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REPETITIVE MANUFACTURING MANAGEMENT INFORMATION SYSTEMS

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In this paper the main functions that characterise a repetitive manufacturing management information system are looked at in relation to those of an intermittent manufacturing management information system, using a conceptual framework based on the three basic production control subsystems: planning, inventory control and shop floor control. Among the most important functions of a repetitive manufacturing management information system when compared with that for intermittent production are: the master production schedule with "control orders" versus "work orders", access key to information by "part number" versus "work order", picking lists for "floor stocks by daily rate" versus "work centre by work order", resources and materials consumption by "backflushing" versus "work order", movement "without record" versus "record at work centre".

INTRODUCTION

This paper on repetitive manufacturing management information systems offers an in depth study of the results of research carried out on a broader theme, that of the operational characteristics and management logic of repetitive manufacturing production systems compared with those typical of intermittent manufacturing.

In an earlier study on repetitive and intermittent production systems [1] the authors proposed a classification of production categories and of their respective classes of production plants, and also identified various categories of plant used for repetitive manufacturing. The fundamental elements that differentiate intermittent manufacturing systems from repetitive systems were also described.

In a second article [2] the authors proposed a matrix of the applicative contexts of production plants which carry out intermittent and repetitive manufacturing. They also analysed the effects of both an increase in annual total production volume and of simultaneous product-process actions on modifications in the operating conditions that require new choices in terms of plant.

In a further article [3] the authors examined the operational characteristics and management logics of repetitive production systems and offered 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 shop floor control.

This article examines the ways in which information systems for repetitive manufacturing contexts are designed and used.

This subject is of particular interest insofar as the structural-logical model on which packages for the management of repetitive manufacturing has not yet

been consolidated. There are still very few packages for the support of repetitive manufacturing available on the market today, and often those that are available have not been derived from specific organic designs, but are the fruit of adaptations and/or extensions of packages originally designed for intermittent manufacturing systems (job shop).

Examination of the characteristics of repetitive manufacturing management information systems is carried out through a framework based on the three basic production control subsystems: planning, inventory control and shop floor control. The aim is to propose a conceptual interpretative framework that will provide a reading key to the new software functions that an information system must be able to offer for the planning and control of repetitive manufacturing.

In order to better understand both the main operational problems and the information tools that may solve them, there follows a brief description of the principal functioning characteristics and management logics of repetitive manufacturing systems as compared to intermittent ones.

REPETITIVE MANUFACTURING MANAGEMENT

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

The Master Production Schedule (MPS) has products, components or functional groups as its object and it is composed of a collection of production orders defined by time period usually equal to multiples of weeks or decades.

The product bill of materials (BOM) used in job-

shop systems is usually multi-level. After formulation of the MPS, the MRP procedure generates both job (or work) orders and purchasing orders. In order to obtain the final product, materials have to be issued and received from and by the stores and this requires accurate registration of numbers proportional to the levels of the BOM.

The work order is the fundamental instrument for the regulation of the entire production process as it enables a lot, moving through the various workshops on the different machine tools, to be accurately identified.

Warehouse issues are done using a picking list which is automatically generated by the information system for each work order. The accounting records of the materials, issued from the warehouse and sent to the various work centres, is carried out in concomitance with issuing. Moreover, the work order, by registering the evolution of lot life during its passage through the various phases of the production process, is the only means of providing cost analysis, analysis of deviation from standards and of monitoring the level of Work In Progress (WIP). In this latter case the movement of a lot from one i -th centre to the next $i+1$ -th centre usually entails the simultaneous registration of the unloading (from the i -th centre), the movement (from the i -th centre to the $i+1$ -th centre) and the loading (onto the $i+1$ -th centre) of the WIP.

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

Production management in these situations is characterised by its holistic vision of the production system: the focus is put on the entire system rather than on each individual production unit. The aim is to obtain as continuous and uniform as possible a flow of materials through the factory from the beginning to the end of the production process [4].

In order to create a flow, a dynamic balance must be both reached and maintained, within the production process, since the lead times, through each centre, of products of the same family passing along the same line are not the same.

Planning plays a vital role here in ensuring regular production flow by defining programmes which are as uniform as possible within operational limits.

In more advanced situations, production planning is developed at a variety of levels with a logic of increasing detail. The following are defined:

- a long term production plan (one year) which by taking sales forecasts into account determines the number of "average" products that are to be produced within each three or four month period;
- a medium term master production schedule (three or four months) which defines the quantities, models and production details for each month of the three or four month period;
- a short term (one month) final assembly schedule

that indicates the daily quantities, per model, that are to be assembled on the production lines. In other words, the assembly plan defines the precise sequence in which the models move along the assembly line each day, over the one month period.

Thus the object of the Master Production Schedule (MPS) is to include elements that gradually increase the degree of detail over time.

Moreover, in repetitive manufacturing, the MPS is formulated using the "cumulate" method [5] [6]. In the cumulate MPS, the quantity of finished products that are to be produced is established in cumulative terms from the outset. These sparse cumulative figures in the plan allow fast and effective evaluations of production activity to be made, as they only have to be compared with finished production figures which are also cumulative.

Final assembly operations are determined on the basis of a Final Assembly Schedule (FAS). The FAS usually has a time horizon equal to, or greater than, the assembly lead time and schedules the daily mix and rate of production on the assembly lines [7].

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 in a given time (e.g. 10,000 finished products in 10 days) are defined through control orders, whereas flow orders specify daily production quantities with reference to the control order (in this example, 1,000 per day). The quantities specified in the different flow orders cannot be arbitrary, but must be consistent with the potential daily capacity of the line. When products are produced according to the programme they are automatically accredited to the control order until the quantity it specifies has been reached (in this example, 10,000).

Clearly, because of the way the control order system works, a minimum amount of paper work, compilation and transmission of documents within the production area is required.

Thus, these programmes, that specify the quantity to be produced in a given time period, are the true regulators of repetitive manufacturing systems. The production rate and the flows of different materials through the plant are the real focus of control activities and not the completion of the various orders as in the job-shop system. In repetitive systems, where production volumes are high and throughput times low, the work order, the traditional control system typically used in job-shops, is difficult to use as it makes it almost impossible to obtain detailed information about the state of the various jobs on the line.

As regards material requirements planning within repetitive manufacturing, it should be noted that MRP procedure is "reduced" to a simple calculation

of requirements for raw materials or for components to be purchased, thus only purchasing orders, not production orders, are issued [8]. The components of intermediate levels of the bill of materials are not normally managed at the warehouse level (phantom components) and calculation of net requirements for them is not used. Bills of material with phantom components at intermediate levels, enable the so-called flat bills to be drawn up. These are characterised by a direct finished product-raw materials link [9].

In repetitive manufacturing, a different method is used to control movements along the line from that used in intermittent manufacturing.

The quantities of the various materials that flow to the main lines are specified on daily production programmes (flow orders) and not according to precise requirements stipulated on a picking list defined by part number. The need for traditional controls is less important given the uniformity of production; issuing is based on plans. The sub-assemblies at work stations along the line are never held in stores but move continuously along with the production flow, thus issues and receipts do not have to be recorded.

Usually, in these production contexts, only raw materials, packing kits and finished products are stored in a centralised area. Purchased components are rarely stored centrally but arrive directly at secondary or main lines and are temporarily stored in special areas or floor stocks at the bottom of the line for fast access. The movement of materials between the store and floor stocks is regulated by a picking list which, see below, is no longer drawn up on the basis of work orders, but rather is defined by

floor stocks on the basis of the daily production rate. The rate of consumption of raw materials, components and resources, rather than being measured at the moment of issue, can be deduced from output volume through the bill of materials and production routings. This technique, which permits retrospective calculation of issuing on the basis of part receipts, is known as "backflushing" or "post-deducting" [10] and requires the preliminary choice of "pilot operations" on the line where recording will take place.

These observations regarding the management of repetitive manufacturing systems in comparison with intermittent systems, are represented schematically in the framework shown in Figure 1. This framework will be used in order to study the characteristics of information systems for the management of repetitive manufacturing.

We shall now present the main software functions that must be available in an information system for repetitive production contexts, regarding each of the three sub-systems of production management: planning, inventory control and shop floor control (see Fig. 1).

It is important to operate with software functions able to direct a production process whose most important characteristics are the speed at which materials flow through the plant and the high volume of production.

This analysis is not intended to be an exhaustive study of all the technical aspects of a repetitive manufacturing management information system, but it does however seek, through description of the fundamental functions, to offer a framework of reference.

OPERATION MANAGEMENT SUBSYSTEMS CATEGORIES OF PRODUCTION	PLANNING	INVENTORY CONTROL	SHOP FLOOR CONTROL
INTERMITTENT MANUFACTURING	<ul style="list-style-type: none"> - MPS WITH WORK ORDER - WORK ORDER FOR EVERY PERIOD (DECADE, WEEK, MONTH) 	<ul style="list-style-type: none"> - MRP - MULTILEVEL BILL OF MATERIAL 	<ul style="list-style-type: none"> - WORK ORDER AS PRINCIPAL KEY TO OBTAIN INFORMATION - PICKING LIST FOR WORK CENTRES BY WORK ORDER - WAREHOUSE ISSUES ON THE BASIS OF QUANTITY RELEASED TO THE FIRST WORK CENTRE - RECORD OF MATERIAL MOVEMENTS AMONG WORK CENTRES - RESOURCE CONSUMPTIONS BY WORK ORDER
REPETITIVE MANUFACTURING	<ul style="list-style-type: none"> - MPS WITH CONTROL ORDERS - DAILY PRODUCTION RATE WITH FLOW ORDER - CUMULATE MPS 	<ul style="list-style-type: none"> - REQUIREMENTS CALCULATION - FLAT BILL OF MATERIAL WITH PHANTOM CODES 	<ul style="list-style-type: none"> - PART NUMBER AS PRINCIPAL KEY TO OBTAIN INFORMATION - PICKING LIST FOR FLOOR STOCKS ON THE BASIS OF DAILY RATE - WAREHOUSE ISSUES OF RAW MATERIAL AND COMPONENTS ON THE BASIS OF QUANTITY OF FINISHED PRODUCT RECEIPTS (BACKFLUSHING) - RECORD OF MATERIAL MOVEMENTS FROM CENTRAL WAREHOUSE TO FLOOR STOCKS - RESOURCE CONSUMPTIONS BY WORK CENTRE

Figure 1 — The conceptual framework used for the analysis of the characteristics of repetitive manufacturing information systems.

THE PLANNING SUB-SYSTEM

The final objective of the planning process is the translation of the production plan, defined at the level of families of products, into the master production plan defined at the level of the single products/sub-assemblies. In intermittent production this is done through the definition of production orders and, in repetitive production, through definition of the daily rate of production.

In intermittent production systems the master production schedule is made up of orders formulated on a weekly basis that are then passed on to the MRP procedure with the aim of formulating a time-phased plan for materials.

In repetitive production systems, the classic MPS uses Resource Requirements Planning and Rough Cut Capacity Planning techniques for long and medium term planning. However here, unlike in intermittent production, the quantities planned at the weekly or monthly level, must be revised before being released to the shop, so as to formulate daily programmes which will allow the lines to be correctly balanced, by taking into account the diverse throughput times of the different codes that pass along them.

Figure 2, taken from the literature [11], illustrates the above. One can see that, even in the repetitive context, Capacity Requirements Planning (CRP) can be used in order to plan for capacity requirements. In any case it is clear that flow production and the uniformity of production programmes make it easier to determine the load on the production system for each work station.

The need to arrive at a new formulation of an MPS based on daily quantities so as to ensure regularity of production flows, by preparing programmes that are as uniform as possible, means that new functions must be made available by a production information system within the MPS module.

These new functions should, on one hand, allow a plan for daily quantities to be formulated, one which

is based on formerly set weekly or monthly quantities, and on the other, should offer the possibility of updating this plan in the face of the progress of daily production on the line. As we shall see, this latter aspect means that there is a need to generate reports that allow production to be monitored by part number and/or work station and not by work order.

As regards the first point, once a software function that we have named the "daily production plan" has been called up through the part number, the system suggests the total quantity that should be produced for each period (usually a week) defined by MPS control order. Thus the planner introduces the single daily quantity (flow order) based, as mentioned above, on the need to balance the lines. If, for a specific period of time, no variation in the daily quantities to be produced are needed to balance the lines, then the planner will be saved from having to put a large amount of data into the system. In this case, an automatic method for sub-dividing the control order, by averages, for that specific time period, can be used.

Once the daily production plan has been formulated on the basis of flow orders, before it is put into action, an accurate feasibility check must be run on it in terms of both materials and available resources.

A check on material is also carried out in intermittent systems, but in the repetitive system, the fact that there is no work order means that innovative software functions must be obtainable to show, by part number and not by work order, those material requirements that are not covered by the quantity available.

To check on available production capacity a second type of function must exist which, for a given time period, can highlight the daily workload of the various work centres, as specified by the daily plan and not by work orders.

Once the daily plan for a specific period has been checked and become active, those functions that permit total visualisation, either by part number or

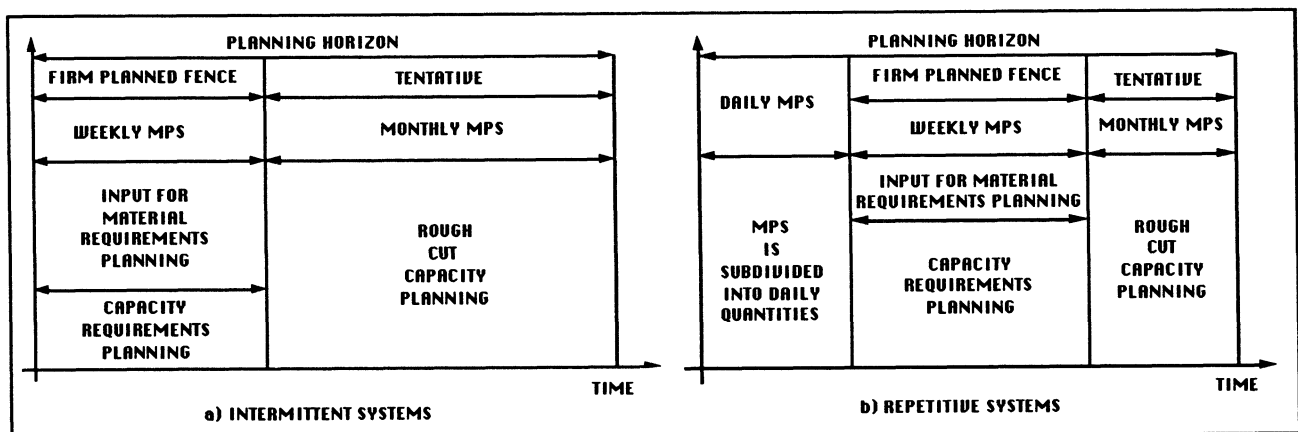


Figure 2 — Relation between MPS, RCCP, MRP and CRP in intermittent and repetitive systems.

by work centre, of the actual state of production are fundamental. Such functions must also allow the production plan to be represented through a "cumulative" method as was described above.

INVENTORY CONTROL

Once the daily production plans have been defined (through flow orders) then it is of fundamental importance that they are aligned with the material requirements plan, already drawn up on the basis of control orders, because materials must reach the line on the basis of daily consumption and not on the basis of weekly or monthly orders. The correct inputting of materials and components at the right places on the line is crucial if the flow is to be maintained.

As already stated, planning for material requirements takes place through an MRP procedure which effectively becomes a simple calculation of raw material or purchased component requirements. A purchasing order is drawn up, and not a work order. The high speed at which materials move along the line means that the components at the intermediate level of the bill of materials cannot be managed at the warehouse, thus, the classical calculation for determining net requirements in order to define planned orders is not done for them. Flat bills are needed to operate by this method. These may be built up using the so-called phantom components which can be defined through the insertion of a new field, with a special flag, within the structure of the record used to memorise data relating to the components. During elaboration of the plan of materials the flag will inform the MRP procedure if the components under examination are phantoms as these do not require planned orders.

As has been said, line production require that the materials are available at special points or areas at each work station along the line. In order to guarantee optimum management of the materials held in these floor stocks, new software functions must be available which are able to operate on the basis of the material requirements that derive from the daily production programme.

A basic type of report, used by warehouse operators even daily, outlines the list of materials that should be sent to the line in order to ensure it is fed correctly. On the basis of quantities planned for in the daily production programme, the report notes the components and their quantities, that should be withdrawn from the central stocks - which are normally subdivided by supply locations - and sent to the floor stock locations along the line.

However, in order to optimise management of the material movements within the plant, the "opposite" information may well be necessary, that is which materials are required in each floor stock location in order to ensure correct feeding of the line. This

second type of report shows, for a specific period and a specific floor stock, all the raw materials and components necessary to maintain the flow of production and includes details of the supply location from which the materials must be withdrawn. In this way, the number of consignments of materials to the same place on the line is minimised and their routes rationalised.

When materials are sent from the supply location to the floor stock location the information system must be told. In order to minimise the number of transactions that have to be put into the system (given the high volumes involved) it is important to use software functions which facilitate the rapid registration of such movements. We have used the term "movement" and not "issue", because in repetitive systems warehouse issuing are automatically updated by backflushing (see below).

Starting from the daily plans, the function that registers movements suggests the materials and their quantities that must sent to the line, from supply locations to floor stocks. If the quantities actually withdrawn from the supply location coincide with planned requirements, then only a simple confirmation is needed in order to quickly record all movements that have taken place. If on the other hand some materials are withdrawn in different quantities (greater or smaller) than was planned for, then this can be expressly noted.

SHOP FLOOR CONTROL

In repetitive systems, unlike in intermittent systems, materials do not move along the production lines in pre-defined lots, but pass in a continuous flow through the machining centres as single pieces with low throughput times and no queues.

Thus, in a repetitive manufacturing environment, the usual distinctions between warehouse issue/receipt and shop floor control are no longer valid, because warehouse movements are closely tied to machining and it is not possible to intervene on the former without immediately involving the latter.

The intermittent production process essentially takes place in three macro-stages: 1) checking and receipt of purchased materials into the initial warehouse, 2) withdrawal of materials and management of Work In Process (WIP), 3) receipt of finished products.

The repetitive production process is based on two macro-stages: 1) receipt of purchased materials in supply locations or directly into floor stock locations along the line, 2) receipt of finished products. The high volumes involved and the low throughput time call for materials to be available that do not need to be checked on entry but which are guaranteed by the supplier (Figure 3). The situation in which components move directly along the line with no further registration of receipt and issue is called Raw Material In Process (RIP) [12].

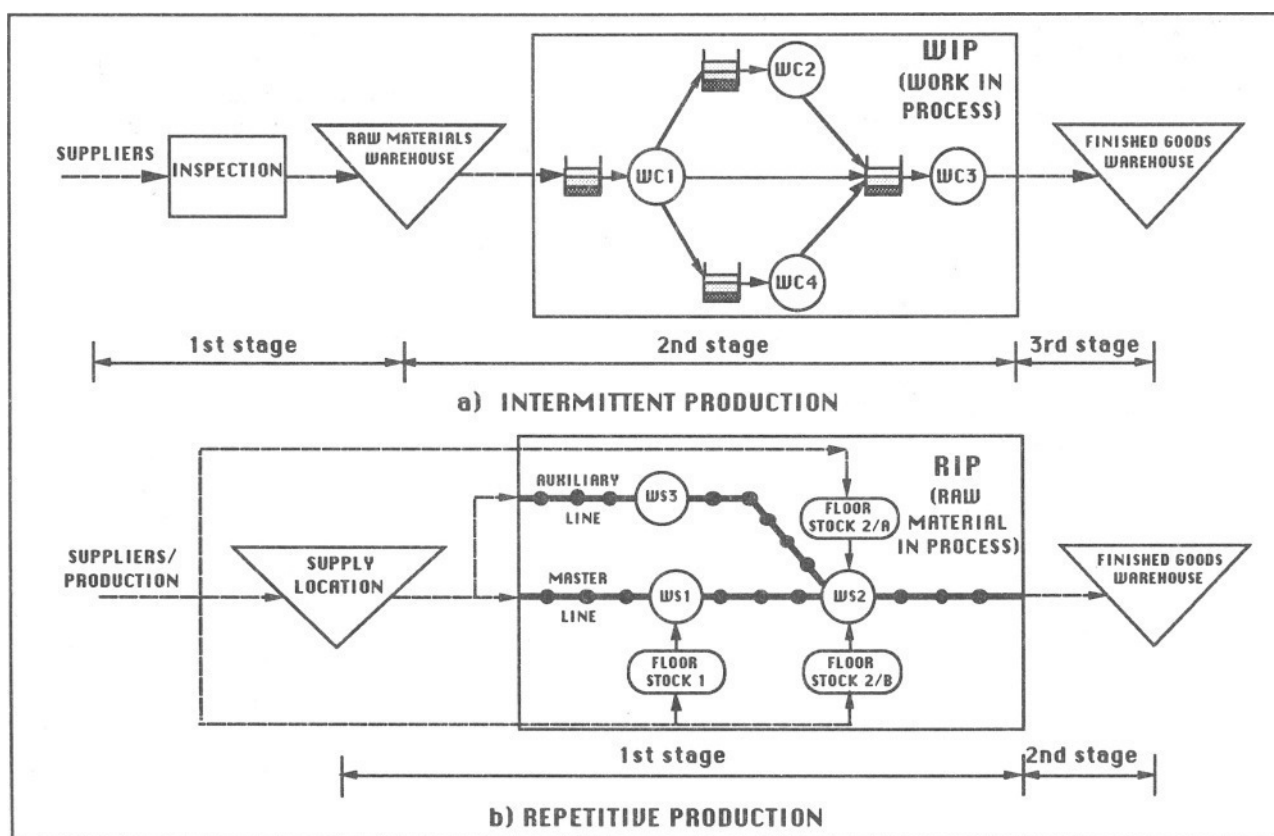


Figure 3 – Intermittent versus repetitive production.

The fundamental objective of SFC system is to control the uninterrupted flow of materials through the plant [13]. The control and registration of production details cannot be carried out using traditional methods because it would be too expensive and not practicable. The basic need here, is to attain a high degree of simplification.

Given this, only the most critical phases, the key operations and the most important events are subject to control. This means using the data collection method known as "checkpoint operations" instead of the "operation by operation" method typical of job shops. Thus a number of key points must be selected at which to collect data both regarding the quantities produced daily and the materials and resources consumed.

This method makes it possible to minimise the number of transactions that have to be recorded into the information system thus making data entry much easier. If the backflushing technique is also used to automatically update the floor stocks and supply stocks issue, then all activities regarding the control of flows are greatly simplified.

Clearly, the possibility of operating by the method described above is inextricably tied to the use of software functions that are not usually included in traditional packages. The absence of a work order requires that information about production events must be gathered by work centres and by part

number. The individual work centres are the cardinal points of shop floor control; the new control and reporting functions record the progress of production using data gathered by them.

Data on finished products

One example of a new software function is represented by the visualisation, once the work centre has been specified, of all the components, with their relative planned production quantities, that have one or more operations scheduled on that day in that centre. The operator can tell the information system how many pieces have been made without having to refer to work orders.

Data on scraps

Analogously data regarding scraps is also gathered at the work centre and not through work orders. After having selected the work centre, the operator only has to specify the part number of the component that has been processed and total up the scraps obtained.

Data on consumption

The method used for recording the consumption of resources (labour and machine hours) is similar to that used for data collection on the finished products and scraps and operates without any reference to the work order. The operator specifies the work centre and the part number and from this obtains the

relative planning data for that component, or rather, obtains the sequence number of the operations that are carried out by that work centre. He also obtains the standard data both for set-up and run times. At this point only data relating to actual consumption of resources needs to be inserted and these are memorised in order to be used as a reference in future activity, for example during the Resource Requirements Planning phase.

Choice of Checkpoints and Backflushing Technique

In repetitive production the traditional needs for control are not felt so strongly because each workshop and every work centre tends to take the same parts according to its role within the whole process and to carry out the same operations. Thus the routings are fixed. This is why the software functions described above are only carried out at certain key points of the production process, where "visibility" is necessary (such as at the end of the line) and not in all the different phases.

A variety of factors are taken into account when selecting checkpoints along the line. It is common practise to prioritise those centres that are at a point where the line branches, or those where particularly complex operations that do not adhere to standard resource requirements are carried out, or those where especially valuable components are used.

In these cardinal points, control and data collection is direct and immediate (i.e. with direct communication from the operator involved in production), while it is indirect (ex-post) at other points along the line. Data collection regarding all consumption of raw materials and components, is not effected at the moment of consumption rather it is extrapolated from the volume of output (using data on the bill of materials and the production routings) by means of the backflushing, or "post deducting" technique.

Backflushing functions through the mechanism represented in Figure 4. By recording the quantity of product X as it passes the end of the line, and with

knowledge of the deduction list associated to each key points (which is obtained by integrating information contained in the bill of materials and in the production routing), the system will automatically update the quantity of:

- finished products X received in the warehouse;
- components A, B and C respectively in the floor stocks (\bar{A}), (\bar{A} , Ω , ζ) and (Ω , ζ).

For example, if 2,000 pieces of X are produced each day, then, 2,000 pieces of component A, 12,000 pieces of component B and 12,000 pieces of component C will be issued from floor stocks each day.

Central stores always uses the backflushing technique when issuing those materials that are not stored directly along the line, but which have been initially sent to one or more central stores and only later forwarded to centres on the line. This fits with an earlier point made here, which stated that only movement and not withdrawal is registered when materials are sent from the supply location to the floor stocks.

In such a system, the evolution of the stock levels becomes a dynamic representation of production activity.

What is special about backflushing is its ex-post characteristic: the components are "consumed" only after the products has been received and not vice versa. This is in fact the only truly practicable method, given the low throughput times in repetitive production.

To apply the backflushing technique correctly the following factors must be accurately defined:

- the points on the line where direct control is required; these are defined as key points or "Milestone Operations" [14]. The backflushing procedure involves all the upstream centres back as far as the preceding key point.
- the so-called deduction lists, one per key points defined in the production process, for each product made on the line.

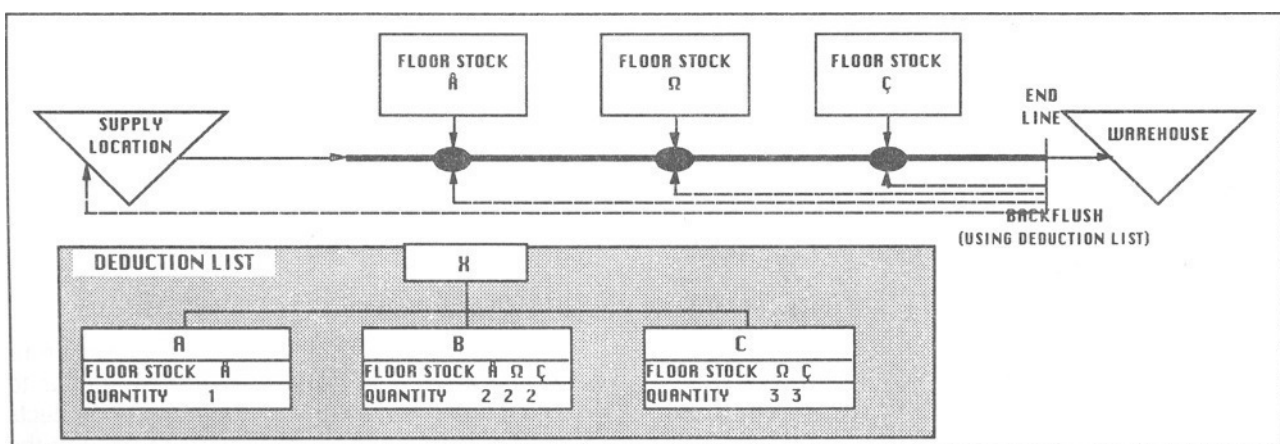


Figure 4 — Backflush technique and deduction list.

Knowledge of the deduction list is fundamental for the backflushing procedure. A "background" software technique is usually used here instead of a real time or batch technique when a certain number of units of a specific product have been completed at a Milestone Operation.

When there are some Milestone Operations in the line backflushing can only take place if the system knows the exact quantities of materials and components consumed and the respective stock points for all the operations between two Milestone Operations. This information is what we have defined as the "deduction list" for that particular Milestone Operation within which the backflushing process is primed.

CONCLUSIONS

This article has examined how information systems are designed and used in repetitive manufacturing systems.

The basic operating characteristics of repetitive manufacturing systems have been described and compared with those of intermittent production systems in order to better understand the main operating problems and the information system tools that might resolve them.

A reference framework, based on the three basic production control subsystems - planning, inventory and shop floor control - has been used to examine the characteristics of an information system for the management of repetitive manufacturing. The proposed conceptual framework is a reading key to analyse the software functions that characterise information systems for repetitive manufacturing.

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