The Capacity Requirements Planning Implications of the JIT Philosophy

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Abstract
Batch manufacturing occurs when basic products are produced in a modest variety of types and models. Demand volumes are not sufficient to justify dedicated plant and equipment as under mass production, and, at the same time, demand volumes are not so small as to warrant irregular job shop production. The assembly shop throughput time is short and therefore should be supported by a full inventory of necessary parts before assembly runs begin. This complicates production planning in the processing shop. Examples of basic products which commonly fall into the batch manufacturing production category include hand tools, small electrical appliances, and food industry products.

A multi-criteria variant of the capacitated lotsizing model is used to implement JIT principles in a processing shop organized as a batch manufacturing environment. The approach involves a pre-emptive priority for JIT processing schedules, and a secondary priority for desirable load profiles.

Keywords: just-in-time; batch manufacturing, capacity requirements planning; production planning.

1 Introduction
The increasing competition of a modern business environment is an external driver of increasing variety across product lines. The resulting production environment is controlled by demand levels for the various models which are often too small for dedicated plant, and too large to ignore the economies of batching. This production environment is called batch manufacturing and it is particularly common for hand tools, small electrical appliances, and food processing products. Batch manufacturing necessarily highlights inventory management of final products, work in-process and materials.

Increasing competition also promotes a continuous need for productivity and quality improvements. This, combined with the focus on inventory management, may trigger an interest in general management science, including process re-engineering and just-in-time (JIT) techniques.

In this paper we formulate a mathematical model for batch manufacturing when JIT methods are implemented. In Section 2 JIT principles are presented. In Section 3 a multi-criteria variant of the capacitated lotsizing model is developed for a batch manufacturing plant operating under JIT production planning. In Section 4 the model is
analysed to reveal the implications for capacity requirements planning of implementing JIT principles in a batch manufacturing environment.

2 The JIT Approach

Inventories are assets for accounting purposes. However, the components of inventory cost are substantial and include warehousing, insurance, obsolescence and damage costs, along with capital charges. Finch and Luebbe (1995, p.167) indicate that these costs can account for up to 60% of product costs under traditional production methods. For these reasons Inman (date p.41) refers to the accounting asset as "the flower of all evil". Dealing with the root is the task of JIT planning.

True JIT production processes provide the right product (or wip), in the right place, at the right time, and, in the right quantity. The focus of the management science aspects of JIT is on the last two "rights" and JIT influences these through intervention at the level of production technology and production culture which impact upon the cost structure.

The general JIT approach is to progressively reduce the level of inventory to expose production problems which have created the need for high inventory levels. These production problems are Inman's (date) "root of all evil" and in this section our interest is in specific JIT approaches to pulling the root. This is a competition induced process for which there is no finish-line. We will consider the JIT approach under three headings: materials; work-in-process; and, end products.

The cause of high materials inventories is erratic supply. The JIT approach is to reduce the number of suppliers and establish a commitment from the remaining supplier(s) which is translated into reliability of supply and frequent deliveries. The ultimate result is raw materials arrive on demand, perhaps through EDI systems.

There are three causes of high work-in-process inventories: the first is the uncomfortable feeling of being idle which may be translated into production as an alternative; the second is big set-up times/costs which encourage big production runs; and the third is a high defective rate and/or breakdown risk. The JIT approach is to install a demand-pull system like kanban; install new changeover processes, and/or new processes with lower changeover times (perhaps FMS); and, to introduce quality circles, multiple skilled employees who have preventative maintenance as one skill. The ultimate is smaller batch sizes and minimum safety stock.

The JIT approaches indicated under work-in-process may also apply to end products. The extra cause of high end-product inventories is seasonal demand profiles combined with low design capacity levels. The JIT approach is to install protective capacity cushions, which allow different production regimes of level loading over different seasons.

The batch manufacturing model that follows derives a production plan for a 2-stage production process. A processing shop processes n parts to supply an assembly shop which turns out a variety of end-products. The whole operation has attained a level of progress in its JIT no-finish-line quest which is defined by the following assumptions:

Assumption 1 (Materials supply). Committed relationships with materials suppliers have established reliable and frequent material deliveries, and no further JIT action is contemplated at this stage. The material flows and stocks are therefore ignored in current production planning.

Assumption 2 (Processing shop). Improved changeover processes in the processing shop have reduced setup times/costs and allowed small batch sizes ($r_i$) to be introduced for all parts. Quality circles and preventative maintenance have reduced the defective rate
and the breakdown risk so that a minimum safety stock (zero) is required. Processing is to operate under an assembly-shop-demand-pull system

**Assumption 3** (Assembly shop). Efficient changeover processes in the assembly shop have reduced setup times/costs and allowed small batch sizes to be introduced. Protective capacity cushions are installed in the assembly shop allowing level loading over production regimes which follow demand seasons. This is translated into a constant rate of parts usage \( (d_i) \) by the assembly shop for a given regime.

### 3 The Batch Manufacturing Model

Our task in Section 3 is to design an optimum demand pull system for the processing shop given that \( r_i \) and \( d_i \) are already established by the extent of JIT progress made to date. In this way we can assess the impact of introducing a demand pull system in a batch manufacturing environment where the philosophy of JIT has already been at work. The focus is on the demand-pull system as this is the JIT concept that unites the various workstations into a system. We are especially interested in the capacity planning implications of this JIT system.

A two stage batch manufacturing process has common application particularly in the food-processing industry, and is illustrated in Figure 1. The processing shop combines \( m \) resources or workstations in the production of \( n \) parts which are processed in batches of size \( r_i \) and placed in a store ready for assembly. The short assembly batch times imply that the store must carry a full batch of parts at the start of the period in which they are required for assembly. We further assume that for each part \( i \): batch size \( (r_i) > usage \ rate \ (d_i) \). Otherwise production of all batches is required every period. The base load is therefore eliminated to remove this uninteresting aspect of production which is not influenced by the demand-pull system.

To standardise our comparisons of production plans we will compare the workload of any production plan to a level-loading plan for all resources that meets demand requirements but is not based on batching. viz.

\[
    p_j = \sum_{i=1}^{n} \left( \frac{t_{ij} d_i}{r_i} \right)
\]

where \( p_j \) is the regular workload of the \( j \)th resource, and \( t_{ij} \) is the processing time of a batch of the \( i \)th part. Such a plan is consistent with a capacity minimization approach to capacity planning which gives design capacities of \( p_j \) and translates into a capacity-push production system of the sort presented in common MS texts like Krajewski and Ritzman (1992, p.309). Our capacity-requirements-planning focus would then compare the production plan with these design capacities.
The model is a variant of the discrete lotsizing and scheduling problem (DLSP) as formulated by Salomon (1991). The variations introduce the JIT position of the company and allow a CRP focus. In particular the variations include: pre-set batch sizes ($r_i$); constant parts usage rates ($d_i$); a demand pull system in the processing shop; and, design capacities in the processing shop as shown in (1). The model is presented as model 1 below to emphasise that the approach is multi-criteria with a pre-emptive priority for the first objective.

**MODEL 1:**

\[
\text{min: } \sum_{i} \sum_{\tau} \frac{h_i}{2} (I_{i,\tau+1} + I_{i,\tau}) \quad (2)
\]

\[
\text{st: } \sum_{i}^{n} t_{j} y_{i\tau} \leq p_{j} + x_{i\tau} \quad \text{... all } j, \tau \quad (3)
\]

\[
I_{i\tau} + r_{i}\gamma_{i\tau} - d_{i} = I_{i,\tau+1} \quad \text{... all } i, \tau \quad (4)
\]
\( y_{i\tau} = 1 \ldots \) if a batch of part \( i \) is produced in period \( \tau \); \( 0 \ldots \) otherwise; \( \{ \)

\( x_{i\tau}, y_{i\tau}, I_{i\tau} \geq 0 \ldots \) all \( i, \tau \) \( \)

where ...  
- \( h_i \) = holding cost/part \( i \)/period;  
- \( I_{i\tau} \) = opening inventory of part \( i \) in period \( \tau \);  
- \( i_j \) = batch processing time (inc. setup) for part \( i \) by resource \( j \);  
- \( y_{i\tau} = 1 \ldots \) if a batch of part \( i \) is produced in period \( \tau \); \( 0 \ldots \) otherwise;  
- \( p_j \) = design capacity of resource \( j \) (capacity utilisation push):  

\[
p_j = \sum_i \left( \frac{t_{ij} d_i}{r_i} \right) \]

- \( x_{i\tau} \) = increase in effective capacity of resource \( j \);  
- \( r_i \) = batch size for part \( i \);  
- \( d_i \) = constant demand rate/period for part \( i \);  
- \( T^* \) = processing shop horizon  

\( \tau = 1, 2, 3, \ldots, T^* ; \quad i = 1, 2, 3, \ldots, n ; \quad j = 1, 2, 3, \ldots, m \)

Overtime is the only acceptable CRP strategy since the non-negative inventory levels requirement eliminates backward rescheduling, and subcontracting is not admissible. Batch production is triggered by the \( y_{i\tau} \) and the mass balance equation (4) ensures that production is not late. The objective function (2), on the other hand ensures that production is not early and thereby introduces the demand-pull feature of the model. Equation (3) allows capacity to be increased above design capacity, by \( x_{i\tau} \) which is unrestricted.

The unrestricted nature of \( x_{i\tau} \) allows the processing of the \( i \)th part to be JIT for assembly requirements, independently of processing requirements elsewhere. Schedules for each part are therefore cyclical, and over the processing shop horizon there will therefore be a fixed set-up cost for each part. Processing shop schedules are also cyclical.

The \( y_{i\tau} \) define a processing shop schedule with workloads that fluctuate above and below the design capacity, \( p_j \). Low workload periods must be accompanied by managerial restraint, or a kanban system, to avoid over-production in violation of the demand-pull requirement. High workload periods will feature the overtime CRP strategy.

Load swings in the Model 1 solution are a function of the opening stock positions for each part which can be changed at insignificant cost as required to make available a set of alternative JIT solutions. Following goal programming procedures, as described for example by Schniederjans (1995), Model 2 implements a second load-smoothing criterion to optimise among the alternative JIT solutions. The second criterion is given by the cost of implementing the CRP strategy in the high workload periods, viz.

\[
\min \quad \sum_j \sum_\tau c_j x_{j\tau}
\]

where \( c_j \) = cost/unit extra capacity of resource \( j \) (O/T). Model 2 then gives the JIT solution with the smoothest workload. The Model 2 problem is NP-hard and an efficient heuristic is presented in Houghton and Portougal (1995).
The structure of the basic model allows efficient solution procedures to be applied. The primary decision variables for both models are the \( y_{\tau} \). The JIT solution to Model 1 determines the \( \{ y_{\tau} \} \) matrix directly from the period of each part, and the load-smoothing solution to Model 2 is found by production-point phasing, through row rotations. The approach is illustrated for a single resource in the example below.

**Example:**
A company has been implementing JIT principles for some time in a 2-stage batch-manufacturing production facility which is organised as in Figure 1 and utilises a single resource. The results of the company's JIT approach have been:
- an EDI link with a dedicated supplier;
- the establishment of small batch sizes in the processing shop and in the assembly shop;
- the effective elimination of the need for safety stocks;
- the effective elimination of breakdowns;
- the establishment of level-loading regimes in the assembly shop which correspond to demand seasons.

The processing shop produces five parts, the technical information for which is shown in Table 1 where the \( d_i \) gives the demand rates for the current assembly shop production regime.

**TABLE 1: PROCESSING SHOP DATA**

<table>
<thead>
<tr>
<th>part</th>
<th>batch size</th>
<th>batch proc. time</th>
<th>demand rate</th>
<th>opening stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>4</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>9</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>3</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>5</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>

With a single resource the \( c_j \) is redundant and can be assumed equal to unity.

The design capacity, \( p \), for the single resource is 11.5 from (1).

The model 1 solution is given in Table 2 which shows the \( Y \) matrix and the corresponding load profile. The load profile show work loads in the interval \((0\%, 222\%)\) of design capacity.

**TABLE 2: MODEL 1 SOLUTION**

<table>
<thead>
<tr>
<th>Y</th>
<th>1</th>
<th>0</th>
<th>1</th>
<th>0</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

load profile: 18 7.5 18 0 25.5 0

The significance of the load smoothing problem of Model 2 is highlighted by the workload levels of periods 4-6. An improvement to the load profile would clearly follow a one-period rotation of row 3, for example which would give a new load profile as shown in Table 3.

**TABLE 3: IMPROVED LOAD PROFILE**

| load profile: | 9 | 16.5 | 9 | 9 | 16.5 | 9 |

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Optimising the row rotations by the Houghton and Portougal (1995) heuristic gives the solution shown in Table 4 which shows work loads in the interval (78\%, 113\%) of design capacity. The dramatic improvement in load profile has been achieved at the small cost of a once-over correction to the opening stock levels which then allow the optimally smoothed production plan to operate over the whole assembly shop regime. The stock corrections involved are (6, 12, 0, 8, 0) respectively for the five parts. The CRP strategy will be implemented during the periods 1, 2, 4, and, 5. The corresponding CRP costs are minimised over JIT policies. Production will be under design capacity for periods 3 and 6, when managerial restraint is required to preserve the JIT system. This accords with the JIT philosophy that it is better to pay labour (and other resources) to do nothing, than to produce surplus inventory.

### 4 Summary and Conclusions
The JIT philosophy is a current business option which is subject to prominent discussion. In this paper we have attempted to isolate the impact of JIT processes on a 2-stage production process operating under batch manufacturing. Variations were introduced to the DLSP model in order to focus on the implications of introducing a demand pull production planning system to an organisation which has already made significant progress in implementing the JIT philosophy. The production planning policies that result are compared to traditional design capacities and the overtime costs from CRP processes are optimised. We have seen that the secondary load smoothing process has an important damping effect on what otherwise may be overwhelming load swings. The approach may alternatively be used to analyse cases where the processing shop has protective capacity cushions and the objective is simply load smoothing which may not involve overtime, as shown in the example presented.

The paper analysed a deterministic demand model wherein safety stocks had no role. However, the assembly shop regimes which accommodate predictable demand seasons can be augmented to similarly accommodate stochastic demand shifts.

Traditional cost accounting which allocates overheads to products according to direct labour usage, also adopts labour (and capacity) utilisation rates as product performance measures. This encourages high production and high inventories and is inconsistent with the JIT approach. A company committed to the JIT philosophy as in the model of this paper would allocate overheads to products by some alternative system like the time a unit spends in the system.
References