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Alberto De Toni Roberto Panizzolo

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How do the characteristics of repetitive and intermittent manufacturing compare, and what relevance does this have for manufacturing today?

Repetitive and Intermittent Manufacturing:

Comparison of Characteristics

Alberto De Toni and Roberto Panizzolo

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Introduction

In this article the authors develop the theme of repetitive manufacturing compared with intermittent manufacturing in manufacturing firms. The ever growing interest in repetitive manufacturing is due to the great possibilities that such a system offers in achieving simultaneously efficient and efficacious performance. The opportunities offered derive from easier application of the just-in-time (JIT) philosophy[1-4].

The increasing attention that is paid to repetitive manufacturing has led to meetings, debates, seminars, articles and book contributions in both the academic and industrial world. The main themes of debate today are the following:

- What are the characteristics of repetitive manufacturing compared with those in intermittent manufacturing?
- How does manufacturing management in the context of repetitive manufacturing differ from that used in intermittent productive systems?
- What are the characteristics of manufacturing planning and control systems in repetitive production systems?
- What are the possibilities for a firm presently working with intermittent production processes of working with repetitive processes and what action should be taken in this respect?

The first theme, that of the characteristics of repetitive manufacturing compared with those of intermittent manufacturing represents the object of this article. The second theme, regarding repetitive manufacturing management, will be the object of a further article by the authors. The arguments that will be developed therein are of particular interest for manufacturing firms that intend to evolve as far as possible towards repetitive manufacturing; in these firms management techniques have been conceived and developed for intermittent manufacturing environments like job shops. The greatest difficulties lie in the application of innovative management techniques within the shopfloor control subsystem[5,6].

The third theme, regarding management information systems for repetitive environments, refers to the ways in which information systems used in repetitive manufacturing contexts are designed and used. Informatic procedures used in intermittent productive systems, which are obviously based on the management logics of productive systems like job shops, cannot be applied *tout court* to repetitive contexts[7,8,9]. The reference is to manufacturing planning and control systems, based on MRP[10], which evolved from simple planning systems for material requirements to what is universally known today as manufacturing resources planning (MRPII)[11], or rather manufacturing planning and control systems (MPCS)[12].

The fourth debated theme regards the actions that must be undertaken by firms in order to obtain a greater degree of repetitiveness in the operative system. There are numerous references to these aspects in the literature[2,13-16].

This article aims to:

- clarify what is meant by the term repetitive manufacturing, since its meaning is still not universally accepted in literature;
- propose a classification of production categories which includes — among the classes defined — that of repetitive manufacturing and a corresponding classification of respective production plants;
- describe the disposition of a line typical of repetitive manufacturing;
- examine the possible applications of repetitive manufacturing in regard to production volumes required and the degree of flexibility necessary;
- classify flow shop plants;

- describe among intermittent productive systems those with strong analogies to repetitive manufacturing systems; in particular the Zanussi-Electrolux plant in Susegana (Italy); and
- describe the fundamental elements which differentiate intermittent and repetitive manufacturing systems.

The Meaning of the Term "Repetitive Manufacturing"

We consider it opportune, before analysing the characteristics of repetitive manufacturing, to give a correct definition of the term "repetitive", in order to determine clearly the object of the analysis; in doing this we will also try to eliminate any ambiguities which can be found in various contributions to literature.

The term "repetitive manufacturing" is relatively new. It was coined at the beginning of the 1980s by a group of scholars and professionals belonging to APICS (American Production and Inventory Control Society). APICS, in view of the increasing interest in the Western world in Japanese manufacturing techniques, promoted the formation of a specific group — "The Repetitive Manufacturing Group" — aimed at examining the characteristics of repetitive manufacturing and at determining with precision the nature of the planning and control systems used therein. Hall, who belonged to this group, defines repetitive manufacturing as:

> the fabrication, machining, assembly and testing of discrete units produced in volume, or of products assembled in volume from standard options. Where repetitive manufacturing has been used for assembling units in high volumes, it has more popularly been known as mass production[17].

The *APICS Dictionary* defines repetitive manufacturing as:

> the production of discrete units, planned and executed to a schedule, usually at relatively high speeds and volumes. Materials tend to move in a continuous flow during production, but different items may be produced sequentially within that flow[18].

From these definitions we can already grasp some of the peculiarities of repetitive manufacturing systems. Above all, they are usually designed to meet requirements for high volumes of a single type of product or of a narrow range of products, generally using line processes. Secondly, the output volume, besides being very high, is made up of a discrete and non-continuous flow of objects.

This means that the term "repetitive" does not include those systems called process industries, where the products are obtained thanks to operations such as mixing, separation, deformation or more generally chemical or physical reactions. We consider it important to underline this because some contributions to the literature can create confusion and lead to a lack of belief.

These misunderstandings are probably due to the extensive use of the term "continuous" which, before the adjective "repetitive" was introduced for discrete production, was often believed to have the same meaning and thus used as a synonym. Continuous systems have always been understood as those characterized by:

- a lay-out where the productive units are arranged in sequence according to production stages;
- fixed machining routeings; and
- material flows which are in continuous movement, following pre-established itineraries.

It is clear that with this definition it is not possible to establish unequivocally if these productive systems refer to discrete or process manufacturing.

Dilworth[19, p. 10], for example, uses the term "continuous manufacturing" to indicate indifferently both process and part production. Hall[20], on the other hand means, by continuous manufacturing, the transformation without interruption of non-discrete materials through operations such as extraction, distillation, lamination, forging and so on.

The entire organization can be seen as a pipeline

In order to overcome these problems of classification we consider it necessary to focus attention not only on how the product is obtained (by parts or discrete units or by process), and therefore on the nature of the output, but also on how the production volume is obtained; by single products, by batches or by flow. By crossing the two classification methods, the matrix of Figure 1 is obtained, in which six categories of manufacturing are defined:

(1) individual;
(2) unique;
(3) intermittent;
(4) discontinuous;
(5) repetitive; and
(6) continuous.

The expression "flow production systems" means a production organization where the arrangement of the plants and machining centres allows stable routeings, rigidly defined and generally complex. The connections between the different stages of each routing are very close, the level of specialization of plants, machines and movement systems is high, and this allows an uninterrupted flow of materials during the production process resulting in a short or very short throughput time. The itinerary of each item is

Figure 1. *Classification Matrix of Manufacturing Categories*

Classification according to how the production volume is obtained / Classification according to how the product is obtained	Single production	Batch production	Flow production
Discrete production (integral products)	1 Individual manufacturing	2 Intermittent manufacturing	3 Repetitive manufacturing
Process production (dimensional products)	4 Unique manufacturing	5 Discontinuous manufacturing	6 Continuous manufacturing

predetermined and passes through a sequence of operations that can also vary according to the routeings established for the range of products to be produced.

The most distinctive element of these systems is the presence of a flow of materials, so the entire organization can be seen as a pipeline where what goes in one end must necessarily come out at the other, after appropriate transformations, without having the possibility of "getting out" in the middle.

Materials are machined and moved in predefined quantities

The definition given by flow production does not necessarily imply the determination of the type of output, which can be obtained by discrete parts or by process, as indicated in the matrix of Figure 1.

Using Woodward's distinction[21] — which subdivides productive systems into two classes: "those that produce integral products (defined objects) and those that produce dimensional products (measurable by weight, capacity or volume)" — the category "integral products" is associated with discrete production, while the category "dimensional products" is associated with process production.

The matrix proposed (see Figure 1) shows in square 1 "individual manufacturing" (or by distinct units) as a single production obtained by discrete parts, while square 4 shows "unique manufacturing" as a single production of a product obtained by process. Square 2 shows "intermittent manufacturing" as a batch production of products obtained by discrete parts. These productive environments are characterized by a productive process where the materials are machined and moved in predefined quantities (batches), according to extremely variable machining routeings, with fairly frequent receipts and issues of materials. The *APICS Dictionary* defines intermittent manufacturing as "a form of manufacturing organization in which the productive resources are organized according to function. The jobs pass through the functional departments in lots and each lot may have a different routeing"[18]. Square 5 shows "discontinuous manufacturing" as a batch manufacturing of products obtained by process. Finally, square 3 classifies "repetitive manufacturing" as a flow manufacturing of products obtained by parts and square 6 shows "continuous manufacturing" as a flow manufacturing of products obtained by process. Both repetitive and continuous manufacturing are characterized by an homogeneous and incessant flow of materials along the productive units until the finished products are obtained.

Figure 2 shows production plants which carry out the six manufacturing categories above and examples of products from relative industrial applications. Individual manufacturing refers to large civil constructions such as bridges or dykes, or industrial ones like ships. The construction of such works is usually carried out in yards (square 1: yards). Unique manufacturing is representative of "just once" production of products deriving from research and development activities (square 4: laboratories).

Figure 2. *Classification Matrix of Production Plants and Products taken from Relative Industrial Applications*

Classification according to how the product is obtained / Classification according to how the production volume is obtained	Single production	Batch production	Flow production
Discrete production	1 Yards — Civil construction — Ships	2 Job-shop and cells — Machine tools	3 Discrete lines — Cars
Process production	4 Laboratories — Chemical synthesis products	5 Batch plants — Polymers — Petrochemical products	6 Process lines — Fertilisers — Drafts

Classic manufacturing systems where intermittent manufacturing is obtained are job shops and cells. Cells, obtained through group technology philosophy[22], are aimed at machining families of parts and are distinguished from job shops by smaller production lots, less work in progress and shorter lead times. In other words cells are productive systems with a lesser degree of "intermittence" than job shops. When the cells are equipped with highly specialized machinery they are known as dedicated cells, to underline their predisposition to the machining of families with fewer components, carrying out a greater productivity even if associated with less mix flexibility. A "classic" cell production system presupposes that each cell carries out all the operations in the production routing for the parts belonging to a determined family. The cells of such a layout are disposed parallel to each other, each cell operating independently. An evolution of this system consists in dedicating the entire transformation process to one family of products and in structuring it according to areas of 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 more or less complex combinations, with one main branch that can be subdivided into two or more secondary branches and other auxiliary branches converging on the principal one, with the possibility of bypassing entire cells. In order to distinguish this second type of productive system from the first, here we will use respectively the terms "sequence cells" and "parallel cells". By the term "sequence cells" is meant a productive system composed of technological cells — each of which carries out one stage of the product routing — arranged in such a way as to individuate the main direction of the productive flow in order to favour the flow of materials. Sequence cells will be described in more detail in the section "Manufacturing Systems with Sequence Cells". A typical industrial application of intermittent manufacturing is that of machine tools (square 2: job shops and cells).

Cells are arranged according to more-or-less complex combinations

Discontinuous manufacturing concerns chemical products carried out at plants in batches and for this reason is also known as "batch processing". Examples are polymer production and, more generally, petro-chemical production (square 5: batch plants).

Repetitive manufacturing is mainly used at plants with machines arranged in lines, as is typical of the car industry (square 3: discrete lines). Continuous manufacturing is carried out in specifically dedicated process plants, as in the fertilizer and draft industries (square 6: process lines).

The matrix proposed in Figure 1 overcomes the ambiguities of meaning attributed to the terms of "repetitive manufacturing" and "continuous manufacturing". Production systems with conditions typical of repetitive manufacturing are distinguished by a line layout of the operating units. The line, in fact, is the primary condition for obtaining flow production. The themes inherent in line layout will be discussed in the next section.

Line Layout in Repetitive Manufacturing

Once the conditions of applicability of repetitive manufacturing have been verified (that is, sufficiently high manufacturing volumes) and once the necessary technological units have been individuated (machinery, machining centres, movement systems, warehouses, etc.), it is fundamental to have a line layout of the productive units in order to carry out production with a repetitive flow.

The definition of the layout and the sizing of the capacity of the various resources requires a careful planning activity[23] which aims to:

- maximize system efficiency by better use of machinery and manpower;
- minimize material handling;
- keep the inventory levels to a minimum; and
- obtain the maximum flexibility possible within the required productivity.

The choices made in this area are important because they determine, in relation to the physical characteristics of the plants, a group of conditions which limit line management. A repetitive manufacturing system, where the sequence of operations is already predefined, does not aim at guaranteeing the attainment of a certain quantity of products by a certain date, but rather aims at maintaining a constant long-term manufacturing flow.

System control regulates the input flows and global outputs □

The fundamental concept here is the flow (a repetitive and not intermittent movement) of materials through the various stages of the process, which are carried out in a synchronized way; the absence of queues allows reduction of the throughput time relative to the machining time. The synchronized flow is the most representative element of repetitive manufacturing processes, so much so that some authors, when speaking of repetitive manufacturing, use the term flow shop without any previous definition.

A layout which allows a flow means that the machines must be arranged in the sequence in which operations take place. It is called a line layout. There are no work in process inventories between the different manufacturing centres: system control regulates the input flows and global outputs linking the entire system with the outside world and regulates the internal flows between each centre and also upstream and downstream flows.

Each centre is generally characterized by a high degree of technological specialization and is sized according to the quantity of products carried out in the line. Loading and unloading of the materials can be manual or automatic and movement between the centres follows predefined itineraries, often automated, as in the case of belt conveyors.

Movement between the centres follows predefined itineries □

The rigidity of the line can be reduced by introducing greater versatility and adaptability to the workstations, machines and movement systems in order to obtain a wider range of products. A typical case is that of "mixed-model" flexible lines described below.

Production Unit Volumes and Mix Flexibility in Repetitive Manufacturing

As already mentioned, repetitive manufacturing presupposes sufficiently high part-unit production volumes. Only these volumes can in fact justify a line lay-out aimed at a continuous flow of materials and at high efficiency.

Annual production volumes can derive from the production of a single part or from a pre-established mix of parts. Ever-growing market demand for a large variety of products means that firms must differentiate their final products. Therefore, related to the total number of products sold, the production volume for each individual finished product belonging to the mix will diminish. Thus, for industrial firms wishing to reach high efficiency by obtaining finished products in a repetitive way, it is increasingly important to reach minimum volumes which justify such production by concentrating a large part, or the entire range, of the products offered on the same assembly line. Sufficient volumes to justify the choice of manufacturing one or more parts in a line lay-out can be obtained when a standarization policy is followed which leads to the use of these components for a large part or all of the production range.

Repetitive manufacturing allows high efficiency, but it requires high unit volumes in both the fabrication and assembly stages. Fabrication in dedicated or partially flexible lines of a few components is possible if standardization policies increase the component unit volumes. The need for product differentiation also requires the use of assembly lines which are sufficiently flexible and able to assemble all the products (or at least a family of products).

The product structure which is able to respond to these requirements is known as the "hourglass" structure[12]. The finished products are available in a wide range starting from a reduced number of components, subassemblies and functional groups. The hourglass product structure allows both flexibility and efficiency; the first is obtained in the final stages of assembly carried out on flexible lines, and the second through standardization of components produced on dedicated or flexible lines.

The search described above for greater part-unit volumes in order to allow flow manufacturing leads, in most cases, to optimum conditions for the introduction of high degrees of process automation. In fact, in repetitive manufacturing the products and processes have a high degree of reciprocal dependence and the operations are carried out in a continuous way in a sequence closely linked to the routing.

The operations are obtained according to the "mushroom" concept

The most appropriate automation classes for dedicated and flexible lines, as mentioned above, are respectively rigid automation and flexible automation. The application of rigid automation presupposes a fixed manufacturing routeing and products with no variants or optionals. Flexible automation allows the machining of different parts with different routings. The same machining centre can carry out diverse operations on the same piece or the same operation on different pieces with very short setup times called "hidden times". Classic flexible systems are flexible transfers (manufacturing or assembly), FMS (flexible manufacturing systems) and FAS (flexible assembly systems)[24].

Flexible transfers are automated fabrication or assembly lines with a certain degree of flexibility. They are characterized by a flow of materials which passes through the machines in a fixed sequence by means of an automatic transport system; flexibility derives from the multifunctional capacities of each operative unit and from the possibility that a piece can avoid one of the line stations (bypass) or at least pass through it without being machined. FMS and FAS are characterized by a greater degree of flexibility than flexible transfers since a predetermined itinerary does not exist. Each piece to be machined moves depending on its assigned routeing, on the dynamic machine load profile and on the effective mix.

The fabrication and assembly operations are obtained according to the "mushroom" concept[25]. Product customization operations occur in the final stages of the production routeing in order to carry out product differentiation as late as possible, thus responding more efficiently to demand variability.

The structure allows both flexibility and efficiency

A classification of the plants which carry out repetitive manufacturing is now proposed, and six line typologies are identified.

Classification of Plants for Repetitive Manufacturing

Once it is clear that repetitive manufacturing is flow manufacturing of discrete products on a line lay-out, it is opportune to classify the different lines to be found in various productive realities in order to have a greater understanding of the production characteristics in this manufacturing context.

There are four variables which we will use in order to obtain the classification scheme[26]:

(1) flow pattern;

(2) type of operation sequence;

(3) the variety of the different products that can be carried out on the line; and

(4) the product production type.

As regards the first variable, *flow pattern*, it can assume two values depending on whether the materials can be moved along the line in one direction only or in both:

- unidirectional flow; and
- bidirectional flow.

The second variable identifies the *type of operation sequence* that can be carried out on the line. The sequence can be one of three types:

- fixed;
- variable with bypass; or
- variable with backtracking.

The fixed sequence is the classic situation where the various stations along the line perform the same operation on all the parts passing through it. With the bypass system it is possible for products to skip one or more operations of the routeing. On a line characterized by a backtracking system it is possible to send parts back to the upstream stations in order to repeat one or more operations or to carry out operations previously skipped. On lines distinguished by a unidirectional flow of parts either a fixed or a variable sequence is possible, while bidirectional lines allow all three sequences: fixed, variable with bypass and variable with backtracking.

The third variable, *the variety of the products*, specifies the number of different parts that can be obtained on a single line. From this point of view the lines subdivide into two classes:

- monoproduct, where a single product is carried out; and
- multiproduct, where two or more products are obtained.

The fourth and last variable, *the product production type*, concerns only lines able to handle different products. The two alternative ways to obtain production volume are through:

- successive production; and
- mixed production.

In systems with successive production, the different products are handled on lines that are dedicated for significant periods of time to the production of a single part. The line must be reconfigured between the different products. So-called "mixed" production rather presupposes the machining of sequences of different products which reproduce, in a short or very short time, the long-term production mix according to the principle "micro mix = macro mix".

If we consider the four variables just described, and their mutually interdependent relations, it is possible to reduce them to two "macro" variables:

(1) "Flow type", combining the two variables, flow pattern and type of operation sequence; the values that can be assumed by this variable are:
   - unidirectional flow;
   - unidirectional flow with bypass; and
   - bidirectional flow with backtracking.

(2) "Number of different products and production type", combining the last two variables; the values that can be assumed by this variable are:
   - monoproduct line;
   - multiproduct line with successive production; and
   - mixed multiproduct line.

The crossing of these two "macro' variables gives rise to the classification matrix of repetitive manufacturing plants as represented in Figure 3. The matrix shows nine possible theoretical classes of plants using lines. Six of these are effective:

Figure 3. *Classification Matrix of Repetitive Manufacturing Plants*

Number of different products and production type \ Flow type	Uni-directional flow (fixed direction and operation sequence)	Uni-directional flow with bypass (fixed direction and variable operation sequence)	Bi-directional flow with backtracking (variable direction and operation sequence)
Monoproduct line	1 Dedicated line	2	3
Multiproduct line with successive productions (high set-up times)	4 Multiproduct line with uni-directional flow and successive productions	5 Multiproduct line with uni-directional flow with bypass and successive productions	6 Multiproduct line with bi-directional flow with backtracking and successive productions
Mixed multiproduct line (low or no set-up times)	7 Mixed model line	8 Mixed model line with bypass	9

(1) dedicated line;

(2) multiproduct line with unidirectional flow and successive production;

(3) multiproduct line with unidirectional flow with bypass and successive production;

(4) multiproduct line with bi-directional flow with backtracking and successive production;

(5) mixed model line; and

(6) mixed model line with bypass.

Squares 2 and 3 represent plants which do not have real applications, since there is no sense in having bypass or backtracking for monoproduct lines. Square 9 also shows a non-existent operating condition. In fact the "macro-mix = macro-mix" principle presupposes the machining of similar products, belonging to a family with similar routeings and thus a bidirectional flow is useless.

Movement is generally obtained through automatic systems

Square 1 of the matrix in Figure 3 contains the classic unidirectional dedicated line, aimed at producing a single part that requires a sequence of predefined and constant operations carried out by a group of machines disposed in a line. Movement is generally obtained through automatic systems, from which the term "transfer line" derives. Line balancing is established at the design stage of the line with the objective of productive capacity saturation. The situation described presupposes high unit volumes of the single product. These repetitive manufacturing systems present such peculiar characteristics as to require particular production management systems with control functions typical of process industries.

The multiproduct line with unidirectional flow and successive production, the multiproduct line with unidirectional flow with bypass and successive production and the multiproduct line with bi-directional flow with backtracking and successive production are positioned respectively in squares 4, 5 and 6 of the matrix. These lines 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. Between one product and the next it is necessary to reconfigure the entire line and, generally, setup becomes very important in this context. The balancing of the line must be redefined at each product change; the degree of saturation obtainable depends on the stations which become bottlenecks. The flow can be unidirectional and in this case the sequence of operations is fixed (for each product) as in the case of square 4, or the flow is unidirectional with bypass (square 5) or lastly the flow is bi-directional with backtracking (square 6).

The balancing of the line must be redefined at each product change

If bypass and backtracking on one hand allow an increase in line flexibility, and therefore a wider product range on the other, they obviously lead to greater difficulty in balancing and more generally in the management of the line itself. Multiproduct lines with successive production are used in productive contexts where, even if the output global volume is high, the product families have low unit volumes that do not therefore justify various dedicated lines. The variety of products obtainable and the more complex management activities mean necessarily adopting a planning and control system which is more sophisticated than that previously used for dedicated lines.

Within mixed multiproduct lines both mixed model lines and mixed model with bypass lines can be distinguished, as represented in squares 7 and 8 of the matrix in Figure 3. Analogously with the previous case, it is possible to carry out different parts also on mixed multiproduct lines, belonging however in this case to one family. Thanks to greater line flexibility the importance of setup is notably reduced: the quantities of single parts passing through the line are drastically lowered since the line has been equipped with machines and movement systems able to adapt easily and quickly to the different parts that pass through it. In this way the part flow is such that temporal uniformity of the mix is achieved, i.e. a state of productive continuity where it is possible to mix the products uniformly over time[16].

These mixed lines therefore — by allowing a production in the short term of a mix analogous to that required in the medium term (micro mix = macro mix) — allow a balance to be reached between the outgoing flow of products and market demand. This condition is important in order to obtain low stock levels of finished products, unlike what occurs with multiproduct lines with successive production. Moreover, the production of different products in a mixed line, by leading to a uniform use of components, allows synchronization between final assembly lines and the activities of upstream fabrication shops and therefore simplifies the activities of production programming.

In these mixed lines, on the other hand, balancing becomes extremely complex since the difference in models passing through the line makes it necessary to alternate parts with high and low machining times. Every time the production mix is varied (for example every month) the line balancing must be redefined. The degree of saturation obtainable is conditioned by the particular mix required.

A main application of mixed lines is for assembly. Mixed fabrication lines are rarer as the flexibility necessary requires significant investment:

> In the United States we have generally rejected the very notion of running mixed models in subassembly and fabrication. But the Japanese try hard to do so. Kawasaki's carousel conveyor-equipped punch presses are an example of attempts to move toward mixed-model processing even in fabrication[27].

Manufacturing Systems with Sequence Cells: The Zanussi-Electrolux Plant in Susegana

As we have said, mixed fabrication lines are still at the experimentation and development stage; in fact, up to now repetitive manufacturing at the fabrication stage has only been obtained with dedicated lines or multiproduct lines with successive production operations. The attainment of efficient and sufficiently flexible production systems requires construction of cell manufacturing systems arranged in sequence both at the assembly and fabrication stages. In this manufacturing context entire production stages are carried out by specially designed cells. Each cell performs a single complex production stage with high levels of flexibility.

A sequence cell system presents aspects similar to those of repetitive manufacturing, even if the main characteristics are typical of intermittent manufacturing as the parts are machined and moved in lots. In fact, the sequence cell system allows individualization of a main flow direction — which can also present auxiliary branches converging on the main branch — along which the flow of materials unwinds across the whole system. At the same time the high flexibility characteristic of intermittent manufacturing is maintained, since complex stages of different product routeings are carried out inside the cells.

The Zanussi-Electrolux plant in Susegana (Italy), which produces domestic refrigerators, is representative of such a production configuration. The main features of the factory are the following[28]:

- The production process is organized into 14 cells arranged in sequence, with two parallel branches in the middle stages, dedicated respectively to the fabrication of the cabinet and to the formation of kits of components before final assembly, as can be seen in Figure 4.
- High production volumes: more than 1,100,000 parts a year, produced at a rate of about 4,200 a day.
- Wide range: about 40 basic models are produced with a total of 1,000 variants.
- Ability to produce the entire range of products in reduced times, i.e. one week.
- The minimum production batch of a particular product is equal to 16 units.

The production system allows high efficiency and mix flexibility. Efficiency is obtained by production in automatic cells, while flexibility is obtained at two levels: at a global level, thanks to a production philosophy which produces the refrigerator through final assembly of a cabinet and a kit of components; and at a local level thanks to the cell's independence of the mix. The production philosophy at a global level justifies the presence of two parallel branches in the middle production stages, dedicated respectively to the fabrication of the cabinet and to kit formation.

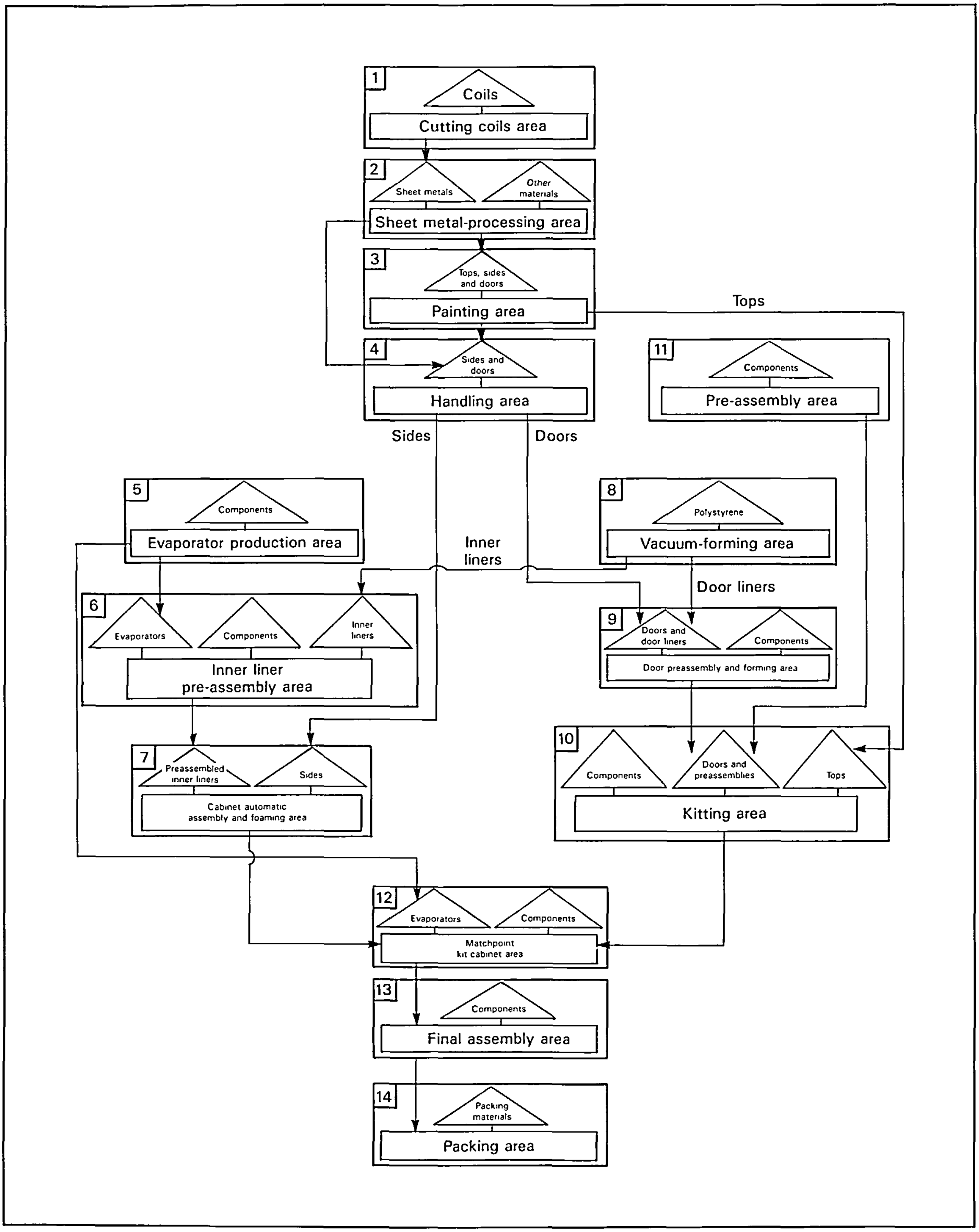
The product underwent deep revisions in its design

The factory is therefore a production system made up of a group of autonomous production areas with a reduced number of intraoperational warehouses and a high level of automation and integration. The arrangement of the production cells has been defined in such a way as to allow a continuous flow throughout the factory. The design of the cells is intended to concentrate either automatic or manual operations on one cell in order that operating problems are homogeneous and management simplified.

Automation is used for the basic operations: cabinet and door automatic assembly/foaming, compressor assembly, soldering, packing, automatic material handling. As regards the material handling system, with the aim of reducing and simplifying scheduling within one cell or between different cells, movement is by standard quantities or multiples of the standard. Each cell includes one or more input warehouses and some machines which allow fabrication of a part. Single cells are connected by material and information flows.

To reach a production system characterized by a high degree of efficiency and flexibility, it was necessary to carry out a number of actions both on the product and on the process. The product remained substantially the same in functional terms, but underwent deep revisions in its design; the actions carried out concerned:

Figure 4. *Representation of the Sequence Cell Organization at the Refrigerator Plant of Zanussi-Electrolux in Susegana (Italy)*



- The cabinet which, instead of being a "C-shaped" sheet, became a group made up of draw sides, press-forged ties, plastic back: all parts being produced and assembled with a good degree of flexibility.
- The door in painted sheet metal which now contains the door liner and the insulation.
- The inner liner which is now directly linked to the cabinet by foaming.
- The general structure: the product is now structured in subassemblies which are the sides, the door, the inner liner, the cabinet, the electrical components, the compressor bar, etc.

The attainment of a production process characterized by greater flexibility came about through:

- elimination of the die operation;
- simplification and despecialization of the painting operation;
- introduction of the foaming operation which represents an assembly stage;
- introduction of stages for the production of the main subassemblies; and
- formation of specific assembly kits according to a plan, which facilitate distribution to the workplaces of the components to be assembled and ensure the presence of all the components before the assembly operations.

The principles of product/process action can be summarized as:

- product design in subassemblies;
- process design in production stages;
- more flexible operations; and
- revision of material selection with the introduction of the kit concept.

From the logistic-flow point of view, it is possible to classify the cells which make up the production system into three categories (numbers refer to Figure 4):

(1) "Head cells", which machine only purchased materials: cutting coils (1), evaporator production (5), vacuum forming (8) and preassembly (11).

(2) "Appointment cells", which machine semi-worked parts coming from upstream cells: handling (4), inner liner preassembly (6), cabinet automatic assembly and foaming (7), door preassembly and foaming (9), kitting (10), match point kit-cabinet (12).

(3) "Flow cells" which machine semi-worked parts coming from one upstream cell: sheet metal processing (2), painting (3), final assembly (13) and packing (14).

The cells can also be classified according to their degree of flexibility; three types of cell are distinguished:

(1) "Limited-flexibility preproduction cells", among which are cutting coils (1) and evaporator production (5); they are cells with very little automation and with production machines guided by an operator, for production of semi-machined parts.

(2) "Limited-flexibility main production cells", among which are sheet metal processing (2) and vacuum forming (8); they use the semi-machined parts from the preproduction cells and other components to feed downstream cells; in particular, the cell carrying at the vacuum forming of inner liners, with large dedicated machines, is critical in the set-up times which condition downstream production.

(3) "High-flexibility main production cells", located downstream of the previous ones, which are indifferent to the mix: painting (3), handling (4), inner-liner preassembly (6), cabinet automatic assembly and foaming (7), door preassembly and foaming (9), kitting (10), preassembly (11), match point kit-cabinet (12), final assembly (13), packing (14).

Three production programmes, which are updated daily, are used for short-term scheduling:

(1) The "operating programme": the factory production programme which defines the quantity of finished products, with respect to the production capacity and the present and expected component and raw material availability.

(2) The "executive programme": the programme which, on the basis of the operating programme and of the production capacity, gives each production cell its detailed programme and machining sequences.

(3) The "production programme": the programme which, for limited-flexibility cells only, is extracted from the executive programme which refers to the day before, and constitutes an anticipated production programme for the downstream warehouses; this programme is necessary to overcome the limited flexibility of these cells due to significant set-up times.

For the head cells the carrying out of the three-above-defined programmes requires the availability of raw materials and purchased components. For the appointment and flow cells, on the other hand, as well as the availability of originally purchased components, the availability of semi-machined parts coming from upstream cells is necessary. In the converging upstream cells, where the semi-machined parts are the input for a downstream appointment cell, the production order release is through two distinct modalities: on the basis of "material issue" and on the basis of "semi-machined part receipt". Both these modalities require the use of a control system able to monitor in real time all the activities within the production process.

Regulation of the order production release on the basis of material issue is illustrated in Figure 5(a). After a production order release (time T1) to cell C2, issue from the internal warehouse of the materials is communicated externally (time T2). This information is used to regulate the production order release cell C1 (time T3). After the semi-machined parts coming from both C1 and C2 have been received in the internal warehouses of cell C3, the production order release for cell C3 (time T4) occurs.

Regulation of the production order release on the basis of semi-machined part receipt is represented in Figure 5(b). Starting with a production order release to cell C2 (time T1), only after the receipt of the semi-machined parts at the internal warehouse of cell C3, is a signal sent to communicate the receipt (time T2). This information is used to regulate the production order release to cell C1 (time T3). The release to the cell C3 (time T4), occurs only after the semi-machined parts from cell C1 have reached the internal warehouse of C3.

Given the great variety of semi-worked parts or components that flow through the production-system cells, it is important that the control system is able to carry out good management and synchronization of the arrivals from the various flows. In particular, it must be remembered that the throughput times of the different cells are not constant as they vary according to the part mix.

If the appointments are not managed correctly, some semi-machined parts may arrive a long time before the others; this would lead to long waiting periods for the materials in the input warehouses of the cells. If waiting times build up in the scheduling chain, they create heavy imbalances in the production progress. To avoid this, the so-called "conditioned production order release" is used which is based on "if. . .then" logic. This management technique, which can be applied to the production order release criteria of both Figures 5(a) and 5(b), is represented in Figure 6.

After a production order release to cell C2 (time T1), in order to avoid a long wait by components in the C3 input warehouses, the production release to cell C2 is checked (time T1*bis*), in order to verify the availability, in the warehouse of cell C1, of the necessary parts to produce the converging components for the same appointment in C3. If the reply is positive, the production order release to C2 is carried out. After this the production order releases to cells C1 and C3 are carried out, using one of the two ways described in Figure 5.

A production system with a sequence-cells layout, like the one described above, allows a high degree of automation through the introduction of FMS and FAS, which represent the natural evolution of cell automation respectively for fabrication and assembly stages[29]. The whole production system is automated to a significant degree of flexibility, and presents similar characteristics to in-line flow production, if not within a single FMS or FAS, at least within the entire production system.

Figure 5. *Production Order Release Based on (a) Material Issue and (b) Semi-machined Part Receipt*

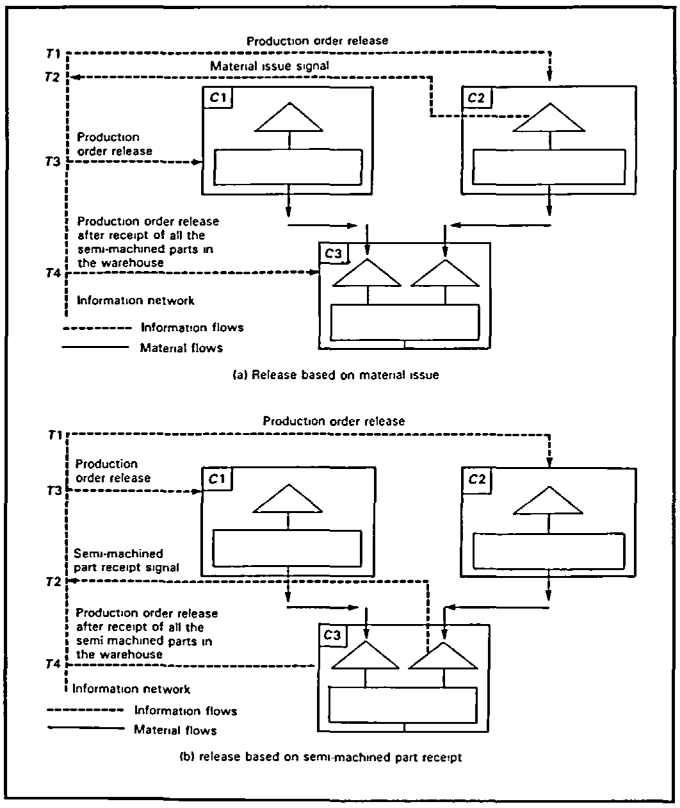
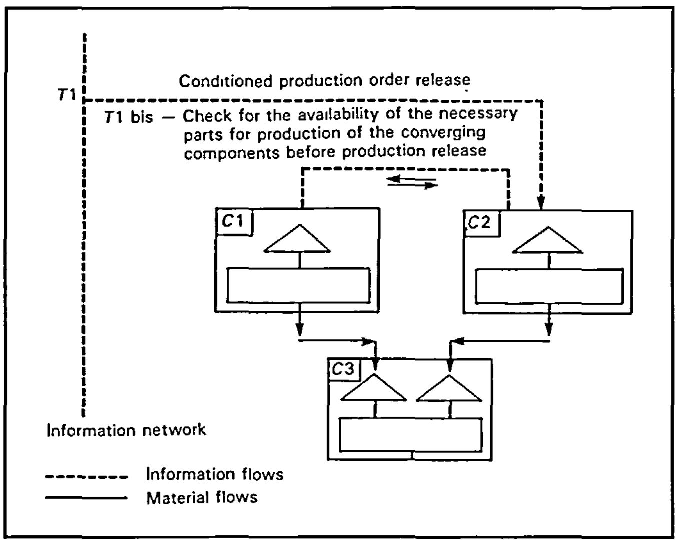


Figure 6. *Conditioned Production Order Release*



Characteristics which Differentiate Intermittent from Repetitive Manufacturing

Individual, intermittent and repetitive manufacturing are illustrated in Figure 1 through the crossing of the nature of the output (how the products are obtained, by parts or by process) and how the production volume is obtained, that is by single products, batches or by flow. The fundamental elements which differentiate the three productive contexts are:

- the itinerary of the materials;
- material handling; and
- the relevance of the set-up activity.

Figure 7 shows schematically the differential characteristics of individual, intermittent and repetitive manufacturing. For a complete description of all the aspects characterizing single-product, batch and flow manufacturing see Hill[30, pp. 51-3].

In individual manufacturing, the materials follow predetermined itineraries when delivered to the product construction area and are moved in quantities determined by requirements. Generally the set-up activity is not important.

In intermittent manufacturing it is necessary to distinguish between job shops, parallel-cell systems and sequence-cell systems. Once a machine has finished an operation, the materials move from machine to machine in different areas in a job shop, from machine to machine within the same cell both in parallel- and sequence-cell systems and from cell to cell within sequence-cell systems. Movement is through lots in all three job shop, parallel-cell and sequence-cell systems. Within the single cell the movement between the machines can also be by piece rather than by lot if the "overlapping" technique is used, where each piece, on completion of an operation, is sent on to the next machine.

Materials flow from station to station arranged in a line

In the example we have described of the sequence-cell system at the Zanussi-Electrolux plant in Susegana, movement within the cell is piece by piece by alternation of pieces belonging to different batches on the machines. Movement between cells — in the most complex management situations — is of minimum batches of 16 units with reconstruction of the batch before moving towards the next cell, as occurs in the synchronization between cabinet and kit flows before the final assembly.

Figure 7. *Differential Characteristics of Individual Intermittent and Repetitive Manufacturing*

Ways of carrying out the production volume / Differential characteristics	Individual manufacturing	Intermittent manufacturing			Repetitive manufacturing		
Type of plant	Yard	Job-shop	Parallel cells	Sequence cells	Mixed multiproduct line	Multiproduct line with successive productions	Monoproduct line
Material itinerary	Converging towards the construction area	Between machines of different workshops	Between machines within the same cell	Between machines within the same cell and between different cells	Between flow line stations		
Material handling	By single pieces or groups	By lots	By lots (with or without overlapping) between different machines in the same cell	By lots (with or without overlapping between different machines in the same cell and by lots between different cells	By single piece		
Reconfiguration or set-up	Not relevant	Set-up of the single machine	Set-up of the single machine or the cell	Set-up of the single machine or the cell	Reconfiguration at each mix change	Reconfiguration at each product change	Reconfiguration not necessary

As regards set-up in intermittent manufacturing, this occurs on single machines in job shop systems, while in cell manufacturing systems it can involve the entire cell.

In repetitive manufacturing the materials flow from station to station arranged in a line, while the materials are moved piece by piece by automatic transport systems such as conveyor belts. For monoproduct lines set up is not necessary. Instead, for multiproduct lines with a successive production, a set-up of the machines is necessary at each product change. Finally, for mixed lines it is in general necessary to reconfigure the entire line at each mix change in the macro period (for example every month), by set-up of the single machine, re-sizing focused warehouses, etc.

Conclusions

In this article a classification of productive categories has been proposed in order to overcome the ambiguities sometimes found in the literature about the meaning of repetitive manufacturing. Six classes of manufacturing can be distinguished (individual, unique, intermittent, discontinuous, repetitive and continuous) and respective categories of productive plants ("yards", laboratories, job shops and cells, batch plants, discrete lines and process lines).

Following this, the focus was placed on repetitive flow manufacturing, by describing the characteristics of the line disposition and examining the applicative possibilities with regard to production volume required and necessary degrees of flexibility.

A classification of plants aimed at repetitive manufacturing was thus arrived at which includes six classes of line: dedicated, multiproduct with unidirectional flow and successive production, multiproduct with unidirectional flow with bypass and successive production, multiproduct with bidirectional flow with backtracking and successive production, mixed model line, mixed model with bypass.

Sequence cell systems have thus been defined — among all the intermittent manufacturing systems — as those which present the most analogies with repetitive ones. The Zanussi-Electrolux plant in Susegana has been described as an example of such a production system.

Finally, the fundamental elements were described which differentiate intermittent manufacturing systems from repetitive ones: the itinerary of the materials, how they are moved and the set-up activity.

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Alberto De Toni is Associate Professor of Operation and Production Management at the University of Udine. Roberto Panizzolo is Assistant Professor at the Department of Industrial Innovation and Management, University of Padua, Italy.

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