Artigo 12

The Flexibility of Technological and Human Resources in Automotive Manufacturing

Este documento faz parte do material que compõe o livro:

Planejamento, Programação e Controle da Produção
MRP II / ERP: Conceitos, Uso e Implantação

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Editora Atlas – 4ª edição – 2001
ISBN 85-224-2502-7

Este e outros documentos associados ao livro estão disponíveis em:
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Research findings give insight into the flexibility of structural manufacturing resources.

The Flexibility of Technological and Human Resources in Automotive Manufacturing

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Integrated Manufacturing Systems, Vol. 5 No. 1, 1994, pp. 33-40

The Research Method

The general approach used in the research was the use of case-studies. For details of the overall research methodology see[1, ch. 6 and 7]. A number of case organizations were chosen and analysed in depth. The choice of the organizations was not made at random. Rather, the criteria adopted in choosing them was related to their potential contribution to help analyse the studied relationships. The data collection process was done through extensive plant tours and interviews with a number of decision makers within the selected organizations. A semi-structured questionnaire was used during the interviews in order to identify the managers' perception with regard to a number of aspects related to the research question. All the interviews and plant tours were tape recorded. Efforts were made to ensure that the treatment of the data from the cases was as systematic as possible. Detailed "within case" analyses were written up, all structured in a similar comparable way. Cross-case analyses were then performed in search for patterns, relationships, similarities and differences between cases. The result of the analyses performed was the development of an original theoretical framework which aims to help managers understand and analyse flexibility and its relationship with unplanned change in manufacturing systems. This article relates to the part of the framework which deals with flexibility of structural manufacturing resources.

Level of Analysis

As Gerwin[2] points out, a basic aspect in addressing manufacturing flexibility issues is the level of aggregation on which the research is to be based. In this research, the level of analysis is the manufacturing systems and its constituent elements, the manufacturing resources. Such a level does not necessarily encompass the whole factory within companies (which can sometimes mean huge plants) but can also apply to relatively autonomous production units or cells within the plant.

Choosing the Companies

In case-study research, the cases are not chosen at random, but selected to fill theoretical categories and polar examples[3,4]. The cases in this research were chosen from companies, both in the UK and Brazil, for two main reasons.

First, the industrial environment in Brazil has notoriously a high level of unpredictability and uncertainty with regard to supply chains' performance, government regulations, inflation levels, among others. According to Pettigrew's[4] advice it makes "pragmatic sense" to choose such an extreme situation to allow for the analysis of environmental uncertainty. UK companies, on the other hand, are more likely to provide valuable data in terms of variability of outputs. An alternative approach would have been to keep the whole sample either totally Brazilian or British, but in doing so the richness of the "extreme" cases would be partially lost.

Second, Britain and Brazil were specifically chosen for the ease with which the author could gain access to companies in both countries because of his academic and professional previous experience.

The Cases

The number of in-depth studies, determined by research resource constraints, was four companies (two in Brazil and two in the UK). Four other companies were also analysed during the research pilot phase. All companies are manufacturers of metal engineering products, belonging to the automotive industry. The sample companies of the in-depth case studies will be called here A, B, C and D.

(1) Company A – the British engine manufacturer – an automobile manufacturer located in the Midlands region of England, manufacturing parts to stock and assembling vehicles to order. This research focuses on the engine manufacturing plant within company A.
(2) Company B – the Brazilian carburettor manufacturer – located in São Paulo, Brazil. It is the main OEM supplier of carburettors for the Brazilian automobile assemblers and part of a large transnational corporation with headquarters in Europe and interests in a broad range of industrial products.
(3) Company C – the Brazilian shock-absorber manufacturer – manufactures and distributes parts to the domestic automotive market and also for export. It is an entirely Brazilian-owned company and the largest domestic producer of automotive parts.
(4) Company D – the British vehicle manufacturer – a vehicle manufacturer located in the Midlands, part of a large multinational corporation with headquarters in North America and interests focused on automotive products, industrial machinery and engines. Of the 65,000 vehicle sets produced at company D's plant each year 90 per cent are exported to over 140 countries.

Flexibility of the Manufacturing Resources – Structural and Infrastructural

The classification of the manufacturing resources as "structural" and "infrastructural" is proposed by a number of authors in the literature. However, not all the authors agree on which resources should be considered as structural and which should be considered as infrastructural.

Hill[5] defines infrastructural resources as the set of structures, controls, procedures, systems and communication combined with attitudes, experience and skills of the people involved with the manufacturing system and structural resources (Hill calls the structural resources "process") as the technology, equipments and facilities of the manufacturing system. Hill thus includes characteristics of human resources as part of the infrastructural resources.

Workforce is also considered as one of Hayes and Wheelwright's[6] four infrastructural decision areas, together with quality, production planning and materials control and organization. They consider these decisions as more tactical and easy to reverse than the ones which they consider as structural (capacity, facilities, technology and vertical integration). This view is arguable, since the workforce has increasingly been regarded by many authors as the most important asset of organizations and reversing decision concerning people's attitudes, commitment to the company's objectives and motivation, have generally proved to take a long time and considerable amounts of organizational effort. The workforce therefore seems to be more adequately classified as a structural resource.

According to Slack[7], infrastructural resources include only the systems, relationships and information couplings which bind the operation together, thereby supporting the operation of the structural resources – labour and technology. In this research, Slack's classification of manufacturing resource types will be adopted: the manufacturing system is a configuration of interacting individual resources which can be classified as structural resources (technological and human resources) and infrastructural resources. Each of them is defined below:

(1) Technological resources – the facilities and technology, or the hardware side of the manufacturing system.
(2) Human resources – people in the manufacturing system.
(3) Infrastructural resources – the systems, relationships and information couplings which bind the operation together.

In this article we will be particularly interested in the analysis of the flexibility of the structural resources: technological and human.

The Flexibility of the Technological Resources

In order to understand the flexibility of the technological resources of a certain production process it is important to understand the concept of economies of scale. Economies of scale are said to occur when the marginal cost of the production of a specific product is decreasing, in other words, when the total production costs is less than proportional to the quantity produced. This happens because of the so-called "fixed" costs (e.g. set-up costs) in the production process. The cost of the equipment set-up, in general a function of the set-up time, is a very important factor to be taken into account when considering the equipment flexibility. The smaller the set-up cost, the less relevant are the economies of scale and therefore short machine runs become virtually as economic as long runs. This makes it possible to produce smaller quantities of a number of different products as economically as large quantities of one of a few, provided there is the necessary level of equipment capability and capacity. Reducing the set-up times of the equipment is one of the ways to achieve higher levels of equipment flexibility, at least in terms of response[8].

The literature can be divided in two different and important streams when it comes to discuss the means of reducing set-up or changeover times (the time necessary for the process to be set-up in order to change from making one product type to another). One stream suggests that flexible automation (such as computer-controlled machines) is the principal way to achieve equipment flexibility: this can be called the "technology-based" approach. The other stream, more linked to the Japanese thought, suggests an approach which could be called the "methodology-based" approach, which is based more on the concepts of organization, methods and rationalization of the use of conventional equipment. Both approaches will be discussed in turn.

Flexible Automation or the "Technology-based" Approach

Some authors consider that the key aspect for a manufacturing system to achieve high levels of flexibility is technology, or "flexible automation". Zelenovic[9, p. 332] argues that "…increased flexibility of the production elements can be successfully achieved by changing the production elements' structure to more highly automated concepts enabling the maintenance of optimal levels with changing products and process conditions…". Stecke and Raman[10, p. 2] add that "…while the one-to-one correspondence between respective stages of the product and process life cycle could possibly be established for conventional manufacture, flexible automation tends to de-link the product from the process…"[11]. This way, not only some of the processes (e.g. the conventional job-shops) would be flexible but even the most cost-effective processes (e.g. the assembly lines) could also be flexible, being able to produce a variety of products rather than only one or a few. Hill[5] argues that the numerical control (NC) base (the heart of flexible automation) of the new processes brings with it a level of flexibility which is far greater than that which is inherent with non-NC alternatives.

The Methodology-based Approach for Flexibility Development

Much effort has been spent, initially in Japan and later all around the world, to find ways and develop techniques to reduce equipment set-up times. Shingo, the originator of the SMED (Single Minute Exchange of a Die) system has contributed to this effort. Reductions to 1/18, on average, of the time previously spent in setting-up conventional equipment are reported in his book[12] and attributed to his method which is based on the principles of the "scientific management", originated by Frederick Taylor at the beginning of this century. Schonberger[13] also suggests some ways of increasing equipment flexibility without using flexible automation. He claims that the important point in achieving flexibility is the reduction of set-up times. He also highlights some desirable characteristics of equipment such as modularity and transportability which could contribute not to the flexibility of the specific machine but to the flexibility of the manufacturing system.

The Literature on the Flexibility of Technological Resources – Summary and Conclusion

In terms of technological resources, or equipment, flexibility (at least in terms of response) the costs, time and effort spent in order to perform changeovers are relevant considerations. The literature is divided into two main streams with regard to the ways to achieve better levels of performance in terms of machine changeover: one stream suggests that flexible automation is the principal means of developing technological resources flexibility. The benefits of this approach are changeover speed and consistency, achieved in general through numerically-controlled machines, either stand-alone or integrated. The main disadvantages of this approach are the high capital costs involved in equipment acquisition and implementation, and the lack of modularity and transportability of the equipment. There is still great difficulty in proving that investments with flexible automation are viable using conventional financial analysis techniques and indicators. On the one hand, the cost of such systems is still very high. On the other, appropriate methods to consider fully the benefits (strategic as well as operational) of flexible automation are still lacking further development[14].

The other stream advocates the use of conventional and modular equipment of which the set-up times should be reduced basically by methods such as Shigeo Shingo's SMED method. The main disadvantages are the need for change in people's attitudes and the greater dependency on people's skills which are necessary. In order to change people's attitudes and level of skills, a considerable amount of organizational effort and capital have to be spent in training, changing the relationship of organization and labour, the style of supervision and other[15].

The two main approaches to technological resources flexibility – methodology-based and technology-based should not be considered mutually exclusive. Probably no manufacturing system could achieve high levels of flexibility by relying exclusively on for example, technology, at least in the near future. A certain amount of both approaches may be necessary in any case and the more or less emphasis on one or on the other seem to depend on the specific contingency faced by the individual organizations. If a hypothetical organization, for instance, intends to develop the flexibility of its technological resources but lacks the capital necessary for the adoption of flexible automation (as seems to be the case of some companies in developing countries for instance) it appears plausible that it should seek to emphasize the methodology-based approach. In another hypothetical situation it also seems plausible that the firms which have problems with labour unions in terms of making their workforce more flexible tend to adopt flexible automation, in which case possibly fewer multi-skilled flexible workers are needed, since the flexibility is partially "embodied" in the machines.

The Flexibility of the Human Resources

Some characteristics which would be desirable, according to the literature, for the workforce to possess in a company aiming to achieve higher levels of flexibility are discussed below:

(1) Multiple and better skills[16,17]. The larger the range of skills of a worker, the more flexible he or she is, either in terms of the mix of products or in terms of interchangeability of workers between workstations that can be produced in order to cope with absenteeism and temporary shortages. With regard to flexible automation, Adler[16, p. 25] found "a surprising degree of convergence in a series of studies conducted in numerous countries, all pointing to advanced automation's new and higher skill requirements".

(2) Ability to make decisions/solve problems[17,18]. This is a particularly important characteristic in order to obtain quick responses to changing circumstances. It allows decentralization of decision making and therefore avoids wasting time waiting for decisions to be made in upper echelons.

(3) Ability to work in teams[18,19]. Integration is important in order to achieve product flexibility. Multi-functional task forces or teams are being increasingly used when a company needs to launch a new product or change an existing one. Design engineers, for instance, need to have close contact with the production team so that manufacturing problems can be foreseen at the design stage, avoiding a future waste of time and effort. This kind of interaction should happen between all the areas involved and teamwork seems to be the most appropriate approach.

(4) Communication capability[18]. To achieve integration, efficient communication, intra- and inter-areas is essential. The more this communication is practised, the easier it becomes. Some areas of the company have their own jargon which should be standardized or at least understood by the other areas with which they interact. In this way misunderstanding is minimized and misunderstandings can be resolved quickly and effectively.

(5) Ability to understand the process as a whole. A good appreciation of the process as a whole helps understand the consequences of the decisions which become more consistent. This would avoid making decisions which would lead to undesirable consequences as well as making it possible to identify decisions which lead to consequences which are desirable at other stages of the process[20].

(6) Ability to adapt to new situations. This helps avoid resistance to change which can jeopardize flexibility. The acceptance of change as an intrinsic part of the production process rather than an exception is important in dealing with changeable or unpredictable environments[17].

(7) Ability/disposition for continuous learning. This point is stressed by[17] as essential for the creation of what they call the "learning organization". This characteristic is a condition for the creation of an effective capability of the system to adapt to new circumstances. Resistance to change is (at least partially) a result of fear of the unknown, often caused, by lack of information. If there is the predisposition to learn then the barriers of resistance are more easily broken.

The Literature on the Flexibility of the Human Resources – Summary and Conclusion

It is now broadly accepted that it is necessary to abandon some traditional managerial concepts in order to develop a flexible workforce. One such concept is the complete separation between planning/controlling and executing the tasks. These tasks are not any more the old, simple, repetitive ones, designed by the management based on "scientific management" principles. The new reality demands flexibility and flexibility requires decentralized decision making, skills to solve non-repetitive problems, planning and self-control skills of who performs the job or, in other words, managerial skills beside technical excellence.

To develop this kind of ability and skills it is necessary to give workers special conditions for which the idea of teamwork seems to be an important building block. These conditions are imposed largely by the way the workers are managed, basically regarding supervision which should change from directive to supportive; continuous learning, not only on technical aspects but also on managerial aspects; and finally, the forms of reward which should also be based on the group performance and skill levels of the worker rather than solely on individual performance. After the results of "flexible automation" have proved to be more modest than anticipated (at least up to the present), it seems that a flexible workforce is increasingly important for a firm which intends to achieve high levels of manufacturing flexibility.

The Flexibility of the Structural Resources – Some Relevant Empirical Findings in the Automotive Industry

Although the main objective of the overall research was not to analyse structural manufacturing resources specifically, the case-study approach allowed an unexpected theme to emerge during the interviews. According to the manager's view there always seemed to be some sort of structural resource "reserve" (or "redundancy") involved in the achievement of manufacturing system's flexibility. Three managers at company A, for instance, described flexibility explicitly as a reserve, an asset, something which is possessed by the system but is not used all the time. In their own words:

> Flexibility is definitely an asset, something that is not currently used but you can use when you need. I can use that asset, the flexibility to change things. It could be a reserve of ability, capacity or both (*Assembly lines manager*).

> Flexibility is like a commodity, something you have to possess, the willingness to change, the experience, the knowledge. …It is a little accumulator of knowledge, abilities and capacity. It is an actual thing – either you have it or you don't (*Conformance manager*).

> Flexibility is like a reserve, a reserve that has been planned (*CNC cell manager*).

In fact, if a system is able to respond effectively to changing circumstances, it means, implicitly, that the system is able to assume different states and therefore to perform more activities than the activities it is performing at each one time. It has therefore some sort of "redundant" or "excess" capabilities. A totally dedicated machine, for instance, is not flexible because it is only able to perform one single task. Therefore a dedicated machine's capability is not "redundant". During the fieldwork, after studying company A, the first in the sample, the issue of "flexibility as a reserve" was included in the research questionnaire so that it could be explored further. Another interesting aspect soon emerged from the managers' views. Not only redundancy would be necessary for the structural resources to contribute with the system's flexibility, they would also need to be "switchable" (the term borrowed from Dooner and De Silva[21]) in order to respond quickly and easily to the changes. In other words, they would have to be able to change quickly, easily and cheaply between the activities they are "redundantly" able to perform. This point was made, albeit in other words, by the managers at company B as soon as they were asked about considering flexibility as a "reserve", possibly because they had just started to benefit from a comprehensive programme of set-up time reduction. Based on the contributions of the company managers of company A and company B, a basic framework started to be developed, which encompassed both concepts redundancy and switchability.

During the remainder of the fieldwork this basic framework was further developed, based on discussions with the managers and during the plant tours. Several examples of different resource redundancy types were identified. Some of the most representative examples are briefly described below. For further examples see[1].

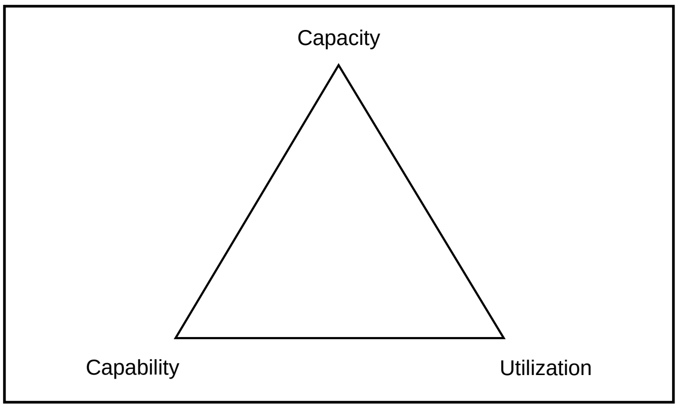
Examples of the Use of Resource Redundancy Found in the Fieldwork

In order to be able to respond to changes in the number of available assembly line workers, caused by absenteeism company A, for instance, provide the assembly line with some extra labour capacity (3 per cent) to cover for absentees. This means that company A's assembly line has redundant capacity of the (labour) resource. However, they also have to make sure that the assembly line team has the right skills to perform all tasks. Company A overcomes this problem by training a number of members of the team in order to enable them to perform a multitude of tasks. In doing so it becomes possible to transfer people between tasks and therefore to accommodate the necessary skills. In providing people with multiple as opposed to dedicated and specialized skills, company A is creating a "reserve", or redundancy of the capability of the labour resource. Both types of redundancy can also be created in the technology resource. A multi-capable machine (such as the CNC ones used by company C in its flexible cell) has redundant capability and a production unit with extra machine capacity has redundant capacity (such as company C which keeps a certain level of excess capacity in the "Zamac" injection shop in order to cover for the frequent machine breakdowns).

Beside redundancies with capability and capacity, a third kind of resource redundancy was identified in the field study. Company D, for example, builds up stocks of semi-finished goods in order to be flexible in responding quickly to it variable demand. To build up these stocks the structural resources "machine" and "labour" are activated before the time in which such activation would be strictly necessary. The build-up of stocks allows the system to be more flexible, allowing the company to respond in a quicker way to changes in demand. It would not be enough for the company to attain this objective only by retaining its current level of extra capacity or extra capability. Aiming at responding more quickly, the system had to activate its resources earlier than would be strictly necessary to respond to firm orders. A stock of parts or products is typically a "reserve", built up in order to help the system respond better to a changing circumstance. This reserve is built up by a redundant (or excessive, compared with the needs) utilization of the structural resources.

Therefore, there would be three kinds of resource redundancy, which can translate into resource flexibility, provided that they are managed properly: capability,

Figure 1. *Structural Resource Redundancy Types*



capacity and utilization (see Figure 1). Each is further analysed below.

(1) Redundancy in the structural resources capability is a function of the range of abilities which the resource possesses but which are not being used all the time. If a machine, for example, has the capability of making ten different product or part types, it is more redundant in term of capability than another one which is able to make only three different product types (given that both make one product type at a time). The ability of a machine, expressed as the range of different product types it can produce[22], is in general a design characteristic. Considering the labour resource, the redundancy of capability of a worker can be increased by training and/or experience. If workers are trained to perform a number of different tasks, for example, their capability reserve or redundancy is increased.

(2) Redundancy in the structural resources capacity is the difference between the level of output the resource is normally producing and the maximum level of output it is able to produce. If a machine has the capacity of manufacturing 1,000 parts per hour and is normally assigned to produce 700 parts per hour, it has a larger redundancy in terms of capacity than a similar machine assigned 900 parts per hour. The same concept applies to a worker or to a group of workers.

(3) Redundancy in the resources utilization occurs when a resource is activated more than was strictly required (such as the build-up of stock-buffers) or before it was strictly required (such as the build-up of time-buffers), generating a physical amount of stock. Here "stock" (generated by redundancy in the utilization of structural resources) is defined as the amount of raw material, semi-finished or finished goods within the system, which has been produced or purchased either in a larger amount or before it was strictly needed to respond to a specific firm customer order. This is an alternative way of looking at the stocks in the production systems. It is not being advocated here that stocks are desirable in principle, only that stocks (or the "redundant" or "excess" utilization of structural resources) are one of the elements which managers can manipulate in order to achieve higher levels of manufacturing system flexibility. The appropriateness or not of its use, complementary or alternatively to the use of the other types of resource redundancies, depends on a thorough analysis of tangible and intangible costs and benefits specific for each particular contingency.

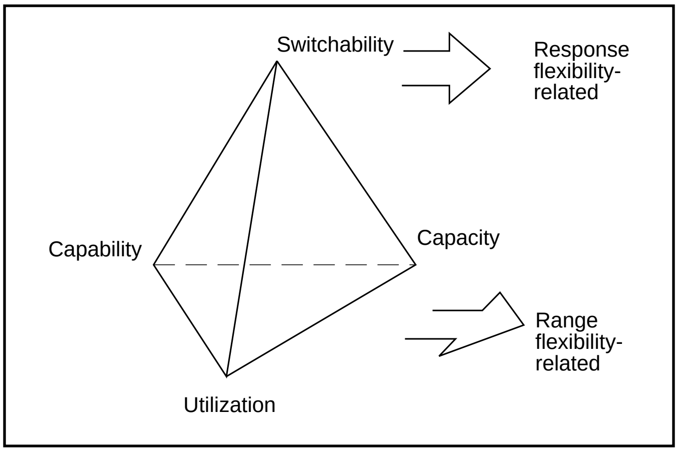
There is another characteristic of the structural resources which is not related to any sort of redundancy, but it is also important in the achievement of higher levels of flexibility, mainly response flexibility: the switchability of the infrastructural resources.

(4) Structural resource switchability relates to how quickly, cheaply and easily a resource switches the activity which it is currently performing into another one (companies A, B, C and D are running programmes of set-up time reduction in order to increase response flexibility or, in other words, technological resources switchability). In terms of technological resources it relates to changeover times which in turn are usually linked to the equipment set-up times. In terms of human resources it relates to the ease and to the time it takes for the person to switch between tasks up to the point when he or she is performing the subsequent task at the same levels of performance they were performing the previous one.

Summarizing, according to the proposed framework, a structural resource is flexible as long as it has the appropriate amount and types of redundancy and levels of switchability which are required in order to respond effectively to the system's flexibility needs.

It seems plausible that the redundancy aspect of the structural resources can be more directly associated with the range dimension of manufacturing flexibility whereas the switchability aspect could be more readily associated with the response dimension as represented in Figure 2. If this is true, the proposed framework can be useful in understanding and managing the links between flexibility at the manufacturing system's level and the operational characteristics of the particular structural manufacturing resource. This is important because if this type of relationship is understood well, it becomes easier to link manufacturing strategic decisions, which normally relate to the manufacturing system as a whole, to the manufacturing operational level. This link, in turn, is the heart of the manufacturing strategy development process.

Figure 2. *Structural Resources Contribution to System's Flexibility*



Looking Forward: Some Questions Which Are Still to Be Answered

The intention of this article is to outline the basic foundations of an alternative framework to help analyse the flexibility of structural manufacturing resources, based on the amount of three types of redundancy and its switchability. Further research is necessary in order that the proposed framework can be fully and practically utilized by decision makers. There are many questions which are still to be answered, some of which are discussed below.

The relationship between desired or required system flexibility levels, set by the manufacturing strategy and the system's resource characteristics which are necessary in order to achieve them, is something which needs further exploration. The literature frequently does not discriminate properly between different levels of analysis with regard to flexibility. It is important to have a consistent set of system flexibility types and dimensions which can be linked to the organization's strategic objectives, when analysing the flexibility of manufacturing systems.

If a particular manufacturing system has to achieve a determined level of manufacturing flexibility, what specific manufacturing resources should be developed in what way? That is a question which has not been sufficiently explored, either in the literature or in the present research work, and certainly is an issue which deserves further attention.

In order to achieve the appropriate mix of flexibilities required, choices of the adequate configuration of resource redundancies should be made. Some choices are quite clear. To achieve product range flexibility a firm has to use its redundant capability because neither stocks nor capacity will help. However, in some situations, managers do have alternatives between which to choose. For example, if a system is being designed to have a highly flexible response to volume changes, some alternatives are available: redundant stocks may be used as well as redundant capacity or still a mix of both. If a system needs high flexibility in terms of response to mix changes, a choice between very flexible machines and workers and, some level of stocks of finished and semi-finished goods has to be made. The trade-offs involved must be considered for each and every situation. At the system level, therefore, a plant can be flexible using different configurations of the three types of redundant resources. Alternatives at the resource level represent trade-offs to be made at the system level. In order that these alternatives can be analysed and traded-off against each other, more research work is needed in terms of measuring both the different types of resource redundancy and their respective costs.

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8. This concept is by Slack[7]. The author suggests that four types and two dimensions of manufacturing flexibility can be identified at the system's level: new product flexibility (related to the system's ability to introduce different products or modify existing ones), mix flexibility (related to the system's ability to manufacture a broad range of products within a given period of time), volume flexibility (related to the system's ability to change its aggregated level of output), and delivery flexibility (related to the ability of the system to change delivery dates). Slack also defines two manufacturing flexibility dimensions: range flexibility – the total envelope of capability or range of states which the operations system is capable to achieve, and response flexibility – the ease, in terms of cost or time, with which changes can be made within the capability envelope.

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22. This is just a simple example. Other considerations are also important in assessing the capability of a machine, such as how different are the products it is able to produce.

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