Production Planning for Products with Complex Product Structure

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Abstract

The major difficulties when dealing with complex products are long lead times that require long planning horizons and also that there are dependent demands and multiplicative effects on the ingoing items in the products. Small disturbances on high level can in the end give considerable problems on low level.

This paper shows an example of the difficulties with handling complex products with long lead times and suggests a four step decision model to get smoother production planning, mainly by simplifying the product structure. The decision model includes the following steps:

1. The first step is to re-design the product in order to simplify it.
2. Next step is to identify the critical path and the cumulative lead-time by sketching a dynamic bill of material.
3. After the dynamic bill of material is sketched, the possibilities to shorten some lead times on the critical path should be analysed. Outsourcing of parts of the production or creating a ”plant within a plant” configuration can reduce lead times. Reduced batch-sizes on specific items along the critical path can also be a way to do this.
4. When all possible lead times are reduced it is time to decide which planning method to use.

Keywords: Production planning, Product structures, Lead-time reduction, Dynamic Bill of Material, D-BoM

Introduction

When dealing with complex products containing many ingoing parts it is sometimes hard to get a smooth and efficient working system. Under such circumstances, it is necessary to use some kind of method to plan the production. Which method to use is dependent on the structure of the product. Complex products with many ingoing parts are more difficult to control and must therefore be planned in another way than simpler products.

A prerequisite for successful planning is a correct product structure. Items missing result in incorrect product pricing, poor product quality, excess inventory, and missed deliveries (Wacker 2000). A careful specification of the product structure means on the other hand that right components are in the manufacturing process when needed (Wacker 2000).
The product structure is normally shown in bills of materials (BoM), which define the relationships of assemblies and their components (Orlicky 1975). The BoM is used for all long-term planning as well as short-term operations scheduling and is therefore a fundamental building block (Wacker 2000). The number of levels in BoM, or the product depth, determines the sequence of steps in which a product is made from raw material to end item (Orlicky 1975). Many companies deal with products that have several numbers of levels in their BoM structures and ingoing parts with long lead times. According to (Ho 1997) most of the BoM in real-world manufacturing firms involve more than five levels in depth.

One example is Ericsson Radio Systems AB, effective in the telecommunications industry. Many of its products have complex structures and contain components with long lead-times, half a year in worst case. Because of the fast changing telecommunications industry, 50-70 per cent of the ingoing parts of a product can be changed in a year, which means that the bills of materials change continually and makes the risk for inaccurate planning relatively high. Besides that, the parts on the lowest level in the BoM, the electronic components, are the most vulnerable ones. Missing, excess, and obsolete material is of this reason usual and causes high costs (Brander & Erickson 2001).

The aim of this paper is to present a decision model for the handling and production planning of complex products with long lead-times. To illustrate the difficulties with complex products and long lead-times an analysis of the product structure and the production situation for a fictive product is given in the next section.

**Problem analysis**

The fictive product is a switchboard (called end item A), shown in figure 1.

![Figure 1: Switchboard](image)
The structure of the product is shown in figure 2.

The switchboard is newly constructed and the first deliveries are planned 10 periods from now. There is a forecasted demand for these switchboards in form of a production plan for period 11 to 15, shown in table 1:

<table>
<thead>
<tr>
<th>Period</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>10</td>
<td>12</td>
<td>14</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 1: Production plan for switchboards period 11 to 15

The lead-times in figure 2 are estimated from experiences in earlier production of similar products since the switchboard is not yet produced. The critical path through the product structure and the cumulative lead-time (Orlicky 1975) can also be identified. The critical path is A-B-D-G and the cumulative lead-time is 10 periods, \( LT(AB+BD+DG) = 3+3+4 = 10 \).

The shortest possible delivery time for the switchboard is the same time as the longest cumulative lead-time, in this case 10 periods. This means that it is not possible to deliver the product earlier than in 10 periods, unless some lead times could be shortened. Furthermore, it also means that the shortest planning horizon is 10 periods and a forecast for this product must be given at least 10 periods before delivery.

The demand for end item (A) creates dependent demands (Peterson & Silver 1985) for underlying items. Figure 3 shows more specifically how the demand from the production plan propagates along the ingoing items on the critical path in the switchboard. The arrow shows actual time period.

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1 Production plan = A forecasted demand plan
Figure 3 shows that the demand for item (G) propagates from the end item (A) in the production plan. The arrows pointing at left shows how a demand for 10 units (A) in period 11 creates a demand for 640 units of item (G) in period 1. The demand for underlying items is thus time phased, which complicates the production planning.

There is also a multiplicative effect on item (G), which is a result of the number of ingoing parts in the structure (see figure 2). 2*B, 8*D and 64*G are needed for one A and due to the lead times the demands appear in different periods, as shown in diagram 1.

Diagram 1: Multiplicative effect from dependent demand in the product structure

The planning of the production for this switchboard is not easy. Because of the lead times it is necessary to act in time, but it is difficult to plan for such a long time in advance even if everything occurs according to the plan. Furthermore, the multiplicative effect makes the consequences of inaccurate planning more serious. Some small disturbances can in the end give considerable problems, a little disturbance in the demand for item (A) can for example create a magnified disturbance in the demand for item (G).
In reality, nothing goes as planned. Suppose for example that the situation changes in the beginning of period 2. The lead-time for item (B) is underestimated and must be prolonged to 4 periods instead of 3, depending on disturbances in the production. This occurrence leads to a situation with a longer planning horizon as shown in figure 4.

The circle for the order in period 1, in figure 4, shows that this order is open\(^2\) and under execution. 640 units were ordered in period 1. According to figure 4, 768 units more should already have been ordered. This means that there is a backlog on 768 units of item (G) due to the prolonged lead-time. According to figure 4, 896 units now should be ordered. To get everything right the order must be 768+896 = 1664 units in period 2. This gives the following situation in period 3:

\(^2\) Open orders = Orders that have been placed but not yet received
Figure 5: Dependent demand for underlying articles from end item (A) in period 3

In period 3 orders can be placed according to the production schedule. If the production schedule is compared with the production plan, it is obvious that a, from the beginning, quite regular demand now is very irregular. This irregularity is, as shown in table 2, spread and aggravated to item (G), due to the dependent demand and the multiplicative effect.

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned orders in period 1 (from figure 3)</td>
<td>640</td>
<td>768</td>
<td>896</td>
<td>640</td>
<td>512</td>
</tr>
<tr>
<td>Planned and open orders in period 3 (from figure 5)</td>
<td>640 (Open order)</td>
<td>1664 (Open order)</td>
<td>640</td>
<td>512</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2: Comparison between planned and open orders for item (G).

As this example shows it is rather difficult to reschedule one item if some disturbance occurs and this kind of disturbances cascade to all items in the product with the biggest effects on the deepest levels in the product structure, level 3 in this case (figure 2).

To simplify the planning situation and reduce the effects of disturbances the number of levels in the product structure should be diminished and lead-times should be cut. A decision model that performs such changes is presented in next section.

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3 Production schedule = An established production plan
**Decision model for production planning**

What can actually be done to minimize the difficulties with complex products and long lead-times? A structured way of analyzing the product structure is illustrated in figure 6.

- **Step 1**
  First thing to do is to analyze the design of the product. Is there any way to simplify the product? Is it possible to re-design some ingoing parts in such a way that a number of items disappears? Fewer ingoing parts in the product lead to a simpler product structure and less levels, which leads to easier production planning.

- **Step 2**
  Second step is to sketch what here will be named a Dynamic BoM, D-BoM, in order to find the critical path through the product structure. This critical path gives us the cumulative lead-time that determines the earliest time that the product can be built. The only way to shorten the total lead-time is hence to attack the critical path. For example would the D-BoM for the switchboard look like figure 7.

![Decision model](image)
In this figure the total cumulative lead-time (10 periods) can be identified immediately. The lead-times between ingoing parts can also easily be read between the middle of two circles. The lead-time for item (C) is for example 10-9 = 1 period (arrow AC). The critical path is easy to find, start with the item having the longest cumulative lead-time and find the way to the end item, in figure 7 marked with bold lines.

**Step 3**

When the critical path is identified it is important to reduce its lead-times. A systematic investigation of the lead-times should therefore now be done. Lead-time reduction can be done in many ways, this paper suggests three different courses of action.

The first course of action is to analyze if it is possible to buy or outsource the production of some item and thus gain shorter lead-time. In some cases a subcontractor may be better suited to produce the item, and can therefore give better delivery precision and shorter lead-times.

Next course of action is to investigate the possibilities to separate the production of some item or sub-assemblies from the ordinary production, a so-called Plant-within-a-plant (PWP) configuration. “This involves physically dividing sites (even to the point of using partitions, different entrances and other facilities), thus providing a ‘separate’ plant within which manufacturing is focused to the needs of different parts of its total business. This reduces units to a more manageable task, attracting the advantages of both focus and smaller size.”(Hill 1985). As with outsourcing this can lead to a higher focus on the reduction of lead-times.

The last course of action is to examine if it is possible to reduce queue time. The lead-time consists often of queue-time and actions to reduce this must therefore take place.
One way is to reduce batch-sizes and it is a good idea to work with smaller batch-sizes on items along the critical path than on non-critical items. Non-critical items are items that not are in the critical path. A lead-time reduction on those items will not result in a shorter total lead-time and they are therefore of less interest than items on the critical path.

If a lead-time is cut, return to step 2 and sketch a new Dynamic BoM. Repeat this procedure until no lead-time, on the critical path, can be cut. Observe that the critical path may change along the process.

**Step 4**

When the first 3 steps in the decision model are executed it is time to decide how the production should be planned. This step is not further analyzed in this paper, but some possible choices may be Material Requirement Planning (MRP), Cover-Time Planning or Reorder Point Systems. For more information see Segerstedt (2000).

**Example of how the decision model can be used**

The switchboard from figure 1 is now used to exemplify how the decision model can be used. In step 1 the product design is examined with the purpose to simplify it. In this case no such abilities are found. Next step is to sketch the D-BoM and find the critical path. Because no changes are made in step 1, the D-BoM is the same as in figure 7.

In step 3 the lead-times on the critical path are in focus. The first question is if outsourcing can be an option? Further examination shows that a sub-contractor can produce boxes with boards. Negotiations with the sub-contractor result in a maximum lead-time of 3 periods. This probably means that the sub-contractor has to build stocks and the gain in total lead-time is in some ways won because someone else takes the extra stock. The situation may be hypothetic, but helps to illustrate the example. The new product structure is given in figure 8.

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![Figure 8: Product structure after outsourcing](image-url)
A new D-BoM (figure 9) is made.

![Diagram of D-BoM after outsourcing](image)

*Figure 9: D-BoM after outsourcing*

The product structure is now shallower because one level is eliminated. The cumulative lead-time is also shorter (7 periods) and the critical path has changed. In next loop, when item (E) is examined, it is found that its lead-time can be reduced 1 period by using smaller batch-size in the production. Earlier the lead-time was not critical, but now when the item is in the critical path, it is important to cut its lead-time if possible. This gives once again a new D-BoM (figure 10) and a new critical path where both D' and E are involved.

![Diagram of final D-BoM](image)

*Figure 10: Final D-BoM*

It is not possible to reduce any more lead-times at the moment.
Figure 11: Planning situation for the switchboard after the decision model

Figure 11 shows how the production now can start in period 5 instead of period 1, which was the earlier case. This means that there is either a safety interval in four periods that can take possible disturbances or the products can be delivered earlier.

The result of the model is a shorter planning horizon and in reality a much easier planning situation.

Conclusions

In this article a structured way of attacking problems derived from long lead-times and complex product structures is presented. The main idea is to focus on the product structure and the inevitable influence the product structure together with lead-times have on the planning process. The findings can seem very basic, but in our opinion it is necessary to point them out since many companies are not aware of the effects that the product structure and lead-time have on the production planning.
References


