

## **Manufacturing Flexibility and Industrial Networks**

Luis Araujo  
Department of Marketing,  
The Management School  
University of Lancaster  
Lancaster LA1 4 YX  
e-mail: [L.Araujo@lancaster.ac.uk](mailto:L.Araujo@lancaster.ac.uk)

Martin Spring  
Operations Management Group  
Manchester School of Management  
UMIST  
PO Box 88  
Manchester M60 1QD  
e-mail: [Martin.Spring@umist.ac.uk](mailto:Martin.Spring@umist.ac.uk)

### **Abstract**

The concept of flexibility has occupied an increasingly central role in the operations management and strategy literatures. Despite this surge of interest, the concept of flexibility and the means employed to deliver flexibility remain under-researched topics. This paper critically examines the literature on manufacturing flexibility and lists a number of unresolved tensions and issues in this literature. In the second half of this paper, we examine the potential contributions of the industrial networks literature to the study of flexibility and propose promising new avenues for further research in this area.

Paper prepared for the 18<sup>th</sup> IMP Conference, Groupe ESC Bourgogne, Dijon

## **Introduction**

In recent years, there has been an increasing concern in the academic and management studies literatures with the notion of flexibility. These arguments have been developed under different guises in areas such as strategic management (Sanchez, 1997), operations management (Gerwin, 1993) and economic geography (Harrison, 1994).

Sabel and Zeitlin (1997, p. 20) argue that “...for nineteenth century and early twentieth-century firms [...] and again for an increasing number of large and small firms today, the central problem in industrial organisation was and is the coordination of decentralisation”. The solution for the coordination of decentralisation, according to Sabel and Zeitlin (1997, pp. 20-1) depends on the stability of the economy. If the economy is stable, it pays to organise production in large, vertically integrated firms in which output from one stage serves as input to the next. Economies of scale allow production costs to fall and markets to extend sufficiently to justify investing in specialised assets that cannot be easily redeployed elsewhere. If the economy is volatile or difficult to predict, it pays to organise each step of the production process as an independent unit. In these conditions, each unit is encouraged to protect itself against demand vagaries by learning to deploy its resources flexibly and not investing in assets that are specialised to a narrow range of market opportunities. These specialised and flexible businesses can then contract with one another to respond to evolving market opportunities.

Sabel and Zeitlin’s (1997) historical summary sets the scene for our discussion of the notion of flexibility. In this story, hierarchies are opposed to networks of independent and specialised producers, vertical integration is associated to rigidity and flexibility with versatile resources and their configuration in networks of specialised producers. The value of flexibility thus lies in providing reserves against an unpredictable future, through resources that are intrinsically versatile as well as developing a set of routines and capabilities allowing for rapid reconfiguration of outputs in response to volatile markets.

The purpose of this paper is to offer a relational approach to flexibility by regarding it as a set of connections linking distributed resources, at an intra and interfirm level, deployed to anticipate or adjust to changes in demand. Our approach favours a multi-level and processual approach to flexibility and eschews any notions that flexibility is

embodied in physical resources or belongs solely to the domain of firm-level processes. We suggest that flexibility resides in capabilities under the control of a focal firm as well as capabilities external to the firm, accessible through relationships with third parties. Whereas existing literature has developed robust typologies of manufacturing flexibility, we argue that the processual (*how* do firms enact flexibility) and multi-level (*where* are demands for flexibility absorbed) aspects have been neglected. A subsidiary strand of our argument relates to the dialectics between flexibility and its opposite, rigidity. Rather than seeing flexibility and rigidity as opposite sides of a continuum, we regard these two dimensions as dialectically related and necessary for the operation of firms and industrial systems.

This paper is organised as follows; in the first section, we will review the flexibility literature focusing mainly on the contributions found in the operations and strategic management literature. In the second section, we will discuss alternative views and critiques of the conventional approaches before introducing our proposal for a relational, multi-level and processual approach in section 3. In the final section, we will offer an agenda for research and concluding remarks.

### **Defining Flexibility**

Flexibility has long been a concern of operations management writers. At a broad level, flexibility can be understood as an absorber of environmental uncertainty and variability (Gerwin, 1993; De Toni and Tonchia, 1998; Beach et al, 2000). The operations management and related literatures are largely united in identifying as the motivation for increased flexibility, the existence of a market or environment which is uncertain, unpredictable or turbulent. Flexibility is regarded as a positive feature since it contributes to the firm's ability to absorb or even benefit from variations in its environment.

In their extensive review, De Toni and Tonchia (1998, pp. 1588-9) advance two general perspectives on flexibility:

- 1) Flexibility as a filter and uncertainty absorber, shielding the firm from external disturbances;
- 2) Flexibility as a homeostatic mechanism, preserving internal stability in the face of exogenous changes.

These definitions involve the notion of an adaptable organism with internal procedures to preserve a degree of integrity and coherence, in face of environmental volatility. As De Tonni and Tonchia (1998) remark, these definitions invoke a tension in that flexibility involves both stability and change.

This tension was earlier identified and elaborated upon by Weick (1982). For Weick 1982 (p. 386):

“Flexibility is required to modify current practice so that non-transient changes in the environment can be adapted to. This means that the organisation must detect changes and retain a sufficient pool of novel responses to accommodate to these changes. But total flexibility makes it impossible for the organisation to retain a sense of identity and continuity. Any social unit is in part defined by its history, by what it has done repeatedly and chosen repeatedly.”

Loasby (1999, p. 13) makes a similar argument: “...if everything is perfectly flexible, nothing can be relied on”. On the other hand, as Weick (1982, p. 387) argues: “Stability also provides an economical means to handle new contingencies; there are regularities that can exploit if it has a memory and a capacity for repetition. But total adherence to past wisdom would be as disruptive as total flexibility because more economical ways of responding would never be discovered and new environmental features would never be noticed.” Similarly, Adler (1988) claims that flexibility has to be understood against a backdrop of stability. Thus flexibility should be seen as a type of response to environmental variations that enables a measure of adaptability without causing undue disruption to organisational processes.

One typical way of operationalising the broad definition of flexibility offered above is by focusing on the ability to change “the nature, volume and timing of the output” of an operation (Slack and Corrêa, 1992). Upton’s (1994, p. 73) oft-quoted definition is “flexibility is the ability to change or react with little penalty in time, effort, cost or performance”. Upton (1995) discusses different strategies for a firm may to become flexible and suggests that flexibility is both a multidimensional and multilevel attribute. For example, a firm may develop the ability to produce a broad range of products through a network of focused plants and subcontractors. The same degree of flexibility may be achieved through the ability to supply the same range from one flexible plant, through the development of specialised capabilities. Similarly, the

flexibility to respond quickly to customer orders may be achieved through building appropriate inventories rather than developing complex manufacturing capabilities to enable just-in-time production.

Upton's (1995) arguments suggest that flexibility is enacted as a response to different classes of problems and there are usually multiple responses to the same set of problems. Recent writings on manufacturing flexibility have emphasised the notion of flexibility as a multidimensional construct and the various responses available to meet different flexibility challenges. Gerwin (1993) attempts to link types of uncertainty to strategic objectives and flexibility dimensions. For example, aggregate product demand as a type of uncertainty maps on to the strategic objective of maintaining or increasing market share and demands volume flexibility. Koste and Malhotra (1999) define 10 dimensions of flexibility and introduce a hierarchy of flexibility dimensions ranging from individual resource, to shop floor, plant, functional and business unit. Parker and Wirth (1999) propose a framework for measuring different flexibility types. D'Souza and Williams (2000) define and test four dimensions of flexibility, with volume and variety flexibility categorised as externally driven dimensions and process and materials handling flexibility classified as internally driven dimension.

These attempts at categorising flexibility can be seen as distinguishing between the ability to change output either qualitatively (e.g. make different products) or quantitatively (i.e. make more or less). Whilst these typologies acknowledge that different aspects of demand change require different types of flexibility, the interaction between different forms of flexibility, namely qualitative and quantitative dimensions have been less well analysed. Reduced demand levels may encourage plants to accept business they would not normally consider, in order to utilise spare capacity. They might do this by making a wider range of products, perhaps including customised items (Spring, 1996) or bring in-house activities that were previously subcontracted (Dubois, 1998). In turn, the relative lack of familiarity with both the requirements and the processes will make the capacity demands of this type of business less predictable. If custom-designed products are used significantly to fill production capacity, this leads to extra demands on the applications and design capacity and there may be a need for extra process support and unfamiliar activities are undertaken (Spring and Dalrymple, 2000).

In short, attempts at categorising flexibility tend to look at discrete and directed responses to specific types of uncertainty. However useful these typologies have

proved to be in cataloguing the multidimensional attributes and implications of flexibility, they have tended to ignore that responses to demands for flexibility can often be distributed across different levels and be indirect (i.e. the demand is met through other means other than a directed response to the stimulus).

The manufacturing strategy literature has developed a set of operations objectives or competitive criteria, typically consisting of quality, speed, dependability, flexibility and cost (e.g. Anderson et al., 1989, Mills et al, 1995). This treatment of flexibility as a performance outcome in the same way as, say, cost, is at variance with earlier formulations. Wild (1980) and Slack (1983) saw flexibility as a “second-order” characteristic, one that gives the *potential* to achieve certain levels of operations performance. Easton and Rothschild (1987) adopt a complementary position by suggesting that as a second-order organisational variable, flexibility is concerned with changes in state rather than states themselves.

This suggests a more comprehensive conceptualisation of flexibility. If flexibility can also be regarded as a reserve rather than simply a predetermined response to a range of specified situations, then it is important to specify how this reserve is built up, maintained, enhanced or depreciated. Carlsson (1989) draws on Knight’s (1921) classic distinction between risk and uncertainty to introduce two different types of flexibility. For Knight, risk belongs to repetitive sequence of events whose probability can be measured and uncertainty belongs to those events that cannot be assigned probabilities. For Carlsson, there are two types of flexibility that follow from this distinction between risk and uncertainty: type I (static) flexibility is concerned with routines for dealing with foreseeable events and type II flexibility (dynamic) relates to the capacity to react to unpredictable environmental or technological changes.

Carlsson goes on to distinguish three types of flexibility: operational (short-term), tactical (medium-term) and strategic (long-term). Operational flexibility corresponds to built-in procedures that permit a large range of responses to operational variables (e.g. sequencing, scheduling). Tactical flexibility refers to the embodiment in technological and organisational routines of responses in how to deal with quantitative and qualitative changes in rates of production, product mix over the course of a business cycle, etc. Strategic flexibility relates to how the firm is positioning itself with respect to future challenges and opportunities.

Carlsson’s distinctions between the three classes of flexibility attempts to capture the notion of flexibility as a portfolio of routines evoked in relation to foreseeable

environmental variations as well as a capability, always conjectural and fallible, to supply innovative responses to novel problems. Carlsson's strategic flexibility appears to stretch the notion of flexibility beyond the scope of most accepted definitions. Carlsson regards the barriers to operational and tactical flexibility as being embodied in physical assets and the way they are deployed whilst the barriers to strategic flexibility are deemed to "... be more likely to be of a mental or organisational nature" (*op. cit.*, p. 187).

Similarly, Sanchez (1997, p. 72) adopts a Penrosian approach to flexibility and defines strategic flexibility as the "...the condition of having strategic options that are created through the combined effects of an organisation's coordinating flexibility in acquiring and using flexible resources". A firm's strategic flexibility is regarded as dependent on the inherent flexibility of its resources available as well as on the organisation's flexibilities in applying those resources to various uses in pursuing alternative courses of action. The key to addressing strategic flexibility thus lie in the ability of the firm to identify, develop or acquire resources that can be deployed in alternative courses of action and in developing coordination processes that allow resources to be used in multiple courses of action. Sanchez's framework as Carlsson's, highlights the problems of stretching the notion of flexibility to encompass long-term adaptation.

Easton and Rothschild (1987) draw a distinction between adaptation and flexibility. Adaptation may be regarded as long-term, discontinuous and resource-expensive process whereas flexibility is associated with short-term, continuous and resource-inexpensive changes. Easton and Rothschild (1987) warn that the capacity for adaptation may or may not be correlated with flexibility, and there may be cases where flexibility inhibits adaptation.

Weick (1982) makes a parallel distinction between adaptability and adaptation, and discusses their relationship to the nature of loose and tight couplings in organisations. For Weick (1982, p. 387): "...loose coupling is the source of adaptability in most organisations whereas tight coupling is the source of most adaptation. [...] in a loosely coupled system there is less need for major change because change is continuous. Frequent local adjustments unconstrained by centralised policy keep small problems from amplifying." Thus adaptability requires loosening whereas adaptation requires tightening. For Weick, a loosely coupled system is a system that has the ability to update itself and can address any number of continuous, small scale,

accommodative and local changes, without the need for formal interventions aimed at altering the hard-wired routines of the system. The implication for organisational change is that when adjustments can have discontinuous, long term and resource expensive effects change should be centralised and when adjustments have continuous, abbreviated and inexpensive effects (Weick, 1982).

In this paper, we build on these insights and contrast flexibility with agility. Agility refers to the other end of the uncertainty spectrum where firms face major, frequent and unpredictable shifts in their environment due to step changes in technology, markets emerging and collapsing, mergers and acquisitions, etc. (Duguay et al, 1997). It is concerned with the organisational meta-structures and processes that help firms respond to highly turbulent environments and only peripherally with flexibility. The agility approach espouses value-based pricing strategies, co-operation that enhances competitiveness, organisational mastery of change and uncertainty and investments that leverage the impact of people and information (Gunasekaran, 1999).

### **A Critique of the Manufacturing Flexibility Literature**

In this section, we present a critical analysis of the flexibility literature and suggest a number of areas where progress might be made. Our critical comments focus on the notions of firm, environment and the relationship between the two as well as on the notion of flexibility as a discrete and directed response to environmental variations. Whereas most studies of flexibility adopt an aggregate and abstract conception of the environment (e.g. Paggel and Krause, 1999), we regard firms not as solitary actors confronting an atomistic, faceless and hostile environment but as embedded in structures of relationships to identifiable counterparts (Pfeffer, 1987; Håkansson and Snehota, 1989; Axelsson, 1992). In short, the environment firms confront is neither atomistic nor solely characterised by abstract dimensions.

This view has two important consequences. First, environmental variability or unpredictability does not impinge upon atomistic firms but is transmitted through the structure of relationships in which a firm is embedded. Secondly, environmental uncertainty is not an intractable force than impinges upon helpless victims but is often the object of negotiations and bargaining in interactions with identifiable counterparts (e.g. customers, suppliers).

Firms can choose a variety of strategies to react to demands for flexibility; they can reflect back those demands, they can adapt those demands, they can absorb them internally or transmit them to other parties (Easton and Araujo, 1997). In the first case, the firm simply refuses to accept the changes requested by customers and it reflects the change back to the initiator. In the second case, the demand for flexibility is adapted and negotiated within the context of an ongoing relationship. The focal firm might return to the initiator and attempt to iterate the process of problem solving so that the flexibility demand can be translated into parameters the firm can address.

In the absorption case, the firm attempts to meet flexibility demands with sole reliance on its human and material resources. This case corresponds most closely to the typical case envisaged in the manufacturing flexibility literature. Firms attempt to find ways to use the best combination of internal resources and ways of deploying those resources in order to meet particular flexibility requirements such as wide variety of parts with fluctuating volumes (Venkatesan, 1990). In the transmission case, the focal firm finds ways to pass on the effects of flexibility demands to other actors. For example, demands for extra volume are transmitted to subcontractors or even cooperating competitors. Finally, in the configuration case a firm may mobilise a temporary network of third parties to meet particular demands for flexibility. Complex products and systems in industrial markets often involve consortia of firms formed for the explicit purpose of designing a specific solution for a customer.

The ways in which variability and uncertainty are absorbed to by a focal firm depends on the structure of intra and interfirm relationships in place. Too often, the flexibility literature tends to treat the firm as a closed system, within which all flexibility demands have to be absorbed. But modern firms are often multi-plant, diversified and geographically dispersed entities. They are rarely tightly coupled structures with little room for adaptability and improvisation. Firms can often transmit flexibility demands to other parts of the same organisation (e.g. sister plants, other divisions) and third parties (e.g. subcontractors, suppliers). Flexibility demands have to be understood in terms of these web internal and external relationships with differential abilities to respond to those demands.

The literature on manufacturing flexibility has tended to look at physical resources, namely flexible manufacturing systems, as the method to deliver flexibility (Jaikumar, 1986). Recent studies have begun to address the delivery of flexibility as a complex process of interdependence amongst of factors, namely the interaction between

manufacturing systems and human factors. Upton (1995) study found that the determinants of plant mobility, defined as the ability of change the product manufactured quickly, did not include size or the computer technology of the plant. Thus buying flexibility embodied in computer-integration technology and new equipment is an illusory aim. Instead, Upton's study found that the capabilities that support plant mobility tend to be infrastructural in nature, such as operator experience and managerial factors, such as the extent to which managers are perceived to emphasise a particular type of performance. Suarez et al's (1996) empirical study found that newer and more automated methods of production tend to be associated with less flexibility in terms of product mix and new product introductions. Instead, factors such as high involvement of workers in problem-solving, close relationships with suppliers and flexible wage schemes seem to correlated with combinations of new product, mix or volume flexibility. Narashiman and Das (2000) investigate the contribution of sourcing policies to manufacturing flexibility and conclude that supplier involvement in matters such as product design and responsiveness to delivery changes have positive impacts on certain types of flexibility.

These empirical studies highlight that the firm may be the wrong unit of analysis to focus on and that flexibility cannot be easily associated with one type of resource, be it a physical or human. Firms are often loosely coupled systems composed of different business units, manufacturing plants, etc. Lawrence and Lorsch (1967) argued that in order to cope with complex environments, organisations needed greater differentiation and this in turn, creates problems of integration. But as Weick (1982) remarks, high differentiation does not necessarily lead to high integration. The combination of high differentiation with low integration may be less effective than high differentiation-high integration combinations regarding efficiency, but may prove more effective regarding flexibility, improvisation and capacity for self-design.

The association of flexibility with one type of resource, namely automated manufacturing equipment, is thus misguided. Many users of flexible manufacturing systems, for example, seem to use their equipment for large-batch production rather than produce mixes of different products (Suarez et al, 1996). Venkatesan (1990) reported that flexible machines at Cummins were used as hedges against design changes, race products to market and as complements to dedicated machining cells when part variations were large enough to make the changeover troublesome.

In the rest of this paper we will argue for a broader notion of flexibility based on our critique of the manufacturing flexibility literature. We propose that flexibility be treated as a portfolio of routines or programmed responses to identified uncertainties as well as set of capabilities that can be extended in novel ways. Furthermore, we regard flexibility as a systemic property, residing in patterns of connections between resources and activities rather than an attribute of stand-alone resources, and emphasise its negotiated and distributed character at an intra and interfirm level.

### **An Industrial Networks Approach to Flexibility**

In the industrial networks approach, industrial systems are analysed in terms of patterns of actor bonds, activity links and resource ties. In this approach, the firm is seen from a Penrosian perspective as “...a collection of productive resources the disposal of which between different uses and over time is determined by administrative decision” (Penrose 1959, p. 24). The productive resources the firm controls are regarded as a bundle of possible services, rather than a fixed set of attributes available as public knowledge. As Penrose (1959, p. 75) remarks, it is the heterogeneity rather than the homogeneity of both human and material productive services that makes firms unique.

Richardson (1972) replaced Penrose’s (1959) notions of resources and productive services by capabilities and activities, and extended the concept of capability to address issues of the division of labour and coordination of capabilities in industrial systems. Richardson (1972, p. 888) argued that “...organisations will tend to specialise in activities for which their capabilities offer some comparative advantage; these activities will, in other words, generally be similar [...] although they may nevertheless lead the firm into a variety of markets and a variety of product lines”.

In Richardson’s (1972) framework the grouping of activities in an economy can be explained by their interrelationship and by the relationships between the capabilities that underpins them. Activities can be complementary or closely complementary depending on their degree of interdependence. Complementarity arises when activities have to be matched in either level or specification and require some form of sequential coordination. Close complementarity emerges when activities are in some degree specialised to each other and require more elaborate coordination in the way they are combined (Richardson 1972, p. 891). Activities can also be classified as

similar or dissimilar depending on whether or not they draw on similar capabilities and thus offer potential for economies of scope. Similarity amongst activities occurs when the same capability (e.g. involving personnel and equipment) is deployed across more than one activity structure (Dubois, 1998).

Similarity and complementarity may be combined to provide three modes of economic coordination. Complementary but dissimilar activities may be coordinated through market exchange, where the providential law of large numbers can be trusted to match activities without the need for *ex-ante* planning. If markets can link dissimilar activities through incremental coordination via the unintended and aggregate consequence of independent decisions, close complementarity of activities requires concurrent coordination. And concurrent coordination gives rise to intra or interfirm cooperation, where the sequential adjustment of activities can be planned in advance and brought in correspondence.

Firms are institutional devices to organise a set of closely complementary and similar activities that have to be put in place simultaneously and thus require conscious, planned direction (Richardson, 1998)<sup>1</sup>. What is distinct about firms is not simply the professional knowledge and skill its members bring with them but the complex pattern of relationships and “local knowledge” derived from teamwork and continued interaction. This degree of specialisation means that these types of services can no longer be replicated easily or accessed in the open market. Potts (2001, p. 424) makes a related point in this context: “Stable clusters of connections are required for production processes, which is essentially why firms have boundaries”.

By contrast, closely complementary but dissimilar activities may prove impossible to integrate in a single administrative framework and will give rise to a variety of forms of interfirm relationships. Interfirm relationships incorporate important economic, social and technological components and qualify as a quasi-firm in the sense of what Richardson (1998) defined as essential about a firm – the creation of “local knowledge” as the result of mutual specialisation and continuity of association. Some of this “local knowledge” is directed towards improving efficiency through mutually beneficial adaptations of existing structures but new knowledge is often created in the way of relating dissimilar but closely complementary capabilities.

---

<sup>1</sup> Richardson (1998, footnote 7) further notes that close complementarity of activities may require direction because of the complexity of matching activities as well as the speed at which they have to be matched.

Furthermore, even when activities are directed to a specific counterpart, the capabilities that underpin them are often deployed in other relationships and thus are connected to the focal relationship (Hakansson and Snehota, 1995). In other words, business relationships can never be analysed in isolation since the capabilities deployed in them are always embedded in other activities and directed towards other business relationships.

The framework provided by Richardson allows us to distinguish between different modes of economic coordination but does not address the issue of how interdependence is handled within firms. Thompson's (1967) classic work differentiates between three types of intrafirm interdependence and derives implications for how they should be coordinated. Pooled interdependence is the simplest form of interdependence and assumes that each part of the organisation provides a discrete contribution to the whole and is in turn, supported by the whole. Sequential interdependence occurs when the order of performance of two activities has to be strictly sequential and reciprocal interdependence when the output of one activity becomes the input for another activity and vice-versa. In Thompson's framework, pooled interdependence requires coordination by standardisation. Sequential interdependence implies coordination by plan and in pooled interdependence coordination through mutual adjustments is called for.

Thompson's framework invokes the classical trade-off between efficiency and flexibility. Efficiency requires coordination by standardisation and plans whereas flexibility is fuelled by coordination by mutual adjustments. The notion that there is a trade-off between efficiency and flexibility has long been advocated in the organisation theory and strategy literatures (Kurke, 1988; Ghemawat and del Sol, 1998). The manufacturing strategy argument as initially set out by Skinner (1969, 1974) and elaborated by his followers (Hayes and Wheelwright, 1984) has been that there is necessarily a trade-off between manufacturing objectives (e.g. cost, flexibility). The strategic decision, therefore, is to choose what the competitive emphasis is and then to design the operation accordingly. The trade-off view itself has been questioned and revised (Hayes and Pisano, 1994; Spring and Boaden, 1998; da Silveira and Slack, 2001).

Ferdows and de Meyer (1990) and Corbett and van Wassenhove (1993) go as far as suggesting that the traditional trade-offs in manufacturing have been eliminated and suggest that multidimensional improvements in operations can be pursued, if the right

sequence of capability building is adopted. Opposing views have to some extent been reconciled through the idea of "frontiers of performance" (Hayes and Pisano, 1996; Clark, 1996; Porter, 1996). This essentially points to confusion between trade-offs among alternative criteria on which to *improve* over current performance, and trade-offs between theoretically *optimised* performance among alternative criteria. In other words, it has been possible to improve many operations simultaneously on, say, cost and quality because so much of the potential of the operation had been unrealised. However, once various forms of waste had been eliminated from the operation, it would still be apparent that there were trade-offs between criteria due to limitations in, say, process technology or capacity e.g. it may be that in the limiting case a machine simply cannot make two different products simultaneously. Another aspect of the "frontier" concept is that as firms move from their current performance to the frontier, they will learn different things depending on the route they choose to take. Da Silveira and Slack (2001) research concluded that trade-offs were seen as focusing attention on areas of operations that could most benefit from improvements and where these trade-offs were identified, they could be tackled (but not totally eliminated) by developing the requisite resources and capabilities to improve performance along certain dimensions.

The notion of dynamic trade-offs introduces an evolutionary and learning perspective into the study of flexibility, which has hitherto been badly neglected. In a study of plant learning, Upton and Kim (1998) found that the strongest determinant of learning method selection is the way the operation has learned in the past. Once a plant has developed capabilities to improve using a particular method of learning, it tends to carry on along that particular path of improvement. Even in the case of plants with similar starting points, the local character of the learning routines quickly leads to divergent paths of improvement.

Upton and Kim (1998) explain these results invoking Nelson and Winter's (1982) notion of the firm as a hierarchy of routines. A hierarchy of routines defines the lower-order skills and how these are to be coordinated, as well as higher order procedures for invoking and amending what is to be done at lower levels (Nelson, 1991). In Nelson and Winter's approach, the prevailing organisational routines do not signal the edge of what is technically possible to achieve, but the rather the limits of what the organisation has learned (Winter, 2000). Zollo and Winter (2002) suggest that the notion of dynamic capability should be used as "...a learned and stable

pattern of collective activity through which the organisation systematically generates and modifies its operating routines in pursuit of improved effectiveness” (*op cit*, p. 340).

Adler et al’s (1999) study of NUMMI, an American subsidiary of Toyota, provides another insightful angle on the efficiency-flexibility trade-off and its dynamic evolution. They suggest that the trade-off can be shifted by four mechanisms: metaroutines, job enrichment, switching and partitioning. Metaroutines transform non-routine into more routine tasks and correspond to the search routines in Nelson and Winter (1982), devoted to making changes in existing routines and setting up new routines. Job enrichment refers to the addition of improvement to efficiency goals and is consistent with notions of experiential learning arising out of repeated execution of the same tasks. Switching allows people to attend to different types of tasks in sequence rather than simultaneously. And finally, partitioning allows different organisational subunits to specialise in routine and non-routine tasks.

Whereas these four generic mechanisms were initially identified as the intra-organisational level, the empirical results showed that NUMMI’s ambidexterity resulted from both intra-organisational processes and the nature of supplier relations. In particular, NUMMI adopted a strategy of upfront mutual adjustments in their relations with suppliers with the aim of minimising downstream changes; it reallocated tasks across the customer-supplier interface when tasks could be performed more knowledgeably by suppliers; and the costs of mutual adjustments were reduced through the use of a standard master schedule for every collaborative project (Adler et al 1999, p. 57).

The end result was an organisation with a remarkable capacity to continuously shift the efficiency/flexibility trade-off. Metaroutines increased efficiency at given levels of flexibility and provided a platform for opportunities to increase flexibility. Job enrichment, switching and partitioning increased the organisation capacity for flexibility at a given level of efficiency while creating capabilities for further increases in efficiency (Adler et al, 1999).

The NUMMI case demonstrates how responses to flexibility requirements have often multiple consequences, namely on the dynamic trade-off between flexibility and efficiency. Returning to Thompson’s (1967) distinction between different forms of interdependence and their implications for coordination, the NUMMI case highlights how different forms of coordination can be combined in mutually-reinforcing ways to

shift the trade-off between efficiency and flexibility upwards. Flexibility is rarely a discrete response to clearly defined stimuli and that the process of enlarging the range of programmed responses to flexibility demands have often unintended and beneficial consequences.

From an industrial networks angle, the key to flexibility lies in the articulation between resources and activities. Investment in and deployment of specific resources can improve the flexibility of an operation provided their insertion into specific activity structures allows for the versatile properties of that resource can be exploited – e.g. by allowing that resource to be connected to or shared across different activity structures. Flexible resources can be deployed in rigid ways and Upton (1995) goes as far as suggesting that computer systems, in particular, are often a quick fix that helps managers avoid the more difficult tasks of defining what type of flexibility they require and how they may go about achieving it.

From an industrial networks perspective, flexibility is a property of a system of connections involving activities and resources which can be continuously adjusted, through both programmed and improvised responses. Flexible resources realise their potential by their deployment in particular activity structures. Their flexible character is displayed by their ability to be connected to different activity structures either on a regular basis thus making activities more similar, or as occasional hedges against intermittent changes as in the example of Cummins engines reported in Venkatesan (1990).

The framework adopted by Dubois (1998) to analyse activity structures highlights how the impact of a flexible resource (e.g. an FMS machining centre) on a firm's activities is largely a function of how that resource can be connected to different activities thus making them more similar in Richardson's (1972) sense. Activities can be made more similar by moving them to actors who are best positioned to exploit their similarity through resource sharing or activities can be adjusted so that resource sharing can be improved. The ability to explore similarity in activities and to invest in flexible resources that can be shared amongst different activity structures depends on how activities can be connected both within and across firm boundaries. The potential for adjusting the connections between activities inside the firm depends on how these activities are in turn, positioned in relation to the activity structures of suppliers and customers as well as on the type of customer-supplier interfaces in place.

Firms can, for example, negotiate with their customers design changes that enhance their capacity utilisation of critical resources or enhance the degree of activity sharing of a certain resource. The nature of flexibility from an industrial networks perspective thus assumes a distributed and negotiated character.

The ability to adjust the connections amongst activities across firm boundaries depends on the type of resource interface between firms (Araujo et al, 1999). Resource interfaces are primarily concerned with the technical interdependencies that arise when the resource bases of two different actors are confronted through exchange activities. In some cases these interdependencies are handled by simple routines, as in the case of Thompson's (1967) coordination by plan and standardisation. In other cases, these interdependencies will require mutual investments and complex procedures to exploit how mutual adjustments can make the best combined use of the resource bases of both parties.

The most important distinction between different resource interfaces is to which extent the customer and the supplier are aware of each other's contexts. To become aware of others' contexts requires significant investments and the prospect of continuity of association. In this type of interface, investments in relationships become substantial. The development of joint resource combinations can only be achieved with reciprocal investments by customer and supplier, enabling each party to learn about each other's capabilities. Over time, the costs of maintaining an interactive interface can be assumed to decrease once the counterparts have gone through a learning curve on how to make best use of each other's capabilities. Again, The NUMMI case described by Adler et al (1999) illustrates how interactive interfaces allow suppliers to help NUMMI reduce and manage uncertainty.

In short, an industrial networks perspective on flexibility emphasises the connection between activity structures and the resources deployed in those activity structures. A firm based perspective is still crucial to understand flexibility but there is a need for an increased recognition of the role of firms are loosely coupled systems, where the link between different types of activity structures across different parts of the firm (e.g. different plants) may be weak. Loose coupling allows for rapid and inexpensive reconfiguration of links between different types of activity structures. The role of the firm as a site where managerial discretion and control is exercised should not be forgotten either. The definition of performance targets in terms of flexibility (e.g.

what type of flexibility should be emphasised), the design and administration of incentive schemes all play a role in delivering flexibility.

Nevertheless, an industrial networks approach highlights that flexibility is also a product of business relationships and how those relationships are mobilised to help the focal firm adjust its internal processes as well as export some of the adaptations required to maintain or increase flexibility. Often, the process of increasing flexibility, requires negotiations and mutual adaptations in resource interfaces across firm boundaries and these adaptations are facilitated when both sides build a common understanding on how best to make effective use of their combined resource base. Finally, the distributed and negotiated character of flexibility may require multiple and connected sets of adaptations connecting both customer and supplier interfaces. For example, one way to respond to customer demands for flexibility (e.g. in terms of increasing the range of outputs) is partly absorbed internally and partly transmitted to supplier or subcontractor interfaces

## **Conclusions**

This paper has discussed the notion of flexibility from an industrial networks perspective. Our starting point is that the notion of flexibility has to be understood against a background of stability. In this sense, flexibility can be regarded as a way to handle short-term variations in the organisation's environment without undue disruption to the continuity of organisational processes. We contrasted flexibility with agility and adaptability with adaptation. Adaptation is concerned with long-term, discontinuous and resource-expensive process whereas adaptability is associated with short-term, continuous and resource-inexpensive changes. In this paper, we have equated flexibility with adaptability and agility with adaptation and emphasised that the conditions that favour flexibility are often at odds with those that privilege agility. Our critique of the manufacturing flexibility has centred on the excessive attention paid to the flexibility as embodied in physical resources and on the notion that demands for flexibility are met with directed and univocal responses inside the firm. Instead, we have argued that flexibility should be best seen as a systemic property of connections between resources and activities, and that those connections should not be artificially delimited to the boundary of the firm. Firms should be seen as loosely coupled systems, with differential ability to absorb flexibility demands, and systems

which display flexibility in some dimensions may prove to be fairly rigid in other dimensions.

From an industrial networks perspective, the ability to regard demands for flexibility not as impositions of an external and faceless environment but as transmitted to the firm through relationships with specific counterparts opens up a new agenda for research. First, flexibility can be regarded as a negotiated rather than an imposed outcome. Secondly, the focus shifts from a directed response to flexibility demands to a processual and multifaceted approach on how flexibility is delivered. Lastly, the study of flexibility should also encompass the way flexibility requirements are defined and delivered as part of adjustments into patterns of connections between activities and resources carried out by multiple parties (e.g. suppliers, subcontractors, customers).

Our approach has also touched on whether flexibility is best seen as delivered by programmed or improvised responses. This is an area where further research could make useful inroads. Adler et al's (1999) study is virtually unique in its attempt to conceptualise the interaction between programmed and improvised responses through the notion of routines and meta-routines. The notion of flexibility as a the product of path-dependent learning, either through deliberate investments or as a by-product of other activities, is one that needs further exploration and holds much promise.

## References

- Adler, P. S. (1988). "Managing Flexible Automation." California Management Review **30**(3): 34-56.
- Adler, P. S., Goldoftas, B. and D. I. Levine, (1999). "Flexibility versus efficiency? A case study of model changeovers in the Toyota production system." Organization Science **10**(1): 43-68.
- Anderson, J. C., G. Cleveland and R. G. Schroeder, (1989). "Operations Strategy: A Literature Review." Journal of Operations Management **8**(2): 133-158.
- Araujo, L., Dubois, A. and L.-E. Gadde, (1999). "Managing interfaces with suppliers." Industrial Marketing Management **28**(5): 497-506.
- Axelsson, B. (1992). Corporate Strategy Models and Networks - Diverging Perspectives. Industrial Networks: a New View of Reality. Edited by B. Axelsson and G. Easton. London, Routledge: 184-204.
- Beach, R., Muhlemann, A. P., Price, D. H. R., Paterson, A. and J. A. Sharp, (2000). "A review of manufacturing flexibility." European Journal of Operational Research **122**(1): 41-57.
- Carlsson, B. (1989). "Flexibility and the Theory of the Firm." International Journal of Industrial Organization **7**(2): 179-203.
- Clark, K. B. (1996). "Competing through Manufacturing and the New Manufacturing Paradigm: Is Manufacturing Strategy Passé?" Production and Operations Management **5**(1): 42-58.
- Corbett, C. and L. Van Wassenhove (1993). "Competence and Competitiveness in Manufacturing Strategy." California Management Review **35**(4): 107-120.
- Da Silveira, G. and N. Slack (2001). "Exploring the Trade-Off Concept." International Journal of Operations & Production Management **21**(7): 949-964.
- De Toni, A. and S. Tonchia (1998). "Manufacturing flexibility: a literature review." International Journal of Production Research **36**(6): 1587-1617.
- Dubois, A. (1998). Organizing Activities Across Firm Boundaries. London, Routledge.
- Duguay, C. R., S. Landry and F. Pasin, (1997). "From Mass Production to Flexible/Agile Production." International Journal of Operations & Production Management **17**(12): 1183-1196.
- D'Souza, D. E. and F. P. Williams (2000). "Toward a Taxonomy of Manufacturing Flexibility Dimensions." Journal of Operations Management **18**: 577-593.
- Easton, G. and R. Rothschild (1987). The Influence of Product and Production Flexibility on Marketing Strategy. The Management of Strategic Change. A. Pettigrew, Basil Blackwell: 300-326.
- Easton, G. and L. Araujo (1997). Inter-Firm Responses to Heterogeneity of Demand over Time. The Formation of Interorganizational Networks. M. Ebers. Oxford, Oxford University Press: 66-94.
- Ferdows, K. and A. De Meyer (1990). "Lasting Improvements in Manufacturing Performance: In Search of a New Theory." Journal of Operations Management **9**(2): 168-184.
- Ghemawat, P. and P. del Sol (1998). "Commitment versus flexibility?" California Management Review **40**(4): 26 (18 pages).

- Gerwin, D. (1993). "Manufacturing Flexibility - a Strategic Perspective." Management Science **39**(4): 395-410.
- Gunasekaran, A. (1999). "Agile manufacturing: A framework for research and development." International Journal of Production Economics **62**(1/2): 87-105.
- Harrison, B. (1994). Lean and Mean: The Changing Landscape of Corporate Power in the Age of Flexibility. New York, Basic Books.
- Hayes, R. H. and G. P. Pisano (1994). "Beyond World-Class - the New Manufacturing Strategy." Harvard Business Review **72**(1): 77-86.
- Hayes, R. H. and G. P. Pisano (1996). "Manufacturing Strategy: at the Intersection of Two Paradigm Shifts." Production and Operations Management **5**(1): 77-86.
- Hayes, R. H. and S. C. Wheelwright (1984). Restoring Our Competitive Edge: Competing through Manufacturing. New York, John Wiley.
- Håkansson, H. and I. Snehota (1989). "No Business is an Island: The Network Concept of Business Strategy." Scandinavian Journal of Management **4**(3): 187-200.
- Håkansson, H. and I. Snehota, Eds. (1995). Developing Relationships in Business Networks. London, Routledge.
- Jaikumar, R. (1986). "Postindustrial Manufacturing." Harvard Business Review **64**(6): 69-76.
- Knight, F. H. (1921). Risk, Uncertainty and Profit. New York, A. M. Kelley.
- Koste, L. L. and M. K. Malhotra (1999). "A Theoretical Framework for Analysing the Dimensions of Manufacturing Flexibility." Journal of Operations Management **18**: 75-93.
- Kurke, L. B. (1988). Does Adaptation preclude Adaptability? Strategy and Performance. Institutional Patterns and Organizations: Culture and Environments. Edited by L. G. Zucker. Cambridge, MA, Ballinger: 199-222.
- Lawrence, P. R. and J. W. Lorsch, (1967), Organization and Environment: Managing Differentiation and Integration, Cambridge, MA, Harvard University Press.
- Loasby, B. J. (1999). Knowledge, Institutions and Evolution in Economics. London, Routledge.
- Mills, J., K. Platts and M. Gregory, (1995). "A Framework for the Design of Manufacturing Strategy Processes: A Contingency Approach." International Journal of Operations & Production Management **15**(4): 17-49.
- Narasimhan, R. and A. Das (2000). "An Empirical Examination of Sourcing's Role in Developing Manufacturing Flexibilities." International Journal of Production Research **38**(4): 875-893.
- Nelson, R. R. and S. G. Winter (1982). An Evolutionary Theory of Economic Change. Cambridge, MA, Belknap Press.
- Paggel, M. and D. R. Krause (1999). "A Multiple Method of Environmental Uncertainty and Manufacturing Flexibility." Journal of Operations Management **17**: 307-325.
- Parker, R. P. and A. Wirth (1999). "Manufacturing flexibility: Measures and relationships." European Journal of Operational Research **118**(3): 429-449.
- Penrose, E. (1959). The Theory of the Growth of the Firm. Oxford, Basil Blackwell.
- Pfeffer, J. (1987). Bringing the Environment Back in: the Social Context of Business Strategy. The Competitive Challenge: Strategies for Industrial Innovation and Renewal. Edited by D. J. Teece. Cambridge, Mass., Balinger.
- Porter, M. E. (1996). "What is Strategy?" Harvard Business Review **74**(6): 61-78.

- Potts, J. (2001). "Knowledge and markets." Journal of Evolutionary Economics **11**(4): 413-431.
- Richardson, G. B. (1972). "The Organisation of Industry." The Economic Journal **82**(September): 883-896.
- Richardson, G. B. (1998). Some Principles of Economic Organization. Economic Organization, Capabilities and Co-ordination. Essays in Honour of G. B. Richardson. Edited by N. J. Foss and B. J. Loasby. London, Routledge. **8**: 44-62.
- Sabel, C. F. and J. Zeitlin (1997). Stories, Strategies, Structures: Rethinking Historical Alternatives to Mass Production. World of Possibilities. Flexibility and Mass Production in Western Industrialisation. Edited by C. F. Sabel and J. Zeitlin. Cambridge, Cambridge University Press: 1-33.
- Sanchez, R. (1997). "Preparing for an Uncertain Future. Managing Organizations for Strategic Flexibility." International Studies of Management & Organization **27**(2): 71-94.
- Skinner, W. (1969). "Manufacturing - Missing Link in Corporate Strategy." Harvard Business Review (May / June): 136-145.
- Skinner, W. (1974). "The Focused Factory." Harvard Business Review (May / June): 112-212.
- Slack, N. (1983). "Flexibility as a Manufacturing Objective." International Journal of Operations & Production Management **3**(3): 4-13.
- Slack, N. and H. Corrêa (1992). "The Flexibilities of Push and Pull." International Journal of Operations & Production Management **12**(4): 82-92.
- Spring, M. (1996) "Manufacturing Strategy, Product Customisation and the Marketing / Manufacturing Interface, Unpublished PhD thesis, University of Stirling.
- Spring, M. and R. Boaden (1998). "'One More Time: How Do You Win Orders?'" A Critical Reappraisal of the Hill Manufacturing Strategy Framework." International Journal of Operations and Production Management **17**(18): 757-779.
- Spring, M. and J. F. Dalrymple (2000). "Product customisation and manufacturing strategy." International Journal of Operations & Production Management **20**(3-4): 441-467.
- Suarez, F. F., M. A. Cusumano and C. H. Fine, (1996). "Empirical-Study Of Manufacturing Flexibility In Printed-Circuit Board Assembly." Operations Research **44**(1): 223-240.
- Thompson, J. D. (1967). Organizations in Action. New York, McGraw-Hill.
- Upton, D. M. (1994). "The Management of Manufacturing Flexibility." California Management Review **36**(2): 72-89.
- Upton, D. M. (1995). "Flexibility as Process Mobility: The Management of Plant Capabilities for Quick Response Manufacturing." Journal of Operations Management **12**: 205-224.
- Upton, D. M. and B. Kim (1998). "Alternative Methods of Learning and Process Improvement in Manufacturing." Journal of Operations Management **16**: 1-20.
- Venkatesan, R. (1990). "Cummins Engine Flexes its Factory." Harvard Business Review **68**(2): 120-127.
- Weick, K. E. (1982). Management of Organizational Change Among Loosely Coupled Elements. Change in Organizations. New Perspectives on Theory, Research and Practice. Edited by P. S. Goodman. San Francisco, CA, Jossey Bass: 375-408.
- Wild, R. (1980). Operations Management. A Policy Framework. Oxford, Pergamon.

Winter, S. G. (2000). Organizing for Continuous Improvement: Evolutionary Theory Meets the Quality Revolution. The Quality Movement and Organization Theory. Edited by R. E. Cole and W. R. Scott. Thousand Oaks, CA., Sage: 49-66.

Zollo, M. and S. G. Winter (2002). "Deliberate learning and the evolution of dynamic capabilities." Organization Science **13**(3): 339-351.