A discrete-event simulation approach for scheduling batch processes

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ABSTRACT

In this work, discrete-event simulation has served as a general framework for representing the behavior of a multipurpose-multiproduct batch plant. This approach has first been applied to the case of a semiconductor manufacturing facility and is now extended to a chemical batch plant. The basic principles of an enhanced version of a model developed previously in our laboratory is presented in this paper. It takes into account stable intermediates which may be generated at a multiple output step and whose production must, in turn, be scheduled. An illustrative example is given to show the impact of intermediate products on the general performance of the production system.

KEYWORDS

Multipurpose-multiproduct plant; batch processes; recipe; coproducts; subproducts; production scheduling; discrete-event simulation.

INTRODUCTION

Batch processing is the predominant mode of production for multiple, low-volume, high-value added products in a single plant. It is used in many different environments, i.e., in the pharmaceutical, polymer, food, specialty chemistry and semiconductor industries. The key feature of these plants using this mode of production is that a lot of products have to be elaborated in accordance with their own recipe by sharing the same equipment. In this context, scheduling is a complicated task. Mathematical approaches, using in most cases Mixed Integer Linear Programming (Birewar et al., 1989, Patsidou et al., 1991), Mixed Integer Non Linear Programming (Sahinidis et al., 1991) or Branch and Bound methods (Ng et al., 1994) have been broadly studied but they become often impracticable for large scale job shop plants because of a combinatorial explosion. Another approach consists in developing simulation models for batch or batch/semi-continuous plants (Overturf et al., 1978, Kuriyan et al., 1987). Our work lies in this framework and our aim is to develop a detailed job shop discrete event simulation model with a high degree of details to have a realistic representation of a batch plant production, taking into account human constraints wich have most often been neglected. In this model, changes in the system state are caused by the occurrence of a set of allowed events. A simulation module keeps a list of scheduled events which manages and drives the simulation, so that the system evolves from a state to another till the end of the simulation. Although the problem can be formulated in a general manner, the development of a general purpose simulation system is made difficult due to the requirements of each production system.

A discrete-event simulation approach has first been applied in our laboratory to represent the dynamics of semiconductor manufacturing, organized as a job-shop operation (Peyrol et al, 1993). Semiconductor devices are elaborated on raw wafers of silicon grouped in batches, which visit the different equipment units of the workshop. The model developed (MELISSA) has been designed to handle typical problems of a semiconductor workshop : multiple product flow processes, common and parallel resources, reentrant product flows, cadence steps, batch splitting or merging, allocation of steps to specific zones of the workshop, personnel organization… The storage policy in a semiconductor facility does not impose additional constraints since the products are not subjected to degradation and an unlimited intermediate storage policy (UIS) has thus been adopted. A heuristic strategy based on priority rules is used to solve the conflicts which may occur at an equipment unit. This simulation model has turned out to be an efficient tool and has been used successfully in two microelectronics facilities (Motorola Inc., Toulouse and Silmag, Grenoble, France).

In addition, it turns out to be general enough to be also suitable for chemical batch plants involving simple processes with stable products and in which an UIS policy is valid.

But, in practice, the inherent situation of chemical processes is often much more complicated. For instance, in a semiconductor industry, each product keeps its own identity from the first to the last step of its elaboration process. On the contrary, in a chemical process, certain steps may lead to more than one products which then require a specific treatment. In this paper, a methodology is thus proposed to take into account the case of multiproduct output steps.

BASIC PRINCIPLES

Let us consider a job shop structure dedicated to the elaboration of chemical products. We assume that the production of each product can be decoupled into elementary processing steps, each of which manufactures one or more stable intermediates which can be stored in substantial quantities, if required. An unlimited intermediaire storage policy will be considered throughout this study. The steps at which several intermediate species are generated will be referred in the following to as multiple output steps. A multiple output operation, for instance, a separation step, gives rise to one main product and one or more secondary products (sub- or coproducts). If co- and subproducts are not treated in situ during the production campaign, they have obviously no impact on workshop dynamics. But in most cases, it turns out necessary to take them into account, for representing more realistically the production system behavior.

Subproduct recycling and in situ coproduct valorization modify significantly the production managenent problem for two mains reasons :

On the one hand, recycling and valorization operations (called, in the following, secondary operations) increase the total workload among the resources, which have to be shared between main and secondary operations. Invariably, their presence affect the general performance of the workshop as measured by product average waiting time, product completion time, resource utilization rate and so on…

On the other hand, total production is also modified. Coproduct valorization may give rise to some new marketable products whereas subproduct recycling may produce either more main products or raw materials.

The principles of the simulation model have already been described in previous works (Peyrol et al., 1993), so we will just tackle here the modules introduced to treat the specific case of co- and subproducts. Let us recall that the model consists of three components :

1- The input module

The following items have been added in the input module :

Identification of secondary products : the number and type of classes of secondary products are specified.
Definition of recipes for secondary products : processing time at each step, charging and discharging time …

Identification of multiple output operations : This concerns exclusively recipes for main products. The amount of secondary products generated at these steps is defined .

Definition of batch size for secondary products : Secondary products begin their treatment in the workshop as soon as their effective quantity reaches a predefined threshold.

These additional data permit us to treat the case of secondary product recycling or valorization recipes with an adapted simulation module.

2- The simulation module

This module takes into account secondary products generated at a multiple output operation. Their generation is therefore dependent upon some predecessor events. Secondary products are then stored in a storage zone which is supposed unlimited. The release time of each secondary product occurs when the stored volume reaches a predefined batch size. Then, secondary products follow valorization or recycling operations and the simulation module considers secondary products as additional products to be elaborated during a production campaign.

3- The output module

The output of the simulation is a set of information concerning main and secondary products (average waiting time, number of times stored, completion time…) as well as statistics concerning resource utilization rate, idleness and so on …over the simulated interval of operation.

ILLUSTRATIVE EXAMPLE

An example is presented to illustrate the impact of the model modifications on production system performance. Let us consider a fictitious batch chemical structure for which an UIS policy is supposed to be valid. The simulation model (Peyrol, 1992, Peyrol et al, 1993) includes human resources, parallel equipment units, common resources, batch splitting and merging. Three operators are working during the simulated campaign. The workshop structure involves 10 elaboration steps. It is to be noted that steps 3 and 4 (respectively 7 and 8) operate in parallel (see Figure 1), whereas steps 2 and 5 are common steps.

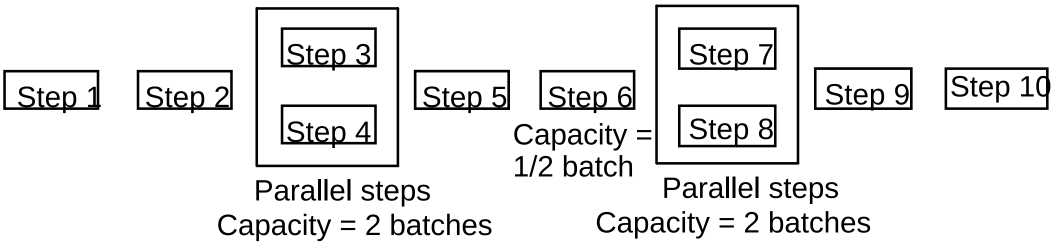

FIG.1. Equipment Units

Two kinds of main products are planned for production, i.e. a top quality product (Class A) and a less value added product (Class B). The manufacture of these products requires the following steps :

Recipe for products of class A	Recipe for products of class B
1 - 3 or 4- 5 - 6 - 7 or 8 - 9 - 10	1 - 2 - 3 or 4 - 6 - 7 - 8 - 9 -10

In this example, a two output step is considered (respectively, step 9 for class A and step 6 for class B). Coproducts of class C (respectively subproducts of class D) are associated with products of class A (respectively with products of class B).
The recipes for secondary products of classes C and D are the following ones:

Valorization recipe for coproducts of class C	Recycling recipe for subproducts of class D
1 - 3 - 5 - 6 - 7 or 8 - 9 - 10	3 - 6 - 7 or 8 - 9 - 10

The processing times of products, sub- and coproducts are given in TABLE.1.

	Steps	1	2	3	4	5	6	7	8	9	10
Product class											
A		10	*	40	40	20	10	40	40	20	20
B		15	15	50	50	*	10	50	50	20	20
C		5	*	10	0	20	10	40	10	20	20
D		*	*	10	*	*	10	40	40	20	20

TABLE.1. Processing times for the different classes of products

Each batch of class A (respectively of class B) produces a volume equal to 0.50 m^3 for products of classes A and C (respectively a volume equal to 0.75 m^3 for products of class B and 0.25 m^3 for products of class D) at each multiple output step considered in this example. The products of class C (respectively D) formed at step 9 (respectively 6) are then stored and accumulated until the level reaches 1 m^3. One batch of class C (respectively D) is therefore released as soon as two product batches of class A (respectively four product batches of class B) have achieved their treatment in step 9 (respectively 6).

Main production campaign

Concerning the manufacture of the main products A and B, two remarks have to be made. First, we consider that two products of both classes have to be released in the same period, in order to facilitate batch merging in the steps having a treatment capacity of two batches. Second, although two products of a same class enter the workshop at a same date, their treatment does not necessarily begin at this date. So we decide to delay the inlet date of one product of class A (respectively of class B) for 10 minutes (respectively for 20 minutes), which in fact corresponds to the processing time of step 1 (respectively 2). The starting up period must be at least equal to T_C, which represents the critical period of the production system and depends of the limitant equipment unit. In our case, step 6, of a half batch capacity, has been identified to be a limitant step: the processing time of both main products in this step is equal to 10 time units; in addition, charging and discharging times at this step are equal to 6 time units. The maximal capacity that this step can treat is then one batch every 32 time units, so the system critical period is of 128 time units. In our example, a start rate of 4 batches (2 of both classes) per 130 min is considered. A time horizon of 1600 time units is adopted (13 starting up periods with a total amount of 52 products of class A and B). Simulation results obtained both with the initial model version, which does not take into account secondary products and with the enhanced version are now presented .

Simulation results with no secondary products consideration

It is important for the practitioner to characterize system performance in the long run, after the system reaches a steady state. In each simulation run, the workshop area is started from an empty state. The simulation is then repeated several times for different batch starting up campaigns, using the results of the previous simulation run which have modified the state of the workshop. The steady state is defined as a regime in which the number of products that have not been yet completed their treatment remains constant from a run to another. These products will be referred in the following to batches through.
After 4 starting up campaigns, a steady-state regime is obtained, with a constant level of 6 batches through, as it can be seen in Figure 2. It has also been observed that the storage level is low and the utilization rate of the limitant step is maximum, about 60 percent, due to charging and discharging times. Results for products of both classes are summarized in TABLE.2. .

PRODUCTS	MEAN CYCLE TIME	MEAN NUMBER OF STORAGE	MEAN STORAGE TIME
Class A	301	5	23
MAX DEVIATION	4	2	3
Class B	229	3	12
MAX DEVIATION	3	2	2

TABLE.2. Results obtained after the establishment of a steady-state regime

In these conditions, four products (2 of class A and 2 of class B) are elaborated every 130 time units. At the end of the simulation, 20 batches of Class A and 22 of Class B batches are produced.

Simulation results with secondary products consideration

In this case, with the same release period as previously adopted, a steady-state regime can no more be obtained, since the number of batches through increase regulary as it is shown in in Figure 2. It is yet critical for the decision's maker to continue working in these conditions since the production system tends to saturation. Another simulation was performed in which the release period was increased to 140 time units. A steady-state behavior is then obtained after 6 starting up campaigns, with a constant level of 11 batches through, as it can be seen Figure 2. Of course, the number of batches through is higher due to the presence of the new products to consider. In these conditions, the mean product storage level is quite low but storage time and cycle time change a lot from a product to another and depend obviously of co- and subproducts release time. The utilization rate of the limitant step, i.e., step 6, is about 60 percent again. Results for main products, co- and subproducts are given in TABLE.3.

PRODUCTS	MEAN CYCLE TIME	MEAN NUMBER OF STORAGE	MEAN STORAGE TIME
Class A	380	5	33
MAX DEVIATION	60	1	10
Class B	450	5	46
MAX DEVIATION	90	1	9
Class C	299	4	53
MAX DEVIATION	89	2	63
Class D	246	4	41
MAX DEVIATION	21	1	8

TABLE.3. Results after the establishment of a steady-state regime (with sub-and coproducts).

Finally, the total production of batches of main products decreases (especially for batches of Class B). At the end of the simulation, only 19 batches of Class A and 18 of Class B are achieved, whereas 8 batches of Class C and 4 of Class D are obtained.

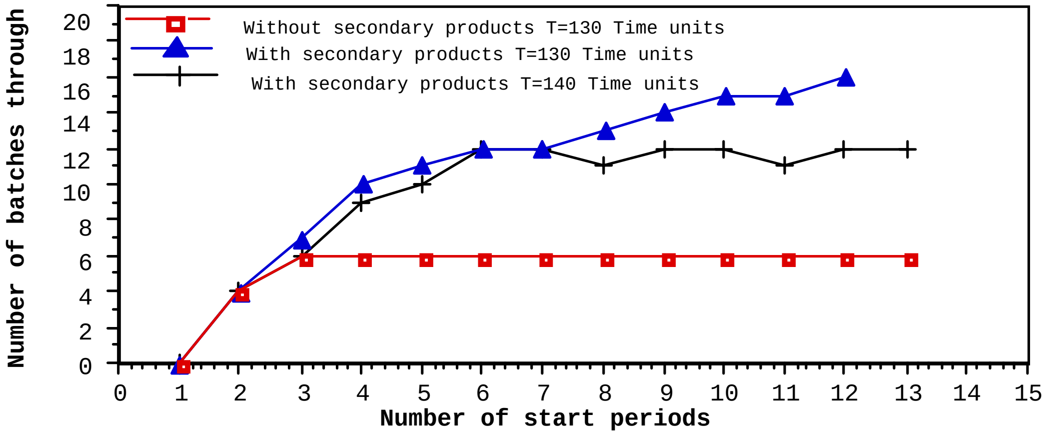

FIG.2. Level of batches through

All these phenomena are caused by the occurrence of new events, due to the treament of secondary product recycling or valorization batches, which disturb the production system. Additional batches may compete for the same equipment and the total product completion time may be increased. This situation is of course compensated by the production of new marketable batches. This academic example is obviously quite simple and results should be more significant when studying a real production system involving more processing steps and products. It can actually be expected that the occurrence of secondary products is difficult to predict in a real job-shop due to the numerous events to consider and it is the purpose of a simulation model to help the manager predict the chronology of successive events.

CONCLUSIONS - PERSPECTIVES

Discrete-event simulation has proven to be a general and valuable tool for predicting the occurrence of events in a chemical batch plant, involving stable intermediate species generated during a production campaign and whose production must be in turn be scheduled.
This approach is now going to be extended to take better account of the inherent features of such plants with respect to various intermediate storage policies and unstability of some intermediate species.

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