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Product and process standardization in intermittent and repetitive production

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After having described the plants used for intermittent and repetitive production, the authors show how the standardization of (both) product and process modifies the operating conditions under which the plants function. These altered operating conditions call for the selection of new plants which are more suited to operating under the new production conditions.

1. Introduction

In industrial firms, the total of all the plant and the other auxiliary technical equipment in the factory are a fundamental element of the whole operating process whose efficiency and effectiveness increasingly determines the success of the firm.

On the other hand, the success of many 'excellent' firms is largely due to an appropriate and coherent integration between product policy and technological manufacturing systems.

Thus, when choosing and designing a production system, managment's attention should be directed towards guaranteeing that the performance required by company strategy is attained. In this area, decisions are taken far more frequently than one would normally suppose, because the decision-making process entails subsequent checks whenever specific factors change, in order to ascertain whether the plants chosen are performing as required.

In this article, after describing the various plants that are used in intermittent and repetitive production and outlining the main elements of differentiation, the authors propose a matrix of contexts in which the plants examined can be applied. In function of the values assumed by two variables, annual part unit volume and production mix range, this matrix outlines the most suitable operating conditions of plants in intermittent and repetitive production.

Then they will show how the decisions taken in relation to the standardization/diversification of a product and the standardization of the process in general, lead to modifications in the operating conditions that characterize the production context in which the firm operates. These modifications require new choices, in terms of plant, in order to operate with systems that are able to function in an efficient and effective way under the changed conditions.

In particular the objectives of this article are the following:

- to define the applicative contexts of plants which carry out intermittent and repetitive manufacturing, in the case of a constant annual total volume and in the case of a growing annual total volume;

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- to analyse the effects of product standardization in intermittent manufacturing, and product differentiation in repetitive manufacturing;
- to analyse the effects of process standardization both in intermittent and repetitive manufacturing;
- to describe the effects of simultaneous product and process standardization in intermittent manufacturing;
- to describe the effects of simultaneous product differentiation and process standardization in repetitive manufacturing.

2. Types of production plants for intermittent and repetitive manufacturing

This paragraph briefly describes the characteristics of three systems where intermittent manufacturing is carried out and three systems where repetitive manufacturing is carried out. A more detailed description of these plants can be found in another paper where the authors classified intermittent and repetitive manufacturing categories and respective plants, and pointed out the main elements of differentiation (De Toni and Panizzolo 1992).

Classic manufacturing systems where intermittent manufacturing is carried out are job-shops and cells. Cells, obtained through the group technology philosophy (Burbidge 1975) are aimed at machining families of components and are distinct from job-shops by smaller production lots, less work in progress and shorter lead times.

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

An evolution of this type of system consists in dedicating 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 more of less complex combinations with one main branch, that can be subdivided into two or more secondary branches, and other auxiliary branches converging on the main one, with the possibility of by-passing entire cells. In order to distinguish this second type of productive system from the first, we will hereon use, respectively, the terms sequence cells and parallel cells. The term sequence cells means a productive system made up of technological cells—each of which carries out one stage of the product routeing—disposed in a way that individuates the main direction of the productive flow in order to favour the flow of materials.

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 (Zanussi-Electrolux, 1988):

- high production volumes: more than 1 100 000 parts a year, produced at a rate of about 4200 a day;
- wide range: about 40 basic models are produced with a total of 1000 variants;
- ability to produce the entire range of products in reduced times: one week;
- organization of the production process 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.

The factory is therefore a production system made up of a group of autonomous production areas with a reduced number of intra-operational 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 all through the factory.

As regards repetitive manufacturing—obtained through a line layout of the productive units—it is possible to individuate three different classes of line. The first class is that of dedicated lines which are 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 re-configured between one product and the next.

Finally the third class is that of mixed multiproduct lines where it is possible to carry out 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 in fact 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.

3. Applicative context of the different plants for intermittent and repetitive manufacturing

Among the numerous contributions in literature to the theme of applicative contexts of different production categories and the respective plants where they are carried out, Wild (1980) classifies productive systems according to the variable 'production repetitivity'.

Vollmann *et al.* (1988), taking up Wild's variable, place the productive classes on a cartesian plan defined by the two variables: repetitive nature of the production—expressed as the time between successive units—and complexity of the manufactured product expressed as the number of sub-parts.

Browne *et al.* (1988) propose, for discrete production, a classification of manufacturing categories using the variables: scale of production and product variety. The same authors define a further matrix in which both manufacturing categories and plants are positioned; the matrix derives from the crossing of the variables process decoupling and product focus. The first refers to what extent the production process for a product is divided into separate operations and decoupled by inventory buffers while the second refers to what extent production facilities are devoted to specific products.

Other authors such as Hayes and Wheelwright (1979) individuate applicative contexts of productive plants through a matrix obtained by the crossing of the variables: product life cycle—with the different stages characterized by increasing productive volumes and growing product standardization—and process life cycle—with stages evolving from intermittent to continuous manufacturing. The matrix proposed by Hayes and Wheelwright is taken up again by many authors, among whom Hill (1983) develops it from various points of view.

In order to individuate the most appropriate applicative contexts of three productive categories—single, batch and flow production in discrete manufacturing—and the various classes of plants where they are carried out (yards, job-shops and cells, and discrete lines), we propose here the use of two variables: production mix range and annual part unit volume. The annual part unit volume of each part represents the key variable in determining whether production should be carried out in repetitive type plants. The higher the value of the said variable, the more convenient repetitive type plants become.

The choice of these variables, production mix range and annual part unit volume allows, moreover, individuation of the above applicative contexts, both in operating conditions characterized by constant annual total production volume and in conditions characterized by increasing or decreasing annual total production volume. The two variables are correlated by the following relationship:

$$\begin{aligned}\text{annual total production}&\\ \text{volume [pieces/year]} &= \text{production mix} * \text{annual part unit volume} \\ &= \text{[parts]} * \text{[pieces/parts year]}\end{aligned} \tag{1}$$

This relationship, represented by the curve of Fig. 1, allows individuation of the applicative contexts of individual, intermittent and repetitive manufacturing according to the production mix and the code annual part unit volume, equal to annual total volume.

Note how the increase in annual part unit volumes allows, equal to the annual total production volume, the descent along the curve from individual to intermittent down to repetitive manufacturing.

From the crossing of the variables in Fig. 1, annual part unit volume and the production mix range, we obtain the matrix of Fig. 2. This matrix shows the applicative contexts of plants carrying out individual manufacturing (yards), intermittent manufacturing (job-shops, parallel cells and sequence cells) and repetitive manufacturing (mixed lines, lines with successive productions, monoproduct lines), equal to annual total production volume.

It is possible to note how, equal to annual total production volume, movement along the diagonal towards repetitive flow productions requires an increase of the annual part unit volume or, which is the same thing, a decrease in the range of the mix obtained.

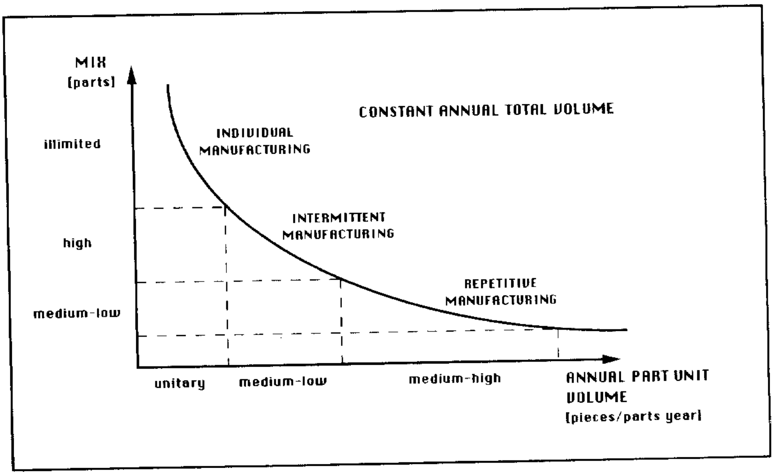

Figure 1. Curve representing the applicative contexts of individual, intermittent and repetitive manufacturing, equal to annual total production volume.

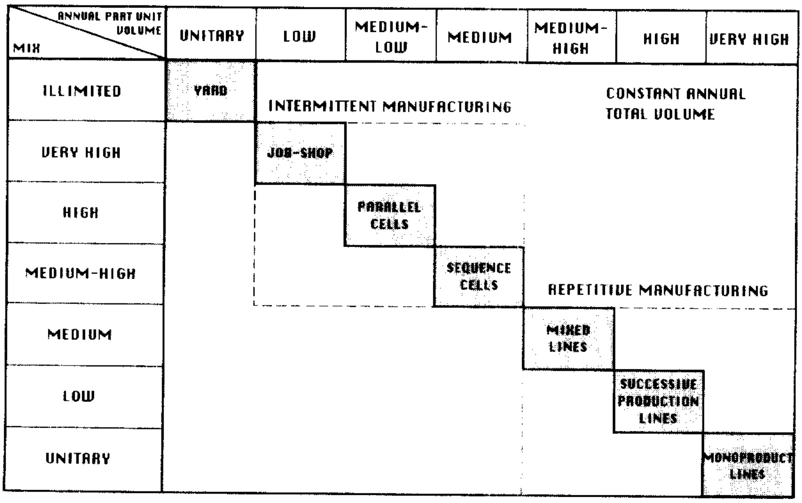

Figure 2. Matrix of the applicative contexts of productive plants that carry out individual, intermittent and repetitive manufacturing, equal to annual total production volume.

The effect of increased annual total production volume on the applicative contexts of production categories and relative plants will be analysed in the next paragraph.

In order to analyse the effects of standardization/differentiation of products and processes on applicative contexts of productive plants that carry out intermittent and repetitive manufacturing, it is necessary to explain in more detail the variable annual part unit volume for the two different production classes, intermittent and repetitive. Starting with the general relationship (1) previously proposed, the annual part unit volume can be expressed by the following relationships in the two different contexts:

Intermittent manufacturing

$$\begin{aligned}\text{annual part unit}&\\ \text{volume [pieces/part year]} &= \text{average lot quantity} * \text{No. lots/year}\\ &= \text{[pieces/part lot]} * \text{[lots/year]}\end{aligned} \quad (2)$$

Repetitive manufacturing

$$\begin{aligned}\text{aannual part unit}&\\ \text{volume [pieces/part year]} &= \text{periodic part unit quantity} * \text{No. periods/year}\\ &= \text{[pieces/part period]} * \text{[periods/year]}\end{aligned} \quad (3)$$

Note how in repetitive manufacturing the concept of average size of the production lot has been substituted by that of periodic part unit quantity, while the number of lots per year is substituted by the number of periods per year. The proposal of using concepts of periodic part unit quantities—that is quantities of pieces of a single part carried out in a production period—and the number of periods per year, derives from the fact that repetitive manufacturing is carried out on productive lines. One of the main characteristics that differentiate these plants from those that carry out intermittent manufacturing is the type of movement: by single pieces rather than by lots (De Toni and Panizzolo 1993). As a consequence, in order to express annual unit volumes of a single part, it is necessary to know on one hand the line production rate, and on the other, to know the length of time in which the line is used for production of that part.

In the case of monoproduct lines the production period is equal to the life of the plant itself. In multiproduct lines with successive productions the production period is determined by the frequency with which the line is dedicated to the production of different parts: this depends on the setup times and the discontinuity of the demand. Finally in mixed model lines the production period is equal to a periodic interval called 'macroperiod' (for example a month or a week), during which different parts are produced in a way to reproduce in the 'microperiod' (for example a day or an hour) the macromix at microlevel. In this way the 'temporal uniformity of the mix' is achieved. This term indicates a production state characterized by an alternation of different parts on the line in a quantity proportionate to the total required mix.

In the following paragraphs effects of variation on the following variables will be analysed:

- annual total production volume;
- annual part unit production volume and/or size of the part mix;
- average size of the production lot and/or number of lots per year in intermittent manufacturing; periodic part unit quantity and/or number of productive periods per year in repetitive manufacturing.

Variations in the above variables determine different operating conditions which lead to different choices of the best plants for realization of intermittent and repetitive manufacturing.

Variations in the above variables are linked respectively to the following factors:

- market share;
- policies of component standardization and product differentiation;
- policies of process standardization.

4. Effect of increased annual total production volume

The increase of the annual total production volume—which is linked to an increase in market demand—has the effect of modifying operating conditions and requires, equal to the productive mix, a choice of plants that carry out a higher degree of repetitivity.

This effect is graphically represented in Fig. 3, where a series of parametric curves relative to annual total production volume is illustrated. Starting with a prefixed mix value, this increase allows, in succession, adoption of productive plants which are gradually more repetitive until monoproduct lines are obtained. In this case the number of lines is equal to the number of mix parts.

5. Effects of component standardization and product differentiation equal to annual total volume

Equal to annual total volume, the increase in the annual part unit volume remains a fundamental objective in realization of a repetitive flow production.

At the level of components, extensive policies of standardization lead to the use of the same components for most or all of the range of finished product (De Toni and Zipponi 1991). The objective here is to obtain sufficient volumes to produce within systems characterized by a higher degree of repetitivity: job-shops, parallel cells, sequence cells, mixed lines, successive production lines and dedicated lines.

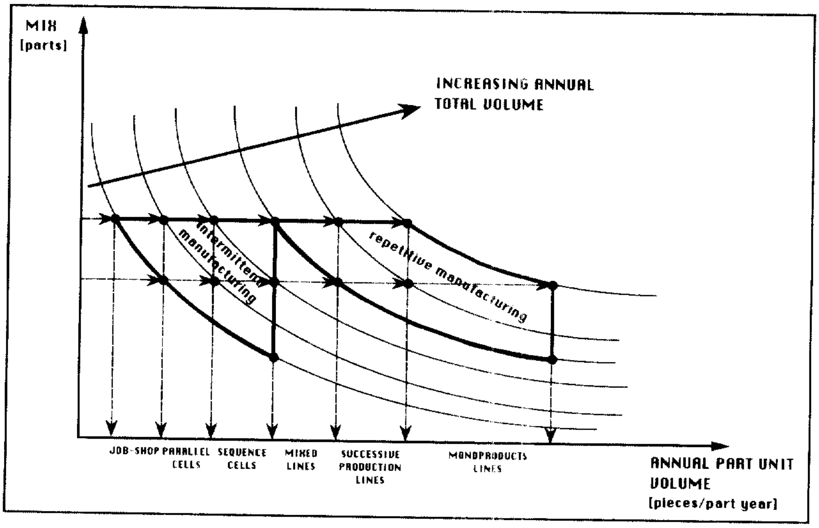

Figure 3. Applicative fields of plants (with a constant productive mix) which carry out intermittent and repetitive manufacturing on increasing of annual total production volume.

Conversely, at the level of finished products, as the product mix is ever greater, it is necessary for companies to differentiate the products. In this way—supposing that annual total sales volumes are constant—production volumes per single finished product decrease. For this reason companies that intend to obtain high levels of efficiency, producing different finished products, must—in order to reach minimum volumes to justify repetitive production—concentrate the assembly of most or all of the mix of finished products on the same line. With the growth in the level of product differentiation there is a progressive shift from assembly on dedicated lines to assembly on lines with successive productions and finally to assembly on mixed assembly lines. If the need for differentiation is still greater, the company will find it necessary to carry out assembly on intermittent plants rather than repetitive ones, for example on sequence cells, each one aimed at preassembly or final assembly stages, or even on parallel cells, where each cell assembles one family of products.

In the operating praxis component stadardization policies lead in general to use of manufacturing plants like parallel or sequence cells, without excluding however the possibility of obtaining some components from dedicated lines. On the other hand, even when strong product differentiation policies are present, it is still generally possible to carry out assembly stages in a repetitive way, using flexible plants like mixed model lines.

The hourglass type product structure is able to respond to the above requirements. The finished products are offered in a wide range starting from a reduced number of components, sub-assemblies and functional groups. The structure of the hourglass product allows joint flexibility and efficiency, through product differentiation obtained in the final assembly stages carried out on mixed model lines and through the production of components in cells.

Equal to annual total volume, standardization or differentiation of parts—thanks to the increase or decrease of annual part unit volumes—allows shift from intermittent manufacturing to gradually more repetitive manufacturing or vice versa. Part standardization or differentiation can be graphically represented by the respective descent or rise along the curve of Fig. 4. These actions cause the respective descent or rise along the diagonal of the matrix of Fig. 2.

As affirmed above, at component level the search for standardization usually leads to manufacturing on plants still typical of intermittent manufacturing, while at finished product level the search for differentiation leads generally to assembly on plants that still present characteristics of repetitive manufacturing.

Starting from this generalization, a more detailed analysis will now be developed on the effects of standardization on just intermittent production and the effects of differentiation on just repetitive manufacturing. The considerations to be expressed here on the effects of standardization and differentiation in the two cases can easily be extended to respectively repetitive and intermittent manufacturing.

The most detailed analysis of the effects of standardization or differentiation on the parts produced, in the respective contexts of intermittent and repetitive manufacturing, requires the use of the previously proposed relationships (2) and (3). They allow representation of parametric curves regarding the annual part unit volume in the two productive contexts equal to annual total volume.

In the plan individuated by the two variables average lot quantity and number of lots per year, Fig. 5(*a*) shows three curves characterized by growing values of the annual part unit volume, respectively low, medium low and medium. These three curves show the applicative fields of job-shops, parallel cells and sequence cells in intermittent manufacturing when product standardization policies with progressive mix reduction are applied.

In the same way, in the plan showing the two variables periodic part unit quantity and number of production periods per year, Fig. 5 (*b*) shows three curves characterized by decreasing values of annual part unit volume, respectively very high, high and medium-high. These three curves show the applicative fields of plants with monoproduct lines, lines with successive production and mixed multiproduct lines in repetitive manufacturing when product differentiation policies with progressive mix increase are applied.

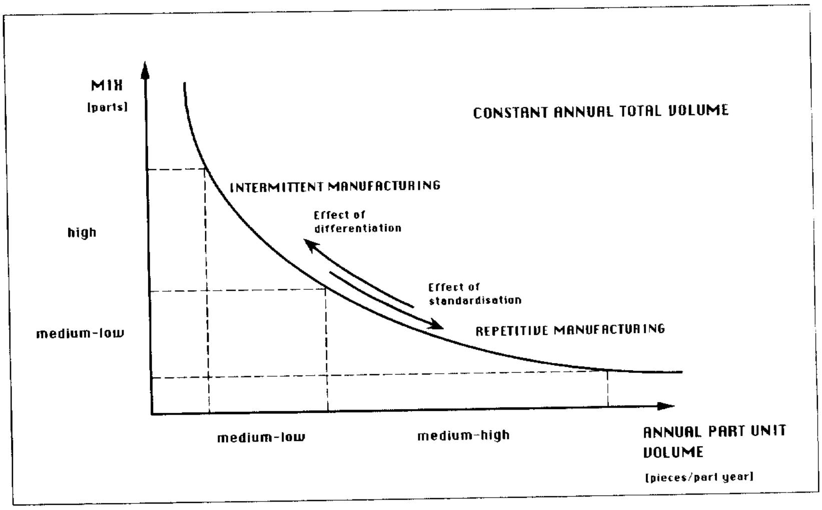

Figure 4. The effect of part standardization and differentiation with a constant annual total volume.

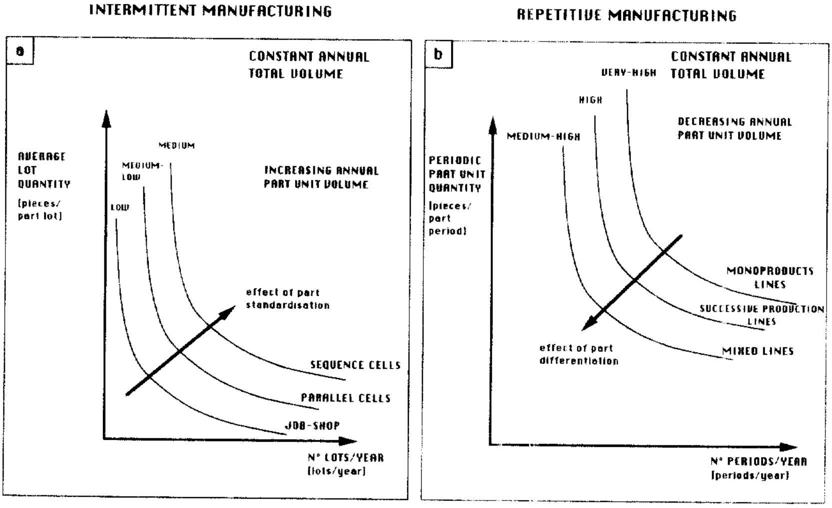

Figure 5. Effects of standardization in intermittent manufacturing and differentiation in repetitive manufacturing with constant annual total volumes.

In Fig. 5(*a*) part standardization—which leads to an increase in average annual part unit volumes, equal to the annual total volume—is graphically represented by the shift from the lower curves to the upper ones, with corresponding modifications of the most suitable plants for the production required.

In Fig. 5(*b*) part differentiation—which leads to a decrease of average annual part unit volumes equal to the annual total volume—is graphically represented by the shift from the upper curves to the lower ones, with corresponding changes in the most suitable plants for the production required.

6. Effect of process standardization with constant annual total volume and constant annual part unit volume

Having clarified the effects of part standardization and differentiation, it is equally important to analyse the effects of process standardization, or rather the increase in the degree of similitude in the production routeings of the various parts. This latter is one of the main objectives in group technology philosophy (Burbidge 1975).

Detailed analysis, in the context of both intermittent and repetitive manufacturing, of the effects of process standardization also requires the use of the previously proposed relationships (2) and (3) that are represented by the curves of Figs 6(*a*) and 6(*b*), equal to annual total volume and annual part unit volume.

In intermittent manufacturing the effect of the search for similarity in component production routeings leads to a reduction in the quantity of the average production lot. In fact similarity of operations means less machine set-up costs and thus allows production lot sizes which are, on average, smaller. Contextually the number of lots produced per year increases, as the annual part unit volume is constant. Thus the ability of the production system to carry out production more consistent with downstream demand increases.

In repetitive manufacturing the search for similarity in part production routeings leads to a reduction in the periodic part unit quantity. Also in this case in fact similarity of operations means less line reconfiguration costs and thus allows shorter production

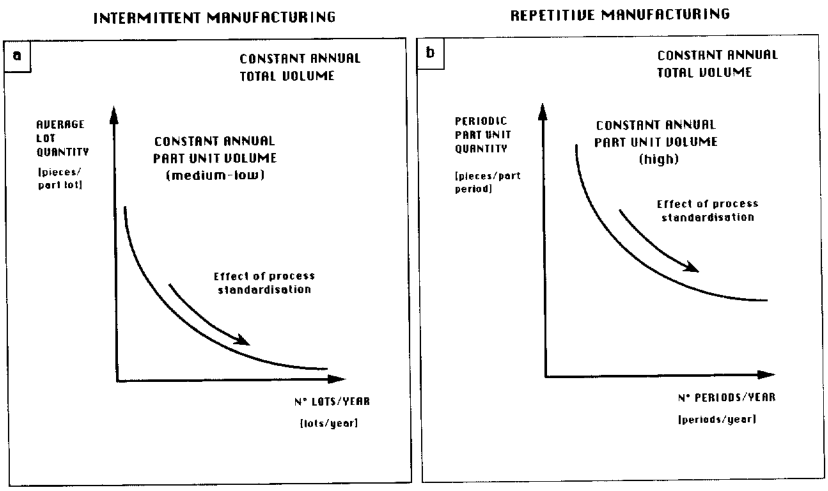

Figure 6. Effects of process standardization with constant annual total volume and constant annual part unit volume in intermittent and repetitive manufacturing.

periods. Contextually the number of production periods per year increases, as the annual part unit volume is constant. The line ability for production more consistent with market demands also increases.

In both cases—intermittent and repetitive manufacturing—process standardization is represented graphically by the descent along the curve respectively in Figs 6 (*a*) and 6 (*b*).

7. Effects of simultaneous product and process standardization with constant annual total volume in intermittent manufacturing

In the case of intermittent manufacturing simultaneous action aimed at product and process standardization leads contextually, equal to annual total volume, to an increase of annual part unit volumes and to a reduction in the average production lot size. The effects of this simultaneous standardization are graphically represented in Fig. 7 (*a*).

Note how, starting with operations in job-shop systems, a first standardization of parts allows production in parallel cell systems. Following this, standardization of production routeings allows a reduction in the average production lot size; thus the ability of the parallel cell system to respond better to variations in the short term of the downstream demand for single parts in the mix increases, equal to part unit volume and mix range. In the same way a second standardization of parts leads to production on sequence cell systems, while further process standardization leads to greater response abilities to downstream demand in the short term, equal to mix range and volume.

In general part standardization increases unit volumes and allows use of more specialized production systems with an increase in efficiency, while process standardization increases the number of lots per year, equal to the mix, and allows an increase in system flexibility so that the system reacts better to variations in mix demand in the short term, allowing faster response to downstream demand.

In reality product and process standardization is often carried out simultaneously, as shown by the dotted line of Fig. 7 (*a*). Design of a parallel or sequence cell system presupposes in fact the search for families of parts with similar production routeings with annual part unit volumes large enough to justify creation of the cells themselves.

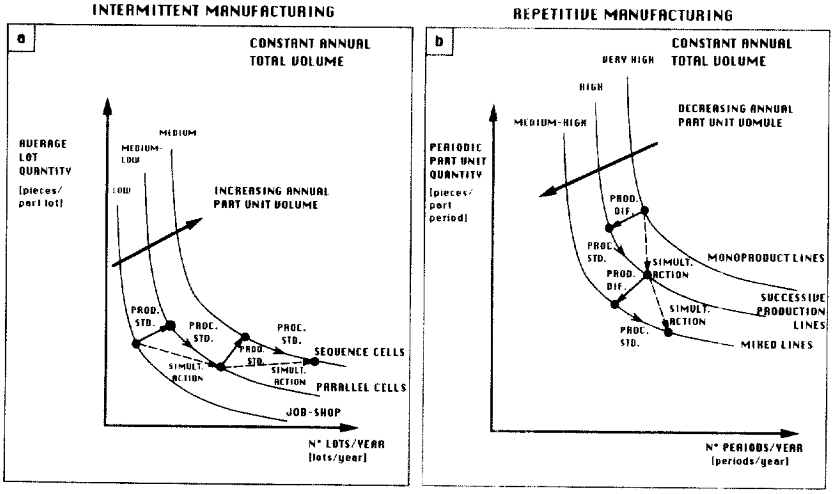

Figure 7. Effects of simultaneous product and process actions with constant annual total volume in intermittent and repetitive manufacturing.

8. Effects of simultaneous product differentiation and process standardization with constant annual total volume in repetitive manufacturing

As clarified in a previous paragraph, in the case of repetitive manufacturing the need for process standardization remains, while the need for product differentiation becomes more important than product standardization.

The two actions that should be carried out simultaneously therefore are product differentiation and process standardization. These actions lead contextually, equal to annual total volume, to a reduction in annual part unit volumes and to an increase in the number of production periods per year. The effects of these actions are graphically represented in Fig. 7 (*b*).

It is noticeable how starting with operations on monoproduct lines a first product differentiation makes it more convenient to carry out production on lines with successive productions. Following this, a production routeing standardization allows a reduction in the periodic part unit quantity. In fact operation simularity—which means less line reconfiguration costs—allows shorter and therefore more production periods per year. In conclusion there is an increase in the ability of the productive system to respond, equal to part unit volume and mix range, to variations in mix demand in the short term.

In the same way further product differentiation leads to production on mixed multiproduct lines, while further process standardization allows, equal to part unit volume and mix range, faster response to market demand.

In general product differentiation decreases part unit volumes and leads to the use of productive systems which are more mix flexible, while process standardization, by increasing the number of production periods per year equal to the mix, allows an increase in the flexibility of the system; that is its ability to satisfy efficaciously and more quickly variations in demand.

As regards discrete lines simultaneous product differentiation and process standardization are indicated by the dotted lines in Fig. 7 (*b*). In particular, design of a multiproduct mixed line presupposes the search for product families with similar production routeings and annual part unit production volumes sufficient to justify line creation.

9. Simultaneous actions on product and process in intermittent and repetitive manufacturing in order to obtain focused sub-factories

The above considerations, which refer to the curves in Fig. 7 respectively for intermittent and repetitive manufacturing, are visualized with the help of the respectively matrixes of Fig. 8 and Fig. 9.

Note how in Figs 8 and 9, in order to move from one given production system to another, it is clearly necessary to act on both the product and process variables. This necessity does not appear in Figs 7 (*a*) and (*b*) where it is sufficient, for example, to standardize or differentiate parts in order to shift from one system to another. This is due to the fact that for the curves in Fig. 7 domains and co-domains have not been defined for values that the variables can assume in abscissa and ordinate.

Figures 10 and 11 are three-dimensional representations of the effects of the actions on the product and on the process, at constant annual total volume, on intermittent and repetitive production.

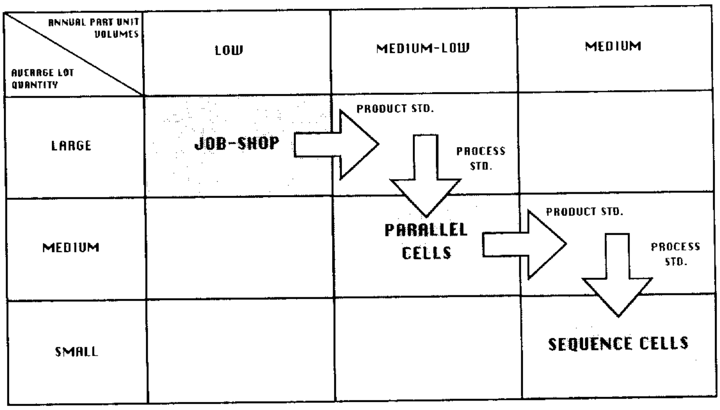

Figure 8. Matrix representation of the effects of process and product standardization with constant annual total volume in intermittent manufacturing.

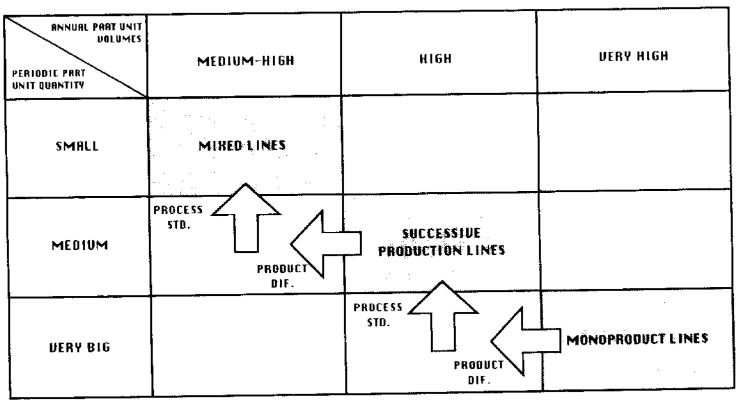

Figure 9. Matrix representation of the effects of process standardization and product differentiation with constant annual total volume in repetitive manufacturing.

The paths represented in Figs 10 and 11 indicate, for intermittent manufacturing, an evolution towards productive systems organized in parallel or sequence cells, while for repetitive manufacturing, an evolution towards production on mixed multiproduct lines.

In both cases there is an evolution towards systems which, equal to annual total volume, are characterized by a greater frequency of operations for different, if similar, products. Greater machining frequency ensures faster response to variations in demand for mix parts in the short term, while similar production routeings allow high levels of efficiency.

The most distinctive characteristics of parallel and sequence cells and of mixed multiproduct lines are the capacity to machine a significant mix of parts and the high machining frequency of different, if similar, parts. These characteristics derive from the individuation of product families and portions of the productive process which constitute independent units within the factory. In the case of parallel cell systems and

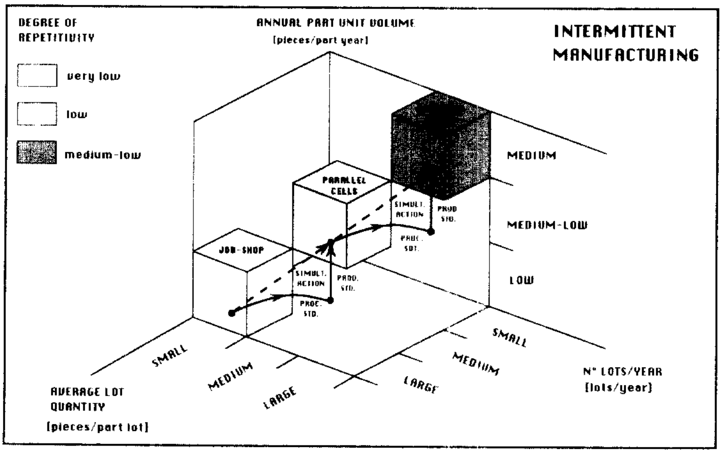

Figure 10. Three-dimensional representation of the effects of process and product standardization in intermittent manufacturing with constant annual total volume.

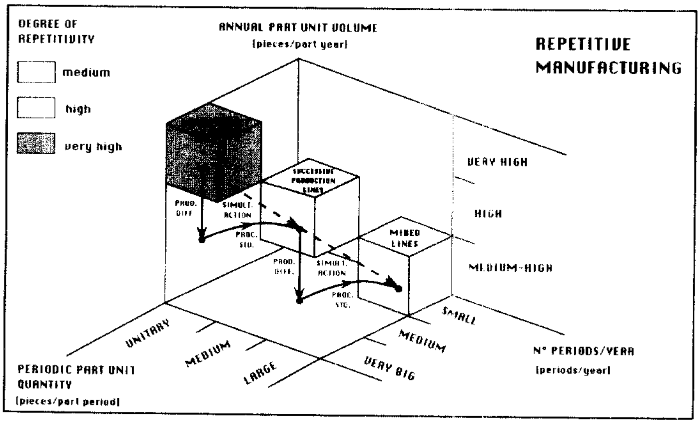

Figure 11. Three-dimensional representation of the effects of process standardization and product differentiation in repetitive manufacturing with constant annual total volume.

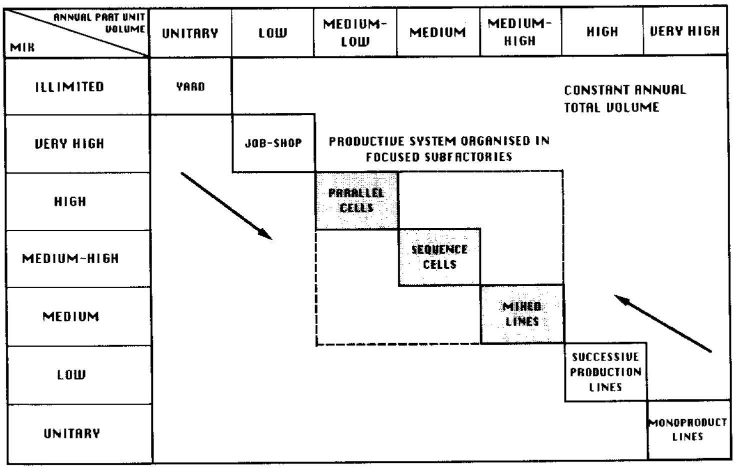

Figure 12. Applicative fields of productive systems organized in focused sub-factories.

mixed lines these units are totally autonomous within the productive process, while sequence cells represent units which, although autonomous, are, however, connected as they carry out together the entire production routeing.

Cells and mixed lines thus represent for the reasons given above focused sub-factories. Structure of the productive process in focused subfactories is desirable as it allows simplicity of flows, fast decisions, less managerial and organizational problems (Schonberger 1982). Hill (1987), when describing focused sub-factories, used in the term 'plant-within-a-plant' (PWP) that is separate productive units each of which is totally dedicated to a precise part of the total production. This means that the productive units are of a size easy to manage, combining advantages of specialization and reduced dimensions.

Focused productive plants are discussed by Hayes and Schmenner (1978), and by Mayer and Agarwal (1980), while Hayes and Wheelwright (1984) analyse the advantages and disadvantages connected with focusing of productive plants.

Figure 12 shows applicative fields of productive systems structured in focused sub-factories.

10. Conclusions

In this paper the authors have proposed, through the use of the variables annual part unit volume and mix range, a matrix of the applicative contexts of productive plants which carry out intermittent and repetitive manufacturing, at constant annual total production volumes. The increase of annual total production volume has the effect of modifying operating conditions leading to a choice of plants that allow less intermittent and more repetitive manufacturing.

Through the use of two groups of variables—average production lot size and number of lots per year in intermittent manufacturing and periodic part unit quantity and number of productive periods per year in repetitive manufacturing—the effect of part standardization/differentiation has been described, equal to annual total production volume which leads to increased efficiency and mix flexibility respectively in intermittent and repetitive manufacturing.

Following this the effect of process standardization was analysed, which leads in the case of intermittent manufacturing to a reduction in the size of the average production lot and in the case of repetitive manufacturing to a reduction of the periodic part unit quantity, with an increase in both cases of the ability of the productive system to carry out productions more consistent with demand.

Finally it was shown how simultaneous product and process actions allow machining with higher performances in terms of efficiency in intermittent manufacturing and in terms of mix flexibility in the case of repetitive manufacturing; with high machining frequencies of different, even if similar, products, these conditions are typical of autonomous units in the productive process and noted with the term focused sub-factories.

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