Making Manufacturing Flexibility Operational Part 1 - A Framework

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Making manufacturing flexibility operational – part 1: a framework

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How to develop flexible manufacturing, consistent throughout, within a corporate decision-making context

Introduction

The strategic importance of the manufacturing function has experienced a renaissance, becoming the focus of many of the latest trends in global competition. FMS, CIM, JIT and lean production are examples that rely on flexibility. The issue of flexibility is complex, relating closely to the overall strategic plan of the enterprise and, at the same time, to single production factors at the operational level. A need for wider product scopes and the trend towards shorter product life cycles are some factors that make flexibility a top priority issue in manufacturing strategy. It is thus evident that flexibility in manufacturing is an important issue and is expected to be even more important in the future[1].

The variety of flexibility definitions has caused the term to lose some of its usefulness. In order to analyse flexibility, the phenomena behind the concept must be brought forth. The flexibility concept has different meanings for different people and a large variety of aspects are discussed in the literature. Many authors (e.g. [2,3]) focus on uncertainties as the origin for the need for flexibility. Slack[4] notes that variety in products, processes and other activities which the system has to cope with is a factor which generates a need for flexibility. Several authors (e.g.[4,5]) have pointed out that flexibility can be considered at different levels. Mandelbaum[6] defines flexibility as "the ability to respond effectively to changing circumstances".

Several of the contributions concerning flexibility in manufacturing are limited in scope. The propositions of previous research have mainly been the following:

- Many articles on flexibility in manufacturing are directed at defining a general classification system of different types of flexibility (e.g.[7; 8, p. 6]), thus not looking at the important issue of how to use flexibility, irrespective of the label.
- Authors often assume that companies must use a top-down approach for developing flexibility in the production system (e.g. [4, p. 46; 9, pp. 38-9; 10, p. 25]). The possibility of using a bottom-up approach to utilize the flexibility potential inherent in the production system is, thus, omitted.
- Many authors assume flexibility to be a reactive response (e.g. [2, p. 46-9; 9, p. 59; 11, p. 514]). The use of flexibility as a proactive response for gaining competitive advantage by means of anticipating and, so leading, the market is neglected.

The realms of flexibility need to be probed more thoroughly beyond the classification systems in order to explore the phenomena behind the concept. A systematization for handling flexibility related issues in companies, such as the one now to be presented, can be useful for managers as well as scholars.

The objective of this article is to develop a framework for manufacturing flexibility which shows how to obtain consistency from manufacturing strategy to the resource characteristics in the production system. The framework provides guidance on how to analyse and develop manufacturing flexibility in a corporate decision making context.

Frame of reference

The concept of flexibility is of paramount importance for the manufacturing function. In this article, flexibility is discussed in terms of the elements in the chain: strategy-manufacturing strategy-manufacturing. For strategy, we rely on the work of Michael Porter[12,13] which is concerned with competitive strategy and competitive advantage. For manufacturing strategy, the predominant references are to the work of Terry Hill[14]. Concerning manufacturing and the subject of flexibility, we are influenced by many authors[4,7,8,10,15].

Porter analyses the strategic aspects of running a company and, in so doing, develops the concept of the value system.

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The value system connects suppliers with the company and onward to the customers. Porter notes that the suppliers have their suppliers and the customers their customers, thus extending the system of interrelations[13]. Within the company, activities are related in a similar manner, creating the value chain. One objective of the company is to align and interconnect the value chain with the value system.

A conceptual model, which explains the role of strategic management in manufacturing, has been presented by Terry Hill[14]. In five steps, the model connects corporate objectives to the marketing strategy and, via qualifying and order-winning criteria, to the manufacturing strategy. The manufacturing strategy comprises two parts: process choice and infrastructure. The steps in the model are not sequential, but rather iterative. Qualifying and order-winning criteria describe the expectations of the market. Qualifying criteria have to be met by the company in order to remain in the market place. "Once the qualifying criteria have been achieved, manufacturing then has to turn its attention to the way orders are won and to ideally provide these better than anyone else"[14, p. 50]. Hill highlights the importance of the manufacturing function and argues that manufacturing strategy should be an integral part of the corporate strategic process. Considering the fact that manufacturing accounts for 70-80 per cent of assets, expenditure and people[14, p. 19], the importance of the manufacturing function should be evident.

Chambers presents "a simple analytical framework which can be used to link flexibility types with the stages of manufacturing strategy which is outlined by Hill"[8, p. 1]. The framework counters the notion that any type of flexibility is desirable by highlighting trade-offs between the different types[16]. Eight classes of flexibility are presented. Chambers shows how to connect manufacturing strategy to flexibility.

Chambers states that "it is first desirable to provide unique classifications of each flexibility type, which can then be used generally in all strategy development"[8, p. 6]. We stress that this is not the important issue. When one wants to communicate flexibility related issues, classifications and definitions of flexibility can be useful. However, the method of slicing the total flexibility cake is contingent on context and, to some extent, personal preferences. As long as it is done in a reasonable way, it is fully sufficient. What is important and has largely been overlooked is that within the same company, different managers can have different perceptions of what flexibility is and how it contributes to the corporate effectiveness[17]. To eliminate this discrepancy it is most important to establish a conformable conceptualization of flexibility within the company. The objective of a classification system should not be to find an optimal system valid for all companies, but rather to find a satisfying classification to which managers in the company can relate.

Authors in the field have made distinctions between flexibility at different levels. Gerwin[5] defines five levels within the company. Slack connects four levels of flexibility in a framework. His framework "identifies the series of managerial action plans for flexibility improvement which will best contribute to company competitiveness"[10, p. 30]. The framework follows a gap methodology of identifying areas for strategic change. The framework highlights the need for action and, in an operative way, shows how to achieve it. Slack argues that the levels should be worked top-down in order to define the resources that match the chosen competitive position. Slack looks at specific types of flexibility and thereby, to some extent, misses the important process of defining what flexibility means in the specific context of a certain company.

At the strategic level and manufacturing strategy level, the frameworks mentioned are helpful. However, few writers go into detail as to how to make the frameworks operational in manufacturing. Our framework is developed to fill this gap and supplement the frameworks of Porter, Hill and Chambers.

The framework

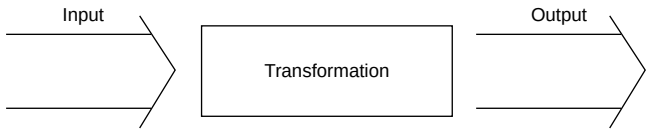
The framework must be useful to managers, i.e. provide guidance on how to manifest manufacturing strategy in terms of flexibility. It should promote consistency between the production system, production resources and the overall strategy of the company. It should also consider factors within the company's environment, such as the market demand and the company's requirements on its suppliers.

Before we proceed, we emphasize that the company must balance the flexibility level it wants to achieve, since trade-offs between flexibility and other vital aspects of the company can exist. It is therefore important to note that what should be achieved is an appropriate level of flexibility for the chosen strategy, not the maximum level.

Foundation of the framework

We begin building the framework and adding features on a step by step basis. The building blocks will be described and discussed as they are added. The framework is conceptual in the sense that it will guide the manager's method of thinking. It is tangible in the sense that it will make operational the flexibility aspects of manufacturing. The model used as a starting point for the framework is the input-transformation output (ITO) model (Figure 1). It describes the flow of goods from suppliers, through the transformation process,

Figure 1. *The ITO model*



and further on to the customers. The model makes a clear distinction between internal and external factors.

The expression *external flexibility* is used for issues concerning flexibility in the relationship between the company and the context outside the company. Two groups of external flexibility exist: *output flexibilities*, which are found in the relationship between the company and its customers, and *input flexibilities*, which are found in the relationship between the company and its suppliers.

According to a survey conducted by Slack[4, p. 39], managers identified four classes of external flexibility to be predominant: product, mix, volume and delivery. In the framework, as in real life, the typology is contingent and, in itself, not a major issue. Flexibility can be classified in many different ways. Which classification managers choose is of minor relevance to the use of the framework and to resolving flexibility related issues of the company.

Flexibility located within the boundaries of the company could be named internal flexibility. However, in order to make the important distinction between the controllable inside of the company and the outside, which the company cannot fully control, we coin the term *characteristics*[18] for flexibility inside the company. It has two levels: the *system level* and the *resource level*. The characteristics which the company can control within its boundaries are clearly distinguished from issues outside the company which the company can not fully control. The characteristics of the production system have to correspond to the external flexibility.

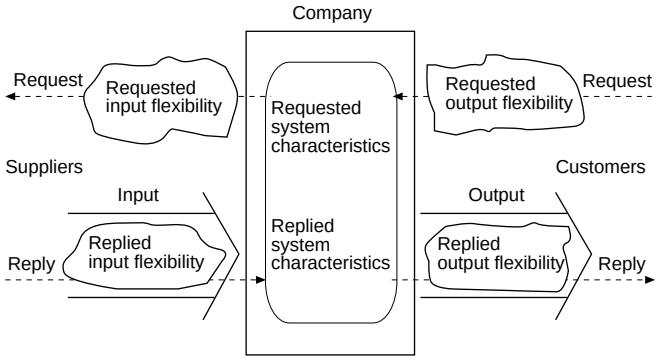
Another way of stating this is that:

- external flexibility is *what* the customers demand from their suppliers and what the suppliers can supply; while
- characteristics are *how* a company, internally, can accommodate its production facilities in order to fulfil the demand for external flexibility.

The ITO model is supplemented with the flow of information, taking into consideration that the *replied flexibility* (what the supplier can supply the customer with, in terms of flexibility) can differ from the *requested flexibility* (what the customer demands from its supplier, in terms of flexibility), both on the input and output side. Combining this with the distinction discussed above between external flexibility and the characteristics of the production system, the first view of the framework is created (see Figure 2).

Information concerning the demand on the company originates from the market and proceeds upwards to the company. If the present production process permits, a reply to the demand will flow downwards. If it is not possible to reply, the company must consider adjusting its production process. Analogous, the relationship between the company and its suppliers implies a constant flow of information leading to mutual adjustments.

Figure 2. *The flow of information in the framework*



It is often not feasible, nor even possible to match the request completely. If the market is rapidly moving, the changes in qualifying and order-winning criteria can force the company out of the market. The company environment is in a constant state of flux. Therefore, a proactive approach can be advantageous. The company can gain competitive advantage by means of anticipating and thus creating the demands.

Structure of the framework

By combining the external level with the two internal levels, the framework consists of three distinct levels:

(1) *strategic*, where input and output flexibilities are defined at the marketplace between the company and its suppliers or customers;

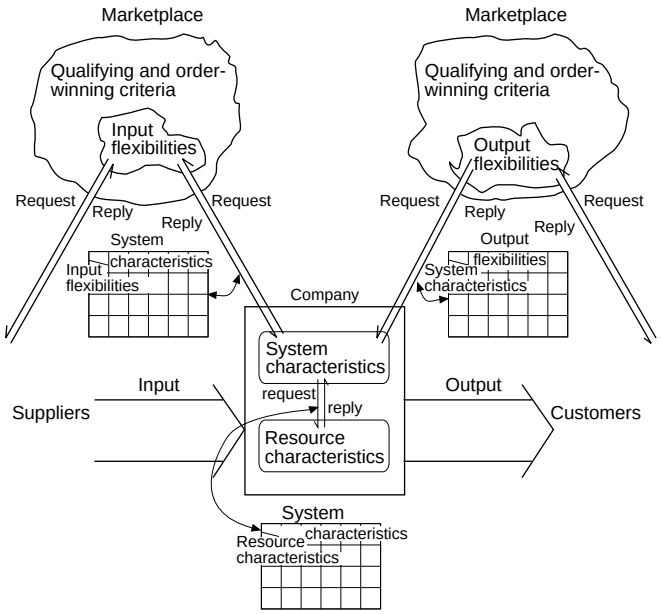
(2) *production system*, where the characteristics of the production system are defined on a tactical level;

(3) *production resource*, where the resource characteristics are defined on an operational level.

Figure 3 shows the connections of the system characteristics to the input and output flexibility. It also shows the two levels of flexibility characteristics inside the company: resource and system. The three levels are interconnected by the request and the reply for flexibility.

The translation from one level to another is made via a transformation matrix. Three transformation matrices are defined (see Figure 3). The matrices are used to create concordance between the flexibilities at the different levels, but are not mathematical in any way. They will provide guidance through the process of making the strategy of the company operational. Depending on whether a top-down or a bottom-up approach is used, the matrices will focus on request or reply. The function of the matrices can also be seen in Figure 3.

Figure 3. *The framework*



Examples of flexibility and their relationships at different levels can be illustrated by the following example. Short set-up times and multiple skilled workers (resource characteristics) provide the possibility to produce in small batches (system characteristics). This can provide the opportunity to manufacture a wide range of products (output flexibility).

Using the framework

In reality, companies must both make effective use of the production resources at hand, as well as exploit possibilities the future. The framework is therefore compatible with both a top-down and bottom-up approach – whichever is more beneficial in making full use of the possibilities inherent in the production system.

When beginning an analysis of a company, any starting point may be chosen. The links of the chain are all inter-dependent, therefore, the analysis becomes iterative. When all the parts of the model are analysed, the process has to be re-run to ensure that accommodations in the latter steps do not necessitate changes in the earlier steps. A beneficial approach in some cases can be a gap methodology where the current state of flexibility is determined. The required state of flexibility is then defined and finally, the existing gap is identified and action taken to reduce it.

The demand for flexibility emanating from the customers is an important factor for flexibility. Therefore, in the following sections, the market is used as the starting point in presenting the methodology of the framework. First, we disclose the interdependencies between output flexibilities and system characteristics. The next step is to look into the transformation process where the interdependencies between characteristics on the system level and characteristics on the resource level are analysed. Finally, the interdependencies between system characteristics and input flexibilities are examined.

Output flexibilities to system characteristics

It is of utmost importance for a company to follow the trends of the market closely and accommodate the manufacturing strategy to the changing preferences of the market. Better still, the company can strive to set trends and lead the market. The dynamics of the market are reflected in changes to qualifying and order-winning criteria. In order to be able to make swift accommodations, the company must be flexible.

The qualifying and order-winning criteria of the market have been identified and transformed into the types of flexibility that the company needs or is assumed to need in the future (for a more detailed discussion on this topic see[8]). The nature and levels of the required output flexibilities are thus defined.

At the system level of the company's transformation process, the chosen flexibilities are to be translated into system characteristics. An outline of this process is formalized in Figure 4.

When the framework is used in a top-down mode, the matrix is used to support the process of defining the production system as a function of the market demand. Note that the labels in the matrix are not predefined, they are specific to each company. The first step is to define the flexibilities and the crucial system characteristics in the company. This process is, in itself, important since it will align the conceptualization of manufacturing flexibility with the managers in the company.

Thereafter, the process of translating the output flexibilities into system characteristics can begin. A useful approach is to work through each of the flexibilities and decide what requirements the desired level of flexibility places on each of the elected critical system characteristics.

Normally there are additional system characteristics that must be decided. In this example only some are listed. When each square has been analysed independently, the matrix is analysed horizontally to decide the total impact of the output flexibilities on the system characteristics of the production system. The flexibilities can place different demands on the specific system characteristic. These demands then have to be adjusted in order to reach a consensus on each of the system characteristics. The adjustments can suggest that the desired level of some types of flexibility is not attainable owing to the counter-acting consequences of other flexibilities. In this case, the implications must be analysed in terms of qualifying and order-winning criteria.

Changes may make it necessary to rerun the processes. Indeed, a change in any square of the matrix will directly affect the squares in the same row, as well as in the same column. Therefore, this single change will indirectly have a "knock-on" effect on all the remaining squares. The iterations continue until a satisfactory solution has been reached. Already at this point in the process changes might have to be made to production on the system level, such as the capacity of the production system or the layout of the shopfloor.

System characteristics to resource characteristics

Often, it is not enough to know the system characteristics. Instead, each and every production resource (machines, labour and infrastructure) has to be examined in order to determine whether each resource can meet the requirements determined by the required system characteristics. This is done by translating the system characteristics of the production system into resource characteristics of the individual resources (see Figure 5).

The aggregated production system is broken down into the components of the system. In the steps to follow, we will emphasize the importance of the performance of the single production resource. It is important to define the characteristics of the single production resource since it is at this level that decisions concerning investments in manufacturing equipment, infrastructure and educational programmes for labour are most often made.

The purpose of this matrix is to support the translation of system characteristics into resource characteristics. The resource characteristics have to be defined in the company context before this process can begin, just as the system characteristics had to be defined in the previous matrix.

The matrix is worked through and the desired resource characteristics are defined. With the desired resource characteristics at hand, a comparison can be made to the actual production system and the gap identified. Action can be taken to reduce the gap. It is, however, quite possible that it is not feasible to close the entire gap. Counteracting

Figure 4. *A matrix for analysing the relationship between the output flexibilities and the system characteristics of the production system*

System characteristics \ Output flexibilities[a]	Product flexibility	Mix flexibility	Volume flexibility	Delivery flexibility	Conclusions
Capacity					
Batch sizes			[b]		
Production lead times					
Conclusions					

[a]The chosen output flexibilities and their definitions are contingent on the company. The four chosen categories are used as an example

[b]In each square the consequences for the next level are articulated, e.g. "The requested delivery flexibility will imply a faster production response. The batch-sizes must be reduced in order to reduce the production cycle"

Figure 5. *A matrix for analysing the relationship between the system characteristics and resource characteristics of the production system*

Resource characteristics \ System characteristics		Capacity	Batch sizes	Production lead times	Conclusions
Machines	Multi-product capabilities				
	Set-up times				
Labour	Labour skills		[a]		
Infrastructure	MPC system				
Conclusions					

[a]e.g. "The requested batch sizes will imply faster set-ups"

demands may make it impossible to fulfil all the demands, thus making it necessary to rerun the entire process from the qualifying and order-winning criteria, through the system characteristics, to the resource characteristics.

System characteristics to input flexibilities

If the process is carried out in the prescribed order, the final step will be to determine if the input flexibilities provided by the suppliers of the company are sufficient to support the system characteristics and thus support the overall strategy of the company. This translation is made with a matrix which is used in a similar manner as the other two matrices.

Discussion and conclusion

When the iterating of the process has come to an end, the gap between the current state of flexibility and the required state of flexibility is determined. The company has thus gained an awareness of what is necessary to be competitive. When the gap is identified, a plan of action can be decided and, finally, action taken to reduce the gap and reach the desired state of flexibility. Thus, the chain from input to output is in concordance with the production process of the company, and all levels are aligned with each other and with the overall strategy of the company.

This article provides guidance on how to analyse and develop manufacturing flexibility in a corporate decision making context. In practice, the process of working through the matrix several times as suggested creates an awareness of flexibility and its impact on the production system, as well as on the overall strategy of the company. Working through the framework can conform the conceptualization of flexibility between managers, thus increasing the possibility of reaching a favourable, mutually agreed solution and creating commitment to this solution.

Having gone through the complete process, aligning all the parts with the overall strategy of the company, corporate managers might be tempted to sit down and relax. Doing that would definitely be fatal. The process described above will merely have given the production system of the company a vitamin injection. However, to ensure that the heart of the company continues to beat satisfactorily, managers must continually scan the entire system for emerging misalignments arising from dynamic changes in the environment, as well as opportunities from technology change.

The environment of the company is in a constant state of flux, so the prerequisites of the company's competitive position are bound to change. Competitors are striving to gain market shares and substitute products are entering the market. Whatever the cause, external misalignments are most likely to manifest in the form of changing customer preferences. However, they can also appear as changing supplier relations. Whether customer- or supplier- oriented, such changes will affect the connection to the system characteristics and, thus, affect all other elements. Corrective actions should be taken immediately. The framework above can assist in this process.

We conclude that the levels of manufacturing flexibility are interconnected by the request for flexibility and the reply for flexibility. The interconnections can be viewed as transformation matrices which transform aspects of flexibility from one level to the next. Depending on whether a top-down or bottom-up approach is used, the matrices will focus on request or reply. This process of defining the flexibilities and characteristics of the company can therefore create a satisfying classification that all managers in the company can relate to and accept.

The framework is congenial since the conception is simple to grasp. It is intuitive, yet still tangible. It allows the managers to make the connection between decisions at the strategy level right down to those decisions on single production resources. Furthermore, the process of analysing the ITO system can begin anywhere in the framework. For example, given the production system, can we increase our competitiveness in the market? Can changes in the supplier relationships further strengthen the company? Are we using the right suppliers – those that are in alignment with the overall strategy of our company? Are we investing in the right equipment and facilities – those which support the goals of our production systems? Are our employees prepared for the expected changes in the market demand? What precautions can be taken to prepare them?

The described process can be time consuming and also costly, especially if the links of the ITO chain have considerable discrepancies when the process starts. A comforting thought, if this is the case, is that the longer the process and the larger the misalignments, the more potential gains can be utilized by using the framework for manufacturing flexibility.

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