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Levels of Analysis in Simultaneous Product-process Design

Simultaneous design actions aimed at rationalising products and simplifying the production process are important for reasons discussed elsewhere[1]. Moreover, these actions represent the first stage of an automated project. The three stages in implementing an automation project are[2]:

- simplification
- automation
- integration.

Simplification can be considered as a preautomation stage. If the production process is not rationalised, for example by eliminating bottle-necks, superfluous movements etc., and if products are not designed with a view to their producibility[3], the automation of a process which is too complex will mean sizeable investment, long implementation times and a high risk of failure; in a nutshell automating chaos means automating waste. The simplification activity coincides with joint action on the product and the process in order to turn a traditional job shop into a manufacturing system organised into focused sub-factories.

Figure 1 shows three classes of action aimed at simplification, which is the stage most closely linked to simultaneous design. The three classes representing three areas of action are:

- product revision
- process revision
- revision of professional roles.

We will turn our attention to the first two classes.

In order to develop the themes of simultaneous product-process design, we will analyse the actions at three different levels of detail, which are distinct for product and process, as indicated in Figure 2. This subdivision allows separation of problems, objectives and solutions, easier reading, and moreover points to the distinct classes of action.

The three-level chart, given in Figure 2 and described below, can be considered as the key to establishing criteria for revision of product-process design or as a methodological indicator for defining operating levels within design and production.

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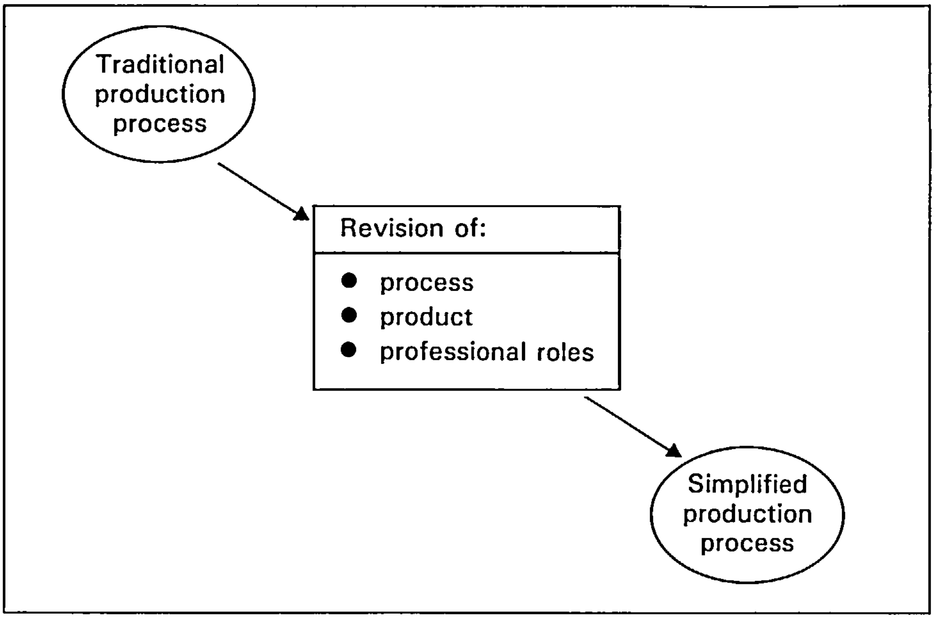

Figure 1. Three Classes of Action for Simplification of the Production Process Needed for Automation

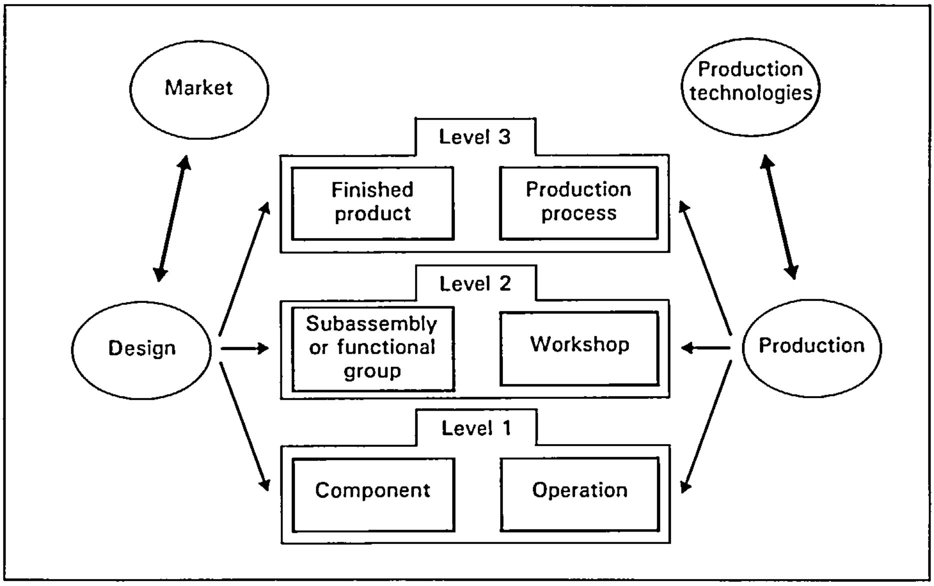

Figure 2. Levels of Product-process Action

For each of the three levels, action variables are described for both product and process. The three levels defined for the product are[4]:

- finished product
- subassembly or functional group
- component.

The three levels defined for the process are:

- production process
- workshop
- operation.

In Figure 2 we represent graphically the interrelations between the design team and the marketing team, who interpret market demand, and between the production team and the industrialisation team, who must study and resolve production problems.

In the following, for the sake of simplicity, the action variables of the two groups, "product" and "process", will be analysed separately, even if the approach to the problem should be holistic, since very strong reciprocal interdependences exist between the two groups of variables.

Action Levers and Objectives at Level 1, Component-operation

The first level of action is represented by the component-operation pair. By component we mean a single piece to be machined, generally without functional characteristics, which is at the lowest level of the bill of materials of the finished product. By operation we mean a single operation on one machine.

The actions possible at this level, which differ from those at levels 2 and 3, do not sensibly affect the characteristics of the product or process and are easily carried out.

In Figure 3 the levers for both component and operation are shown with their respective primary objectives, where the term "primary" indicates an objective which is principally linked to the corresponding lever. Levers and primary objectives will be described in brief below.

Level 1 — Component

Component Standardisation. Standardisation of components has the main objective of reducing the absolute number used. To standardise means achieving a commonality of components, i.e. using them for different products. First-level standardisation is not considered as a product modification and there are no commercial effects. Standardisation leads to high unit volumes per component,

Level 1			
Component revision		Operation revision	
Levers	Primary objectives	Levers	Primary objectives
Standardisation	Reduction of total component number	Operation standardisation	Reduction of number of operations, tools, and fixtures
Functionality	Reduction of component number per product	Analysis of set-up time	Reduction of set-up time
Machinability	Ease of operation	Analysis of loading and unloading time	Reduction of idle time
Transportability	Handling simplification		
Assemblability	Ease of assembly	Poka-yoke devices	Human error elimination

Figure 3.
Action Levers and Objectives of Level 1, Component-operation

lower management costs, less stock and a reduction in defects; in fact use of fewer parts permits greater knowledge of qualitative and productive characteristics, with a consequent increase in their reliability. With regard to purchasing, standardisation of components means greater contractual power over suppliers and lower costs of material quality control. Standardisation of components must also take into consideration external availability with the aim of improving procurement of components or raw materials.

Component Functionality. An analysis of the functionality of each component within a single product is aimed at reducing the number of components. An accurate functional revision of components leads to products with a significantly lower number of components than previously, but still able to perform the same functions. For example, in the design of Fiat's new Fire engine the 386 components of the old version were reduced to the present 273. In the same way a Hewlett Packard personal computer was designed with 150 components in its second version, instead of the original 450[5].

Component Machinability. Problems in component machinability are linked to the type of raw materials used and to the manufacturing technologies adopted. Techniques for improving machinability are those of the "design for manufacturing" approach[6]. In this work we just stress that at the design stage there must be an accurate study which evaluates variables such as machining tolerances, surface roughness, materials, and sizes of the pieces to be machined, while taking into account the technology of the machines available.

Component Transportability. Component transportability is another important variable which must be considered at the design stage. Easily managed components in terms of shape, weight and size, are desirable. In particular, components must be of a size compatible with the space available on the production line, with containers eventually used for transport and with available space in the warehouse. The degree of transportability determines the minimum-movement batches, which limit production flexibility. In the new Zanussi-Electrolux refrigerator production plant in Susegana (Italy), a study of handling problems allowed a reduction in the size of minimum-transfer batches to only 16 items[7].

Component Assemblability. The assemblability of components means the level of ease of their assembly. The objective of a design which considers problems of assembly is to obtain components which are quickly and easily assembled. Variables affecting assembly are: component geometry and size, type of fasteners, attachment point, degree of fixation and direction of assembly[8].

Design for Assembly (DFA) techniques, aimed at improving component assemblability, refer to an even greater number of variables than those mentioned above[9]. Application of DFA packages is carried out in two main stages[10]:

- application of criteria to each part to verify if theoretically it must be preassembled before final assembly;

- estimate of the costs of movement and assembly of each part by applying the appropriate assembly process (manual or automatic).

Level 1 — Operation

Operation Standardisation. Operation standardisation has the objective of reducing the number of operations necessary for the production of different components. This also leads to a reduction in the number of tools and amount of equipment necessary. A reduction in the types of operation per machine leads to fewer set-up times on a single machine, and thus maximises the ratio of run time to idle time. To facilitate the task of standardising components and operations, engineers should use standard components and systematically consult machining manuals, which constitute a reference for engineering choices[11].

Analysis of Set-up Time. A reduction in set-up time is fundamental for resolving problems which greatly affect the flexibility of the production processes. Application of Shingo's SMED (Single Minute Exchange of Die[12]) methodology allowed Toyota to reduce press set-up times from several hours to a few minutes. A low set-up time is an essential condition for attaining effective repetitive manufacturing flows and constitutes one of the principal factors in achievement of the objectives of levels 2 and 3.

Analysis of Loading and Unloading Times. Reduction of loading and unloading times, which in automatic plants means of palletisation and depalletisation times, aims at maximising the ratio between run time and loading/unloading times. Actions to reduce these times are tied to piece geometry, to the fixtures used and to the automatic loading/unloading devices. A reduction in loading and unloading times of Flexible Manufacturing Systems (FMS) allows a reduction in the number of operators and influences the size of the pallet carousel. More generally, actions aimed at reducing loading/unloading times on generic machine tools, obtained by using automatic loaders, must not cause increases in the set-up times, which will in turn reduce machine flexibility.

Poka-yoke Devices. Poka-yoke, literally foolproof, devices are aimed at avoiding human error, thus improving quality and safety at work. Many applied examples of poka-yoke devices are found in mixed-model lines, where alternate different models can cause frequent assembly errors.

In Figure 4 we show the correlation matrix between action levers at level 1 and objectives deriving from simultaneous action on several levers. Primary objectives are not shown in Figure 4 or in the corresponding upper level matrices (Figures 6 and 10), as they are principally linked to the corresponding lever. Note that levers of component standardisation and analysis of component functionality which reduce the number of parts to be produced and managed, have a positive effect on many of the above objectives.

Action Levers and Objectives at Level 2, Subassembly workshop

Actions at level 2, represented by the subassembly-workshop pair, have a more noticeable effect on product characteristics and the manufacturing system than at level 1.

Level 1 / Action levers — Objectives dependent on different levers	Component					Operation			
	Component standardisation	Component functionality	Component machinability	Component transportability	Component assemblability	Operation standardisation	Analysis of set-up time	Analysis of loading and unloading time	Poka-yoke devices
Reduction of worked parts per machine	O	O							
Reduction of type operation per machine	O	O				O			
High production volume per component	O	O							
Reduction of faculty components	O	O	O		O	O			O
Maximum increase of the ratio between run time and idle time				O		O	O	O	
Reduction of work in process	O	O					O	O	
Lower management costs	O	O							

Figure 4. Correlation Matrix between Action Levers and Objectives Dependent on Different Levers at Level 1, Component-operation

By the term subassembly we mean a functional group, or rather a group of components which together are able to carry out predetermined functions. For example a subassembly, or functional group, can be represented by the drum of a washing machine, by the engine or the air-conditioner of a car. From a production point of view subassemblies can be preassembled independently from the finished product, as in the case of a car engine, or can constitute a group of components that are assembled in successive stages directly onto the finished piece, as in the case of a car air-conditioner.

By workshop we mean a section of the production process, technologically homogeneous, aimed at carrying out one or more stages of the production process (manufacturing, heat treatment, assembly, painting, etc.).

We describe below the related action levers and primary objectives of level 2 (see Figure 5).

Level 2 — Subassembly

Product Definition for Functional Groups. Product definition for functional groups is a response to a need for simplification in the manufacturing and assembly stages; in fact subassemblies carried out in suitable workshops reduce manufacturing and assembly difficulties[13]. An example of this is the choice made in Japan, where even such a complex product as a ship is made up of various subassemblies with the aim of simplifying manufacture and assembly[14]. The ship no longer results from the manufacture of a complete frame, which is successively covered with metal plates; the body is constructed by assembling autonomous subassemblies made up of pieces of the frame each covered with the corresponding metal plates. In this way the various subassemblies can be

Level 2			
Subassembly revision		Workshop revision	
Levers	Primary objectives	Levers	Primary objectives
Product definition for functional groups	Reduction in manufacturing and assembly complexity	Standardisation of production routeings, family formation and cell organisation	Similar production routeings, layout consistent with routeing and flow simplification
Analysis of subassembly functionalities	Subassembly modularisation and reduction in their number	Intermediate stock sizing	Cell synchronisation
Subassembly testability	Ease of functionality control	Point of use with dedicated machinery and focused stores	Reduction in management and handling cost

Figure 5.
Action Levers and Objectives of Level 2, Subassembly-workshop

constructed in workshops with the same types of machine tools, technical expertise and equipment. This approach to construction also allows a reduction in the lead times, thanks to the production of different subassemblies at the same time, as well as greater simplicity in the evaluation and allocation of costs.

Analysis of Subassembly Functionalities. If a product is conceived in a modular way, it can be produced through the assembly of interchangeable modules. An analysis of subassembly modules is aimed at reducing the total number of modules and increasing their commonality.

For example in the dishwasher line of Zanussi-Electrolux Grandi Impianti (Pordenone, Italy) where community appliances are produced, while the same number of final product configurations was maintained, the number of subassemblies was reduced in the following way: washing groups 75 per cent, tanks 42 per cent, frames 20 per cent, boiler and electrical equipments 40 per cent, panels 44 per cent[15].

The functional analysis of subassemblies must not, however, lead to excessive standardisation of the groups, which could cause a low differentiation between the finished products. This risk is, however, remote in component standardisation as nothing is visible at the final-product level.

Subassembly Testability. In a complex product it is important to provide for testing of group functions to obtain the following advantages:

- the possibility of identifying faulty subassemblies before sustaining assembly costs;
- greater ease of fault localisation;
- greater facility in obtaining complex products of a higher quality.

For example, many ca. manufacturers carry out functionality tests on car dashboards before assembly.

Level 2 — Workshop

Standardisation of Production Routings, Family Formation and Cell Organisation. The group technology approach provides for a series of numerous and articulated actions, the most important being standardisation of production routings, formation of component families, and creation of machining cells[16]. Standardisation of production routings allows sequences of similar operations, which means a greater channelling of the flow of work-in-process into the manufacturing system. The attainment of similarity in the sequence is necessary for the formation of component families with similar technological routings and for the creation of corresponding machining cells. The objective is to obtain layouts consistent with producton routings and a simplification of the physical flows.

Sizing of Intermediate Stock Points. Synchronisation of the production flow between the various cells requires some intermediate stocks positioned at opportune points of the process. A suitably low level of the intermediate stocks means that work-in-process can itself be an instrument for the transmission of control signals: in the case of the shopfloor control technique named *kanban* system'' (called *kanban* in Japanese) cards on the containers allow supplies with a "pull" logic. Since these stocks must allow synchronisation between the different stages of the production process, it is important that, in comparison to traditional stock points, they have high selectivity, low capacity, and easy access.

Point of Use with Dedicated Machinery and Focused Stores. The creation of a point of use means providing dedicated machinery, placed along the mixed-model lines, at the point where a particular type of machining is necessary[17]. In order to have predetermined components available on line, stores are created alongside the line which are focused on the various components used in the line. Point of use and focused stores reduce management costs (job-order release, shopfloor control, etc.) and material-handling costs.

Figure 6 represents the correlation between the action levers at level 2 and the objectives resulting from several levers. As in level 1, we note how two levers (product definition for functional groups and group technology) influence the majority of the objectives which depend on combined action on several variables.

Action Levers and Objectives at Level 3, Product-process

The third and last level proposed is represented by the product-process pair. Actions at this level definitely have a strong impact on the firm; in fact company strategy is affected by product and process choices. We describe below levers and primary objectives of both product and process (see Figure 7). Marketing aspects of product (design, packaging, distribution, etc.) are not considered.

Level 3 — Product

Definition of Product Families. Aggregation of products into families is the first step in focusing production processes on homogeneous groups of products.

Level 2 / Objectives dependent on different levers \ Action levers	Sub-assembly: Product definition	Sub-assembly: Subassembly functionalities	Sub-assembly: Testability	Workshop: Group technology	Workshop: Intermediate stock sizing	Workshop: Point of use
Lead time reduction	O			O		
Greater process visibility				O	O	O
Stock reduction	O			O		O
High quality	O	O	O	O		
Ease of management	O			O	O	O
Fast learning	O			O		

Figure 6.
Correlation Matrix between Action Levers and Objectives Dependent on Different Levers of Level 2, Subassembly-workshop

Many examples of this come from large industrial companies, which in restructuring their factories choose to focus entire plants on particular product ranges or subassemblies, thus obtaining high economies of scale, while keeping sufficient flexibility. For example Zanussi-Electrolux concentrated its refrigerator production in Susegana (Italy) and its washing machine production in Porcia (Italy); other plants belonging to the company produce the necessary components.

Hourglass Structure. The passage from a trapezium-type product structure to an hourglass type (see Figure 8) enables manufacturing firms to enlarge the finished product range while containing logistical management costs. Action at level 2, that is analysis of subassembly functionalities and thus their standardisation, allows a reduction in their number due to greater commonality; the action described can be graphically represented by a narrowing of the neck of the hourglass. The action of widening a range, shown at level 3, can be represented by a widening of the upper part of the hourglass with the same number of common subassemblies.

End-stage Differentiation. End-stage differentiation, also known as the mushroom concept[18], can be obtained by product customisation in the final stages of the routing. The advantage of this is greater mix flexibility, because it becomes possible to defer the differentiation of products to the final stages of the routing.

A good example end-stage differentiation is represented by the production process in Seleco (Pordenone, Italy), characterised by four main stages: manufacture of printed circuits, automatic component introduction, manual component introduction, final assembly. The number of product versions at the end of each stage is as follows: 5 printed circuits, 20 mother boards, 25

Level 3			
Product revision		Process revision	
Levers	Primary objectives	Levers	Primary objectives
Prduct family definition	Manufacturing processes focused on product families	Vertical integration	Focusing on the stages with the most added value
Hourglass structure	Wide range of products	Flow production	Process continuity
End stage differentiation	Mix flexibility	Dedicated or mixed model lines	Mix flexibility and line saturation
Life cycle cost design criteria	Global cost design and reliability	Splitting of production capacity	Mix flexibility
Product technology	Consistency with process technology	Modular machinery	Expansion flexibility and low management costs
		Production overcapacity	Volume flexibility
		Rationalisation of end stages	Reduction of lead times in end stages
		Stock sizing	Synchronisation between workshops and space saving
		Type of automation	Consistency with product standardisation and process similitude
		Increase in process capability	Process quality

Figure 7. Action Levers and Objectives of Level 3, Product-process

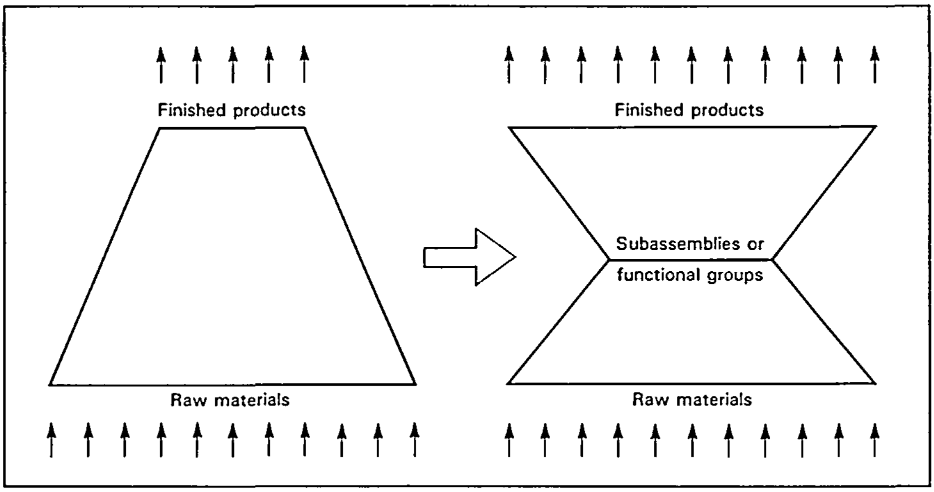

Figure 8. Hourglass and Trapezium Product Structures

complete mother boards, 170 finished televisions[19]. The advantages of end-stage differentiation increase with the value of the materials used in the final stages thereby reducing the cost of stock.

Figure 9 shows end-stage differentiation of the trapezium and hourglass structures. In assembly-to-order companies, generally characterised by hourglass product structures, groups or modules which are graphically positioned at the level of the hourglass neck are the objects of the master production

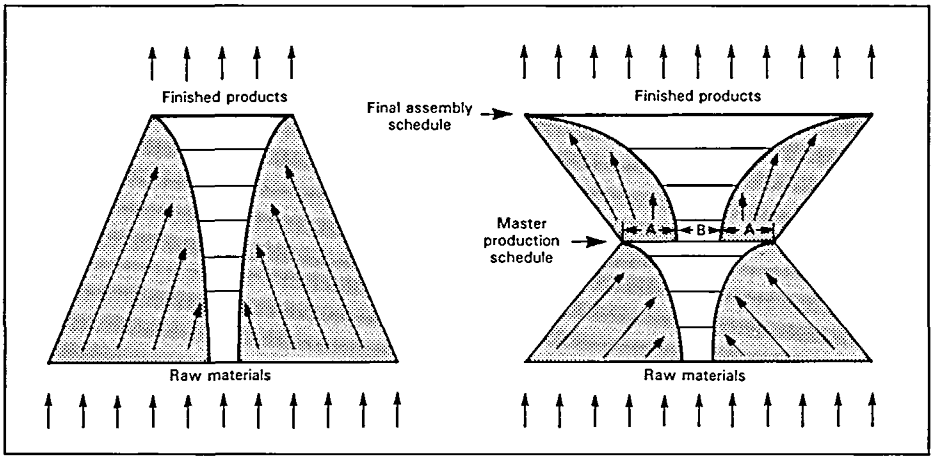

Figure 9. End-stage Differentiation (Mushroom Concept) in Trapezium and Hourglass Product Structures

schedule, based on sales forecasts. Final configurations of the product, positioned graphically at the upper level of the hourglass, are the objects of the final assembly schedule, based on customer orders. Note that in the hourglass neck there are both subassemblies (segment B of Figure 9) and groups or kits that will be used successively during product customisation stages (segment A of Figure 9).

Design with Life-cycle Cost Criteria. Design of products with life-cycle cost criteria arises from the need to obtain products characterised by low costs of use and maintenance. In fact, the costs of use and maintenance of a complex product are comparable to and often higher than production costs. It is, therefore, essential that in the development stage engineering choices are aimed at reducing costs throughout the entire product life cycle. Maintenance, reliability and ease of diagnosis are fundamental in designing with life-cycle cost criteria.

Product Technology. The choice of product technology cannot be separated from the choice of process technology. The relationship between product and process innovations is described in the Abernathy-Utterbach curves[20] which link the process innovation rate to product maturity. Product innovation is very important in the first stages of the product life cycle, where performance is more important than price, while process innovation is fundamental at the stage of product maturity, to reduce costs, increase productivity, and achieve flexible production.

Level 3 — Process

Vertical Integration of the Production Process. Choice of the degree of company vertical integration is a strategic decision[21]. Creation of barriers at the entry to and differentiation of markets are only two examples of modification of the competitive scene deriving from the choice of vertical integration.

Focusing the production process on the stages with greater added value allows greater specialisation in technology, high efficiency and high profitability. The choices regarding the process are also linked to evaluations of the qualitative level of the product; indeed, good connectivity between the critical stages of the product process leads to an improvement in quality which is made possible by feedback from one stage to another.

It is fundamental, however, even for stages which are not integrated, that a partnership exists between the supplier and the customer aimed at guaranteeing good integration of the respective chains of value[22].

Flow Production. A product layout presupposes focusing the production process on product families. Structuring of the process towards flow production is easier in the presence of high production-unit volumes[23]. The availability of flexible work stations widens the application field of production lines, even to the manufacture of many different products, with each product having a low unit volume. Flow production means continuous production; process continuity, i.e. the possibility of production without interruptions between one stage and the next, means a reduction in the ratio of lead time to run time, with low management complexity[24].

Dedicated and Mixed-model Lines. Once specific production processes have been assigned to the various product families, the next objective is to succeed in producing — at the same time — all the articles in the mix required by the market; this occurs either through dedicated lines for high-volume production, or with mixed-model lines for production of component families with low unit volumes[17].

With regard to mixed-model lines, it is important to obtain a temporal uniformity of the mix, that is a continuous production state where it is possible to process the product mix uniformly. This allows reproduction in a short time (days or weeks) of a production mix which is the same as that obtained over a medium period (months); in this way level production can be achieved[25]. The main field of application for mixed-model lines is assembly lines where operator and assembly-robot flexibility allow a mixed-model sequence. Assembly of different models in various stations requires an accurate study of line balancing, alternating models with high and low run times. The sequence of models on the line should, moreover, lead to a constant consumption of components on the line, so that synchronisation between the main line and auxiliary feed lines is easier[26].

Splitting of Production Capacity. Splitting of production capacity into various workshops, lines or machines generally leads to a greater flexibility. In particular, the choice of several machines with lower production capacities, as compared to a single plant with the same total capacity, has the following advantages: easier maintenance, better operator knowledge of the machinery, greater availability with the same reliability, less set-ups, more ease in obtaining over-capacity, possible use of machinery as point of use, and easier conversion of machinery to other production. On the other hand, use of a single plant with greater capacity allows greater production — owing to lower run times — and lower direct minor costs.

Modular Machinery. The adoption of modular machinery is the best answer to the need for expansion flexibility, i.e. flexibility in expanding production capacity. The increase of capacity through machine modules also facilitates installation, start-up and maintenance. Machine modularity is well suited to the splitting of the production capacity, as it is possible to use the machine module in other new production configurations with low reconversion costs.

Production Overcapacity. Production overcapacity is one of the ways to obtain flexibility. An alternative is to invest in stock. The choice of a reasonable over-sizing of the production capacity is justified by the fact that flexibility is obtained without the risks both of reducing stock variety and of obsolescence connected with flexibility obtained through stock investment. Extra capacity versus stocks is the alternative for firms working in seasonal markets. Overcapacity in general eliminates bottle-necks, facilitates synchronisation and allows volume flexibility. A shining example of overcapacity is that of Toyota, which has two or three times more machines than other similar firms, and an average machine usage of 40 per cent[12].

Rationalisation of End Stages. Rationalisation of the end stages is of first priority compared to that of first stages if there is end-stage differentiation of products. Reduction of the lead time in the final stages is more important in assembly-to-order environments. Indeed, lead times in end stages and logistic distribution times determine the delivery time to the customer. Product customisation, possible with an hourglass product structure and with end-stage differentiation, means a real increase in the level of service to the customer only if combined with short assembly times, and consequently short delivery times.

Stock Sizing. Achievement of flow production and process continuity requires suitably low sizing of intermediate stocks. Reduction in stock moreover shows up production problems (set-up, faults, bottle-necks, etc.) which can be removed. A lower stock level also allows a greater reaction of the system to external disturbances; if we compare the stock to a shock absorber, it increases the inertia of the production process, and delays return times of the system to physiological working conditions[27]. Another advantage of the reduction of stocks is the recovery of physical space enabling workshops to be moved closer together, with a consequent reduction in handling costs and an increase in process visibility. Correct sizing of intermediate stocks allows synchronisation between workshops; for example in assembly-to-order firms the subassembly warehouse represents the decoupling point between workshops working to stock and workshops working to order.

In general the reduction, or at best the elimination, of the intermediate stock facilitates production control as there is less need for management of intermediate components; this leads to a lower number of levels in the bill of materials and eventually the achievement of a flat bill of materials.

Type of Automation. The choice of type of automation must be consistent with the degree of standardisation between the various products and with the degree of similarity between production routings. In our preceding article[1] four types of automation and their respective production plants were categorised with respect to product standardisation and process similarity: flexible automation of operations (CNC machining centres); rigid automation (dedicated automatic machines and rigid transfers); wide-mix flexibile automation (FMS with machining centres); and low-mix flexible automation (FMS with special machines and flexible transfers).

Automation constitutes a very important factor in competition; there are two types of potential advantages deriving from it: reduction of costs (greater efficiency) and an increase in income (higher quality due to less variability)[28]. The introduction of automation, if it brings advantages of efficiency and quality compared to manpower, should not, on the other hand, bring about a loss of flexibility.

Increase in Process Capability. Process capability is the capacity of the process to satisfy the required output. An increase in process capability leads to an increase in process quality, i.e. a decrease in its variance depending on the number of variables involved and their variability, so that all the worked parts stay within the established tolerance limits. The variance sources where actions lead to an increase in process capability are for example: man, machine, tool, set-up, material, and working environment[29]. Many of the levers described in this article (standardisation, routing analysis, machinability, poka-yoke devices, etc.) also aim at a reduction in process variance.

Figure 10 shows the correlation matrix between action levers at level 3 — product-process, and objectives whose achievement depends on the joint action on several variables.

Among the other objectives mentioned; it seems to us important to stress that of providing for long-term investment in machinery and automation. The size of the necessary resources for such investment means that attention should be directed not only at process levers (vertical integration, modular machinery, type of automation), but also to product levers (definition of product families, hourglass structure, product technology — see Figure 10). This means that decisions about machinery and automation, in the past made by production personnel and more generally by the company director, will unavoidably also involve the engineering and marketing managers, with respect to the criteria of simultaneous product-process design. However, the rigidity that is introduced, even with flexible automation, must be compensated for by a design of products in terms of modules or subassemblies. These can be assembled in combinations which vary over time and in any case are redefinable if there are limitations caused by plants and their automation.

More generally, only a global design approach allows the attainment of a production system which both can work in a certain number of production states which respond to various market demands (stability), and can change quickly from one state to another (flexibility)[1]. In general the size of the investment involved means forecasting on a long-term basis what future production states will be necessary.

Possible Courses of Action

Each of the actions proposed can be carried out independently of the others within a company. This is not, however, convenient as the synergies deriving from joint action are thus lost.

Level 3 / Action levers — Objectives dependent on different levers	Product					Process									
	Product family definition	Hourglass structure	End stage differentiation	Life cycle cost criteria	Product technology	Vertical integration	Flow production	Dedicated or mixed model lines	Capacity splitting	Modular machinery	Production overcapacity	Rationalisation of end stages	Stock sizing	Type of automation	Process capability
Long-term investment	O	O			O	O				O				O	
Flexibility in new product introduction		O			O	O			O	O					
Repetitive production process	O						O	O	O						
Process visibility			O				O	O	O				O		
Management simplification		O	O				O	O	O		O		O		
Bottleneck elimination									O		O				
Lead time reduction							O	O	O		O	O			
Product customisation		O	O									O			
Quality improvement				O	O	O	O	O	O	O				O	O

Figure 10. Correlation Matrix between Action Levers and Objectives Dependent on Different Levers of Level 3 Product-process

In carrying out simultaneous design actions, it is important to distinguish between planning and implementation.

The planning stage is fundamental in defining the performance objectives for identification of action levers. We can refer to the earlier figures which link levers and primary objectives and to the matrices identifying objectives resulting from several levers. In developing a plan of action on several levers it is important to distinguish level 3 objectives (product-process), attainable generally in the medium-to-long term, from those of level 2 (subassembly-workshop), and level 1 (component-operation), attainable generally in the short-to-medium term. This distinction allows a top-down approach, starting with the higher-level objectives and dropping down to those at a lower level.

Alternatively, a 1-2-3 sequence may be preferable during implementation i.e. bottom-up from the lower level to the upper one. This allows a more gradual impact on the company which increases with the degree of action; it is clear that, for example, action at component level has less effect than subassembly redefinition and much less than product redefinition. The 1-2-3 option is above all preferable when action is taken in production systems which are already operating.

The mixed approach proposed, top-down for the planning stage and bottom-up for implementation, is represented in Figure 11 and is similar to that generally used in automation projects[30,31].

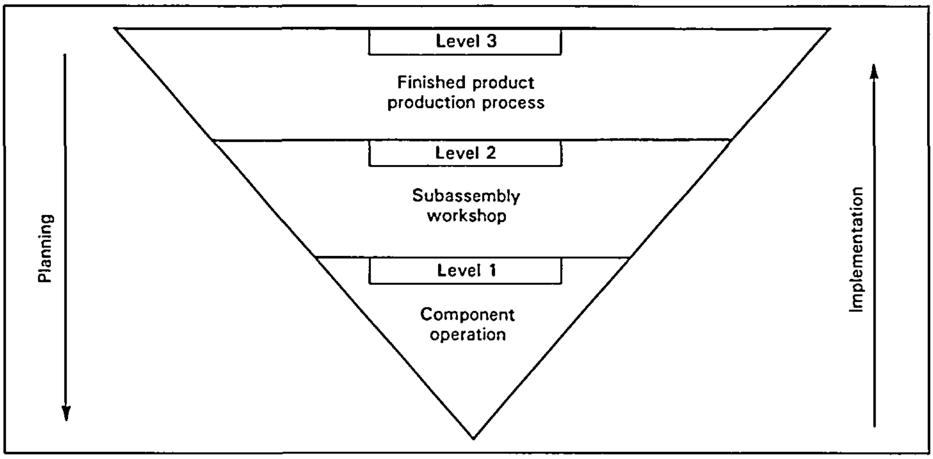

Figure 11. Top-down and Bottom-up Approaches in Simultaneous Engineering

Conclusions

In a previous article we explained the reasons for simultaneous product-process design[1]. In this article we have tried to:

- Show an interpretive chart on three levels, which on the one hand constitutes a key to actions aimed at the revision of simultaneous design criteria, and on the other is a methodological indication of how logically to co-ordinate company actions in product and process areas.
- Describe for each level the action levers and objectives by attempting to identify both single and multiple lever-objective relationships.
- Discuss problems and ways to carry out simultaneous actions on the product and the process.

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