Integrated Manufacturing Systems

Product Standardisation and Process Similitude

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Why we need an integrated product-process approach.

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The Need for Simultaneous Product-process Design

The increase in market needs and rising international competitiveness have led to the need for a close integration between product design and the design of manufacturing systems in order to obtain higher performances at the level of products and production processes.

As regards products, it is easy to see that they are characterised by ever shorter life cycles, pervasive technological content, requests for wide ranges, high degrees of customisation, low time-to-market, short delivery times, high reliability[1,2].

On the side of production processes, we see how they are increasingly focused on the product due to the need for higher productivity[3]; consequently they are negatively affected by introduction of new products not designed with regard to specific production requirements.

Those affected are not traditional systems like job shops, where performances are not heavily influenced by the introduction of new products, but rather recent manufacturing systems based on logics inspired by group technology and just-in-time and characterised by the use of flexible automation technologies.

The introduction into manufacturing systems of group technology and just-in-time logics and of flexible automation systems means that product design must take into account new and different production methods. By applying the principles of group technology, families of products are defined; these products are similar in their production routings and obtained from production cells[4]. From a design point of view, this means a simultaneous definition of an entire product family, or the definition of a single finished product whose characteristics are consistent with the rest of its family.

The production processes which work with just-in-time logic are distinguished by pull shopfloor control systems, mixed model lines, visual monitoring of the manufacturing systems, supplies at the beginning of the line, etc.[5]. This means having to arrange physical space for all the raw materials and components, limiting significantly the introduction of new models not taken into account at the time of designing the manufacturing system for obvious reasons of space.

The adoption of flexible manufacturing systems (FMS) also means that the product will be produced within the limits of the system, i.e. availability of suitable tools, availability of fixtures, overall piece dimensions, guaranteed tolerances, accessibility to the machined piece[6]. The limitations deriving from adoption of FMS at the product design stage are clear.

Reconciliation between product characteristics which are increasingly sophisticated and manufacturing systems which are increasingly efficient must be sought at the product definition stage, or even better through a simultaneous design of both product and process. In literature these topics are known by the term "design for producibility", "design for manufacturing", and "design for assembly"[7,8].

Another fact which justifies paying great attention to product process simultaneous design is that during the design stage many of the costs that will be sustained in the next stages of development, construction and product use, are determined here. This is clearly seen in the well known life cycle cost curves[9]. "Design to life cycle cost" approaches are aimed at a total reduction of operating and production costs.

From this we can see the importance of simultaneous design which considers all the problems connected with the birth of a new product.

The Objective of Simultaneous Design: Flexibility in Stable Operating Conditions

While on the one hand there is a market demanding high flexibility in its various dimensions (mix flexibility, volume flexibility, delivery flexibility, design-change flexibility, etc.), on the other there is a need for efficient manufacturing systems able to guarantee high quality products at competitive costs.

The concept of flexibility is the root of much reflection among many authors. The term is not univocally defined and in general means the ability of a system to cope with changes. Among the most important definitions of flexibility are those of the following authors:

- Buzacott[10]: "job and machine flexibility";
- Zelenovic[11]: "design adequacy" and "adaptation flexibility";
- Gerwin[12]: "mix, parts, routing, design-change and volume flexibility";
- Browne *et al.*[13]: "machine, process, product, routing expansion, volume, operation, and production flexibility";
- Barad and Sipper[14]: "machine set-up, process, transfer, routing and system set-up flexibility";
- Bertelè and Azzone[15]: "volume, product, mix, production, expansion and technological flexibility".

As far as we are concerned, Mandelbaum's definition of flexibility is the most useful[16]:

- *action flexibility:* the ability to undertake new actions in the face of new circumstances; this means leaving a series of options open which allow for further action in order to obtain the desired changes;
- *status flexibility:* the ability to continue to function in spite of changes: the system is able to react by itself to modifications.

In order to apply these general concepts to a manufacturing system, the existence of a group of optimum operating conditions must be supposed. Status flexibility allows the system to operate in the various supposed operating states. Action flexibility allows the system to move into other operating states which were not previously foreseen.

It is clear that the costs associated with action flexibility in a manufacturing context are extremely high, due to the need to equip the manufacturing system with machinery, organisational structures and management procedures able to cope with very diverse and unexpected situations. Conversely, working within a group of known states has decidely lower costs, even if significantly higher to those of a system characterised by a single operating condition. It is therefore reasonable to affirm that manufacturing system flexibility, as understood in the two above classes, should be sought for above all in status flexibility. The need to tend towards status flexibility is still greater in highly automated production contexts. In fact the size of the investments involved means necessarily predefining before hand what production conditions will be needed.

The concept of status flexibility just introduced is presupposed by the concept of stability which we will now formulate. Gupta and Buzacott[17] define "sensitivity" and "stability" as aspects of flexibility. In general the stability of a system can be defined by its ability to keep going and return to an optimum operating state, in the presence of external disturbances. If extended to various operating states the concept of stability presupposes that of status flexibility: we would say a manufacturing system is stable when it is characterised by the ability to operate in various optimum operating states in regard to which it is able to keep going and return in case of external disturbances.

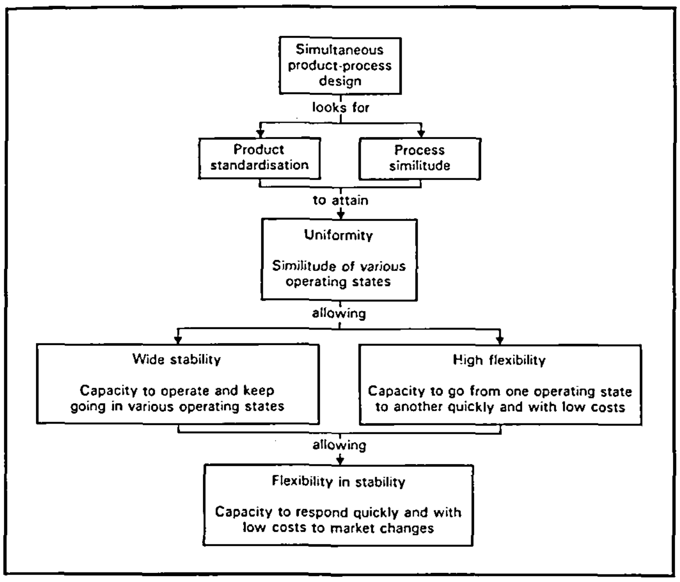
Giving a manufacturing system stability, in the above sense, is not however enough. In fact stability must be accompanied by the possibility of evolving from one operating state to another quickly while keeping costs contained. With reference to the above definition of stability, the flexibility of a manufacturing system can be defined as its ability to pass quickly and at a low cost from one operating state to another.

A fundamental objective in the design and production of a manufacturing system, therefore, must be the simultaneous attainment of stability and flexibility. Stability and flexibility of a manufacturing system are fundamental variables in determining the performance of the system. Stability is important in the long term of guarantee significant investment in plants and automation, lasting organisational structures, continuing relationships with suppliers. Flexibility is important in the short term in order to respond quickly to market disturbances, keeping to a minimum transitions which are due to production changes. The above concepts of stability and flexibility are similar to the two dimensions of flexibility as defined by Slack[18]: the variety of states (corresponding in some ways to stability), and costs and times necessary for changing (corresponding to flexibility).

To attain a manufacturing system equipped with good stability and high flexibility it is therefore necessary to increase the level of similitude between the various operating states. The uniformity of a manufacturing system is linked to the degree of product standardisation and the degree of similitude between the production routings.

A search for product standardisation and process similitude at the design stage means organising in advance the manufacturing system in order to reduce its complexity. In other words, it means creating today the conditions to resolve problems easily which could arise tomorrow. Design thus becomes the first stage where the basis is laid to resolve problems that normally would be found in later stages of manufacturing and assembly. It is at the design stage that by defining the level of uniformity of the systems, its degree of liberty and velocity in changing is established.

Figure 1. *Flexibility in Stability: The Objective of Simultaneous Product-process Design*



In Figure 1 we have tried to represent the above concepts, showing how simultaneous design, through the introduction of product standardisation and process similitude, is a fundamental tool in obtaining uniformity of the various operating states. Uniformity allows greater stability and increased flexibility; uniformity allows finally the attainment of flexibility in stable operating conditions (concisely, flexibility within stability) or in brief the possibility to respond quickly and economically to external market disturbances.

Product Standardisation and Process Similitude as Fundamental Variables in the Choice of Automation

In manufacturing firms the introduction of automatised processes brings about a revision of products as regards their automatic production and requires a systematic product-process approach, as previously stated.

Product standardisation and process similitude attained through actions aimed at conferring stability and flexibility on the operating system are significant variables in directing firms in their choice of the most convenient type of automation.

A high degree of product standardisation is expressed in a reduction in the number of parts. A modular conception of the product, or rather an hourglass structure, keeps the range of products offered very wide by using a reduced number of components and modules[19]. A reduction of the number of parts, equal to the demand for finished products, increases the unit volume of production of the parts and the continuity of demand for them.

A high degree of similitude between production routings allows a group layout with cells intended for the machining of entire product families, and allows organisation of preferential flows inside the manufacturing system. Formation of part families which can be machined in the same cell comes through grouping the parts with similar production routings, as indicated in Figure 2[4].

Product standardisation and process similitude are the variables which determine the various applicative fields of different types of manufacturing systems (see Figure 3).

Brown *et al.*[20] propose instead a classification by matrix of manufacturing systems with the variables: product focus and process decoupling.

The first square in Figure 3 represents a job shop. The production routings of the parts are all different, the production unit volumes of the components are low and determine an intermittent demand for them. The system is intended for machining all the parts.

The second square of the figure shows manufacturing systems of dedicated machines or lines, each respectively characterised by a specific operation or production routing

Figure 2. *Formation of Production Families according to Group Technology Criteria*

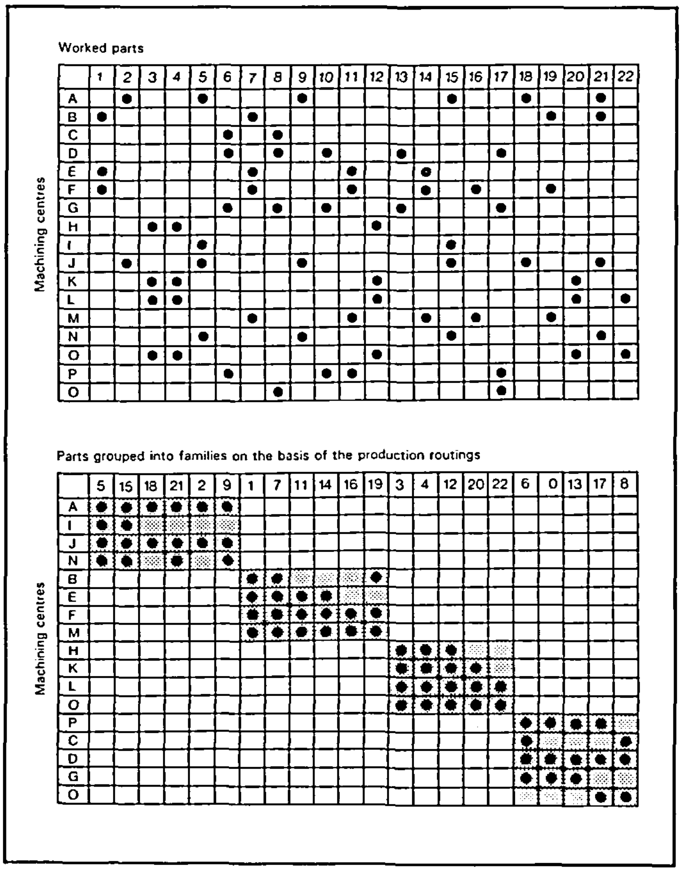
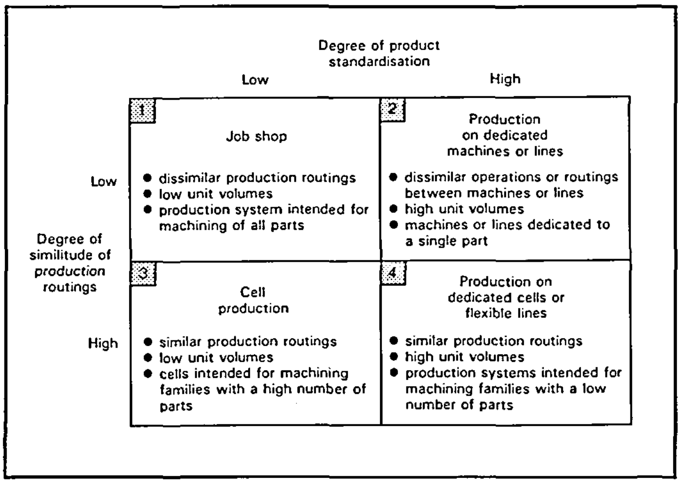


Figure 3. *Manufacturing Systems Matrix on the Basis of Product Standardisation and Process Similitude*



different to the others. The machines or lines are dedicated to machining of only those parts with high unit volumes, which are the result of a search for commonality at product level. The parts with low unit volumes are produced in traditional job shops.

The third square of Figure 3 represents cell manufacturing systems, characterised by homogeneous production routings, low unit volumes and an intermittent demand for single components. The cells are intended for machining families with a high number of parts.

The fourth and last square of the figure shows production on dedicated cells or flexible lines depending on whether it is the process similitude or the product standardisation that determines high part unit volumes. The number of parts of each family is typically low. By dedicated cells we mean cells with special machines capable of specific machining jobs. The presence of special machines is justified by the high volume which allows the creation of families with a low number of parts. Flexible lines are production plants where the presence of machines able to perform more than one type of operation guarantees a certain degree of flexibility compared with a dedicated line. On flexible lines the number of parts making up the family is even lower than those of dedicated cells.

The conditions characterising the fourth square of Figure 3 are high product standardisation and process similitude; these conditions allow individuation of product families and subsystems of the production process which can make up independent units within the factory. These units, autonomous within the manufacturing system, are known by the term of focused subfactories. The structuring of a manufacturing system in focused subfactories is desirable as it allows flow simplicity, quick decisions, less managerial and organisational problems[21].

Realisation of the conditions of square 4 of the matrix is possible through review of both product and process. The actions can be carried out as shown in Figure 4.

Actions on the product and process modify the value of variables such as the total number of parts, part unit volume (volume/part), the number of families, family unit volume (volume/family), the numerosity of the family (parts/family); these variables are linked together according to the following relationships:

Total production volume

= (N° parts)* (volume/part)

= (N° families)* (volume/families)

= (N° families)* (parts/family)* (volume/part)

It is noticeable how, equal to total production volume, action on product standardisation affects the total number of parts and the part unit volume and how action on process similitude affects the number of families, the volume per family and the numerosity of the families. The relationships between the above variables and the actions on product and process are qualitatively shown in Figure 5, supposing constant production volumes.

Actions on product standardisation bring about a reduction in the total number of parts and therefore an increase in the part unit volume.

Action on process similitude has no effect on the unit volume of each part, but increasing the degree of similitude

Figure 4. *Product and Process Actions*

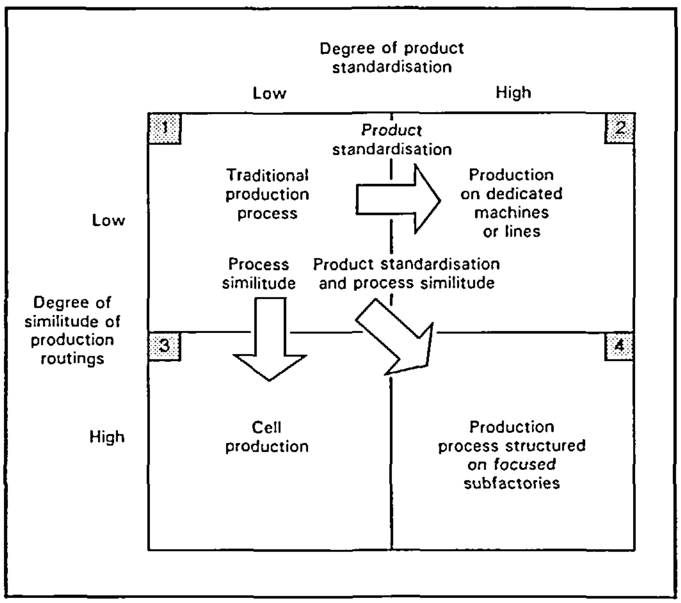
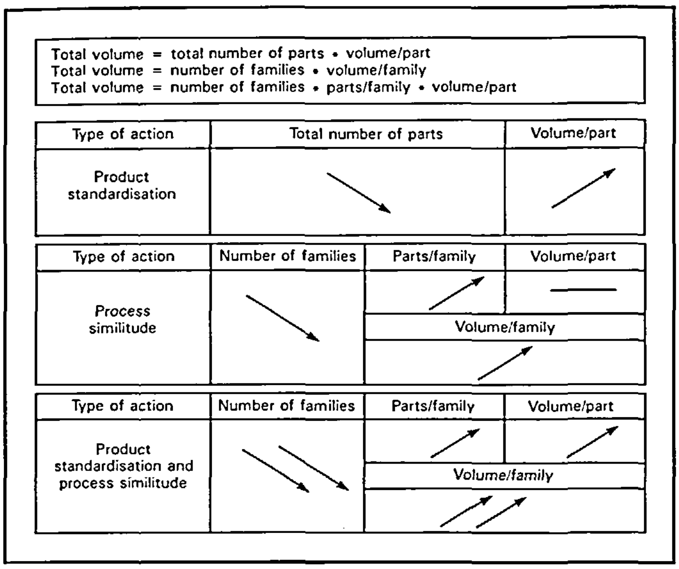


Figure 5. *Relationship between Variables with Constant Production Volume*



of production routings allows better aggregation of parts into families, therefore enlarging family numerosity, and a consequent decrease in their number. The importance of reduction of the number of families is understandable if we consider that in this way the production volumes per family increase; attainment of sufficiently high volumes per family is in fact the basis for the creation of a production cell for each family.

Joint action on product and process allows a big reduction in the number of families, but above all it allows the creation of families, with many parts, that have a high unit volume per family. In Figure 6 the relationship between actions on product and process is shown graphically, supposing constant total production volumes, in the four manufacturing systems of Figure 3.

Figure 6.1 is relative to the job shop. The rectangle at the bottom represents matrix 2.1 of Figure 2; the unit volumes of part production are also represented in rising order.

Figure 6.2 shows how high unit volumes connected to a high product standardisation allow the use of machines or lines dedicated to production of a single part. These parts in general can be individuated as class A of an ABC classification of volumes and are also known as fast parts, with regard to lead time. The remaining parts of classes B and C continue to be produced by job shop or cell systems according to the degree of similitude of their production routings. The effect of introducing product standardisation starting from a job shop (movement from square 1 to square 2 in Figure 4) leads to the use of dedicated machines or plants for class A parts with regard to production volume.

The search for similitude in production routings leads on the other hand to the formation of part families. In Figure 6.3 we can see how the creation of product families must take into consideration the volume of the single part. Note how low unit volumes per part make a search for more numerous families necessary in order to reach minimum production volumes that justify cell creation. Figure 6.3 can be considered as representative of the effects of action aimed at increasing process similitude (possibility of family formation). In Figure 4 the effect is shown by the movement from square 1 to square 3 of the matrix.

Figure 6.4 shows the result of the combined action of introducing both product standardisation and process similitude and corresponds to the movement from square 1 to square 4 of the matrix in Figure 4.

The matrix in Figure 7 determines the applicative contexts of the different classes of automation, showing how appropriate automation choices are dependent on product standardisation and process similitude.

It is not convenient to extend automation in job shop systems to stock and transport phases (see square 1 of Figure 3). The most frequent automation action is the adoption of stand-alone CNC machining centres for automation of the most common operations (see square 1 of Figure 7: flexible automation of operations). A more organic automation plan for the production process must pass through cell definition according to Group Technology approach.

Production in high unit volumes (see square 2 of Figure 3) allows the rigid automation (dedicated machines or rigid transfers), (see square 2 of Figure 7: rigid automation).

Cell automation for the machining of families with a high number of parts (see square 3 of Figure 3) can be possible by introduction of FMS with machining centres for machining wide mixes of pieces: up to and over 500 parts[22] (see square 3 of Figure 7: flexible automation with wide mix).

Automation systems of dedicated cells and flexible lines (see square 4 of Figure 3) are represented respectively by FMS not in line equipped with special machines and by flexible transfer for the machining of a low number of parts (see square 4 of Figure 7: flexible automation with low mix).

The matrix of Figure 7 as constructed indicates how an appropriate introduction of automation is linked to the variables product standardisation and process similitude. Introduction of product standardisation and process similitude enlarges the applicative contexts of low mix flexible automation (square 4), which results in less expensive than wide mix flexible automation (square 3) and allows a greater degree of flexibility as compared to rigid automation (square 2).

Figure 6. *Product Families and Unit Volume per Family on the Basis of Product Standardisation and Process Similitude*

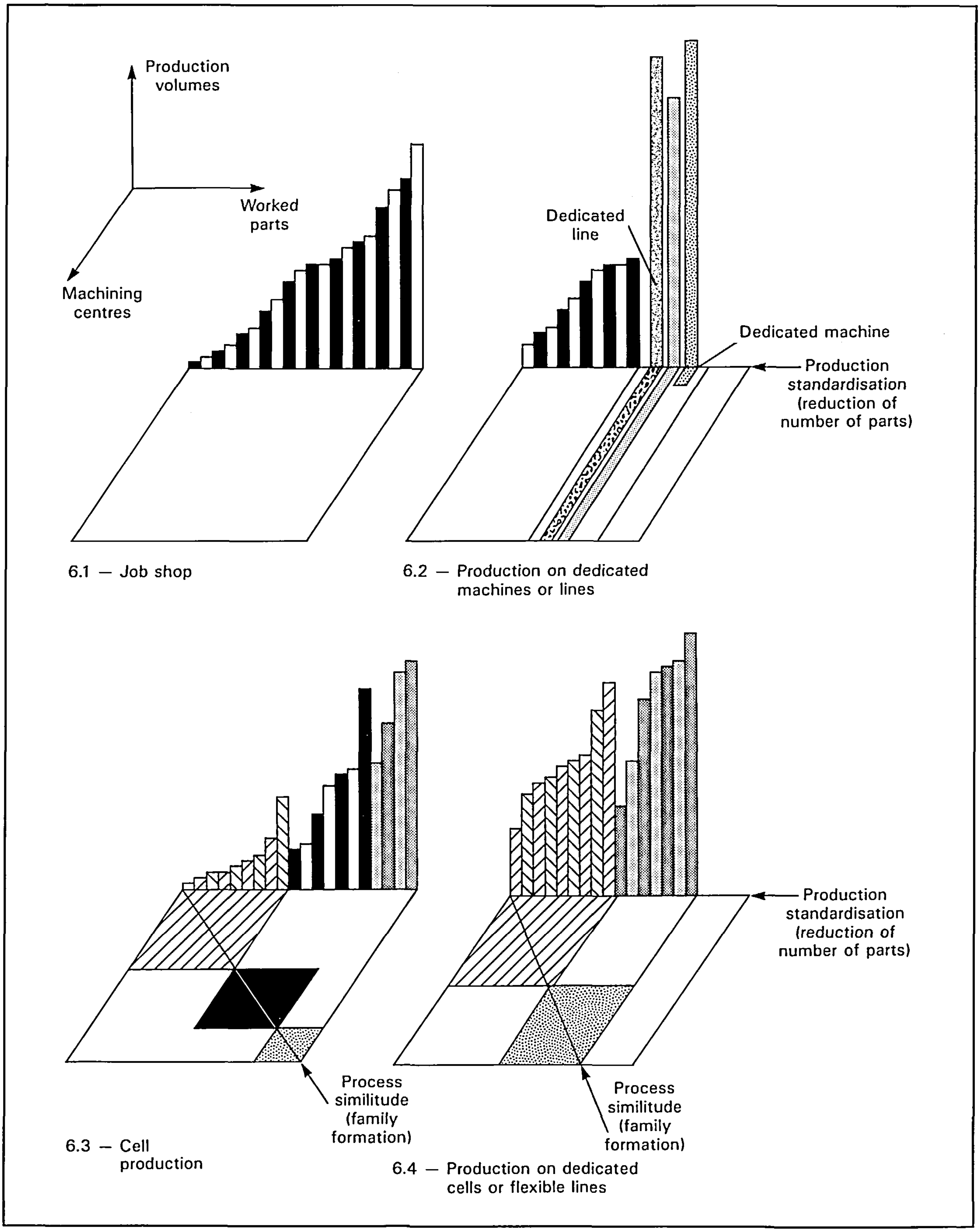


Figure 7. *Automation Type Matrix on the Basis of Product Standardisation and Process Similitude*

Degree of similitude of production routings / Degree of product standardisation	Low	High
Low	1 Flexible automation of operations • NC machining centres	2 Rigid automation • dedicated automatic machines • rigid transfers
High	3 Wide mix flexible automation • FMS with machining centres	4 Low mix flexible automation • FMS with special machines • flexible transfers

The action levers in order to increase product standardisation and process similitude will be described in a later article.

Conclusions

In this article we have tried to show the need for simultaneous product-process design. We have shown the major objective of simultaneous design: attainment of flexibility in stable operating conditions. The fundamental variables to obtain flexibility and stability are product standardisation and process similitude. In particular product standardisation and process similitude are the two variables which determine the applicative context of different automation types.

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