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Flexible workshop: about the concept of flexibility

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Abstract
This paper is an introduction to the problem of flexibility. We would like to show the predominant factors of flexibility, since not being aware of them may lead to a failure in the conception and the management of flexible production systems. After having described the present situation and having judged current achievements, this paper suggests definitions for the notions of polyvalency, apparent flexibility, dedicated activity, and specifies the relationship existing between these notions. Flexibility will be considered in relation to the concept of learning. Finally it shows that the flexible workshop, although production oriented, gives firms using it the appearance of services companies.

1. The perception of flexibility

To be flexible means to have the ability to vary as you like, according to the needs. Flexibility is the ability to adapt, in a reversible manner, to an existing situation, as opposed to evolution, which is irreversible. This notion reflects the ability to stay operational in changing conditions, whether they are predictable or not, completely different or not from conditions known in advance. This adaptability is required from firms that, for economic reasons, are currently turning to efficient techniques of organization and management of the zero stock, just-in-time and tight-flow type which can make them fragile. Competition amplifies the development of the market by creating new situations. This aspect, combined with the above mentioned techniques of organization, reduces the stability of the firm. The impact of an unexpected event immediately spreads across the structure because of the increased tension in the coordination links.

The sources of unexpected events or potential hazards most frequently quoted are:

- accelerated modification of products because of requirements of the market (customizing the products, changing the range);
- deficiencies of operation: breakdown, strikes... bringing about stock ruptures and consequently halting production.

These risks are potential but practically unavoidable. In order to stay operational nevertheless, managers are seeking solutions that avoid interruption of operation regardless of the situation.

On one hand, companies used to operate in the context of a market that was prepared – because of the scarcity of the available goods – to absorb all proposed products and services provided if they were consistent enough with demand (for example in the car industry). In such a situation the existence of inventories is an essential factor that guarantees uninterrupted operation. Building up stock is justified by the certainty of being able to sell it. The current economic context leaves the conflict of scarcity more and more behind us, thus removing the certainty of selling; on the contrary, protection by means of stock becomes a danger in itself. Calling production for stock into question has thus led to just-in-time production.

On the other hand, this kind of operation makes the production system more vulnerable. As the classic organization of production, even though it is effective, high costs of operation are generated under these circumstances. It became necessary to create a new, efficient organization, complex to install, but capable of adapting itself continuously while, at the same time, optimizing the time required and the cost of change. This is how the flexible organization was born.

The flexible firm as a system of production is known today more through limited experimentations in workshops than as a conceptual approach. The flexible system of production is still attempting to find its definition, as well as a homogeneous set of concepts, allowing us to conceive it and to predict its ability to adapt itself.

The concept of the flexible workshop, as a system of management and control of production, was born under these circumstances as an answer to the problem of:

- operation of a firm according to a tight-flow system of management;
- modular production in connection with short series of production;
- amortization of equipment in this context.

This paper is an introduction to the problem of flexibility. We would like to show the predominant factors of flexibility, since not

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being aware of them may lead to a failure in the conception and the management of flexible production systems. It provides an explanation of the inflexibility that has been observed during the implementation of such systems, as indicated by observations we dispose of today. Although we do not want to discuss their consequences, particularly on information referring to accounting data, the interpretation of flexibility suggested here seems to be as relevant for engineers as for managers.

After having described the present situation and having judged current achievements, this paper suggests definitions for the notions of polyvalency, apparent flexibility, dedicated activity, and specifies the relationship existing between these notions. Flexibility will be considered in relation to the concept of learning. Finally it shows that the flexible workshop, although production oriented, gives firms using it the appearance of services companies. The purpose of this contribution is to advance the setting-up of flexible workshops free from the rigidity that still exists today.

2. The flexible workshop today

The presentation of the Renault-Bouthéon flexible workshop suggests the following perception of the flexible workshop:

> It is an entirely automated production system that makes it possible to reconcile productivity with flexibility of small and medium sized series of parts. Management of such systems is taken care of by a computer that regulates the whole workshop in the shortest possible time while optimizing production as well as the rate of use of the machine tools and, at the same time, offering a very large flexibility of adaptation

In addition to the machine tools, the information system is therefore an integral part of such a workshop, and plays a dominating role in the organization and supervision of the means of production. This information system goes far beyond the accounting information system. It integrates technical as well as management information.

The following two meanings are associated with the concept of flexibility:

1. Flexibility in terms of volume or "operational flexibility" (Reix, 1979). The volumes to be manufactured may change in quantity over time by progressively installing the right equipment while adjusting, in the best manner, the increase of pace. It integrates flexibility in terms of stock management, corresponding to the ability to be able to switch quickly from one reference to another in order to make series – that have already started to be manufactured – shorter, leading to a reduction of inventories. The economic challenge lies in optimizing the adjustment time assured by excess capacity and production potentialities with the cost avoiding this excess.
2. Flexibility in terms of products or "strategic flexibility" (Reix, 1979), corresponding to the ability to accept changes or developments of the design of products (Venkatesan,1980).

Such an approach should lead to the conception of structures that have the ability to adapt quickly, as opposed to the rigidity existing in a classic structure considered in the present context as being non-flexible.

How is flexibility viewed today?

On one hand, current conceptions are based on a complex model. This model seeks, a priori, to take into account any possible situation of the tools as well as of management. However this is impossible to conceive, because the model becomes, by nature, more complex than reality.

On the other hand, reduction of the model would create difficulties in re-arranging the tools and the tasks when facing unexpected situations. This is the reason why the flexible workshop has been conceived from the start as a system of polyvalent machines; technical means had to compensate for the fact that it is impossible to predict everything a priori. This judicious choice, as far as the machines are concerned, has been made for current projects (for example, in France with Citroën, Aérospatiale, Renault Bouthéon). But everywhere, observers agree that the cost of switching from one manufacturing profile to another remains relatively high. This may be explained by the existence of undesirable rigidity: though attention has been paid to the machine tools, the software needed for a flexible workshop is missing.

Tested solutions have the following characteristics:

- a large degree of integration of tasks by creating polyvalent machine tools leading to very fragile, complex systems that are difficult to manage (for example: Renault Bouthéon, Caterpillar);
- these machine tools perform tasks that are linked to one another; hypothetically this brings about global polyvalency starting with local polyvalencies (for example: Cummings Engine);
- computer-aided management of production that allows assignments of

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production sub-systems to be redefined depending on the objectives of production (for example: IBM Pessac, Renault Sandouville).

Under these conditions, the flexible workshop represents an integrated collection of "high tech" tools and an information system (Fiore, 1988). Taken as a whole, this collection is considered as being a polyvalent machine. Its global polyvalency is supposed to be guaranteed by the polyvalency of its sub-systems. However, aggregation of elementary polyvalencies does not automatically lead to a global polyvalency. On the contrary, it may even introduce unexpected rigidity, and this explains a certain number of disappointments that have been observed when flexible workshop has been installed. Messine (1987) emphasizes this by quoting Harley Shaiken, a professional worker who has become a researcher at Massachussetts Institute of Technology. "The highly automated and flexible manufacturing systems that exist today nearly never work as their conceivers expected. Generally more human intervention is required than anticipated. The starting periods are much longer than expected".

Here we shall deal with the notion of flexibility being above all concerned with mastering the risks, which do represent the main problem. Indeed, flexibility means the ability to adapt behaviour to needs.

3. General purpose and factorial purpose

Any production system may be perceived as a chain of activities of which every working station can be considered as a fully fledged activity. In a flexible workshop, it is important to know how they become integrated, and what are the connections between them (Fiore, 1988; Messine, 1987; Venkatesan, 1980). The two notions of general purpose and factorial purpose are the characteristics of this type of connection (Figure 1).

Any activity is identified by its purpose which encompasses the objectives the activity is likely to recognize and take on.

Example: The purpose of a man, viewed as an activity, is to work, to live, to communicate, to have fun ... In this context, the purpose of a car is to be a means of transportation, a sports vehicle, a collector's item, a toy ... The purpose of a remote controlled arm of a robot is to put a tool in certain positions and to manipulate it.

This purpose, called general, is a specific characteristic of the activity and does not depend on the structure which it is part of. Once the activity becomes integrated in a structure, it will be dependent on the purpose projected by the structure, called factorial. This factorial purpose is a subset of the general purpose of an activity; it includes all the objectives that will be validated during the operation.

Example: The factorial purpose of a wage-earner is to work, to communicate ... A car used by a racing driver has a different factorial purpose than the same car being used for common transportation. The factorial purpose of the remote controlled arm of a robot on an assembly line may be to tighten screws.

The connection between an activity and its structure of reception always works by superposition of the factorial purpose projected by the structure of reception on the general purpose. The structure of reception itself is an activity that is positioned at a higher hierarchical level (Figure 2).

4. Polyvalency, apparent flexiblity, dedicated activity

Inasmuch as re-assembling of activities in a flexible workshop is frequent and includes installing dynamic links between them, it becomes useful to clarify the three notions of polyvalency, apparent flexibility and dedicated activity. They make it possible to characterize the nature of the connections. Current approaches do not suggest exact definitions of their contents: this often creates confusion in the use of these terms.

Polyvalency should be perceived as the ability to fulfil several purposes independently of knowing whether they will actually be used by an actor. Besides a structure of reception, an activity of which the general purpose includes several factorial, identifiable purposes, is called polyvalent. This polyvalency gives indications on its potential uses. Therefore, in this perspective, polyvalency is judged a priori.

Example: The general purpose of a radio-alarm clock encompasses three sub-purposes: to indicate the time, to broadcast music and to broadcast music at a certain hour. This appliance is then described as polyvalent. A highly developed machine tool may fulfil different purposes: drive holes, cut rivets ... It can then be described as being polyvalent.

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A priori polyvalency is generally obtained by integrating different functional purposes into one activity. If this integration is achieved by simply placing functions side by side, it cannot be considered as being efficient. We shall only consider an integration as being genuine if shared resources are installed. This sharing of resources increases the complexity of the whole system and therefore creates therefore problems of reliability as these resources are called more and more frequently.

Example: In a radio combined with a cassette recorder, the power supply is shared, which characterizes a true integration. If it breaks down, the use of both functions is interrupted.

Figure 1
General purpose – factorial purpose

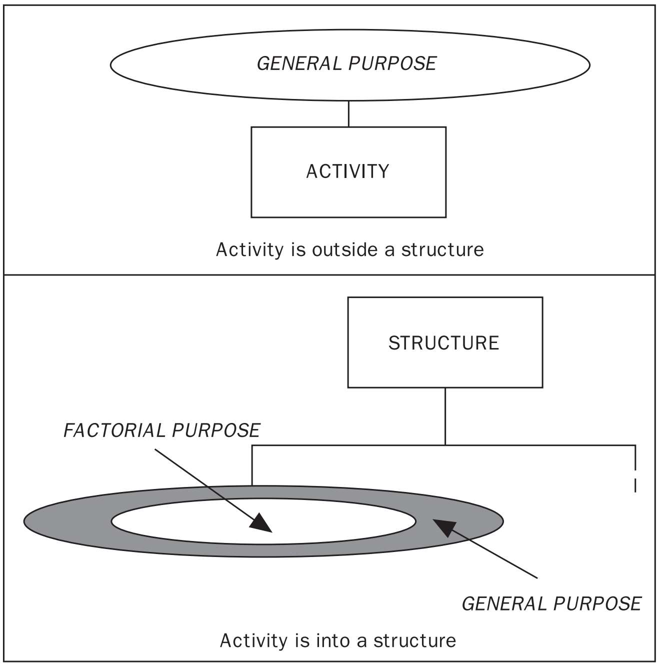
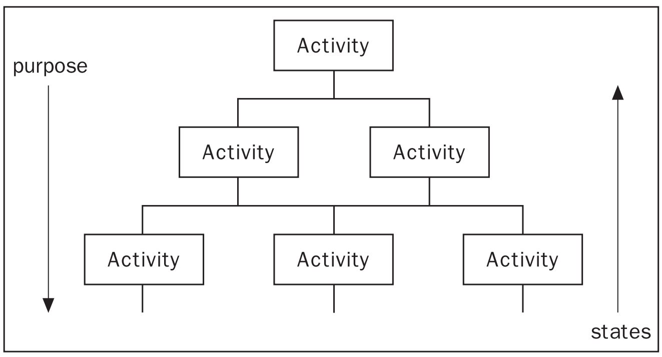


Figure 2
Organization viewed as a hierarchy of activities



This situation is comparable to a machine tool which manufactures two types of goods (the body of the engine and the gearbox). If the tool breaks down, the production of both goods is interrupted.

Apparent flexibility is recognized through the relationship that exists between the general purpose of an activity and the factorial purpose projected by its structure of reception.

The difference, in the topological sense, between the factorial purpose projected by a structure of reception on an activity and the general purpose of that activity, quantifies the apparent flexibility of the connection between them.

The notion of apparent flexibility does not apply to the activity itself but to its link with a structure of reception.

Example: If we consider a robot with its library of programs, it will be able to make as many sequences as those contained in its library. Therefore, it is polyvalent a priori. If it is part of a structure, then the difference between the sequences actually prompted and the sequences that are not prompted characterizes the apparent flexibility.

The equality between the general purpose and the factorial purpose of an activity (maybe a machine) characterizes the dedicated activities (or the dedicated machine).

The label "dedicated activity" (machine) is only significant in its relationship with the structure of reception.

An activity becomes integrated in a structure as a dedicated activity or by creating an apparent flexibility. The apparent flexibility is more or less important in so far as a difference may exist between its general purpose and the factorial purpose projected by its structure of reception. In order to make this integration possible without being regressive for the system as a whole, there must be at least equality between the factorial and the general purpose, i.e. that activity must be dedicated.

Example: An engineering manufacturing workshop is judged polyvalent a priori in so far as it is liable to produce a whole range of mechanical parts. This workshop, integrated in a car factory, becomes dedicated if the range it produces belongs to the parts of a vehicle. In such a situation, the factorial purpose projected by the factory covers its general purpose.

Present solutions have a tendency to solve the problem of flexibility by a priori polyvalency, which anticipates possible needs by holding some of its functions available, i.e. by creating an apparent

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flexibility at the level of equipment. Is this also the case for the activities of computer systems?

The methods of conception currently favour passing on the know-how of a function to computers. The computer, seen in this perspective, is liable to carry out a series of operations, the sequence of which is completely defined in advance.

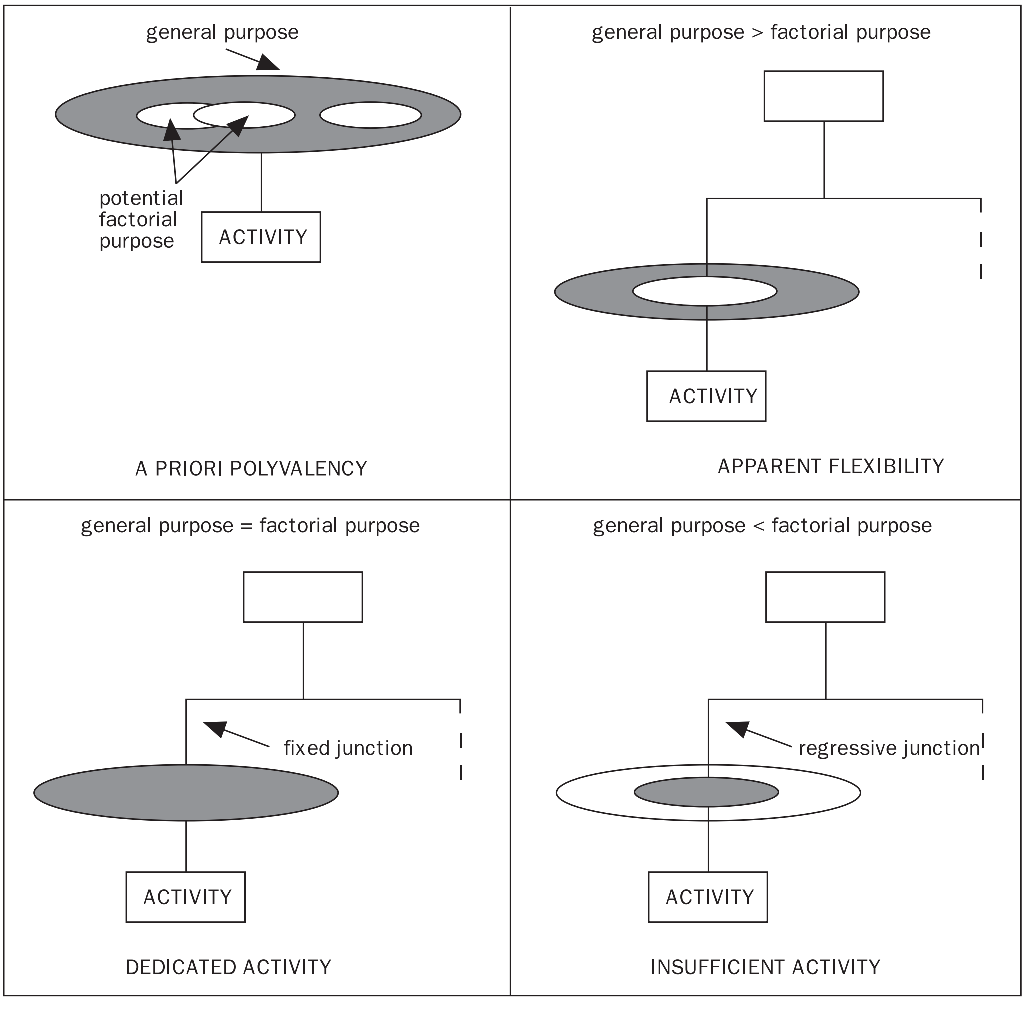
Figure 3 summarizes the possible types of connection as they have been described. In addition it indicates the other theoretically possible case, that is to say insufficient activity, therefore regressive in relation to the needs of the structure of reception.

5. Is flexibility conceivable through polyvalency?

The conception, and subsequently, the implementation of a flexible production system consists in defining all of its activities and the possible connections that may be established between them. A hierarchy of activities exists in a given configuration. Each of these activities is mobilised by the factorial purpose projected on it by the structure of reception which is an activity on a higher hierarchical level.

The choice of the polyvalent means follows on from anticipation of the needs. If the forecast proves to be correct, then the system which has been conceived has the appearance of being flexible because of the fact that it keeps functions available in connection with the polyvalency of the means. This is the case when the functions of those machine tools are kept available, allowing that make it to manufacture parts having other profiles. In a context where operating conditions do develop rapidly, the validity of forecasts is generally poor and the functions kept available may not be used. The use of polyvalent means makes it possible to obtain a certain flexibility of the system in the range of what is predictable.

Figure 3
A priori polyvalency, apparent flexibility, dedicated activity and insufficiency



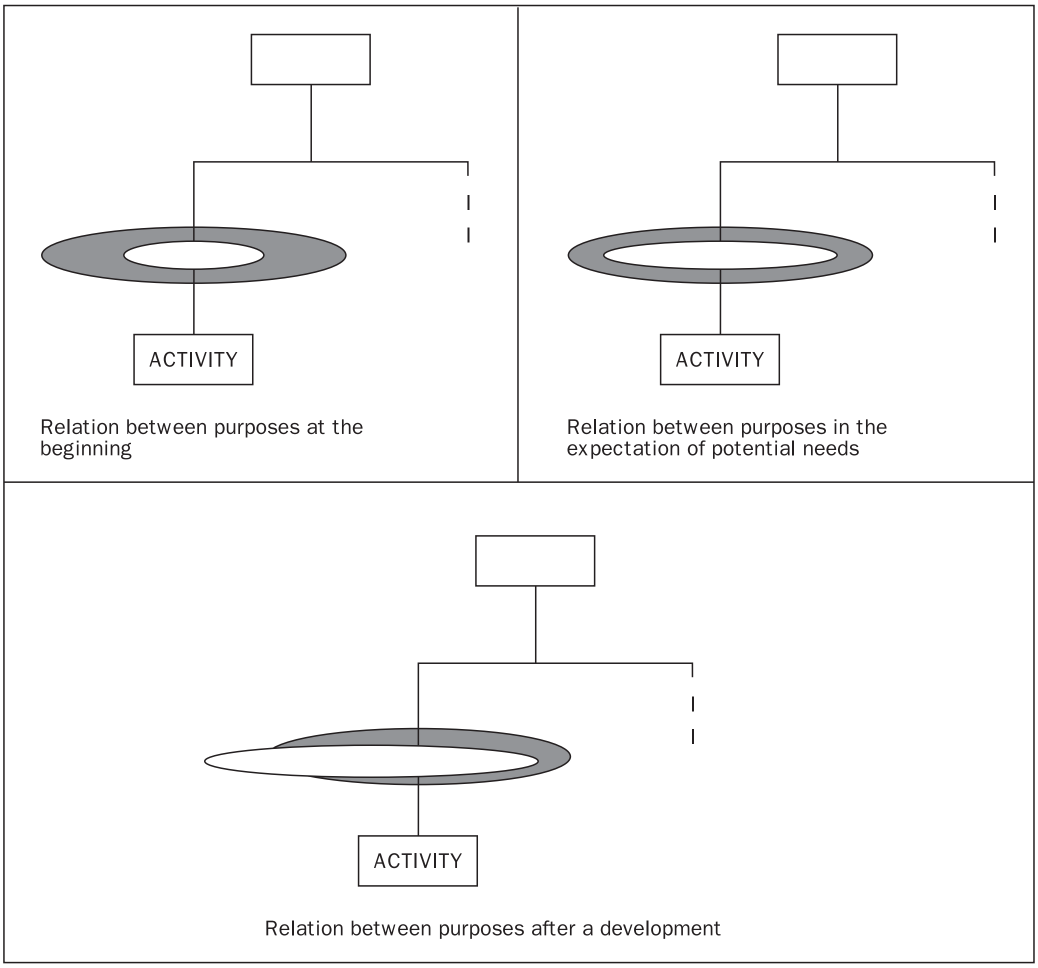
As has already been mentioned, it is this method which is now applied in the conception of flexible workshops. It relies on the a priori perception of the parts which will have to be produced. Two examples of this kind are given by Venkatesan (1980) or Fiore (1988) on Sikorsky and Citroën Meudon.

When a production system is implemented, the connection between the activity and its structure of reception validates a factorial purpose (Figure 4) that is clearly smaller than its general purpose. In anticipation of future needs, this connection may validate a much larger factorial purpose than the one that will be used (availability of functions). Yet development may require a factorial purpose that is shifted in relation to the general purpose. Polyvalency is therefore insufficient to conceive flexibility, for it belongs to the field of the predictable while flexibility is the ability to react to the unpredictable.

6. Flexibility, polyvalency and learning

The distinction between the predictable but unexpected and the unpredictable is justified by the basis of knowledge. The unexpected predictable refers to cases when the behaviour may be shaped by starting from acquired knowledge while, in the case of the unpredictable, acquired knowledge is insufficient to define a behaviour. The flexible workshop should, first and foremost, be able to cope with a situation of the second type (Venkatesan,1980). To be able to be at ease with such a situation requires the acquisition of new knowledge relating to a suitable organization of the means at work, among others economic forecasts. Learning increases the general purpose of an activity and therefore its a priori polyvalency and also its know-how, by accumulating knowledge. Learning is achieved at the level of activities of the information system, and

Figure 4
Relations between purposes during the life of a system



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rarely at the level of the machine tools. This is what is currently slowing down the development of real flexibility for workshops.

Thus it becomes possible to consider flexibility as the ability to learn.

To learn means to enrich the basis of operative knowledge. The notion of availability of knowledge has allowed us to determine a typology; this is essential for structuring the computerized part of a production system (Bucki and Pesqueux, 1991a).

Knowledge itself may be grouped in three classes:

1 *Explicit knowledge*, i.e. immediately available; a manager has the explicit knowledge related to establishing accounting documents; a worker has the explicit knowledge related to performing tasks he is responsible for.
2 *Implicit knowledge* that may be obtained through a deductive or inductive reflexion starting from explicit knowledge; the accounting department is able to deduce the position of cash and liquidities of its firm, starting from the explicit knowledge of the firm's condition and the knowledge that characterizes the profession of accountancy. Starting from elementary operations managed by a flexible workshop, it is possible to deduce the method of production of a given part.
3 *Inaccessible knowledge* – impossible to deduce from acquired knowledge.

Classifying the above mentioned situations covers the classification of knowledge: explicit knowledge corresponds to known situations, implicit knowledge to predictable situations and inaccessible knowledge to unpredictable ones.

The only agents characterized by the ability to learn are human beings and computers, for they are the only ones disposing of a memory. Memory is an essential factor in learning. In this context, we consider that a computer is not a polyvalent machine but a flexible machine. Because of its internal structure, it is possible to give it knowledge by means of software. Its learning is achieved by loading software programs into its memory. Only according to the programs that are loaded, can a computer be considered polyvalent. This illustrates that the polyvalency of an activity (man, machine) depends on its knowledge, its memory and its nature. Generally speaking, an activity (man, machine) can be conceived as being polyvalent and non flexible if it is not able to learn.

It is in this sense that we perceive a flexible workshop as being built with "intelligent" machines. In fact, this intelligence stems from the information system. This fact is quoted by Fiore (1988) in his analysis of the Citroën flexible workshop at Meudon when he speaks of flows of parts and tools, or when he speaks about the flexible workshop at IBM saying that the automation of the operations is based on a classification of parts. This remark is still valid at the assembly line of Renault-Sandouville.

The predominant characteristic of a flexible structure is its ability to learn, requiring a memory.

It is thanks to these two elements, memory and ability to learn, that a flexible production system becomes able to be constantly modified in a reversible manner ("chameleon" type structure). The development of a classic production system is, in general, irreversible. We can consider it as being flexible because of the memory of people and their ability to learn (Figure 5).

Current experiments in flexible workshops are generally built with the assumption of a priori polyvalency of the machines, while neglecting the computer system's ability to learn. Learning widens the general purpose of the workshop and is the only guarantee of its real flexibility. This explains, for flexible workshops, the situation observed by H. Shaiken (Messine, 1987) quoted at the beginning of this paper, emphazing the importance of human intervention.

It is important to note here that learning is always achieved in a period different from the period of operation, and must be, of course, short enough to make such installations profitable. The fact that learning is, in a way, delegated to the information system, comes from the needs of real time management, observed in manufacturing.

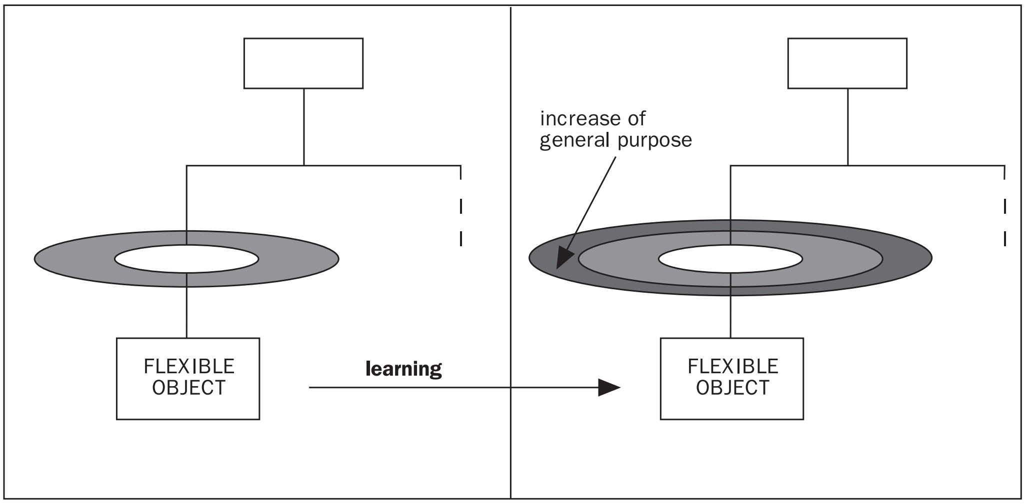
The aim of learning is:

- to enrich existing knowledge;
- to substitute more relevant knowledge for obsolete knowledge.

Anything memorized must be structured around knowledge that is easy to handle. This means that functional techniques of conception of information systems, currently used in the implementation of software, are poorly adapted to the context of a flexible workshop (Bucki and Pesqueux, 1991b).

The approach stemming from the object oriented conception is today a promising alternative as long as it succeeds in integrating the notion of knowledge.

Figure 5
Learning allows an increase of the general purpose



7. The flexible workshop as a servicing company

Today there are two types of economic activities that may coexist in the same firm:
1 those providing products, like a manufacturing workshop;
2 those providing services, like a software house.

The durability of providing products is based on a park of machines, on know-how (of people) and their depreciation, i.e. on production series that are long enough. Its development implies the acquisition and implementation of new manufacturing techniques and this process is irreversible. Reserves of capacity and functions reserves are the only guarantee of their flexibility.

The durability of services is based on knowledge and secondarily on a park of machines. In the context of a software house as in the case of a flexible workshop, long series are excluded. Knowledge kept in their memories is their real value.

This confront us with three problems:
1 *The ability to learn in "reasonable" time limits*, integration of new knowledge or replacement of acquired knowledge by more relevant knowledge in a delay that is appropriate for the economic states.
2 *The possession of memory*, the physical medium of knowledge required to capitalize knowledge in the workshop, whether related to management or to technique,
3 *Maintenance and use of acquired knowledge.*

Today, knowledge is more often than not conveyed through human memory. Turnover means that some knowledge is lost and irretrievable in the case of service firms, for they are particularly vulnerable in this respect.

The flexible workshop has more of the characteristics of service provision than of product provision. The problems that remain to be solved, in the context of a flexible workshop as well as in a service company are:
- maintenance and use of knowledge;
- acquisition of knowledge by the structure, independently of the turnover of personnel.

This fact gives us the opportunity to quote the greatest criticism on today's perceptions of flexible workshop. Actors and researchers are now accepting, little by little, this fact. But they have not, till now, pushed the logic to its end because of the dominant materiality of machines.

8. Conclusion: determining factors of the flexible workshop

As we showed, the predominant characteristics of a flexible system are:
- a non-volatile memory of experience;
- the ability to learn.

The only possible way to react to the unexpected is to acquire knowledge and to make it operative by transferring it to activities.

The unexpected rigidity of today's flexible workshops is not due to the choice of the machine tools but to the methods of conception of the information systems, where knowledge is stocked. Although it is possible to conceive machines that have all the functions one can imagine, as long as the

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connections between the information system tied to these machines remain rigid, the flexibility of the whole system remain jeopardized. These methods currently stem from functional approaches that do not bring the notion of knowledge to the fore. It is difficult, if not impossible, to enrich the system, shaped by functional techniques, by injecting knowledge. This aspect jeopardizes the possibility of obtaining real flexibility. The success of expert systems that have been observed during recent years stems from their ability to manage knowledge. However, the choice of the initial knowledge, of the rules, of the control of their consistency and of their sufficiency, as well as assessment of the response time, i.e. the time the inference motor operates, confronts us with a problem that is difficult to compensate for with the flexibility of expert systems. This technique of implementing systems is today associated with no other conceptual approach.

It is therefore essential to apply methods of conception that go in the opposite direction to classic descending analysis and the division of tasks, i.e. methods that enhance knowledge linkages, that become a strategic tool for the conception of flexible workshops as well as for the survival of service companies (Bucki *et al.,* 1991; Meyer, 1990). Object oriented methods of conception offer in this respect a promising opening. They make it possible to represent a computer system as a hierarchy of objects in which each one of these objects encompasses the model of its behaviour.

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