UPDATE

# Manufacturing process flexibility revisited

Roger W. Schmenner and Mohan V. Tatikonda
*Kelley School of Business, Indiana University, Indianapolis, Indiana, USA*

## Abstract

**Purpose** – To provide an update on a paper published in 1987 in *IJOPM*.

**Design/methodology/approach** – Provides an assessment and update of "An agenda for research on the flexibility of manufacturing processes".

**Findings** – Gerwin's seminal work added welcome rigor to a concept, manufacturing flexibility, which had gained prominence during the previous decade. Finds that many of Gerwin's insights have stood the test of time. A number of things have changed since that time, but others have remained much as they were. Machines have become more capable and computer-based controls have improved machine and process flexibility, but the character of that flexibility has remained very much the same.

**Originality/value** – Revisits Gerwin's conceptualization of manufacturing process flexibility and subsequent progress in understanding it.

**Keywords** Manufacturing industries, Operations and production management

**Paper type** General review

## The definition and domain of "Manufacturing Flexibility"

Gerwin's (1987) seminal work added welcome rigor to a concept, manufacturing flexibility, which had gained prominence during the previous decade. The computer age was upon us showing great promise with new software (e.g. CAD, CAM), enhanced machine tools (e.g. CNC, robots, FMS), and expanded manufacturing information systems (e.g. MRP, MRP II). Gerwin (p. 48) aimed to set us on a path to "the study of manufacturing flexibility on a more scientific basis." His work succeeded notably in that regard, firmly placing "flexibility" into the set of operations choices and initiating significant scholarly research. He helped us define flexibility, categorize and measure flexibility and its performance, and link different types of flexibility to both operational uncertainties and process design.

He defined flexibility as " … the ability to respond effectively to changing circumstances" (p. 39), explaining that "one manufacturing process is more flexible than another … if it can handle a wider range of possibilities" (p. 41). He noted the less time and cost required to implement an alternative, the greater the flexibility. In all, flexibility incorporates the range, achievability and effectiveness (performance and value) of the alternatives.

Gerwin believed that the need for flexibility is grounded in the need to cope with uncertainty in the manufacturing environment. Different kinds of uncertainty directly

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drive the needs for different kinds of flexibility (Table I). Moreover, Gerwin led the way in specifying which aspects of flexibility might not be trade-offs with quality, presaging the whole "cumulative capabilities" debate (Ferdows and DeMeyer, 1990). And, he rightly saw that automation might not always lead to increased flexibility, providing an early caution against super-machines and factory "monuments." He suggested that research continue comparing Japanese and Western factories so that we could understand more about "the 'flexible' factory which attempts to adapt to uncertainty versus the 'proactive' factory which attempts to control it" (p. 48). Such research has continued, and our scholarly understanding of flexibility has grown since the mid-1980s when Gerwin's paper was published.

A number of things have changed since that time, but others have remained much as they were. For example, the kinds of workforce and equipment characteristics that support each type of flexibility are much the same today as when Gerwin outlined them. Workforce multi-skilling and equipment capabilities have advanced over the years, but their advances have been more matters of degree than of kind. Gerwin also cited five "levels" at which flexibility can be considered. He mentioned individual machines, the manufacturing function (e.g. forming, assembly), the process for a product or product line, the factory, and the company's factory system. Indeed, manufacturing flexibility at each of these levels remains much as it was. Machines have certainly become more capable and computer-based controls have improved machine and process flexibility, but the character of that flexibility has remained very much the same.

## Extending Gerwin's domain

Other things have changed, however. Today we need to extend Gerwin's "levels" to include the company's entire supply chain. For many companies today, manufacturing means managing the supply chain, and any contract manufacturing and outsourcing within it, as much as it means managing one's own factory. While the notion of a supply chain has long been well known, the importance of supply chains and their

| Nature of uncertainty | Flexibility type | Ability of a process to ... |
|---|---|---|
| Demand for the kinds of products offered | Mix | "produce a number of different products at the same point in time" |
| Length of product life cycles | Changeover | "deal with additions to and subtractions from the mix over time" |
| Appropriate product characteristics | Modification | "make functional changes in the product" |
| Machine downtime | Rerouting | " [change] the operating sequence through which the parts flow" |
| Amount of aggregate product demand | Volume | "[easily make] changes in the aggregate amount of production" |
| Meeting raw material standards | Material | "handle uncontrollable variations in composition and dimensions of parts" |
| Timing of arrival of inputs | Sequencing | "reorganize the order in which different kinds of parts are [processed]" |

**Note:** *Columns 1 and 2 from Gerwin's Table I (p. 40). Column 3 derived from Gerwin's text (pp. 39-40)

**Table I.**
The domain of manufacturing flexibility*

management has risen significantly in the past 20 years. We now routinely speak of the flexibility of the supply chain (Prater *et al.*, 2001), something that typically was not mentioned then. Such supply chain flexibility can deal effectively with several of the uncertainties that Gerwin identified. In particular, an effective supply chain reduces the uncertainty of materials standards (e.g. conformance quality and functionality), and thus the need for material flexibility, as well as reducing the uncertainty of delivery times, and thus the need for sequencing flexibility. Moreover, supply chain flexibility can aid changeover flexibility. Increased contract manufacturing and outsourcing have limited the exposure of selected manufacturers to the vicissitudes of the market and have helped foster product experimentation. Faster new product ramp-ups and shorter new product development life cycles have resulted, allowing in turn planned, purposeful obsolescence. An effective supply chain reduces a firm's risk and increases its nimbleness (Simchi-Levi *et al.*, 2004).

Time-based competition (Stalk and Hout, 1990) and lean manufacturing (Womack *et al.*, 1991) are other critical developments that have flowered since the time Gerwin wrote. Reduced throughput time, for example, makes forecasting easier and this attenuates the need for both mix flexibility and volume flexibility. More attention to preventive maintenance has reduced the need for rerouting flexibility. Factories today are as flexible as they have ever been, but the advent of different thinking about manufacturing and how the manufacturing firm competes has reduced many of the uncertainties that underscored the need for the flexibilities Gerwin identified so well. Further, the new thinking has increased firms' abilities to achieve desirable forms of flexibility, including wide product variety (modification flexibility), location of production (volume flexibility), and rapid introduction of new products (changeover flexibility).

## The "Flexible" vs "Proactive" factory

Let us return to Gerwin's (p. 48) contrasting of the "flexible" factory (which quickly adapts to realized uncertainty) versus the "proactive" one (which controls uncertainty through advance planning). The study of Japanese manufacturing has caused us to question whether trade-offs (e.g. cost vs quality) we thought were axiomatic actually exist. We have learned that improved quality can actually lower costs (Hardie, 1998). In like fashion, the continued study of the Japanese "flexible" factory and the Western "proactive" factory have led us to question whether being flexible and being proactive are really in conflict.

Today, a factory is "flexible" in part because it is "proactive." For example, the proactive factory's advances in removing waste, incorporating new technologies, and moving information to where it can be used best (e.g. via ERP systems) have certainly diminished the time and cost of being flexible, and this, per Gerwin, enhances the degree of flexibility in the process. What is more, some supply chain flexibility arises due to "proactive" factory management. The proactive, wide-scale sharing of information throughout the supply chain contributes mightily to making a supply chain flexible by controlling the bullwhip effect and other supply dysfunctions, and reducing the time and cost to respond to emerging supply challenges. This complementarity between being proactive and being flexible is captured as well in the notion of "rigid flexibility" (Collins and Schmenner, 1993) where the ability to be flexible (e.g. mix flexibility) demands simplicity and discipline (rigidity) in order to make it happen (e.g. re-layout of work areas, less wasted motion and effort, re-engineering jigs and fixtures, following prescribed methods exactly, actual practice with the equipment and materials).

### Product design for flexibility

Of increasingly greater significance over the past 20 years has been the emphasis on the firm's new product development process in order to design easy to manufacture products of great variety quickly. The result is both a product design and a development process that greatly support manufacturing flexibility.

Today, product architectures and modularity create product platforms and product family streams of wide variety in short periods of time. Terms such as "modular products" (Ulrich, 1995), "platform vs derivative products" (Tatikonda, 1999), and "mass customization" (Duray, 2002) have entered our lexicon. Design of the product architecture is key to support current and future product options (Sanderson and Uzumeri, 1997). Appropriate product design has led to assembly lines that can handle multiple products and in nearly random order; fabrication cells that match the pace and mix of such assembly lines; and modular factories. Such appropriate product design reduces uncertainty in many ways. The product variety aspects show in greater mix flexibility, changeover flexibility and modification flexibility, while easier manufacture shows in rerouting flexibility, volume flexibility, material flexibility and sequencing flexibility.

Quicker product development cycles have also helped to reduce uncertainty. Today, we talk more about the voice of the customer with some confidence that the design and manufacture of the product can answer that voice swiftly and satisfactorily. Such was much less the case 20 years ago. Prototyping can be accomplished quickly and its resulting information can be incorporated into the product in time to reduce the risk of product obsolescence. Rapid and malleable development processes arise through use of: Concurrent engineering and other multi-functional organizational approaches (Tatikonda and Montoya-Weiss, 2001); short iteration prototyping sequences (Thomke, 2003); "open innovation" (von Hippel, 2005), which brings to development what outsourcing does to manufacturing; and "flexibility within a structure" (Tatikonda and Rosenthal, 2000), where structured organizational processes purposefully incorporate select flexibility mechanisms so as to guide rapid and responsive development (analogous to "rigid flexibility"). Faster development cycles aid all of Gerwin's flexibility types, but particularly mix flexibility, changeover flexibility, modification flexibility and volume flexibility.

### The flexibility framework

Figure 1 shows graphically what Gerwin discussed and extensions we propose. Uncertainty types [A] are Gerwin's archetypal uncertainties faced by managers, derived from both internal and external factors. They are the impetus for a manufacturing organization to possess various flexibility types [B]. Flexibility mechanisms [C] comprise the tools, management practices and systems that can be used to achieve given flexibility types (e.g. FMS, ERP, design-for-manufacture principles, multi-skilled workers, holding inventory). Different flexibility mechanisms have different abilities to achieve particular flexibility types.

Gerwin argued persuasively that flexibility measurement [D] is necessary to characterize and evaluate the uncertainty types, flexibility types and flexibility

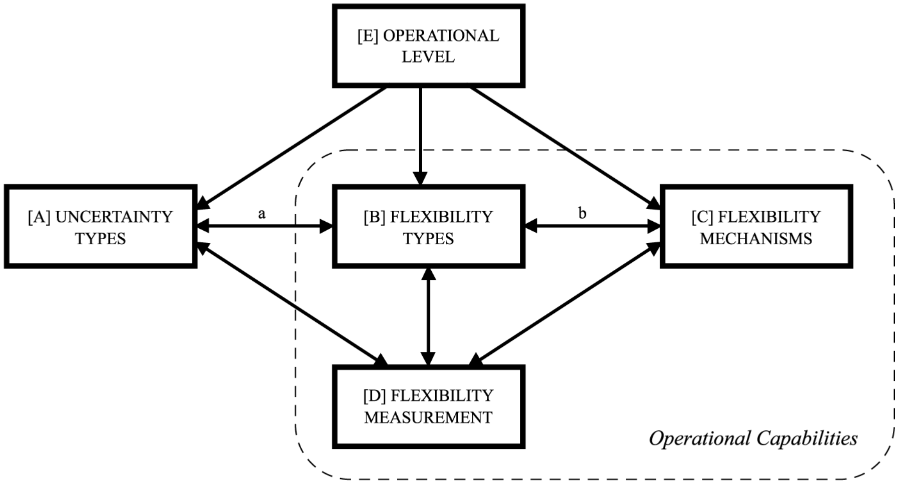


**Figure 1.**
Flexibility framework

mechanisms. Without measurement, management is hard-pressed to effectively assess flexibility-related choices, costs, achievability, performance benefits and trade-offs. Flexibility types [B], flexibility mechanisms [C] and flexibility measurement [D] collectively form a firm's operational capabilities with regard to flexibility. These operational capabilities may differ markedly at different operational levels [E], ranging from the individual machine to the entire supply chain. Different operational levels [E] also represent different process contexts. The framework generalizes beyond Gerwin's manufacturing processes to all types of operations processes, including service, electronic, information transactions, new product development and other business processes.

The structure of this framework, although not explicitly recognized by Gerwin, follows his contributions. However, today's proactive nature of operations strategy allows a perspective on these relationships in reverse from that originally advanced by Gerwin. Note that arrows a and b in the framework are bilateral, rather than rightward facing. A firm need not simply put in place operational capabilities (flexibility types, mechanisms and measurement) to cope with internally or externally induced uncertainty types. Instead, a firm can act upon its operational capabilities to compete in a marketplace with given uncertainty types. The impetus for flexibility is not simply reactive but proactive, deriving from a desire to mould the choice of competitive arena. Indeed, the uncertainty types need not have a negative connotation because they can be opportunities and competitive differentiators for the firm. Consistent with the resource-based view of the firm (Mills *et al.*, 2003), the flexibility-related operational capabilities are explicit resources and competencies of the firm, and firms should consider these operational capabilities in their strategy process.

## Conclusions

We have revisited Gerwin's conceptualization of manufacturing process flexibility and subsequent progress in understanding it[1]. Many of Gerwin's insights have stood the test of time, as witnessed by our flexibility framework (Figure 1). Nevertheless, manufacturing flexibility has a bigger meaning now than it did 20 years ago. It has spread throughout the supply chain and into product development. And, it now encompasses the complementarity of "flexible" and "proactive" factories. Still, a debate rages currently on nuances of the word "flexibility," introducing agility, adaptiveness, responsiveness and other terms. This debate merits the care and insight Donald Gerwin brought us 20 years ago.

## Note

1. Space did not allow evaluation of the evolution of research methodology for inquiry on manufacturing flexibility or in-depth literature review of the flexibility framework constructs. See Slack (1987), Sethi and Sethi (1990), Dixon (1992), Gerwin (1993), Upton (1995), Koste and Malhotra (1999), Beach *et al.* (2000), Vokurka and O'Leary-Kelly (2000), Jack and Raturi (2002), Anand and Ward (2004) and Judi *et al.* (2004).

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