Push Pull Mixed Type of Optimal Compound Production Planning Method

By The Object Oriented Optimization Technology

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Abstract

This paper deals with a production system that produces make-to-order items, make-to-stock items, and the others indispensable for their production all together to feed

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to common processes without discrimination. We present a two phase production planning method that optimizes (in precise, near optimizes) both to make on request and to make deliberately to fluctuation such as seasonal variation and the peak demand at product changeover.

This method is based on the object oriented optimization technology (by our terminology), which has the potential of application to a wide variety of time optimization problems, and yet able to optimize all of the heterogeneous decision features involved in a single problem with high resolution simultaneously.

1. Introduction

1.1 The objective

As diversification of customer demands and products and reduction of product life cycle have been accelerated, it has become much more difficult to discriminate make-to-order items from make-to-stock ones. Therefore, the concern in production has gathered to the method of making a plan for processing make-to-order items and make-to-stock items and the others indispensable to produce them all together to feed to common production processes without discrimination.

Then, in this paper, we present a two phase production planning method that enables us to make an optimal compound production of make-to-order items, make-to-stock items, and the others such as common devices or components and yet applicable to various
companies.

1.2 Definition of compound production way

We will define the production way (or production system) that we deal with in this paper. The compound production is the way in which we produce multiple items involving two types of make-to-order items and make-to-stock items by sharing the same processes.

In the compound production, in the demand of at least make-to-stock items there exists fluctuation such as seasonal variation, trend, and the fluctuation accompanied with changeover from an old product to a new one.

As for product configuration, there exist an item or items that are processed at the preceding process and are build into both of make-to-order items and make-to-stock items in common, e.g. common devices and semi-products before painting, and yet in the demand of at least one of those items there exists fluctuation such as seasonal variation.

1.3. Background of the presentation and review

The presented method is based on the use of the object oriented optimization technology (the O2O-technology) we advocate. Here, briefly we present the background of our presentation. It has been verified in Aditya and Muramatsu [1], Muramatsu, Aditiya, and Kobayashi [2], Muramatsu and Aditya [3] that the O2O-technology has the potential of applications to a wide variety of production problems and to global optimization of the various heterogeneous decision features. We pay attention to these papers.
In fact, in scheduling problem there exist various heterogeneous decision features. Concretely, these are to decide of what we should make, and how much, on which machine, at what time, and so on. As well known, in the conventional approaches, those are classified into sequencing, lot sizing, dispatching, loading, and so on.

As it is difficult to solve all of those heterogeneous decision features simultaneously, traditionally just only one of those specific features has been solved at a time. However, the situation of scheduling has changed with the appearance of the O2O-technology. As for its practical application, its commercial application software package has been on the way of developing under the name of GLOPS (Global Optimization Production Scheduler).

Certainly, there are some open subjects about and some drawback this methodology. Mainly these are the one related to CPU time up to convergence. As to this, we discuss it in section 4. However, we think fundamentally that the O2O-technology has high potential of application to a wide variety of time optimization control problems involving production planning as well as scheduling. The presentation of this paper is based on this series of new movements.

The method that deals with optimization of production planning for the compound production system defined in section 1.2. has not been known so far except the one of this paper.

1.4 Contents
In section 2, presents the definition of the push pull mixed type of optimal compound production planning method and its characteristics. In section 3, we illustrate the solution procedure together with a numerical example. In section 4, we discuss advantages and disadvantages of method. In section 5, we conclude.

2. Push pull mixed type of optimal compound production planning method

2.1 Definition

This is a two phase planning method and, in the phase one planning (we call production planning from now on), for a long planning horizon set in advance, we make an optimal plan of production and inventory by using the algorithm of the O2O-technology.

The aim of production planning is to make the optimal production and inventory plan over the long planning horizon and then to determine the goal of work-in-process inventory level at the terminal time point of a developing phase two plan for each item or for each process. For this aim, the transition data of work-in-process inventory of each item in production plan at the time point corresponding to the terminal of the phase two plan is given to the phase two plan. cf. B in Figure 1.

In the phase two plan (we call scheduling from now on), by use of the O2O-technology we make a schedule for all items involved in the system.

The aim is to make the optimal schedule to meet not only given shipment requirements of each product over the scheduling horizon but also the goal terminal work-in-process
inventory level given by the production planning. cf. B in Figure 1.

Therefore, this two phase production planning method connotes a mechanism that mingles the push way and pull way for compound production consisting of make-to-stock items and make-to-order items and the others, where, “push” and “pull” is used in the sense to “make deliberately” and to “make on request” ,respectively. cf. Figure 2.

Figure 1 Two phase production planning method

<table>
<thead>
<tr>
<th>Push type</th>
<th>Pull type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Key device production process</td>
<td>Make-to-order item assembly process</td>
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</table>

<table>
<thead>
<tr>
<th>Pull type</th>
<th>Push type</th>
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<tbody>
<tr>
<td>Open market part procurement process</td>
<td>Make-to-stock item assembly process</td>
</tr>
</tbody>
</table>

Figure 2 An example of Push-Pull mixed type of compound production method
2.2 Characteristics of the presented method

In this section, we sum up the main characteristics of the presented method.

1. In planning, we use the algorithm of the O2O-technology not only for scheduling but also for production planning.

   By use of this algorithm, first of all, it is able to raise resolution of production planning itself to the extent of the level of scheduling. Second, it is able to reduce lead time of product and work-in-process inventory. Third, it is able to hold computation time for the production planning within a reasonable one even though it raises resolution.

2. As a result, the presented method enables optimization as well as feasibility test by simulation on production and inventory. This is a big advantage of the presented method. As this issue, we will discuss it in section 4.

3. The presented method enables us to smooth production to seasonal variation, i.e. to keep stacking work-in-process items and/or final products up to reasonable levels toward the peak.

4. It presents the production management way much more optimal and yet robust as the inventory level of each item at the terminal of the scheduling is optimized by production planning with the longer horizon than that of scheduling.

5. It presents the production management way much nearer the global optimization as the initial inventory of each item to be the initial condition of production planning is
optimized by scheduling.

We will give a supplementary explanation in turn. As mentioned above, in scheduling, the O2O-technology enabled to near optimize all of the decision features required for indicating real processing. By use of the same methodology, in production planning of the long horizon also, it is able to near optimize those decision features simultaneously almost in the same manner as in a real production.

Difference in the latter is at most that forecasting demand data of item is used in place of actual shipment requirement as the input data and the number of time slots becomes lager than that of scheduling. This is the meaning of raising resolution of the production planning.

Next, we clarify the difference between the conventional production planning and the presented one for the aid of understanding those characteristics.

In the conventional one, usually in advance fixed standard lead time and lot size have been registered with fixed time bucket as the unit of time. Therefore, a plan is made on the basis of these registered fixed standard lead time and time bucket.

And yet the fixed standard lead time has been put to a longer value than the minimum of actual one for fear that production based on the plan will become infeasible.

Therefore, it results in that the accumulative lead time of any product has been set to the value longer than the actual one that we could attain on the circumstances, and hence
already the environment of making a plan itself has been far from the ideal in the sense that it is against reduction of lead time and work-in-process inventory.

Moreover, although the very naming is production planning, actually it does not succeed in reflecting each processing through processes and its related actual work-in-process inventory on planning, but at best it results in that loading or smoothing of work load is made.

On the contrary, in the presented method, almost all things are decided from the viewpoint of global optimization. Namely, in the planning there is no concept of the base unit of time bucket.

Moreover, there exist neither fixed standard lead time nor the concept of standard lot size. Both of lead time and lot size are determined in the optimal manner when the problem is solved. In these senses, the algorithm of the O2O-technology needs neither registration nor artificial constraints put in advance. Furthermore, these depend on the production situation of that time, i.e. input data of that time, and yet these are always time variant, i.e. vary as time goes reflecting the production situation.

3. Solution procedure

We will illustrate the solution procedure by use of a numerical example, the product structure and process flow of which is shown in Figure 3.

- Number of items: 23 items
• Number of machines: 12 machines

• Number with circle denotes item number and 0 means a market out of the system in question.

• Item numbers 16, 17, and 18 are final make-to-order products. (In the case of accepting express orders that will arrive after the planning time point, it is obligatory to save the time required for processing them in developing plan in advance. For this aim, it is allowed to put an aggregated fictitious item together with standardized product structure in the family of make-to-order items.)

• Item number 22, 23 are final make-to-stock products.

![Figure 3 Product structure and process flow](image-url)
3.1 Determination of system parameters

The system parameters to be determined in advance are:

For each of production planning and scheduling,

1. Time slot

2. Planning horizon (1) in Figure 1 and (2) in Figure 1

3. Lead-time (3) in Figure 1 and (4) in Figure 1

4. Cycle times (5) in Figure 1 and (6) in Figure 1

3.2 Input data for production planning and scheduling and monthly demand forecast

Note that monthly demand forecast is not direct input to production planning. This is converted into demand per time slot by item in section 3.3.

• Requirement of item i per one unit of item j in Table 1

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Processing quantity of item $i$ by machine $k$ per time slot, set up time (the number of time slots), and set up cost per once in Table 2.

Usually, these are given as production engineering data.

Table 2 Processing quantity of item by $i$ by $k$ per time slot $p_i^k$, setup time $s_{i,max}^k$, setup cost $c_i^k$

<table>
<thead>
<tr>
<th>Item $i$</th>
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Monthly average demand forecast of product in Table 3.

Data generation method can be anything.

Table 3 Monthly average demand forecast of product

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<th>Item</th>
<th>Monthly average demand forecast</th>
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• **Seasonal index in Table 4**

Data generation method can be anything.

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<tbody>
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</table>

• **Generating monthly demand forecast by product**

Multiply monthly average demand forecast in Table 3 by seasonal index by product. Then, put its results to the demand forecast per month of product (7) in Table 5. In the example in Table 4, index value is assumed to be identical for all items. But, for months close to the initial of the plan, firm shipment requirement data per month (11) in Table 7 and the above forecast data are blended. The concrete method can be anything.

• **Determining the initial stock level in production planning (8) in Table 5**

From the transition data of the item base stock level in the latest scheduling, pick up the stock level data of the time corresponding to the initial time point of the production planning, and let it be the initial stock level data of the developing production planning. cf. A in Figure 1.

• **Determining the goal terminal stock level in production planning**

As for make to stock items (22, 23), determine it on a basis of the overall decision. The method can be anything. cf. (12) in Table 5. As for make to order items (16, 17, 18), set the value to 0 for all (12) in Table 5.
Table 5 Initial stock, monthly demand forecast and goal terminal stock in production

<table>
<thead>
<tr>
<th>Item</th>
<th>Initial inventory</th>
<th>Month</th>
<th>Goal terminal stock</th>
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</table>

- Holding cost of item per time slot in Table 6

The determination method can be anything. Sometimes, policy in management is reflected on this value.

Table 6 Item stock holding cost per time slot

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<th>Item</th>
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</table>
Shipment requirement data of make-to-order item

Put shipment requirement data of items into (11) in Table 7. On the circumstances, the same treatment is allowed for make-to-stock items also. This is used in blending with forecast data and built into demand data.

As for determination of the initial stock level (9) in Table 7 the terminal stock level (10) in Table 7 in scheduling, we state it in section 3.6.

**Table 7** Initial inventory, shipment requirement data, and goal terminal stock in scheduling
3.3 Preprocessing for production planning

- Convert monthly item demand data in (7) of Table 5 into the one per time slot

Blend the item demand per timeslot and shipment requirement (11) in Table 7.

Explode them by use of bill of material data in Table 1 into the requirement data of the lower level items. We get demand per time slot by item in Table 8.

**Table 8 Demand data by item per time slot**

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</table>
3.4 Optimizing production planning

- Optimize production planning (phase one planning) by use of the algorithm of the O2O-technology and generate the optimal production plan, where the input data are bill of material data in Table 1, processing quantity of each item per timeslot, setup time, and setup cost data in Table 2 and demand data of each item per time slot in Table 8.

But actually, it is allowed also to stop the processing on the way at the stage when the number of constraint violations of machine interference and work-in-process shortage decreased down to almost zero. cf. Figure 4.

As to the algorithm, refer to [4], [5], and [6]. We do no duplicate it. In [4] the rule of updating Lagrange multiplier value is improved.

Figure 4 Transition of amount of constraint violations
3.5 Output of production planning

- Stock transition by item or by family over the planning horizon in Figure 5

  This becomes the terminal stock in several times of scheduling, cf. (13) in Figure 5

- Gantt chart by item or family over the planning horizon in Figure 5
This becomes the terminal stock in scheduling (13).

Figure 5 Inventory transition and Gantt chart of production planning
3.6 Preparing input data for scheduling

- The initial stock by item

From the latest schedule, receive the stock level at the time point corresponding to the initial time point of a developing schedule and put it to the initial stock (9) in Table 7. cf. C in Figure 1 also.

- The goal terminal stock level by item

From the latest production plan, take the stock level at the time slot corresponding to the terminal of the developing schedule and put it to the terminal stock of the schedule (10) in Table 7. cf. B in Figure 1 also.

- Input data of make-to-stock item

From the transition data of the item base stock level of the latest production planning, pick up the stock level data of the time slot corresponding to the terminal point of the developing schedule and put it to the terminal point of the developing scheduling. cf. B in Figure 1 also.

- Input data of make-to-order item

Let shipment requirements data in (11) in Table 7 be input data of make-to-order item.

3.7 Preprocessing for scheduling

- Firm requirement data per time slot by item

Explode the firm shipment requirement data (11) in Table 7 and the goal terminal stock
data by use of bill of material data in Table 1. We get the firm requirement data in Table 9.

### Table 9 Firm requirement data per time slot by item

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### 3.8 Scheduling

Solve the scheduling problem by use of the O2O-technology with requirement of item $i$ per one unit of item $j$ in Table 1, processing quantity of item $i$ by machine $k$ per time slot, set up time (the number of time slot) and set up cost per once in Table 2, and requirement data per time slot by item in Table 9.

### 3.9 The output of scheduling

- Stock transition by item over the planning horizon.

This becomes the initial stock in the developing scheduling. cf. (14) in Figure 6.

Moreover, it also becomes the initial stock in the developing production planning (8) in
Table 8. cf. A in Figure 1.

- Gantt chart item over the planning horizon.

\begin{tabular}{|c|c|}
\hline
ITEM & Quantity \\
\hline
1 & 250 \\
2 & 250 \\
3 & 250 \\
4 & 150 \\
5 & 150 \\
6 & 250 \\
7 & 150 \\
8 & 150 \\
9 & 100 \\
10 & 50 \\
11 & 50 \\
12 & 50 \\
13 & 50 \\
14 & 50 \\
15 & 50 \\
16 & 30 \\
17 & 30 \\
18 & 30 \\
19 & 30 \\
20 & 30 \\
21 & 30 \\
22 & 30 \\
23 & 30 \\
\hline
\end{tabular}

Figure 6 Inventory transition and Gantt chart of scheduling
3.10 Rolling of production planning and scheduling

According to each cycle time set in advance, respectively repeat production planning and scheduling.

4. Discussion

In this section we will discuss advantage and disadvantage of the presented method.

Verification of the presentation

First of all we refer to verification of the presentation. Figure 4 shows the process of approaching to a feasible solution under the criterion that it optimizes all of the heterogeneous decision features in the production (and inventory) planning over a long horizon globally. Horizontal axis denotes iteration, and sequential decrease of machine interferences and work-in-process shortage at vertical axis would imply verification of the method.

Dynamic diagnosis of bottleneck

Next, we mention dynamic diagnosis function of bottleneck processes that the presented method has. This method is essentially a dual method. Accordingly, as well known in the field of optimization, Lagrange multiplier value to each constraint reflects the value of corresponding constraint or of the resource related to it.

In this problem, as one of constraints, the constraint to forbid machine interference is put by machine by time slot. Figure 7 shows the Lagrange multiplier value of machine 3 and
12 per time slot as an instance. This is obtained together with the solution of the primal problem. The graph shows when and which machine is at the state of bottleneck.

![Graph showing bottleneck per time slot by machine in production planning (an instance)](image)

**Figure 7** Bottleneck per time slot by machine in production planning (an instance)

Bottleneck changes in accordance with input data. On the circumstances, we can coordinate input data or capacity of process. Accordingly, we could use this function for the aim of dynamic diagnosis of bottleneck and its correspondence.

Finally, we present the disadvantage or drawback. Needless to say, it is the issue of CPU time. We mention the CPU time per one time of production planning. It is expressed as follows:

\[ Cbm \times ((\text{CPU time of sub-optimization per item} \times N_i) + \text{time required to check constraint violations and to update the rule of Lagrange multiplier}) \]
where notation is

\[ C_{bm} \]: Estimate of the number of iterations up to convergence to a near optimal solution or the number of iterations up to computational break

\[ N_I \]: The number of items

For page limit, we cannot explain all of the details. Compared with the computation time of the primal problem, the time of dual problem is negligibly small and hence we disregard it here. We discuss the present state and perspective of the following two subjects in the above expression.

**Estimate of the number of iterations up to convergence** \[ C_{bm} \] :

This number is specified by the rule of updating Lagrange multiplier and there is a big room of improvement. We have been engaged in developing a new method of updating it and have the perspective of being able to reduce it to 1/10 to 1/50. cf. [4] also.

**CPU time of sub-optimization per item:**

This CPU time is fundamentally proportionate to the number of time slots. This property is not disadvantage. However, other than this, there exists a big drawback in the point that it is also proportionate to the square of the number of states upon the digitalized state space.

State is specified by (echelon) inventory state and remaining set up time. cf.[1]. The same width of time slot is used in splitting the planning horizon and in splitting inventory state and remaining set up time in common. Accordingly, splitting state space by small time
slot leads to explosion of CPU time and memory. A means that has been known so far to
dissolve it is unfortunately to expand computer memory. If it were hopeless, we would be
obliged to demand practical compromise at a cost of reducing precision. That is, it is to
chop the time horizon by a not so small value. Even if we allow this practical compromise,
we think that it will bear the objective of the paper.

5. Conclusions

This paper dealt with a production system that produces make-to-order items,
make-to-stock items, and the others indispensable for their production all together to feed
to common processes without discrimination. We presented a two phase production
planning method that optimizes (in precise, near optimizes) both to make on request and to
make deliberately to fluctuation such as seasonal variation and the peak demand at product
changeover.

We clarified its characteristics and solution procedure. Furthermore, we discussed its
advantages as well as disadvantages.

References

Scheduling with Setup Time: Lagrangean Decomposition Coordination Methods,"
pp.385-396


