BATCH SCHEDULING IN TiO_2 PRODUCTION

Boštjan Hauptman

Jožef Stefan Institute
Department od Computer Automation and Control
Jamova c. 39, 1000 Ljubljana, Slovenia
bostjan.hauptman@ijs.si

Abstract: The current business environment demands an instant reply to customers' needs, a short product lifecycle, product diversification, minimal inventories, extremely short lead times, and above all an efficient production process. An efficient production scheduling is one of the most important factors that influences significantly on the production rate, its quality and proper usage of all production resources. The paper presents an efficient and simple rule-based algorithm for batch production scheduling in one of Slovenian chemical plants that is capable to predict the exact starting time for a single new batch and it is suitable for the implementation into real production environment.

Keywords: Scheduling algorithms, Batch control.

1. INTRODUCTION

Company Cinkarna Celje is a plant with 120 years of history in metallurgy and chemicals, and is currently one of Slovenia’s leading exporters. The production programme consists of zinc sheet, products for the graphics industry, fertilisers, paints, teflon products and titanium dioxide pigment. The main product is titanium dioxide pigment, which is used mainly as an important component of paint. The titanium dioxide accounts for about 70% of the plant’s production volume. Increasing and optimising titanium dioxide production is therefore a vital strategic interest for the company, and consequently the need for modernising the titanium dioxide plant is a top priority.

The titanium dioxide sulphate production process consists of a series of batch and continuous operations – subprocesses: Digestion, Reduction, Crystallisation, Centrifuging, Evaporation, Hydrolysis, Washing of the Hydrate, Pigmentation, Calcination, Grinding, Chemical Treatment, Washing of the Pigment, Drying and Micro-Ionisation.

With the aim of expanding its production of titanium dioxide Cinkarna Celje has begun to build a new production line for two-stage gel washing in pressurised candle filters with intermediate bleaching.

2. DESCRIPTION OF TECHNOLOGICAL PROCESS

The technological process *Primary and secondary washing of the gel with bleaching* is essentially of a batch nature. It consists of batch operations in filters and continuous auxiliary operations (supply of raw materials, etc.).

The aim of this subprocess is to remove some impurities from the suspension of titanium dioxide, like iron, vanadium, magnesium, which are removed by two-stage washing in pressurised candle filters, while bleaching occurs between the two washing processes. The impurities present are removed from the hydrate in two-stage washing with lukewarm water. In this process, the titanium dioxide is first separated from the main leacher, and the gel obtained is then washed by passing water through the cake that was previously sucked onto the filter material. Between the two stages of the washing of the hydrate, the suspension is again reduced in hot sulphuric acid. This reduction lowers the valence of the impurities, thus putting them in the solution so that they can be removed in the secondary washing. Almost all of the problematic sulphate is removed in this manner (Šubelj, *et al.*, 2001).

The gel is washed in one of four candle filters on the primary washing and in one of three filters on the secondary washing (Figure 1).

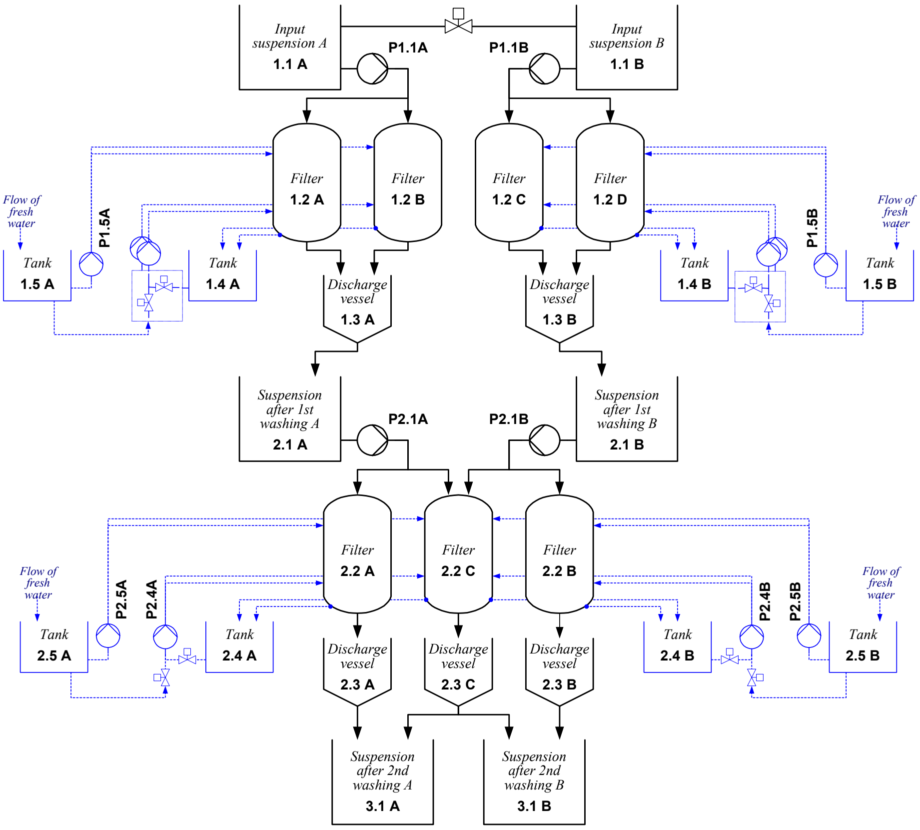

Fig. 1. Flowsheet for gel washing with bleaching

Four filters, split into A and B lines, are envisaged for the primary washing, which lasts approximately 65 to 92 minutes. In each line (each of two filters) there is one discharge vessel of a capacity that allows one filter at a time to be discharged, one dosing pump and one spraying pump. Certain admixtures are added in the discharge vessel and the entire contents are mixed for approximately 10 minutes, and only then is discharge into the storage vessel begun. The whole procedure lasts approximately 25 minutes. The discharge vessel cannot be emptied if there is not enough space in the storage vessel.

Three filters are envisaged for the secondary washing, which lasts approximately 43 to 64 minutes. Filters A and B form their own lines, while Filter C is an emergency reserve and can supplement or replace Filters A or B. Each of the filters has its own discharge vessel. The common resources are dosing, spraying and washing pump.

The batch process of gel washing at the individual level proceeds in nine steps:

- charging of the filter with the suspension,
- formation of solid cake in the candles,
- discharge of the suspension,
- cleaning of the filter,
- filling of the filter with water for washing,
- sucking of water through the cake in the reverse direction to remove impurities,
- discharge of the water,
- drying of the cake with air,
- discharge of the cake into the vessel where bleaching occurs.

The durations of steps differ during the primary and secondary washing. The duration of certain steps is affected by the input suspension, the level of blockage in the candle meshes, the temperature, the pressure, etc. Because the individual parameters are not measurable and their influence on the duration of individual steps is not specified, the duration of 8 steps is defined by a minimum and maximum anticipated time (Table 1).

Table 1 Duration of batch operations in first and secondary washing

Filter	Primary washing								Secondary washing						Air con-sumption	Pdos	Pspray	Pwash
	22.02A		22.02B		22.02C		22.02D		24.02A		24.02B		24.02C					
Step	min	max	min	max	min	max	min	max	min	max	min	max	min	max	in Nm3/h			
1. charging with suspension	5,3	11,2	5,3	11,2	5,3	11,2	5,3	11,2	5,3	11,2	0,2	11,2	0,2	1,0	0,0	X		
2. formation of solid cake	15,0	17,0	15,0	17,0	15,0	17,0	15,0	17,0	3,0	4,5	3,0	4,5	3,0	4,5	0,0			
3.a discharge of suspension a	3,0	6,0	3,0	6,0	3,0	6,0	3,0	6,0	3,0	6,0	3,0	6,0	3,0	6,0	754,6			
3.b discharge of suspension b	1,3	2,3	1,3	2,3	1,3	2,3	1,3	2,3	1,3	1,3	1,3	1,3	1,3	1,3	150,2			
4. cleaning of filter	1,0	1,8	1,0	1,8	1,0	1,8	1,0	1,8	1,0	1,8	1,0	1,8	1,0	1,8	150,2		X	
5. filling filter with water	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	0,0			X
6. washing of cakes in reverse direction	25,0	35,0	25,0	35,0	25,0	35,0	25,0	35,0	15,0	20,0	15,0	20,0	15,0	20,0	0,0			X
7. discharge of water	5,0	6,0	5,0	6,0	5,0	6,0	5,0	6,0	5,0	6,0	5,0	6,0	5,0	6,0	606,5			
8.a drying of cakes a	1,5	2,0	1,5	2,0	1,5	2,0	1,5	2,0	1,5	2,0	1,5	2,0	1,5	2,0	4242,0			
8.b drying of cakes b	1,8	3,5	1,8	3,5	1,8	3,5	1,8	3,5	1,8	3,5	1,8	3,5	1,8	3,5	0,0			
9. discharge	2,5	2,8	2,5	2,8	2,5	2,8	2,5	2,8	2,5	2,8	2,5	2,8	2,5	2,8	895,0		X	

The problems envisaged in the gel washing process are as follows:

- Once a batch is started, it must be completed without interruptions. If interruption happens, flaking of the cake or another problem can occur, and the batch will need to be suspended, and the filter opened and cleaned, which could take several days.
- The compressed air, which is needed in 5 steps, is common to all the filters and represents a constraint, as it not powerful enough for the filters to be able to operate independently of one another (simultaneously). The critical step (most demanding in quantity) is drying, when the aim is to drive out the water using excess pressure. At this point simultaneous drying in more than two filters must be avoided. The required quantity of compressed air by individual steps is presented in Table 2.
- The discharge vessels in the primary washing represent the next bottleneck, as their capacity is only sufficient for the emptying of one filter at any one time.
- Individual pumps are also likely to represent resource constraints.

With regard to allocation of the batches, the client's basic requirements are safe and efficient production despite certain imprecision in the duration of individual steps in the batches, and even production. Coordination of the batches should proceed automatically.

3. BATCH SCHEDULING PROBLEM FORMULATION (DEFINITION)

For the needs of coordinating the initiation of batches, the process machinery can be divided into basic resources (hereinafter referred to as resources), and common or shared resources (hereinafter referred to as constraints). Resources are those items of machinery in which batches are carried out, i.e. all the filters and discharge vessels. The other components needed for carrying out batches can be assigned to different batches, and represent constraints (Table 2).

Table 2 Resources and constraints

Washing	Line	Resources	Constraints	Notes
primary	A	filter 1.2A, filter 1.2B, discharge vessel 1.3A	compressed air dosing pump P1.1A spraying pump P1.5A	
	B	filter 1.2C, filter 1.2D, discharge vessel 1.3B	compressed air dosing pump P22.51 spraying pump P22.59	
secondary	A	filter 2.2A, discharge vessel 1.3B	compressed air	
		filter 2.2C [1] discharge vessel 1.3B	dosing pump P24.50 washing pump P24.52 spraying pump P24.54	additional, if 2.2C is linked to Line A
	B	filter 2.2B, discharge vessel 1.3B	compressed air	
		filter 2.2C [1] discharge vessel 1.3B	dosing pump P24.51 washing pump P24.53 spraying pump P24.55	additional, if 2.2C is linked to Line B

The list of batches to be scheduled and the list of resources to which each can be assigned is given in Table 3.

Table 3 Products and corresponding resources to which each product can be assigned

Batch	Permitted resources	Notes
primary washing in Line A	filters 1.2A or 1.2B and discharge vessel 1.3A or	
	filters 1.2C or 1.2D and discharge vessel 1.3B	if lines in primary washing are not separated
primary washing in Line B	filters 1.2C or 1.2D and discharge vessel 1.3B or	
	filters 1.2A or 1.2B and discharge vessel 1.3A	if lines in primary washing are not separated
secondary washing in Line A	filter 2.2A and discharge vessel 2.3A	
	filter 2.2C and discharge vessel 2.3C	if 2.2C is assigned to Line A in secondary washing
secondary washing in Line B	filter 2.2B and discharge vessel 2.3B	
	filter 2.2C and discharge vessel 2.3C	if 2.2C is assigned to Line B in secondary washing
cleaning of filter mesh	all filters	

[1] Filter 24.02C can be assigned to Line A or Line B in the secondary washing.

All the constraints are tied to steps. The list of steps involving individual constraints is given in Table 1. The level of demand on the compressed air is given in Table 1, too, and the level of demand on the other resources is unitary.

4. RULE BASED ALGORITHM

First of all we have tried to use some computer supported scheduling tools, like Preactor, Taylor, but none of them solve this problem satisfying. So we developed the following rule based algorithm for batch scheduling, presented in Figure 2.

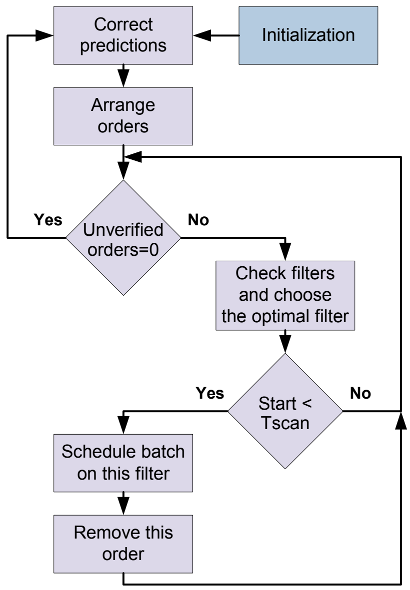

Fig. 2. Rule based algorithm for batch scheduling

Initialization step: Define the scheduling parameters (sampling time, scan period, horizon) and process parameters (quantity of compressed air, allocation of filter 2.2C, separation of lines on the primary washing). Then define the basic contours of occupying the resources and constraints. Let's look, how to define the basic contour for the washing pump, which is needed in steps 5 and 6 (Figure 3).

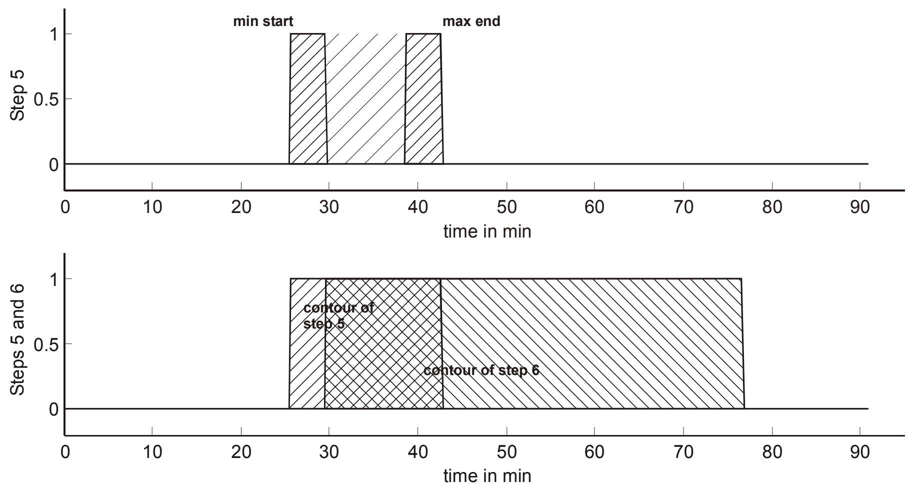

Fig. 3. The basic contour of occupying the washing pump in steps 5 and 6

For each step, it is necessary we have to find out its earliest start – that is, when all previous steps have the minimum times, and its latest end – that is, when all previous and this step have the maximum times (Figure 3 above). That is repeated for all steps, which need the washing pump. So the basic contour is obtain, inside which usage of washing pump can be expected (Figure 3 bellow). In the same way, the contours for all resources and constraints needed for one batch are defined.

The following steps are executed in each scan.

Step 1: First capture current state and correct the common contours of running batches. During batch running, when some steps are completed (remarked with vertical lines on Figure 4), the remaining contours are corrected and new predictions are made so that the contours contract.

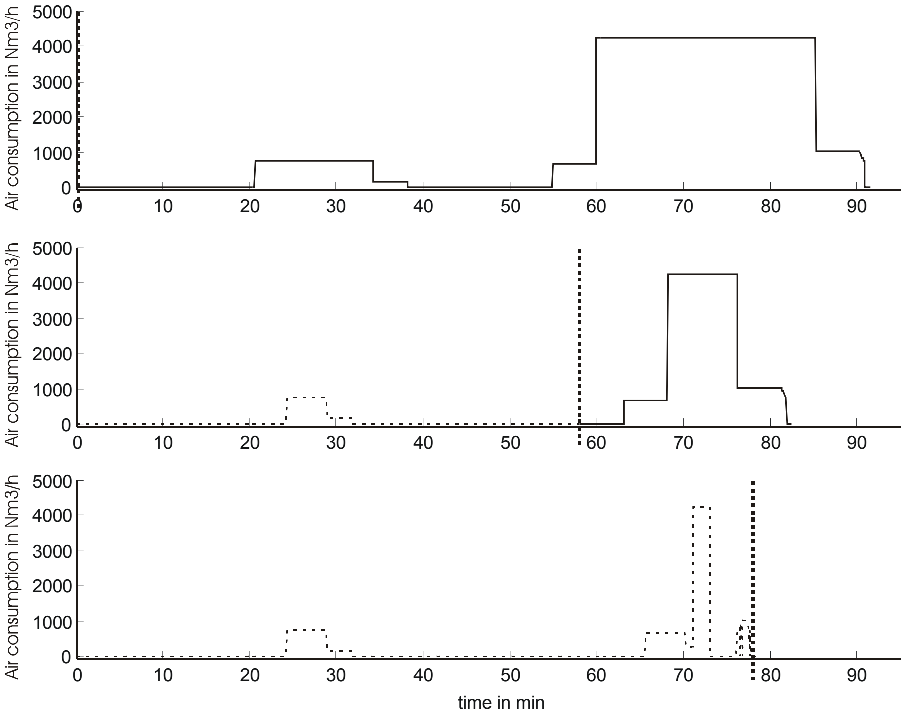

Fig. 4. Contracting of the contour of compressed air consumption of running batch – above: the contour before start of batch (basic contour); in the middle: contour after 58 min; bellow: the contour after the end of batch

Step 2: Because the same orders cannot be scheduled in the same scan, arrange the orders so that only different topic orders are obtained (Figure 5).

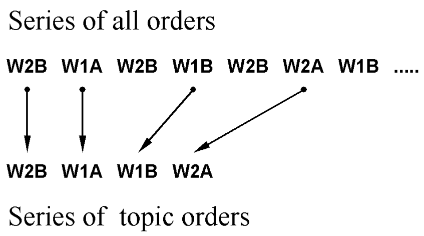

Fig. 5. The orders, which could be scheduled in the same scan

Step 3: Each topic order schedule experimentally on all allowed filter and find an optimal filter for each order.

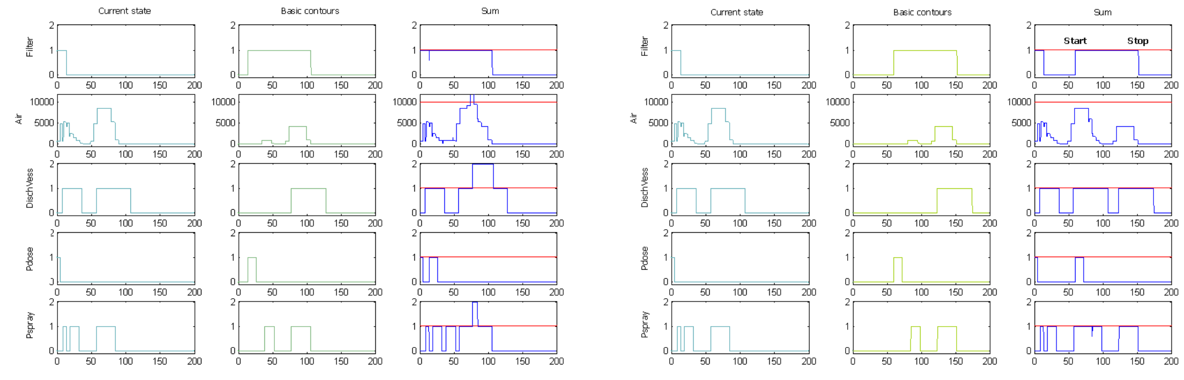

Fig. 6. Test scheduling – left: the initial putting of basic contours; right: the finish putting

Place the basic contours so that the contour of current state of filter and the basic contour of filter are together (Figure 6 left). In that case there are some violations. Then move the basic contours as long, as there aren't no violations. This way, the start and end time for that batch on that filter can be found (Figure 6 right). From all filters, the one, which would complete the batch first, is chosen. When all topic orders are verified, go to Step 1 and wait the next scan.

Step 4: If that batch can start in time before next scan, schedule batch on the selected filter and remove the order for that batch from series of all orders. In the case the batch cannot start before next scan don't do anything, because it will be scheduled again in the next scan. Then go to Step 1, and wait new scan.

5. SIMULATIONS RESULTS

Because the technological line for two-stage gel washing is not finished yet, the presented algorithm for batch scheduling is verified just with simulation in Matlab environment. The following is taken into consideration: there are 50 orders for primary washing, lines are not separate and all filters have the same anticipated times. The simulations results of the primary washing are collected in Table 4. All others results are in Hauptman (2002).

Table 4 Simulations results of the primary washing

	Tolerances	Constraints	Duration of batches	Scan time in min	Occupations of filters in%	Final time in min	Comment
1	no	yes	min	2	100	834	no tolerances
2	yes	yes	half	2	67,0	1455	Pspray is bottleneck
3	yes	partial	half	2	89,3	1137	if Pspray is not constraint
4	half	yes	half	2	89,4	1117	Pspray and DischVessel are bottlenecks
5	yes	partial	half	2	67,0	1455	if Air is not constraint, max(Air) = 8484

If the durations of steps would be without tolerances, the occupations of filters are 100% (1st column in Table 4). Because there are tolerances, the real occupations of filters are just 67% and the spraying pumps represent the bottleneck (2nd column). By doubling the spraying pumps so that they wouldn't represent the bottleneck any more, the occupations of filters would increase on almost 90% (3rd column). Similar occupation would be obtained by halving the tolerances in Table 1 (4th column). It can be seen that the compressed air doesn't represent the constraint in the case of working just four filters and at given conditions (5th column).

6. CONCLUSIONS

Because of the excessive complexity of coordinating the batches in individual filters, it is necessary to introduce a computer-supported process control system. Its purpose is to increase the reliability of operations and to make maximum exploitation of line capacity. The basic function of the computer-supported control system will be coordination of the initiation of batches in individual filters with regard to air consumption and the use of the discharge vessels and pumps.

In this paper, an efficient and simple algorithm for batch production scheduling has been presented, that is capable to predict the exact starting time for a single new batch, so that:

- *no-wait* constraints imposed by the nature of the subprocess should be taken into account,
- *blocking* of any of batch operations should not occur,
- the material flow of the subprocess has to be uniform and,
- is suitable for the implementation into real production environment.

It has been shown that, the capacity of technological line can be increased in two ways:

- by doubling resources, which are bottlenecks (e.g. spraying pumps) or
- by decreasing of uncertainty of steps, which are given by minimum and maximum anticipated times.

In the near future, we will try to improve our algorithm by considering some other factors encountered in the plant and incorporating them into the integrated computer production system.

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