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This article examines the operational characteristics and management logic of production systems characterized as repetitive manufacturing, by comparing them with those typical of intermittent manufacturing; in particular we aim to:

- describe the management characteristics of repetitive production underlining the operational logic compared with that of intermittent manufacturing;
- examine the characteristics of shopfloor control in repetitive manufacturing;
- propose a conceptual interpretative framework as a reading key in order to distinguish the management differences between intermittent and repetitive manufacturing within the three basic production control subsystems: planning, inventory control and shopfloor control.

Intermittent Manufacturing Management Techniques in Job-shop Systems

Job-shop manufacturing systems are essentially characterized by generic production processes, able to produce a wide range of parts. These are produced in lots, which compete for the plant resources and pass through the production system intermittently rather than in a continuous flow.

The Master Production Schedule (MPS) is usually defined according to sales forecasts and has components or functional groups as its object. The Final Assembly Schedule (FAS) is defined in response to orders or to very late forecasts and has finished products with specified eventual optionals as its object.

The product bill of materials is generally multilevel. After the formulation of the MPS the MRP procedure generates both job orders (work orders) and purchasing orders. In order to obtain the finished product it is necessary to issue and receive materials from and to the stores. Therefore accurate registration in proportion to the levels of the bill of materials is needed.

The managers in these production contexts are involved above all in shopfloor control and in detailed assignment of job priorities; this activity becomes more

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complex, depending on the variety of the parts and the quantity of production orders. In order to carry out these tasks it is necessary to have access to fast and accurate information about the different workloads of the centres.

The fundamental tool in regulation and control of the entire production process is the work order, which permits precise identification of a lot moving through the various workshops on the different machine tools.

For each lot being machined a routeing report is produced, automatically showing the succession of operations to be carried out and the machining centres involved. Drawings from the technical office can also be attached and any other information about particular tools and equipment, alternative routeings, etc.

The work order specifies, moreover, the number of elements which make up the lot. It is up to the planner, before order release, to verify that the quantities of materials necessary for that lot are in stock. Warehouse issue occurs through the use of a picking list, also generated by the information system.

The work order, moreover, by registering the evolution of lot life during its movement through the various phases of the production process, is the only means of providing cost analysis, analysis of deviation from the standards, monitoring of the level of work in progress (WIP) and despatching.

Despatching is extremely important. In fact at any moment different machining centres can be engaged in different orders, all at different stages. In this situation on completion of one operation the lot moves towards the next centre where it cannot usually be immediately machined and thus has to wait.

It therefore becomes necessary to know the correct machining sequence of the innumerable orders which can contemporaneously be present in one machining centre: by the despatching activity it is possible to define, automatically through pre-established priority rules, the despatch list which is usually valid for a day. Obviously the quality of the daily output is closely linked to the quality of the order scheduling as the orders compete for the same resources.

Repetitive Manufacturing Management Techniques in Line Systems

In repetitive systems, that is line flow systems, operational logics are very different from those in intermittent systems.

Management in these situations is characterized by a global vision of the production system which leads to focusing on the entire process. Attention is no longer given to detail but to the whole, and "success" lies not so much in the efficiency of single phases, as in maintaining a high throughput speed through the entire production system[1].

The objective is to obtain a process characterized by a flow, as continuous and uniform as possible, of materials across the factory, until they become finished products. Raw materials are transformed into semi-machined parts and then into finished products at a constant rate. Between the various stages there are no decoupling stocks. It is more important to work with machines aimed at fast set-up than efficiency.

In order to obtain a flow it is necessary to reach and maintain a dynamic balance in the production system, since the lead-times for products of the same family passing through the system are different.

Research is continuously aimed at maintaining fluidity of the stream through the centres which are arranged in order to reach the planned production rate.

In repetitive production the materials move almost continuously along the plant following determined flows. The phrase, "on-line fabrication", is sometimes used to underline the fact that component fabrication and assembly of subassemblies are often carried out at the same time as final assembly operations. The machining routeings are predefined and so the flows, as we have already partly pointed out, are relatively fixed, in the sense that they are carried out on machines arranged in a line.

The high production volumes and low throughput times mean that the traditional control system typical of job-shops – the work order – is difficult to use in these situations.

Owing to the high production rate, it is almost impossible to obtain detailed information about the state of various jobs on the line. It would in any case be too expensive and useless: if many different parts are produced in high volumes for long periods of time, for example with a daily rate of 1,000 pieces each, it is obvious that it is not important to identify individual parts and lots during production.

Moreover, the quantities of materials which flow to the main lines are defined on daily production programmes, not according to precise requirements on a picking list. It is obvious that control tools in repetitive manufacturing should not focus on detail, on a single order or lot, but should concentrate on monitoring the total flow and the volumes obtained in a certain period of time. In order to do this it is necessary to have tools which differ from the work order and, more generally, to control the production with management systems different from those used in job-shop type systems[2].

Within this scenario, planning has an important role in ensuring a regular production flow, by using programmes which are as uniform as possible within the operational horizon.

In the next two subparagraphs we will describe ways to define production plans in repetitive manufacturing environments, starting with the example of planning processes developed in a large Japanese automobile company.

Definition of Production Programmes in Toyota

In order to understand more clearly how the Master Production Schedule (MPS), and the Final Assembly Schedule (FAS) are defined in repetitive manufacturing environments it is useful to describe the planning activities carried out at Toyota. The production programmes are developed in three phases[3,4]:

(1) A general production plan, which determines according to sales forecasts an approximate number of units to be produced in a year (millions of automobiles).

(2) An intermediate production programme which defines for each production month:
- models and quantities two months in advance;
- production types and details a month in advance.

(3) A detailed assembly programme which indicates, for each production month, daily quantities per model to be assembled on the lines.

Figure 1 shows the ways in which production programmes are defined at Toyota.

At the beginning of January the number of automobiles per model to be produced during March is defined according to sales forecasts. These data are transferred to the factory and the suppliers.

At the beginning of February the types of automobiles and other production details are decided according to sales forecasts, and these too are communicated to the factories and suppliers.

In the second half of February the assembly plan for each line is determined, according to sales forecasts. The plan is communicated only to the beginning of the assembly line and not to any other workshop.

If there are modifications to the plan, only the beginning of the final assembly line is informed. The *kanban* procedure automatically adjusts the upstream production processes, requiring production of the components necessary for the modified plan simply and accurately.

Upstream workshops (foundry, forging, moulding, etc.) are, however, more generally informed about the monthly assembly plan. On the basis of expected production quantities the manager of each workshop can organize the manpower for the month being programmed.

The assembly plan defines the daily sequence with which the vehicles advance along the assembly line over a month. The month is considered to be subdivided into decades. Shingo[3] defines the subdivision of the plan in periods (decade, week or day) as a "subdivided production system". This subdivision depends on the fact that the orders from the distributors arrive three times a month and seven days before the decade to which they refer (for simplicity in Figure 1, five days before the decade). On the basis of the decadal orders the daily sequence is revised.

At Toyota, the orders which their distributors send daily are also taken into consideration. These orders, defined as daily alterations, are sent by the distributors according to the effective client request (optionals). The daily orders are received four days before the vehicle comes off the line and are used to rectify decadal orders and to review production.

Finally, the method used by Toyota transforms, as the production period gets nearer, from a production programme to forecast into a production programme to order. The advantages are obvious: satisfaction of client requirements and reduction to zero of finished product stocks.

In conclusion, Monden's[4] observations are interesting. When, comparing Toyota's management with traditional techniques, he identifies the rigidity of the production programme as the main difference: the production programme

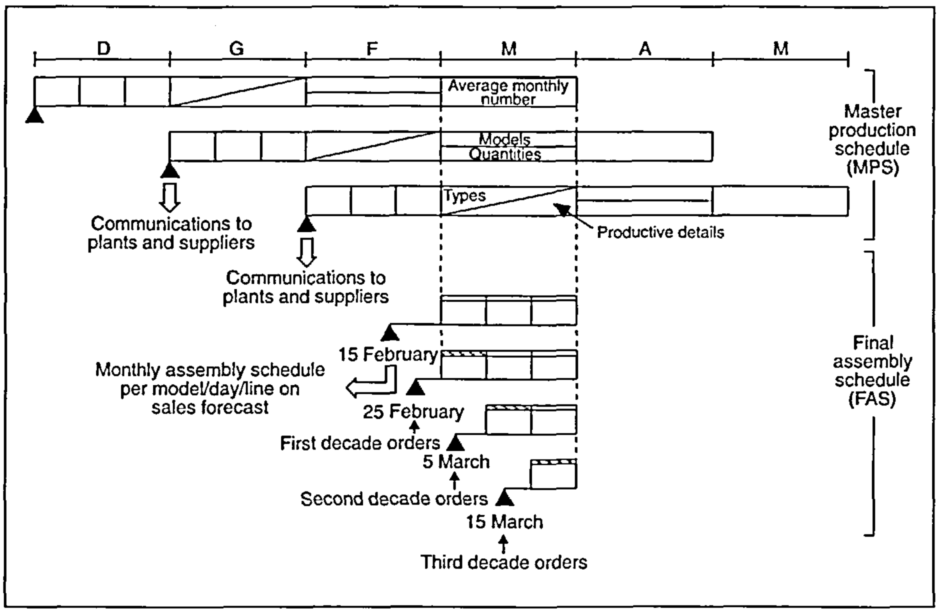

Figure 1.
Ways of Defining Production Programmes at Toyota: Growing Detail MPS and Lead Time Discretionalization

does not strictly limit production but represents a flexible scheme, where it is possible to organize, at plant level, both personnel and material purchasing.

If we consider manufacturing activities structured in the three subsystems of planning, inventory control and shopfloor control, unlike the classic system of MPS/MRP/Despatching applied in job-shops, the Toyota system is a model which we can define as MPS/Requirements Calculation/*Kanban* for upstream workshops[5, p. 712] and MPS/Requirement Calculation/Daily Rate for downstream assembly lines. The term "Daily Rate" will be explained in the next paragraph.

Planning and Control Activities in Repetitive Manufacturing

As seen in the Toyota example the MPS has as its aim elements which increase the degree of detail gradually as time goes on. For this reason we can define it as a "growing detail MPS".

The MPS in this case is defined three times: first, in order to define total product quantities, so that eventual modifications to production capacity can be made in time; second, in order to calculate the requirements of components with longer lead-times and, third, to calculate requirements of components with shorter lead-times.

Note that "lead-times discretionalization" has been carried out, that is the lead-times of the various components have been placed equal to one or two or at most three months, so that temporal increment is equal to the frequency with which production programmes are redefined. It is clear that a component with a lead-time, for example, equal to 1.5 months would be planned according to the plans for components with lead-times equal to two months. Therefore lead-times of components must be defined as multiples of the intervals between formulation of successive MPS.

Note also how the classic MRP procedure has been reduced in the example to a mere calculation of requirements. In fact starting with the MPS at the beginning of January and February, necessary quantities of components are calculated and ordered from suppliers or upstream plants. These orders in turn regulate deliveries of raw materials and components within agreements which the company and suppliers reached during the aggregate long-term planning or production plan.

Finally the final assembly operations are determined on the basis of a Final Assembly Schedule (FAS) with a daily production sequence of a mix of products[6].

In general, in repetitive manufacturing contexts the MPS, defined according to sales forecasts of finished products, is formulated with the so-called "cumulate" method[7,8]. If the number of finished products produced in the unitary period of time is very high, it is opportune, in order to keep the amount of information to be managed to a minimum, to define an MPS in cumulative terms usually on an annual basis. A scheme which exemplifies this concept is shown in Table I.

As can be seen, in the cumulate MPS the quantity of finished products to be produced is not planned according to period, but are defined in a cumulative manner from the beginning.

These few cumulate figures of the plan allow fast and efficacious evaluations of the evolution of production activities, as it is sufficient to compare them with effective production, also cumulate. The cumulate MPS represents a useful tool as its simplicity allows easy monitoring of the repetitive manufacturing activities characterized by a high number of produced parts.

Regarding assembly plans in repetitive manufacturing contexts, the FAS has in general a time-horizon equal or in a few cases greater than the assembly lead-time and is established consistent with the MPS. The FAS, formulated as late as possible, allows response to variation of demand, determining mix and daily production rates on assembly lines.

Definition of the FAS means the formulation of control orders and flow orders, as described below, instead of job-orders typical of intermittent manufacturing in job-shops.

The total quantities to be produced (for example, 10,000 finished products) in a period (for example ten days) are defined through so-called control orders. Flow orders, instead, are orders which, depending on the quantities in the control order,

Periods	1	2	3	4	5	6	7
Standard MPS	1,500	2,000	2,000	2,500	2,500	2,000	2,000
Cumulate MPS	1,500	3,500	5,500	8,000	10,500	12,500	14,500

Source: [9]

Table I.

specify the daily production quantities (in the example 1,000). The quantities specified for the different flow orders cannot assume arbitrary values, but must be consistent with the daily capacity characterizing the line. When products are produced according to the programme, they are automatically credited to the control order until the quantity to be produced is reached (in the example 10,000).

Automatic crediting of production to the control orders, for example through barcode reading, must always be carried out on the oldest (and therefore the nearest temporally) of the control orders open for that part. When a control order is completed, additional production of the part is automatically credited to the next control order, and so on. Working in this way, it is obvious that the control orders require the minimum quantity necessary for compilation and transmission of paper documents within the production area.

The uniformity of daily objectives ensures efficiency; every programme is defined so that it is similar to the previous one. These programmes, therefore, which define the quantity to be produced in a determined period, are the true regulators of repetitive manufacturing systems. The production rate and the flows of different materials through the plant are the objects of the control activity, rather than the completion of various orders, as in the job-shop: the objective to be attained is that of guaranteeing perfect synchronization in order to keep the established production rate constant.

The daily production rate of product mix, which we can define as the "daily rate", is thus established at the planning level. At executive level production is carried out according to the sequence defined – using the FIFO (first in first out) rule – and thus perfect identity between planned orders and machined orders is reached. In production the only managerial activities carried out are corrective measures on the basis of the real progress of operations.

The planning activity of Capacity Requirements Planning (CRP) becomes less important, if these planning methods are adopted. Flow production and the uniformity of production programmes means that it is easier to determine the load of the production system for each workstation. A careful balancing activity of the lines, which takes into account the different times of routeing operations of the different parts passing through, is sufficient. This differs from intermittent manufacturing, where the results of CRP lead to modifications, although limited, of production programmes.

Issue cards or other documents are not used to keep track of warehouse movements. Traditional operating control needs are less important, given the productive uniformity; issues are based on plans. The subassemblies at work stations along the line are never stocked in stores, but move continuously along the production flow.

In these production contexts normally only raw materials, eventual packing kits and finished products are stored in a centralized area, while purchased components are often not stored centrally but arrive directly on secondary or main lines, and are momentarily stored in dedicated areas or deduction points at the bottom of the line for fast access.

It is a situation similar to that of continuous process industries, where stock movements can derive directly from the analysis of production plans. The volume of transactions necessary to maintain the control of stocks is much less, compared with assemblies not in line. Periodic physical counts allow the checking of the data reliability. Consumption of raw materials and components, instead of being effected at the moment of issue, can be deduced by the output volume through the bill of materials. Scraps and reworks impose further data correction[10]. This technique, which allows ex-post construction of issues on the basis of part receipts is known by the term "backflushing" or "post-deducting"[11].

In a repetitive manufacturing environment, therefore, the usual distinctions between warehouse issue/receipt and shopfloor control are no longer valid, since warehouse movements are strictly connected to machining and it is not possible to intervene on the former without immediately involving the latter.

Regarding materials requirement planning, in the context of repetitive manufacturing, note that normally the MRP procedure, as in the Toyota case, is "reduced" to a simple calculation of requirements of raw materials or purchase components, with formulation only of purchasing orders and not production orders[12, pp. 35-8; 13]. In fact the components of intermediate levels of the bill of materials are not normally managed by warehouse (phantom components) and therefore their net requirements are not calculated in order to arrive at job-orders. The bills of material with phantom components at intermediate levels carry out the so-called flat bills, characterized by the direct finished product-raw materials link[14].

Figure 2 shows schematically distinctive characteristics of intermittent manufacturing in job-shop systems and repetitive manufacturing, according to the reading key of the three subsystems: planning systems, inventory control and shopfloor control. Shopfloor control includes priority assignment, issue/receipt and movement activities.

Shopfloor Control in Intermittent and Repetitive Manufacturing

Figure 2 shows the fundamental differences characterizing the production management subsystems for intermittent (job-shop) and repetitive (discrete lines) manufacturing.

The different contents of the activities carried out in the planning and control subsystems do not, however, emerge clearly. In order to reach a clear distinction between one subsystem and another in the two manufacturing contexts, it is necessary to examine the different activities which go on within Shopfloor Control (SFC).

Shopfloor control within the production management system has executive control of the production plans. Its task is to carry out that group of activities which orders released by the planning system require, while still respecting general instructions. It can therefore be said that the planning process on the one hand determines and fixes a series of objectives which make up the main input to the SFC and on the other hand plans the necessary resources for its working.

OM subsystems / Production categories	Planning	Inventory control	Shopfloor control
Intermittent manufacturing (job-shop)	• MPS • FAS with job-order formulation	• Multilevel bill of material • MRP with formulation of job-orders and purchasing orders	• Queues of materials at the machining centres • Production on the basis of the despatch list • Physical issue of materials and its registration on the basis of the picking list
Repetitive manufacturing (discrete lines)	• Growing detail MPS with lead-time discretionalization • Cumulate MPS • Mixed daily FAS with formulation of flow order (daily rate)	• Flat bill of material • Requirements calculation with formulation of purchasing orders	• Materials in areas or deduction points along the line • Production on the basis of daily rate (first in first out) • Physical issue of materials on the basis of the programmes • Registration of issues from the deduction points along the line by means of backflushing

Figure 2.
Distinctive Characteristics of Intermittent and Repetitive Manufacturing in the Three Management Subsystems

SFC is organized in the following classic activities, carried out in a sequential order[15]:

- order review and release;
- detailed assignment;
- data collection/monitoring;
- feedback/corrective action;
- order disposition.

The review and release of orders consists of a series of operations, before the opening of a production order, necessary for evaluation of order feasibility, through an accurate examination of available information. The aim of this is to make sure that the orders can effectively be completed within the planned dates. The measures which are carried out are based on acquisition of documentation about the order, checking the stocks for necessary materials, evaluation of the available capacities and load level. This latter operation is aimed at identifying eventual overloads on machining centres and their levelling-off, avoiding in this way an increase in work in progress and lead-time.

The second detailed assignment activity lies in the precise assignment of resources, that is materials, labour and machines, to the various orders competing for them. This leads to formulation of the despatch list, valid in the very short term, which defines for each centre the sequence of operations to be carried out, according to determined priorities. One of the most common priority rules is the critical ratio, defined as the ratio between the interval of time between today and the expected delivery date and the lead-time required for the remaining operations.

The third activity, that of data collection and monitoring is extremely important for SFC. It is fundamental for correct regulation of the operating system to have fast and up-to-date information, for example, regarding order progress, the current operation, the resource used, eventual delays, etc. Through reporting, these data are made available for consultation by the foreman, who can then take the most opportune corrective actions. The collection centres are generally placed along the key points of the production process, where the most significant operations are carried out, and where the data to be monitored can be:

- operation start;
- move reporting;
- scrap and rework reporting;
- operation completion;
- inventory receipt reporting;
- other types of reporting determined by company information requirements.

After data collection/monitoring comes the fourth activity of feedback/corrective actions. The previously collected information is now evaluated. In the presence of orders which do not conform to the production programme actions are taken in the very short term leading to variations of the plan. Obviously it is not always possible for SFC to overcome these difficulties autonomously; in this case a feedback operation informs the planning system of the situation.

The fifth and last activity of order disposition comes into play when the order has completed its final operation. The task of the SFC is then to modify the order status from open to closed and cancel it from the updated list of active orders. At this point SFC order management is finished, unless it is necessary to carry out reworks of some parts of the order.

In this last stage information about the closed order is recorded. This information is of crucial interest for such activities as cost accounting, cost planning and review of standard data used in planning of medium- and long-term capacities. This information contains, for example, the manpower hours used, machine hours used, scraps and reworks, etc.

These five SFC activities are carried out in very different ways in the two productive contexts: intermittent manufacturing (job-shop) and repetitive manufacturing (discrete lines) (see Figure 3).

In job-shop systems the central element around which SFC control revolves is the job-order. The materials are moved within the plant, grouped together in lots with a single order number, through which the SFC system is able to know at any moment the precise status of all the production activities and to follow the progress of the different lots through the operating units.

The order is transmitted to the SFC by the planning subsystem. The order review and release activity is immediately activated, followed by the activity of

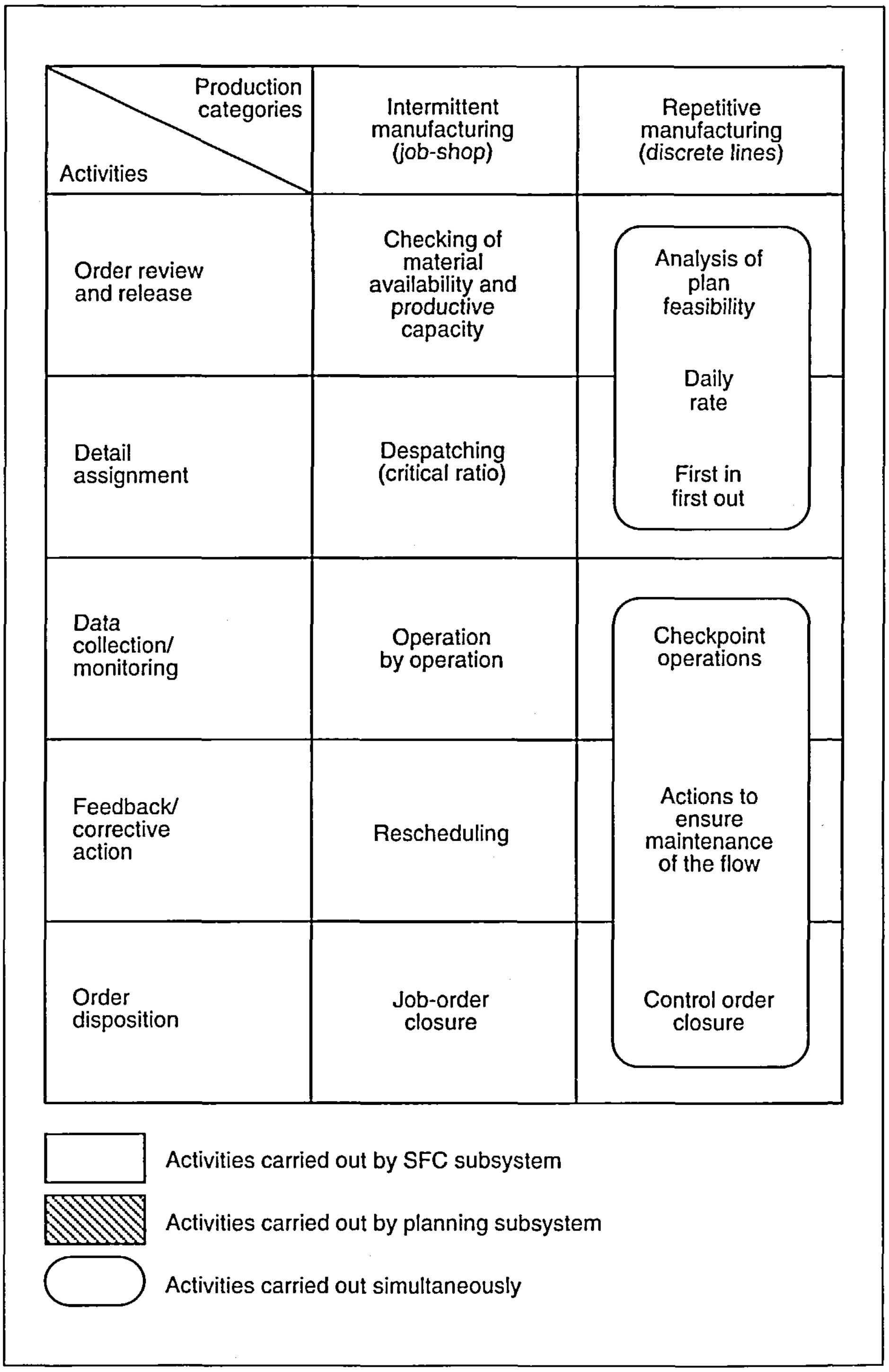

Figure 3.
Activities Carried out in the Planning and Shopfloor Control Subsystems and the Different Ways of Effecting Operations in the Two Production Contexts

detailed assignment, which, by assigning the resources to the order, determines the sequence in which the operations in the single machining centres will be effected (despatching). The data collection and monitoring activity provides information about evolution of the order status. In general a system for collection of working data uses an operation-by-operation-type method, where the data collection points are situated next to each operation. In this way a detailed photograph of the production system is obtained. Any problems which might emerge during lot progress are evaluated and resolved by feedback/corrective actions which can lead to rescheduling. Order disposition is carried out on completion of the job-order.

Vice versa in repetitive manufacturing materials move through the machining centres according to a continuous flow, not in predefined lots[16]. High volumes of finished products are obtained through operating units, the productive capacity of which is aimed at the production of a family of parts, and as a consequence machining routeings are relatively stable, with low throughput times and no queues. Within this scenario the fundamental objective of SFC is to control the uninterrupted flow of materials across the plant[17,18].

For these characteristics the first two typical activities of SFC – review and release of orders and detailed assignment – are not carried out by the shopfloor control subsystem, but rather by the planning subsystem. Formulation at planning stage by day and by line of the production mix to be carried out – previously called daily rate – substitutes the first two SFC activities. The definition of the daily rate, moreover, leads to contemporaneous instead of sequential carrying-out of the two activities.

The review and release of orders activity has been indicated in Figure 3 within the "daily rate" as analysis of plan feasibility, intending, by this term, verification of material availability and production capacity effected in the planning subsystem. Verification of material available and preparation of the picking list and other paper documents are no longer necessary at executive level. For raw materials, stocked in a central warehouse, issues to the lines are made on the basis of noted programmes and not on the basis of the picking list. Other materials are placed directly along the lines in dedicated areas or deduction points to allow a continuous feed of the flow[11]. The recording of the issues from the central warehouse and from these "warehouses" situated along the line occurs through the backflushing technique on the basis of the quantity of finished product receipts in the warehouse and product bill of materials.

For detailed assignment or despatching, the sequence of orders has already been established at the planning stage, and consequently the order released first on the line according to the First In First Out (FIFO) technique is machined first.

Data collection and monitoring techniques for repetitive and intermittent manufacturing differ. As production volumes in the former are high and throughput times are short, it is convenient to use the data collection method known as checkpoint operations, as an alternative to operation by operation. The collection centres are associated only with the most critical stages, with the key operations and the most significant events of the transformation process[19].

The checkpoint operations method compared with the operation by operation method leads to a redefinition of the cost-accounting system, no longer aimed at evaluating the efficiency of single operations but rather at the whole production process.

If repetitive manufacturing is characterized by even more favourable operating conditions (product simplicity and reduced range), it is possible to have an even simpler data collection system, which records only the order opening and closing: auto-open/auto-close[20]. This occurs when the flow speed is such that the throughput times are so short as to render any intermediate collection inconvenient.

Whatever the technique used for data collection, high volumes and short lead-times mean that the focus of control is on resources rather than orders. As a consequence precise data on resources used and levels of stocks in the different dedicated areas along the line are acquired, proportionate to the level of production control desired.

Collection and monitoring of data are carried out simultaneously with the last two activities of feedback/corrective actions and order disposition. The close connection of data collection/monitoring and feedback/corrective actions is because a group of machines arranged in a line is generally more vulnerable to breakdowns or sudden stops than a job-shop system: for this reason it is important to identify problems quickly and to take fast corrective actions to maintain the flow. The close connection between data collection/monitoring and order disposition derives from the high volumes in play and the low production lead-times which require immediate recording of the quantity of finished products at a given moment to be assigned to the last control order opened, eventually closing it when the prefixed quantity for the order has been reached.

Characteristics of Shopfloor Control in Repetitive and Intermittent Manufacturing

The five SFC activities in repetitive production systems are therefore carried out in quite different ways from those of intermittent systems, as can be seen in the scheme of Figure 3.

The different management techniques are characterized by the values of the following variables[15]:

- level of detail;
- decision-making latitude;
- time horizon of decisions;
- amount of uncertainty.

The first characteristic relates to the type of information and level of detail required by the SFC. While in job-shop systems SFC must know in detail data such as the order number, order quantity, bill of materials, machining routeings, etc., this information is not required in line production: it is the planning system which defines and manages the total information on the basis of standard routeings and bills of materials.

Decision-making latitude relates to the level of autonomy which foremen have during the control of production schedules. In repetitive manufacturing, once the production programmes have been determined and the daily production rate defined during planning, the task of personnel involved in SFC is only to guarantee maintenance of the production flow. Decision-making latitude is reduced: the situation is obviously very different from job-shop systems.

The third characteristic regards the time-horizon of decisions understood as the interval of time within which foremen must take a decision in the face of problems. Obviously, the more time at disposal, the more the impact of such decisions on the production system. In the case of flow production, decisions generally require a long time-horizon: choices involve aspects which are beyond the SFC environment and touch on objects typical of the planning activity, for example, definition of the line rate. Vice versa in job-shops the time-horizon is reduced and the decisions are taken in respect of short-term aspects, for example, determination of which machine is most suitable for a certain job at a given time.

The last characteristic, level of uncertainty, reflects the degree of indeterminacy of the context within which SFC activities are developed. The degree of indeterminacy can be expressed as the number of unexpected events to be faced during the executive stage. This number is very high in job-shops, given the vast range of manufacturable parts and the consequent routeing complexity. Conversely, in repetitive systems the variability of routeings does not allow much variation from what was established at the planning stage and as a consequence the amount of uncertainty is much less in SFC.

In Figure 4 the values assumed by the described characteristics are represented qualitatively.

Types of Plants Where Intermittent and Repetitive Manufacturing Is Carried Out

Here, in order to comprehend the different management techniques in repetitive and intermittent manufacturing, the characteristics of systems carrying out intermittent manufacturing (job-shops, parallel cells, sequence cells) and repetitive manufacturing (dedicated lines, multiproduct with successive production lines, multiproduct mixed lines) are briefly described. A more detailed description of these plants can be found in another article, where intermittent and repetitive manufacturing categories and the respective plants which utilize them are classified, showing the main differentiating elements[21].

Classic manufacturing systems, where intermittent production is carried out, are job-shops and cells. Cells, obtained through the group technology philosophy[22], are aimed at machining families of parts and are distinct from job-shops owing to their smaller production lots, less work in progress and shorter lead-times.

A typical cell production system presupposes that all the operations in the production routeing are carried out within each cell for the parts belonging to a determined family. The cells are parallel to one another in the layout of such a system, each operating independently of the others.

An evolution of this system consists in predisposing the entire transformation process to one family of products and in structuring it according to areas or technological cells, aimed at carrying out all the operations relative to a determined stage in the transformation process. In this case the cells are arranged according to complex combinations, which have a main branch with other auxiliary branches converging on it, with the possibility of by-passing entire cells. In order to distinguish this second type of production system from the previous one, we will use the terms respectively of sequence cells and parallel cells. The term sequence cells is used to indicate a production system made up of technological cells – each of which carries out a stage of the production cycle – arranged to focus the main direction of the production flow to favour the flow of materials.

In repetitive manufacturing, obtained through a line disposition of the operating units, the above class of dedicated lines determines the lines aimed at production of a single part requiring a sequence of predefined and constant operations.

The lines belonging to the second type – herein called multiproduct lines with successive productions – are generally dedicated for one or more days to the production of a single product. Once the quantity defined in the production schedule is reached, the line is dedicated to another product. The entire line needs to be reconfigured between one product and the next.

Finally the third class is that of mixed multiproduct lines, where it is possible to carry out operations on various parts, belonging, however, in this case to one family. Thanks to greater line flexibility the quantities of single parts passing through the line are drastically lowered. The line is equipped with machines and movement systems able to adapt quickly and easily to the different parts passing through it. In this way it is possible to produce in the short term a mix similar to that required in the medium term (micro mix = macro mix), reaching a balance between the outgoing product flow and market demand.

Proposal of a Conceptual Interpretative Framework of the Characteristics Distinguishing Intermittent and Repetitive Manufacturing

Job-shops and discrete lines present, within discrete production, two system types characterized respectively by the minimum and maximum value which can be assumed by the variable "degree of repetitivity", understood as the time between successive units[23].

With regard to intermittent manufacturing, starting with a job-shop system, an increase in the degree of repetitivity through product and process standardization leads to an evolution, first towards parallel cell production systems and then to sequence cell systems.

In the case of repetitive manufacturing, starting with mixed model lines, standardization leads, first to successive production lines, then to dedicated lines[24].

In the previous paragraphs the different ways of carrying out SFC activities were compared with reference to job-shop systems and line systems, that is systems characterized respectively by low and high degrees of repetitivity; the comparison is shown schematically in Figures 2, 3 and 4.

In job-shop floor control, the typical technique is known as Despatching. This term has been attributed with a wider significance than that understood up to now, and includes all SFC activities represented in the first column of the matrix in Figure 3.

The shopfloor control technique typical of lines has been defined as the "daily rate". Also in this case the term has a wider significance than that usually understood and includes the group of all the SFC activities represented in the second column of the matrix in Figure 3.

In contexts characterized by intermediate degrees of repetitivity between the typically low value of job-shops and the very high value typical of lines, other shopfloor control techniques are applicable, such as the Synchro-MRP, developed at Yamaha[25] and the famous *Kanban* introduced at Toyota[4].

Figure 5 shows a matrix which specifies for each of the four SFC techniques mentioned (Despatching, Synchro-MRP, *Kanban*, Daily Rate), the reference production category (intermittent or repetitive), the degree of repetitivity of the manufacturing context in which it is convenient to apply such techniques (respectively low, medium, high or very high), and finally the production release methods, which lead to definition of the machining sequence in the operating stations. Production release occurs in different ways and precisely:

- on the basis of production programmes, that is on the basis of priority rules like the critical ratio in despatching;

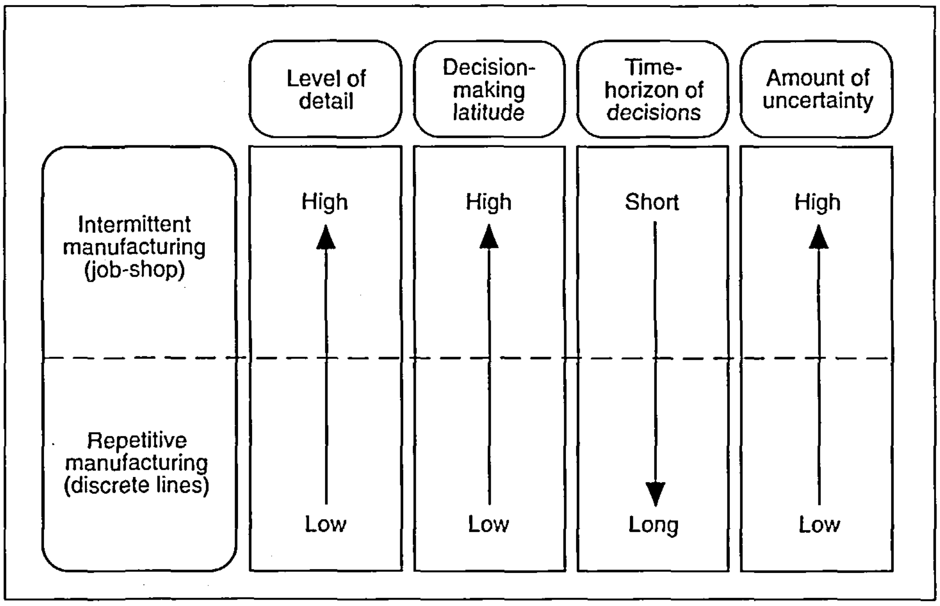

Figure 4. Characteristics of Shopfloor Control Variables in the Two Considered Productive Contents

Variables \ Shopfloor control techniques	Despatching	Synchro-MRP	Kanban	Daily rate
Productive categories	Intermittent manufacturing			Repetitive manufacturing
Degree of repetitivity	Low	Medium	High	Very high
Order release	On the basis of production programmes (priority rules)	On the basis of downstream consumption and production programmes	On the basis of downstream consumption	On the basis of production programmes (first in first out)

Figure 5.
Productive Categories, Applicative Contexts and Order Release for Various Shopfloor Control Techniques

- on the basis of downstream consumption and production programmes in Synchro-MRP; in this case the downstream consumptions are regulated by Synchro II cards situated in the relative rack, while production programmes are effected through the classic Despatch List, which in this situation carries out only production authorization functions[25,26];
- on the basis of downstream consumption in *Kanban*, regulated through *Kanban* production cards, situated in the relative rack;
- on the basis of production programmes, that is according to the First In First Out (FIFO) sequence in the Daily Rate.

We wish to specify that in repetitive manufacturing the Daily Rate, even if developed within the planning subsystem, as indicated in Figure 2, covers the two activities of order review and release and detailed assignment typical of the SFC subsystem as indicated in Figure 3. If, moreover, the Daily Rate is understood not only as an order review/release and detailed assignation activity, but also as an activity for data/monitoring collection, feedback/corrective actions and order disposition, it is correct – from a methodological point of view – to put Daily Rate on the same plane as classic techniques belonging to SFC, such as Despatching, *Kanban* and Synchro-MRP.

In production systems, therefore, the choice of the most appropriate SFC technique is not reduced to the alternative between the technique typical of job-shops – Despatching – and the technique typical of highly repetitive manufacturing – but also includes Synchro-MRP and *Kanban*.

In highly repetitive environments, for example downstream assembly lines, management techniques such as the Daily Rate can be chosen, while in upstream productive workshops management techniques such as *Kanban* or Synchro-MRP can be chosen. *Kanban* techniques generally simplify synchronization between assembly on the main downstream line – scheduled according to the Daily Rate – and production plants such as parallel or sequence cells aimed, like secondary lines, at feeding the main line[27].

A synthetic and schematic description of the different characteristics of the four shopfloor control techniques is shown in Figure 6. For further information on the subject see the existing literature [3,4,25,28,29].

Figure 7 shows a scheme which summarizes the synthesis of Figures 2 and 5. The scheme represents an interpretative conceptual framework, which constitutes a reading key to the differences in management of the two main manufacturing contexts – intermittent and repetitive manufacturing – within the three basic production control subsystems: planning, inventory control and shopfloor control.

Note how within the subsystem shopfloor control the four specified SFC techniques are shown with the relative degree of repetitivity.

Within the inventory control subsystem observe how, with respect to Figure 2, the use of MRP in intermittent manufacturing is provided for in a simplified way defined as Requirements Calculation. It is in fact possible to use flat bills also in intermittent systems and to use MRP only to calculate material needs. This occurs, for example, when production and movement management within the entire production process is carried out using *Kanban*, while MRP is used only for purchase order formulation.

Regarding the planning subsystem, the term, growing detail MPS, refers to the Toyota model, where the objects of MPS are the elements which increase the degree of detail gradually, as time progresses, while the term, mixed daily FAS

Characteristics \ Shopfloor control techniques	Despatching	Synchro-MRP	Kanban	Daily rate
Work in progress	Queues of materials upstream of the machining centre	In standard containers upstream and downstream of the machining centre	In standard containers upstream and downstream of the machining centre	In areas or deduction points along the line
Machining priority assignment	Despatch list	– Despatch list – Rack with synchro II productions cards	Rack with Kanban production cards	First in first out
Issue and registration of materials	Picking list	Synchro I cards for movement from first centres	Kanban cards for movement from first centres	• Material issue on the basis of the programmes • Ex-post registration in backflush
Material handling	Lot movement on operation completion	Movement of standard containers on request of downstream centres by means of *synchro II* movement cards	Movement of standard containers on request of downstream centres by means of *Kanban movement* cards	Piece movement in a continuous flow

Figure 6. Different Characteristics of Shopfloor Control Techniques

OM subsystems / Categories of production	Planning	Inventory control		Shopfloor control
Intermittent manufacturing	• MPS • FAS with job-order formulation	MRP (multilevel bill of material) or requirements calculation (flat bill of material)	Low repetitivity	Despatching
			Medium repetitivity	Synchro-MRP
			High repetitivity	Kanban
Repetitive manufacturing	• Growing detail MPS with lead time discretionalization • Cumulate MPS • Mixed daily FAS with formulation of flow order (daily rate)	Requirements calculation (flat bill of material)	Very high repetitivity	Daily rate

Figure 7.
Conceptual Interpretative Framework of the Characteristics Distinguishing Intermittent and Repetitive Manufacturing

with flow order (Daily Rate), refers to the definition of a daily rate of the productive mix per assembly line, through flow order instead of job-order formulation. Finally it is important to stress how ways of defining the MPS and the FAS according to repetitive logic are possible even in production systems characterized in just a few productive stages (for example assembly) by very high degrees of repetitivity. In fact in the case of Toyota, production in the upstream fabrication workshops is carried out according to intermittent production in lots regulated by *Kanban* cards.

Conclusions

In this article about planning and control systems of repetitive manufacturing the authors have described the management characteristics of repetitive manufacturing by stressing the production logic compared with that of intermittent manufacturing. The concepts of growing detail MPS, lead-time discretionalization, cumulate MPS, mixed daily FAS with flow order, Requirements Calculation with flat bills and Daily Rate were developed in particular.

A further analysis of the shopfloor control subsystem in the intermittent and repetitive contexts distinguished the activities carried out within this subsystem from those carried out in the planning subsystem. In this way it was possible to compare techniques like Despatching, Synchro-MRP, *Kanban* and Daily Rate, defining the applicative contexts according to the degree of repetitivity.

Finally, it was possible to reach a proposal of an interpretative conceptual framework, which constitutes a reading key for distinguishing differences in management in the two main manufacturing contexts – intermittent and repetitive manufacturing – within the three basic production control subsystems: planning, inventory control and shopfloor control.

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