system, and they are used for the assembly of electronic modules. The automatic storage system is expensive and restricted in volume. Consequently, it should work with one day stock limit, if possible. So, this line and storage system should be able supply the next assembly line just-in-time. In other words, the following policy is applied: all the items used for assembly in period $r+1$ must be in the storage system by the end of planning period r. At the beginning of the period r, the demand for all items types for assembly in the planning period $r+1$ is known (taking into account the current stocks in the automatic storage system, if they exist, and the production plans of the assembly line for period r and $r+1$). Thus, for each period r, the following question has to be answered: how many items of each type must be released to production in the beginning of the period r to obtain the necessary quantity for all components in the next production run $r+1$ of the assembly line? With this sort of production, there is a non-negligible percentage of rejects, because some finished components are produced with unacceptable quality. Quality control is made at the end of the line with no intermediate quality control. In addition, the machines of the line are often stopped briefly because of breakdowns.

This leads to a new and very interesting production control problem dealing with optimal lot-sizing and scheduling under uncertainties. There are two types of possible policies which are in conflict. To diminish the influence of random breakdowns, the safety time (the difference between the duration of the planning horizon and the time necessary to produce all lots) can be increased, but in this case, it is necessary to reduce the sizes of lots, so the production plan can be more easily perturbed by rejects. On the other hand, the size of lots can be increased to diminish the impact of random rejects, but the line will be more

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sensitive to random breakdowns, because of insufficient safety time. There would be not enough time to repair of all these breakdowns and the line cannot produce the necessary quantity of items. Moreover, a set-up time is necessary between processing of two different products for reconfiguration of manufacturing facility. The set-up time depends on type of already manufactured product and new items to process. Thus, for the both policies mentioned above, there is an additional level of action affecting the safety time.

In this paper, we will reexamine the probabilistic formulation of this lot-sizing and scheduling problem, initially evoked in Dolgui (2002). For this problem, a first approach was suggested in Dolgui et al. (2005): authors have shown that this problem can be reduced to a single machine problem with sequence-dependent set-up times and that its optimal solution can be obtained using a decomposition into several optimization sub-problems: enumerating, sequencing and lot-sizing. Note that the latter two problems are NP-hard but the sequencing sub-problem can be transformed in a well-known Traveling Salesman Problem, for which there exist a large number of effective algorithms. For lot-sizing sub-problem, in Dolgui et al. (2005), the authors presented an idea how dynamic programming (DP) approach could be used to solve it. Nevertheless, only the decomposition framework and a recursive DP expression for lot-sizing were provided. No evaluating tests were performed. Thus, the question on the effectiveness of this approach for small, medium and large size cases is still open. This needed to be explored further which is the motivation of the current paper.

We present a global approach intended to treat actual problems of industrial sizes. This study will employ the earlier proposed overall decomposition approach. DP will be tested on several numerical examples and a memetic algorithm (MA) based on a local search (LS) and a genetic algorithm (GA) will be suggested for large scale cases.

The rest of the paper is organized as follows. Overall assumptions and problem statement are presented in Section 2. A review of related literature is given in Section 3. Section 4 introduces the solution framework: how the uncertainties are modeled and decomposition is accomplished. In Section 5, a Memetic Algorithm (MA) with its elements is presented. In Section 6, several experimental results comparing the algorithms (DP, LS, MA) are reported. Section 7 contains some concluding remarks and further perspectives.

2. Problem formulation

In this paper, a paced flow line that produces items of several types in lots is considered. This consists of several machines located sequentially according to a manufacturing process. One lot is a set of items of the same type that pass through the line sequentially without any other types inserted. A machine can produce no more than one item at the same time. There are no buffers between machines. The processing times are known and transfer times between machines can be integrated in processing times. There is a setup time between adjacent lots and before the first lot (these values are known for each pair of products). It is considered that in the beginning of the day (or planning horizon) production line is idle. To start any manufacturing process, the line needs a set-up procedure that depends on the type of product. As all products pass through all machines of the line, thus it is necessary to reconfigure each machine when changing the type of product.

The machines are considered as imperfect in sense that they: (1) can produce defective items; (2) are liable to breakdowns.

There is no intermediate quality control, thus defects are only detected after the last machine. These items cannot be reworked, and are rejected. The probabilities of defective items for each item type and each machine are known. When a machine breakdowns, the line is stopped for a certain time for repair, during which no new items can be manufactured.

Machine breakdown rates are known. It is supposed that breakdowns occur only during ongoing manufacturing (when the line is stopped for maintenance or setup, breakdowns are not possible).

The decision variables are the sequence of lots and their size. The difficulty of this problem comes from the interdependence of the two types of decision variables: the optimal sequence depends on the sizes of lots and, vice versa, the optimal sizes of lots depend on the sequence selected. We need to find both the optimal sequence and sizes of lots maximizing the probability of obtaining the required quantities of items for each type by the end of the current planning period. The benefit of this optimization is evident. Without any additional resources, we will reduce the production cost and planning nervousness, because the next assembly line will produce with less of stoppages.

This problem has to be solved at the beginning of each production run. Thus, a one period model can be used. It must take into account two kinds of uncertainties: random lead time induced by machine breakdowns and random yield to take into account defective parts. An additional difficulty is a sequence-dependent set-up time between items of different types.

There are n types of items and m machines. The planning period duration (run) is equal to T. For items of type i, $i=1,\ldots,n$ the following parameters are given:

- d_i—demand level (defined by the assembly line);
- t_{iq}, $q=1,\ldots,m$—processing time required for manufacturing item i on machine q. Let T_{tr} be the transfer time of an item between two successive machines. We consider that transfer of all items on the line is simultaneous between all machines. So the takt time t_i for the production of item of type i is $t_i = T_{tr} + \max_q t_{iq}$, $i=1,\ldots,n$. In the following we will use the t_i notion to represent the item's i unitary processing time. As this is a paced line, this assumption is not restrictive for the model proposed, and is used only to facilitate its presentation.

The following notations will be used to present sequence-dependent set-up times:

- $s_{i,j,q}$—set-up time required in order to switch the production from items of type i to items of type j on machine q, i, $j=1,\ldots,n$; $q=1,\ldots,m$. Set-up time begins only when the production line is empty, i.e. the last item of precedent lot has left the last machine of the line. As production of the product j begins once the set-up of all machines is finished, we can integrate the notion of the "line set-up time" and use the notation of $s_{i,j}$ to represent it. Line set-up time $s_{i,j}$ can be obtained as the maximum of the times for machine set-ups, i.e. $s_{i,j} = \max_{q=1,\ldots,m} s_{i,j,q}$, were m is the number of machines in the line, $s_{i,j} > 0$, $i \neq j$.
- $s_{0,i}$—line set-up time required to start processing of items i, if the lot of items i is the first on the line, $s_{0,i} > 0$, $i \neq 0$.

Hereafter, it is assumed that the set-up times satisfy the *triangle inequality* $s_{i,j} + s_{j,k} \geq s_{i,k}$ for $i=0,\ldots,n$ and $j,k=1,\ldots,n$.

The decision variables are $x=(x_1,x_2,\ldots,x_n)$ and $\pi=(\pi_1,\pi_2,\ldots,\pi_n)$, where x_i is the size of lot for item i, $i=1,\ldots,n$, and π is the sequence of all lots. Each $\pi_i \in [1,n]$, $\pi_i \neq \pi_j$ when $i \neq j$, $i,j=1,\ldots,n$. The solution of the problem is a specific production plan that determines the quantity of items for all product types to manufacture and the order of lots on the production line.