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Reengineering the production planning process in the food industry

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Abstract

This paper addresses managerial process reengineering and in particular the reengineering of the production planning process. The reengineered process highlights planning options to avoid the process imbalance and loss of production potential that can follow innovation in a facility that is fully committed to JIT production.

The study was motivated by production problems following product innovation within the food industry but the reengineering conclusions and procedures are applicable to all similarly structured industries. An example based on data from a snack food manufacturing company illustrates the reengineered procedure for a plant that is typical of the food processing industry.

Keywords: Managerial process reengineering; Production planning; Batch manufacturing; Multi-stage processing; Innovation

1. Introduction

The ability to innovate is a central determinant of business success in a business environment which is increasingly characterised by competition, technological change, and resource restrictions. The innovation process includes technological and managerial innovation and efficient innovation management requires a balance of both. Managerial innovation is a software innovation which includes the development of new management processes and can occur in isolation or as an adjunct to technological innovation. In general, technological innovation will not deliver a production level up to potential capacity without an accompanying managerial innovation. Urabe (1988) emphasises the relations between technological and managerial innovation and offers the kanban system as an example of managerial innovation which accompanied a programme of incremental process innovation. The reengineering of operations management processes has attracted little attention in the literature of business process reengineering (BPR). Bowman and Singh (1993) observe the literature has focused on strategic restructuring in the context of portfolios, finance and organisational responsibility, at the expense of operations management processes.

Managerial innovation includes the reengineering of management processes and in this paper the focus is on the production planning process. The structure and functioning of the production planning system are primarily defined by plant layout and material flows. Since technological and product innovations cause changes to both these features, the performance of an existing planning system will deteriorate on the implementation of such innovations forcing production below its potential capacity.

Over the last two decades, growing competition in the market place has led to an expansion of variety across the spectrum of product lines. This increase in variety is one aspect of product innovation which has

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been associated with an expansion of batch manufacturing. Batch manufacturing occurs when basic products are produced in a modest variety of types and models, for which demand volumes are not sufficient to justify dedicated plant and equipment as in mass production; at the same time, demand volumes are not so small as to warrant irregular job-shop production. Products are processed in separate processing runs, or batches, between which the shared processing resources are reset. While batch manufacturing is easy to recognise in complex products, such as hand tools and small electrical appliances, some examples in the food industry are not so obvious, though they possess the same characteristics. A product line may offer salt and oil content choices, sweeteners and preservative choices, container type and volume choices, and may be packaged together with other complementary end-products from the line to provide a potentially large number of choices between combinations of end-products.

Growing competition also imposes a continuous need for improvements in productivity and therefore drives the on-going just-in-time (JIT) production philosophy. Small inventories are a primary JIT objective, in keeping with Inman's (1993) description of high inventories as the "flower of all evil" which grows from and hides inefficient processes and management. Under JIT, plant is designed for efficient change-over processes to keep set-up times and costs low and thereby allow small batch sizes and small inventories. The plant implements JIT operating systems whereby processing is driven by stock levels at each stage; end-product demand reduces warehouse stocks which authorises processing and packing through releasing kanbans or through some alternative demand-pull system. Depending on kanban numbers, JIT systems will maintain stock at a level which is as low as considered desirable and this level may be established by an optimisation problem with respect to number of kanbans. A prominent feature of the JIT production philosophy is to progressively reduce stock levels to expose continuing management challenges for system improvements and productivity gains. One such challenge is the workload variations which follow product innovation in a JIT system.

Abernathy (1978, pp. 68–81) distinguishes between two patterns of innovation, viz. radical product innovation and incremental process innovation. Incremental product innovation is a third pattern which delivers a recurring problem of workload variations management that may be addressed by BPR. This paper addresses the JIT production planning process, and presents a reengineering which facilitates workload smoothing in a multi-stage facility that is fully committed to JIT processing, in an environment of incremental product innovation.

The driving force of a competitive business environment is summarised in Fig. 1 where technological responses are shown in Field 2 and managerial responses in Field 3. In pursuit of productivity gains on the processing side, firms will implement technological or managerial innovations, as shown by the top two arrows from the competition box. Technological innovations, which include JIT technologies, are expected to require BPR to avoid a loss of effective capacity as shown by the arrow from the technology box. It is understood that JIT technologies and the managerial innovation required for their effective implementation, are usually regarded as joint aspects of a JIT production philosophy package. In the on-going pursuit of marketing gains, firms will implement incremental product innovation in the form of increasing diversity across product lines as shown by the bottom arrow from the competition box. Such product innovation, which is associated with batch manufacturing, calls for a managerial response to reengineer the production planning process for workload variations management. This is shown in the BPR box of Fig. 1, where the shaded cells indicate the focus of the current paper.

The present study was motivated by production problems following incremental product innovation within the food processing industry, where it is usual for linear material flows to connect multiple processing stages as described in Finch and Luebbe (1995, p. 34). The food processing industry is highly competitive and it is not uncommon to find incremental product innovation proceeding within a batch manufacturing environment that operates under JIT production planning processes. Single-stage batch manufacturing which is committed to JIT production was analysed by Houghton and Portougal (1995a). In Section 2 the earlier model is extended to describe a multi-stage, batch manufacturing line. The analysis of the model in the context of incremental product

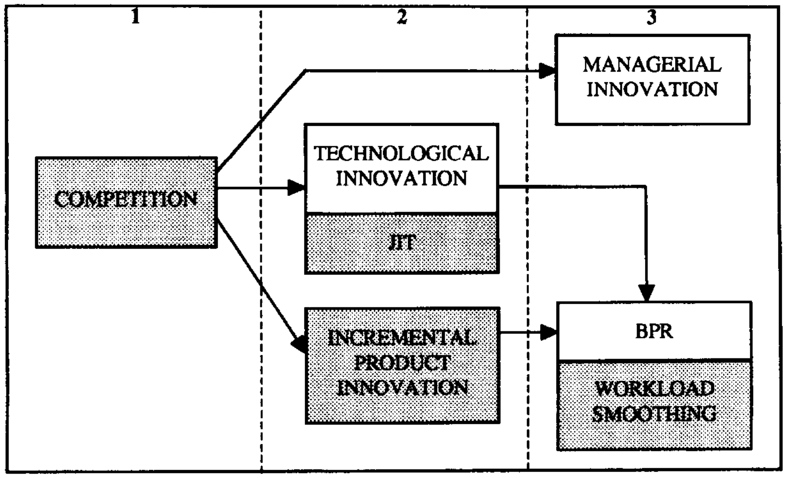


Fig. 1. Competition innovation and BPR.

innovation leads to a reengineered JIT production planning process for multi-stage processes. The model and its analysis are appropriate for all plants with the described lay-out and processes. In Section 3 an example based on data from a snack food manufacturing company illustrates the reengineered process for a two-stage line.

2. Modelling and analysis

Consider an m stage manufacturing line where n parts are processed and adjacent stages are separated by a store. The store at stage k holds the processing product from stage k and provides the feed-stock for processing at stage $(k + 1)$. At the end of the processing stages, parts are assembled into a variety of end products in an assembly shop which is identified as stage $m + 1$. The processing stages are indexed in increasing order from raw materials processing through to assembly. The configuration of stages is shown in Fig. 2.

We suppose that in this environment JIT technology and processes are installed. In the following sections, the JIT production planning process is reengineered to retain efficiency in the face of incremental product innovation. The reengineering is derived from an analysis of a plant processing model which incorporates the multi-stage process design of Fig. 2.

2.1. *The primary production planning process*

The model assumptions are formally listed below, after which the model is presented.

2.1.1. *The model assumptions*

1. The production technology is designed as a multi-stage line as described in Fig. 2.
2. Production is organised according to batch manufacturing, under which batch sizes are fixed by current state of the on-going reductions in set-up time/cost and batch sizes under the JIT approach. Batch sizes are further assumed to be constant across production stages.
3. The plant is designed and operated as a JIT production system. Consequently, (a) the processing of batches is triggered by demand pull from the next stage; (b) set-up times and set-up costs are all small and reflect the influence of efficient change-over technologies, possibly involving FMS; (c) batch sizes and batch processing times are small; (d) the assembly shop operates under level-loading regimes which correspond to constant demand rates for parts; (e) close links with committed suppliers, possibly including EDI, allow the planning of material supplies to be disregarded; (f) consistent with the JIT history of the plant, initial opening stocks are small; and (g) on-going maintenance and quality

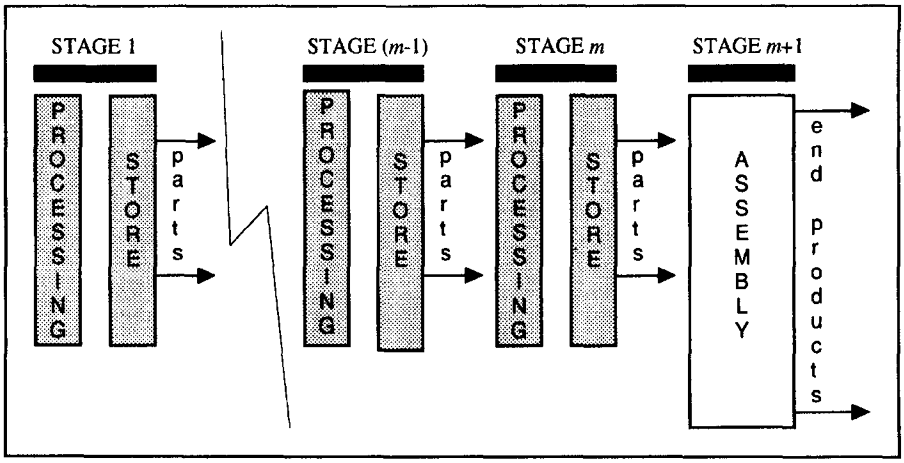


Fig. 2. The multi-stage plant.

management have effectively eliminated defectives and breakdowns and the corresponding need for safety feed-stocks.

4. The batch size exceeds demand/period for all parts.
5. Production decisions are made for discrete periods of time corresponding to a shift or a day.
6. A design capacity is installed for the resources at each stage based on level-loading requirements.
7. Load smoothing may be implemented by in-house capacity requirements planning (CRP) strategies only. Of these, subcontracting is excluded and JIT requirements preclude forward and backward rescheduling which leaves overtime as the only acceptable CRP strategy. Design capacities can be exceeded only through the overtime strategy.

These assumptions lead to the multi-criteria model presented below.

2.1.2. *The production planning model*

The production planning model is a variant of the discrete lot-sizing and scheduling problem as presented by Salomon (1991) and corresponds to a primary production planning process which generates JIT production plans for a multi-stage facility in an environment of incremental product innovation. JIT production plans are induced by a first criterion which requires the minimisation of holding costs. The model analysis that follows leads to a secondary load smoothing criterion in Section 2.2 and a reengineering of the production planning process. The model with its primary criterion is defined by (1)–(9) below:

$$\min \quad \sum_{k}^{m-1} \sum_{i}^{n} \sum_{\tau}^{T} \left(\frac{h_i^k}{2}\right) (I_{i,\tau}^k - r_i y_{i\tau}^{k+1}) + \sum_{i}^{n} \sum_{\tau}^{T} \left(\frac{h_i^m}{2}\right) (I_{i,\tau}^k - d_i) \tag{1}$$

(inventory cost)

$$\text{s.t.} \quad \sum_{i}^{n} t_{ij}^k y_{i\tau}^k \leqslant p_j^k + x_{j\tau}^k \quad \text{all } j, \tau, k, \tag{2}$$

(capacity and CRP)

$$I_{i\tau}^m + r_i y_{i\tau}^m - d_i = I_{i,\tau+1}^m \quad \text{all } i, \tau, \tag{3}$$

(feed-stock balance: assembly)

$$I_{i\tau}^m \geqslant d_i \quad \text{all } i, \tau, \tag{4}$$

(feed-stock supply: assembly)

$$I_{i\tau}^k + r_i y_{i\tau}^k - r_i y_{i\tau}^{k+1} = I_{i,\tau+1}^k \quad \text{all } i, \tau, k < m, \tag{5}$$

(feed-stock balance: processing)

$$I_{i\tau}^k \geqslant r_i y_{i\tau}^{k+1} \quad \text{all } i, \tau, k < m \tag{6}$$

(feed-stock supply: processing)

$$y_{i\tau}^k = \begin{cases} 1 \\ 0 \end{cases} \quad \text{all } i, \tau, k, \tag{7}$$

$$x_{j\tau}^k, I_{i\tau}^k \geqslant 0 \quad \text{all } i, j, \tau, k. \tag{8}$$

the indexes are $k = 1, 2, 3, \ldots, m$ for processing stage; $i = 1, 2, 3, \ldots, n$ indicates part; $j = 1, 2, 3, \ldots, J$ for resource; and, $\tau = 1, 2, 3, \ldots, T$ for processing period.

The constants are h_i^k the holding cost/part i/per period at stage k; t_{ij}^k the batch processing time (inc. set-up) on resource j, for part i at stage k; r_i the batch size for part i; d_i the constant demand rate/period for part i; T the facility horizon; and p_j^k the level-loading design capacity of resource j, at stage k, in processing time units. The variables are

$I_{i\tau}$, the opening inventory of part i in period τ;

$$p_j^k = \sum_i^n \left(\frac{t_{ij}d_i}{r_i}\right), \tag{9}$$

$$y_{i\tau}^k = \begin{cases} 1 & \text{if a batch of part } i \text{ is produced} \\ & \text{in period } \tau, \text{ at stage } k, \\ 0 & \text{otherwise; and} \end{cases}$$

$x_{j\tau}$, the increase in effective capacity of resource j in period τ.

Following assumption 1, a linear technology is introduced by a linear transfer of feed stock in (3)–(6). Following assumption 2, batch manufacturing is introduced through the batch size, r_i, which is common across stages for a given part. Batch production is triggered by the $y_{i\tau}^k$. Following assumption 4, the production planning problem is defined to exclude the uninteresting batches that must be produced every period. The model is, therefore, designed to address JIT production planning for a multi-stage batch manufacturing line. Incremental product innovation is introduced through a switching of assembly regimes designed under assumption 3(d). The remainder of this section analyses the model and specifies its main properties.

It is clear that the above model optimises across JIT production plans. Constraints (3) and (4) ensure that production is not late for stage $m + 1$, and constraints (5) and (6) ensure that processing from stage $m - 1$ is not too late to be feed-stock for processing at stage m, etc. Constraints (4) and (6) also ensure that feed-stock for each stage is available at the start of the period in which it is required, consistent with the small set-up and processing times of assumptions 3(b) and 3(c). The unrestricted nature of $x_{j\tau}^k$ is an important feature of constraints (2) and this combined with the *holding cost* objective function (1), ensures that production is not early. The demand pull requirements of JIT production are therefore met; production is in the correct quantity at the correct time to satisfy the demand-pull assumption 3(a). In each assembly regime, the demand pull originates from the regular demand rates for parts from stage m. For a given part and stage, therefore, the $y_{i\tau}^k$ define a production plan with a JIT structure.

In this JIT environment the processing plan for each part has a cycle of T_i given by r_i/d_i which is constant over all processing stages and prevails for the assembly regime. The overall plant will have a cycle of T given by the smallest integer number divisible by every T_i without remainder, or, LCM(r_i/d_i). The solution may therefore be specified by the m production point matrices, $\underset{(n\times T)}{\boldsymbol{Y}^k} = \{y_{i\tau}^k\}$, where row i of $\boldsymbol{Y}^k$ describes the cyclical plan for part i over the plant cycle, $\tau = 1, 2, 3, \ldots, T$. Such cyclical JIT plans are well known in practical management and Miltenburg and Goldstein (1991, 905) note that "$\cdots$ the [JIT] schedule usually consists of a relatively short sequence which repeats again and again".

Given a decision horizon equal to the plant cycle T, it is clear that the processing of part i at every stage, completes $T(d_i/r_i)$ cycles over a shop horizon, and therefore requires the same fixed number of set-ups, located by the $y_{i\tau}^k$, where $\sum_\tau^T y_{i\tau}^k = T(d_i/r_i)$ for all k. Set-up costs are, therefore, excluded from the objective function of the planning model.

To focus on load smoothing, a level-loading design capacity, p_j^k, for processing by resource j at stage k is defined by (9), as recommended, for example, by Krajewski and Ritzman (1992). The design capacities can be adequate only if loadings are constant at the average rate over time. This is only possible for a perfectly balanced line where $\sum_i r_i y_{i\tau} t_{ij}^k = p_j^k$ and not for the non-dedicated lines of batch manufacturing under incremental product innovation. However, in an incremental product innovation environment, JIT plans under batch manufacturing will require production in some periods to be below the design capacities of (9), and production in other periods will exceed the design capacities. According to assumption 6, constraint (2) permits the design capacity for each resource to be exceeded through the implementation of a CRP strategy involving $x_{j\tau}^k > 0$.

Defining criterion (1) as primary and pre-emptive, permits lower priority criteria to pursue lower priority objectives. In the next section we introduce a secondary workload criterion which reengineers the planning process to minimise variations in resource workloads across solutions with the minimum holding cost.

2.2. Reengineering the production planning process

By introducing recurrent changes in the product set, incremental product innovation will disrupt any degree of balance that may have been achieved with-in the cyclical plan. This is the motivation for a reengineering, to facilitate the smoothing of the recurrently disrupted workload profile. Inevitably the plan is cyclical, but the objective of the reengineering is to minimise its amplitude.

Following goal programming procedures, as described for example by Schniederjans (1995), a secondary load-smoothing criterion is optimised across the alternative JIT solutions to the primary criterion problem. The secondary criterion is given by the cost of implementing the CRP strategy in high workload periods, viz.,

$$\min \sum_k \sum_j \sum_\tau c_j^k x_{i\tau}^k, \tag{10}$$

where c_j^k is the cost/unit overtime capacity for the jth resource in stage k. Opening stocks may be regarded as model variables to permit the secondary criterion problem to be solved by a process of production-period phasing in discrete time, conducted on the partitioned matrix $\underset{(n\times mT)}{\boldsymbol{Y}} = (\boldsymbol{Y}^1|\boldsymbol{Y}^2|\boldsymbol{Y}^3|\cdots|\boldsymbol{Y}^m)$. In this section we develop the phasing process; the implications for stock adjustments are considered in the next section.

For a given i and k, all production periods may be moved forwards or backwards by any given number of periods without changing performance under the first criterion and therefore the JIT structure of the plan. Since each row of $\boldsymbol{Y}^k$ is cyclical, or circular, these movements will wrap around the end periods 1 and T. Rotations may be clockwise or anticlockwise. A multi-stage row rotation for a given part i, rotates row i, for every $\boldsymbol{Y}^k$, in the same direction, and through the same

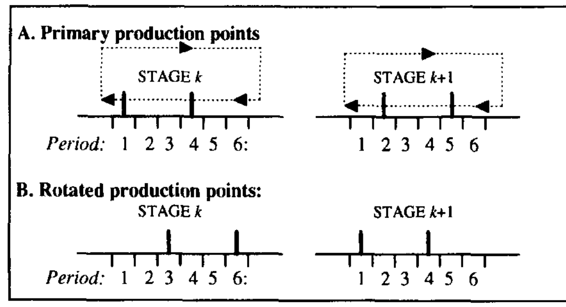


Fig. 3. Multi-stage row rotations.

number of time periods. This process is illustrated in Fig. 3 for clockwise rotations over two stages for a part with a three period cycle and a facility cycle of six periods. The bold verticals in Fig. 3 locate the unit elements of row i. A clockwise rotation through one period moves the stage k batch from periods 1 to 6, and the stage $(k+1)$ batch from period 2 to period 1, etc. Since multi-stage row rotations change the production points of a given part across all stages whilst retaining the JIT property of the part production plan, they permit the phasing of production points between parts across the whole facility and thereby establish alternative JIT production plans with different workloads. The workload of all stages may be optimised across JIT production plans by optimising (10) across multi-stage row rotations.

As all stages are rotated simultaneously in the multi-stage row rotations procedure, the optimisation may be implemented through a variant of the Store Heuristic, a single-stage rotation heuristic presented in Houghton and Portougal (1995a). The heuristic phases the processing of new parts corresponding to the current innovation, together with existing parts from the previous regime and gives a final $\boldsymbol{Y}$ matrix which defines a JIT production plan with optimum workloads that fluctuate around the design capacity, p_j^k, as indicated by the $x_{i\tau}^k$. High workload periods will be serviced by an overtime strategy and low workload periods must be accompanied by managerial restraint, to avoid overproduction in violation of the JIT requirement.

For purposes of the reengineering, the p_j^k could be interpreted as level-loading benchmarks, rather than design capacities. In this case, the $x_{j\tau}^k$ would represent the extent of above-benchmark processing. The c_j^k would specify a penalty for exceeding the benchmark for the jth resource, at stage k. Since without above-benchmark production there will be no below-benchmark production, no under-benchmark penalty would be required. Clearly, level loading is not consistent with JIT production and the reengineering would minimise above-benchmark processing.

2.3. Opening stocks and regime transitions

The multi-stage row rotation example in Fig. 3 demonstrates the opening stock implications of row rotations. After the rotation, stage k opening stock must be sufficient to provide feed-stock for stage $(k+1)$ in period 1 whereas this was not required before the rotation. A transition period is required to join the old and new regimes, creating stock levels consistent with the new regime. Given the configuration of the stages, a new regime may be phased-in, starting with processing stage 1 in period 1 and introducing a new stage each period of the phase-in period. After m periods, the new regime will be fully implemented in the processing shop.

Our assumptions for initial opening stock for other stages within the regime, include

$$0 \leqslant I_{i1}^{k} \leqslant r_i, \quad \text{for all } i \text{ and } k = 1,2,3,\ldots,m$$
$$\text{(from assumption 3}(f))$$
$$I_{i1}^{m} \geqslant d_i \quad \text{(from (4))}$$

and

$$I_{i1}^{k} \geqslant r_i y_{i1}^{k+1} \quad \text{(from (6)).} \tag{11}$$

No feed-stock shortage or surplus will occur at stage 1 as this is the responsibility of the committed raw material suppliers operating under JIT contracts. The first period of the new assembly regime, is the $(m+1)$th period after the commencement of the phase-in plan. This period is denoted by $\tau = 1$, or, the first period of the new regime plan. It is clear that if $I_{i1}^{m} = d_i$, then $y_{i1}^{m} = 1$ from (4), and that $I_{i1}^{m-1} = r_i$ from (6). If these opening stocks and production periods are not part of the new regime plan, then a transition plan must be established to avoid these shortages. A transition plan must implement once-over "stock adjustments" during the m period phase-in period to effect a "seamless" transition between regimes, as discussed, for example, in Johnston (1995) and Sengupta (1996). In the context of the current paper, a seamless transition involves the creation of opening stock surpluses at stage m in phase-in period $m+1$. The surpluses are necessary to avoid these shortages, given the batch sizes, and they are phased-out over post-phase-in time through workload relaxation.

There are, therefore three optimising problems within the reengineering: the optimum phasing of parts processing for the new regime; the optimum stock adjustment problem of the transition plan; and, the optimum workload relaxation problem of the phase-out period. The first problem, involving the multi-stage variant of the Store Heuristic, is presented in the next section. The second problem is of short duration compared to the frequency of innovations, and of low cost compared to production costs over the new regime. However, in a limited capacity environment it may be desirable to increase the phase-in period beyond m periods. This optimum transition problem is not considered in this paper but is addressed in Houghton and Portougal (1997). The third problem is influenced only by internal labour policy and is not discussed further.

2.4. A multi-stage production planning heuristic

This section presents a heuristic for the multi-criterion problem in the single resource case when costs per unit overtime capacity are constant across stages. The heuristic computes an asymptotically optimum production plan for the new assembly regime corresponding to a given step in the incremental product innovation process. The heuristic, which is illustrated in the example of the next section, is presented in two modules below.

2.4.1. The primary production planning module

This process solves the primary criterion problem, defined by (1)–(9), locating the production periods for each part, sequentially across stages beginning at stage m.

1. For stage m, for each part, i, arbitrarily locate production points according to the part cycle: For each row, $1 \leqslant i \leqslant n$, of $\boldsymbol{Y}^m$, set $y_{i1}^{m} = y_{i,1+T_i}^{m} = y_{i,1+2T_i}^{m} = \cdots = y_{i,1+T}^{m} = 1$.
2. For each upstream stage, $(m-1) \geqslant k \geqslant 1$, in turn, locate production periods of stage k one period before the production points for stage $k+1$, in a circular sense, to supply processing feed stock to

stage $k+1$, just-in-time: For each row, $1 \leqslant i \leqslant n$ of $\boldsymbol{Y}^k$, and each time period, $1 \leqslant \tau \leqslant T$, set $y_{it}^k = y_{i,t+1}^{k+1}$, where circularity transforms $\tau > T$ to $(\tau - T)$ and $\tau < 1$ to $(\tau + T)$.

A primary production plan is specified when production points for the last part are located in stage 1. An unsupported primary process would locate y_{i1}^m to satisfy (3) and (6) given the opening stock levels. However, the simpler procedure above is equivalent as an initial solution for the reengineering module, given that the reengineered plan is implemented via a transition plan.

2.4.2. The reengineering module

This process, which is initiated by the primary module, phases production periods across the facility cycle.

1. Subdivide the set of parts into common part cycle (CPC) groups: All parts in CPC group g, where $g = 1, 2, 3, \ldots, G$, have a CPC denoted by T_g, and, the number of parts in group g is denoted by n_g. The plan for group g is defined by the partitioned matrix $\underset{(n_g \times mT)}{\boldsymbol{Y}_g} = (\boldsymbol{Y}_g^1 | \boldsymbol{Y}_g^2 | \boldsymbol{Y}_g^3 | \cdots | \boldsymbol{Y}_g^m)$ where $\boldsymbol{Y}_g^k = \{y_{gi\tau}^k\}$ is the stage k production period matrix for all parts $i \in g$.
2. For each CPC group, $1 \leqslant g \leqslant G$:
   (a) For each period $1 \leqslant \tau \leqslant T$, compute the workload, given by

$$L_{g\tau}^k = \sum_{k=1}^{m} \sum_{\substack{i=1 \\ i \in g}}^{n_g} y_{gi\tau}^k t_i^k;$$

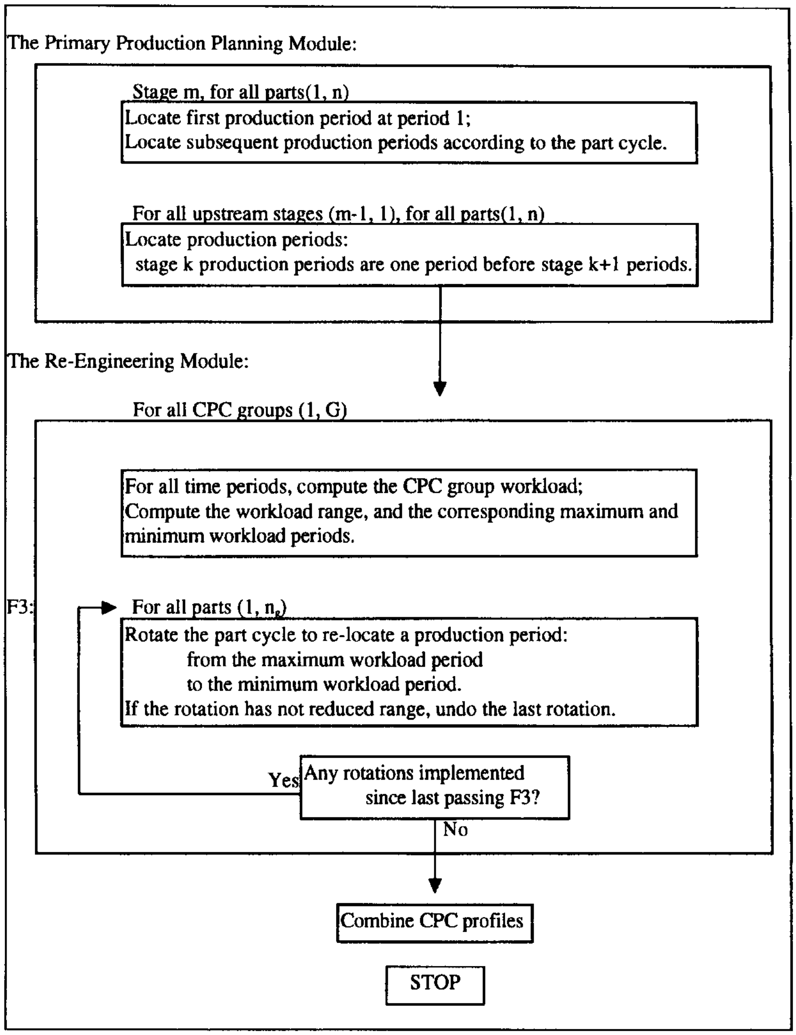
   compute the workload range, R_g, and the production periods, τMAX and τMIN, of the corresponding maximum and minimum workload.
   (b) For each row of $\boldsymbol{Y}_g$, $1 \leqslant i \leqslant n_g$, and for each multi-stage row rotation which relocates a production period from period τMAX to period τMIN, implement the rotation and re-compute R_g. If R_g is not reduced by the rotation, then undo the rotation. Otherwise the new rotation defines a new $\boldsymbol{Y}_g^k$ and reduces R_g correspondingly.
   (c) Group g phasing is complete when no further reductions in R_g occur for a complete pass through the n_g rows of $\boldsymbol{Y}_g$.
4. Combine the final workload profiles of all cycle groups.

A performance bound for the reengineered production planning process follows from Houghton and Portougal (1995b) and establishes the final workload as asymptotically smooth. Performance can be improved by forming, between steps 3 and 4, power rotation cycle groups from G, like $R2$, which collects parts with cycles given by $2, 2^2, 2^3, \ldots$ Workload profiles within a power group are then optimally phased, as demonstrated for inventory processes in Houghton and Portougal (1995c). The phased group profile replaces the included Common Part Cycle profiles in step 4. If power groups are implemented, no benefit accrues from phasing the group profiles at step 4. A non-mathematical flow chart of the reengineered production planning procedure is shown in Scheme 1.

3. An example with two processing stages

This example is based on data from a snack food manufacturing company which produces hundreds of "shelf stable" food products. The products are manufactured and packed on several lines. Some of the lines are designed as flow-shops, where the production and packing are performed continuously. Other lines perform production and packing separately, with a large buffer store between the stages. These "two-stage lines" are operated under batch manufacturing. For some time, management has been committed to a JIT production philosophy and the two-stage lines were designed with fast set-ups to accommodate small batch sizes. A third, order-assembly stage is conducted in the finished goods warehouse.

Demand is fairly stable and the production system is completely stock-driven. The two-stage lines are planned by JIT processes whereby end-product demand reduces warehouse stocks and thereby authorises processing and packing. The operating system seemed to be working well and the lines were well balanced until the introduction of what seemed to be a minor product innovation, which required existing products to be packed in smaller bags. The small pack products were a market success, and gradually "small packing" increased. Since small and large bags are filled at approximately the same rate the packing stage



Scheme 1. Flowchart of the reengineered process.

became seriously overloaded. It was time to consider a reengineering of the JIT production planning process.

All high volume raw materials are supplied according to JIT agreements with a few major suppliers who accept orders after the weekly production plan is finalised, and deliver JIT. These materials can be ignored in the planning process. In the example below we consider the planning for a single two stage line which is required to produce five parts. The technical information is shown in Table 1, where d_i gives the parts and daily demand rates for weekly assembly in the new regime. Since our interest is in a single resource at each stage, the subscript j is not used in the example. The p^k specify level-loading processing benchmarks given by $p^1 = 24$ and $p^2 = 12$ processing time units for stages 1 and 2, respectively. The c^k specify a penalty for exceeding the benchmark in each stage k and are assumed equal to unity for both stages.

A solution to the primary production planning process is given in Table 2 which shows the Y^1 and Y^2 matrices and the corresponding load profiles. For part 1 the Stage 2 plan is given by production

Table 1
Process data

Part	Line	Stage 1		Stage 2		Assembly
	Batch size	Batch proc. time	Opening stock	Batch proc. time	Opening stock	Assembly demand rate
i	r_i	t_i^1	I_{i1}^1	t_i^2	I_{i1}^2	d_i
1	12	10	12	6	6	6
2	36	6	36	4	24	12
3	14	18	0	9	7	7
4	16	8	16	3	8	8
5	18	12	0	5	12	6

Note: In this example the I_{i1}^2 values are less than r_i and are a multiple of d_i for all i, and the I_{i1}^1 values are either r_i or zero. This is computationally convenient but is not a requirement of the heuristic.

Table 2
Primary production plan

Part	Stage 1						Stage 2					
	Period						Period					
	1	2	3	4	5	6	1	2	3	4	5	6
1	0	1	0	1	0	1	1	0	1	0	1	0
2	1	0	0	1	0	0	0	1	0	0	1	0
3	0	1	0	1	0	1	1	0	1	0	1	0
4	0	1	0	1	0	1	1	0	1	0	1	0
5	0	0	1	0	0	1	0	1	0	0	1	0
L_τ^k	6	36	12	42	0	48	18	9	18	0	27	0

periods which are specified by the $y_{1\tau}^2$. The first production period is located randomly at period 1 and the 2 period part cycle then establishes the remainder of the $y_{1\tau}^2$ profile. Stage 1 processing must provide the feed stock to support $y_{13}^2 = 1$ as required by (5) and (6) and the corresponding production point is located at period 2. Again the two period cycle establishes the remainder of the workload profile for part 1. The production points for other parts are located similarly.

The primary production plan of Table 2 is clearly JIT but the load profiles, shown in Table 2 as L_τ^k, highlight the significance of reengineering. Workload swings in periods 4–6 are in the interval (0, 200%) of level loading in stage 1, and (0%, 225%) in stage 2.

Table 3
Improved load profile

	Stage 1						Stage 2					
	Period						Period					
	1	2	3	4	5	6	1	2	3	4	5	6
L_τ^k	24	18	30	26	18	30	9	18	9	9	18	9

An improvement to the load profile would clearly be achieved by a one-period forward rotation of row 3, for example, which would give a new load profile as shown in Table 3.

Clearly, $G = 2$. Group 1 includes parts 1, 3, and, 4; and $T_1 = 2$. Group 2 includes parts 2, and, 5; and $T_2 = 3$. The reengineering module establishes the optimum row rotations as a 1-period forward rotation for product 3, and a 1 period backward rotation for product 5. No phasing of the resulting group profiles can reduce the maximum workload of the facility below the sum of the group maxima. The corresponding optimum plan is given in Table 4 which shows work loads in the intervals (75%, 125%) of level loading for stage 1 and (75%, 117%) of level loading for stage 2.

The plan which minimises penalties across JIT policies operates above benchmark during periods 1, 2, 4, and, 5 in stage 2, and, periods 2, 4, and 5 in stage 1. Processing will be under benchmark for other periods, when managerial restraint will be required to preserve

Table 4
Reengineered production plan

Part	Stage 1						Stage 2					
	Period						Period					
	1	2	3	4	5	6	1	2	3	4	5	6
1	0	1	0	1	0	1	1	0	1	0	1	0
2	1	0	0	1	0	0	0	1	0	0	1	0
3	1	0	1	0	1	0	0	1	0	1	0	1
4	0	1	0	1	0	1	1	0	1	0	1	0
5	0	1	0	0	1	0	1	0	0	1	0	0
L_τ^k	24	30	18	26	30	18	14	13	9	14	13	9

the JIT system. This accords with the JIT philosophy that it is better to pay labour to do nothing, than to produce surplus inventory.

The solution for the new regime shows a smooth workload profile at stage 2, as well as at stage 1. The small bags are a raw material for the second stage and do not influence the transition plan, which was implemented over two periods; the phase-out was also implemented over two periods involving short shifts.

4. Summary and conclusions

A competitive business environment is characterised by on-going innovation within a production culture that embraces both batch manufacturing and JIT technology and processes. These characteristics together constitute a balanced response to competition that consistently pursues marketing gains through product diversity and productivity gains. The associated incremental product innovation, however, lowers the performance of the production planning process by regularly introducing significant workload variations in parts processing. In this paper, that process was reengineered to facilitate workload smoothing and thereby introduce a greater flexibility for the implementation of product innovations. The facility modelled was a multi-stage batch manufacturing line that is committed to JIT production as is typical of the food processing industry. A holding cost criterion which was given a preemptive first priority, introduced JIT production as a requirement of production plans. The reengineering was presented as a secondary workload criterion problem.

The reengineering is simple in implementation and is currently operating in a JIT snack food manufacturing plant, where it has significantly improved workload variations and has encouraged a managerial attitude for product innovation. Furthermore, the processing psychology of setting up a line for a regime of smooth workloads, has provided real gains in worker morale.

Further work in this area will address facilities which are not fully committed to JIT production, and for which trade-offs of JIT production structures for workload smoothing may be evaluated.

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