An Empirical Analysis of the Product-Process Matrix

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Process choice, a major part of operations strategy, is a key decision that links operations to business strategy. Hayes and Wheelwright, among others, argue that the emphasis given to product customization and other competitive priorities should agree with process choice. Our empirical study investigates whether firms actually link their process choice to product customization and other competitive priorities as hypothesized, and whether compatible decision patterns lead to better performance. Analysis of data collected from managers at 144 U.S. manufacturing plants shows a strong correlation between process choice, product customization, and competitive priorities. Process choice is highly related with the degree of product customization, and also with the emphasis placed on the quality and cost competitive priorities. Job shops and batch shops tend to have more product customization, higher costs, and higher quality. Some continuous flow shops use part commonality and flexible automation to achieve more customization than would otherwise be expected. Without these initiatives, customization in continuous flow shops results in weak performance.
(*Operations Management; Process Choice; Operations Strategy; Manufacturing Strategy*)

1. Introduction

The association between operation strategy and business strategy has received increasing attention in the field of operations management (see Skinner 1969; Hayes and Wheelwright 1979a, 1979b; Wheelwright 1984; Hill 1989; and Miller and Roth 1994, among others). A pivotal decision for the operations function is "process choice." This decision determines whether the production system is organized by grouping resources around the process or around the product. At one extreme, a "process-focused" process is characterized by job shops producing low-volume, customized products. These shops set aside a single area for each process (such as drilling or welding), and various products move from one process to another. Similar types of machines and workers are grouped together to handle all products requiring a certain function. By organizing equipment and work force around the process, resources often can be better utilized. At the other extreme, a "product-focused" process is characterized by continuous flow shops producing high-volume, highly standardized products. Here the equipment and work force are organized around the product. This approach often allows more simplified and efficient work flows, but duplicates operations which can be a disadvantage if volumes are not high enough. Multiple process choices are possible, even within the same plant, to achieve the desired focus (see Berry et al. 1991). Other terms used for process choice include "production technology" by Woodward (1965), "production process stage" by Abernathy (1976), "process structure dimension" by Hayes and Wheelwright (1979a), "process life

0025-1909/96/4211/1576$01.25

cycle stage" by Fine and Hax (1985), "process positioning" by Hill (1989), and "process technology" by Ward et al. (1992).

While there is no consensus on terminology, there is general agreement that process choice is a key decision that links operations to business strategy. Hayes and Wheelwright (1979a, 1979b) suggest, in their landmark articles on the product-process matrix, that product plans and process choice should be linked together. Product plans determine the degree of product customization and volume that process choice should accommodate. For example, extensive product customization is said to favor a job shop. Equally important in choosing a process choice are the other competitive priorities that a firm plans to emphasize. Two firms with a similar degree of product customization may make different process choices depending on the relative emphasis placed on flexibility, cost, quality, or other competitive priorities. But there are reasonable process choices corresponding to the degrees of customization; and, alternatively, there are reasonable degrees of customization corresponding to each process choice. For example, job shop and "standardized product in large volumes" are not considered to be compatible decisions.

Such postulated associations of process choice with product plans and competitive priorities are based on deductive reasoning and case analyses. No systematic empirical analysis has tested these relationships. There is a growing recognition, however, that deductive-based propositions and theories should be verified through inductive analyses (Adam and Swamidass 1989, Amoako-Gyampah and Meredith 1989, Flynn et al. 1990, and Swamidass 1991). Empirical analyses, in particular, are needed to better understand interaction of variables in the production system so that we can piece together various parts of an evolving field into an organized whole (Swamidass 1991). In that spirit, this paper reports on an empirical investigation of three propositions concerning the relationships between process choice, product plans, competitive priorities, and manufacturing performance. The propositions relate to the descriptive and normative implications of the product-process matrix in its static form and focus on three questions about manufacturing firms: 1) Does the process choice correspond to product plans? 2) Does the process choice correspond to the selected competitive priorities? 3) Do firms operating on or close to the diagonal of the product-process matrix outperform those with extreme off-diagonal positions? The first two questions are descriptive, testing whether firms do make process choices as predicted by the product-process matrix. The third question is normative, testing whether firms with specific product plans *should* make a specific process choice to improve their performance.

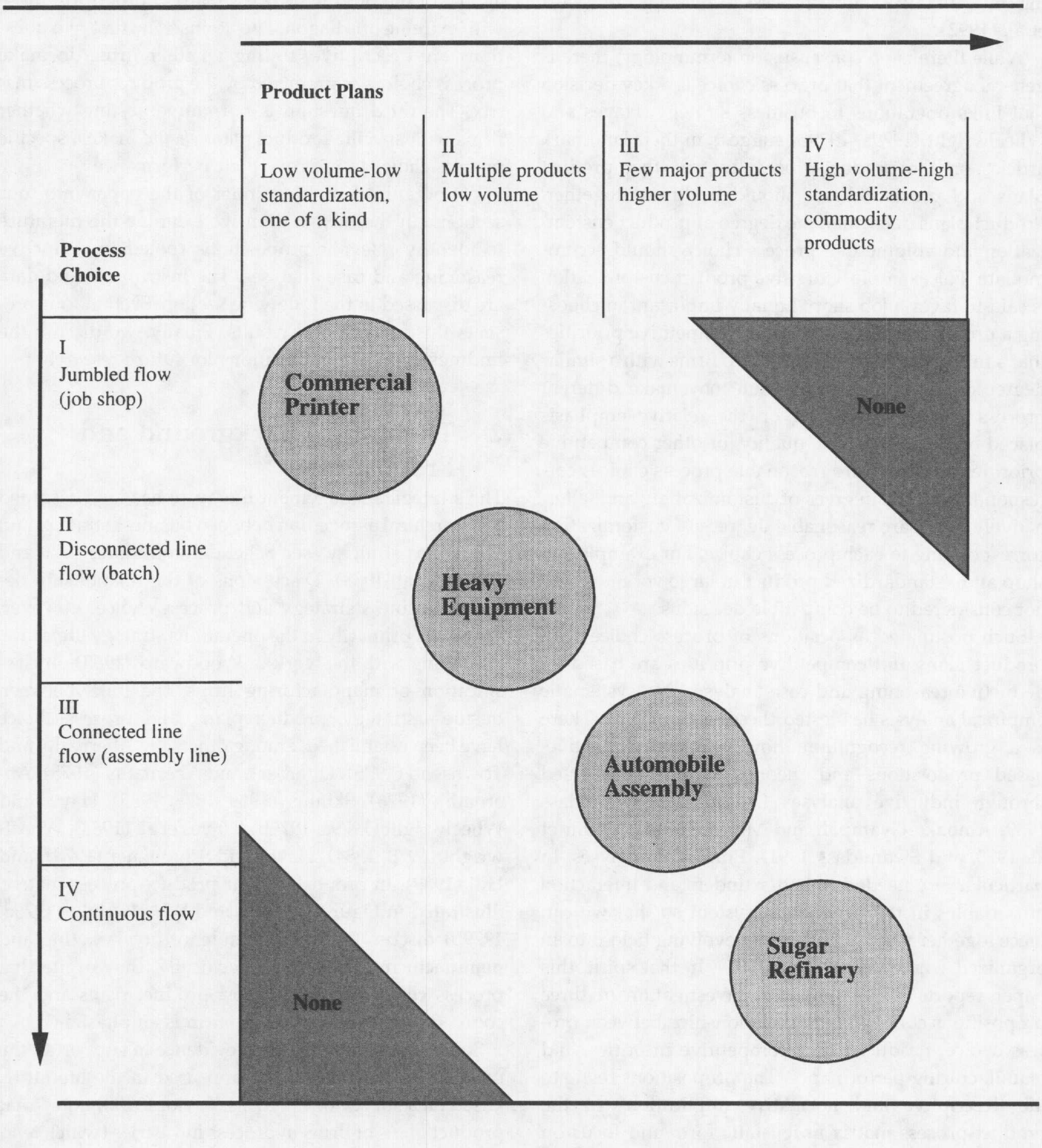
We organized the remainder of the paper into four sections. In the next section we examine the literature to identify relevant propositions rooted in deductive reasoning and case analyses. The instrument and data are discussed in the following section. Section four presents the analysis and results. Finally, we discuss the findings and their implications for future research.

2. Theoretical Background and Propositions

The strategic management literature has long assumed a hierarchical association between business strategy and operations strategy (see Schendel and Hofer 1979 and Quinn et al. 1988). Discussions of the relationship between business strategy and process choice, however, are found primarily in the operations strategy literature. Beginning with the work of Woodward (1965) on classification of manufacturing firms, the links between business strategy, product plans, and process choice have been established, among others, by Abernathy and Townsend (1975), Utterback and Abernathy (1975), Abernathy (1976), Skinner (1969, 1978, 1985), Hayes and Wheelwright (1979a, 1979b), Hayes et al. (1988), Wheelwright (1978, 1984), Hayes and Schmenner (1978), and Hill (1989). In proposing their product-process matrix, illustrated in Figure 1, Hayes and Wheelwright (1979a, 1979b) discuss the interdependence of marketing and manufacturing decisions. Specifically, they argue that process choice should support product plans and the competitive priorities that the firm is emphasizing.

Some *exploratory* empirical evidence in support of the product-process matrix has appeared in the literature. Based on a survey of 150 firms, Taylor (1980) noted that product plans of firms in process industries (which tend to use a continuous flow shop) agree with the descriptive implications of the matrix. Richardson et al. (1985), in their investigation of Canadian electronics firms,

Figure 1 **Hayes-Wheelwright Product-Process Matrix**



Source: After R.H. Hayes and S.C. Wheelwright, "Link Manufacturing Process and Product Life Cycles," *Harvard Business Review*, January-February 1979, 133-140

Table 1 Demand Characteristics, Principal Competitive Priorities, and Attributes of the Two Extreme Process Choices

	Job Shop	Continuous Flow Shop
Demand Characteristics	Uncertain	Certain
	Heterogeneous	Homogeneous
	High variance, low volume	Low variance, high volume
	Frequent design changes	Slow design changes
	Shorter life cycles	Longer life cycles
Principal Competitive Priorities	Customization	Efficiency
	High performance design	Consistent quality
		Low unit cost
		Timely delivery
Process Type Attributes	Flexible	Rigid
	General Purpose Equipment	Special Purpose Equipment
	Low fixed cost	High fixed cost
	High variable cost	Low variable cost
	Low change-over cost	High change-over cost
	Low degrees of automation	High degrees of automation

found that a concise and focused definition of manufacturing task was positively related to performance. In an exploratory study of executives in six industries, Marucheck et al. (1990) support the view that operations strategy is formulated under the umbrella of corporate strategy and that it reacts to marketing strategy. Ward et al. (1992) investigated the predominant process choices in manufacturing industries. They found that "typical producers" in each industry have diagonal positions on the product-process matrix.

While case studies and deductive arguments have emphasized the virtues of aligning manufacturing operations with business strategy, researchers have only recently begun to support these arguments with more extensive empirical analyses. St. John and Young (1992) have explored patterns of priorities and trade-offs among operations managers. Vickery et al. (1993), Vickery (1991), and Cleveland et al. (1989) have reported relationships between production competence, production capabilities, business strategy and performance. Miller and Roth (1994) have developed and analyzed a numerical taxonomy of manufacturing strategies. After identifying three clusters, they found significant differences between clusters in regard to competitive priorities, business strategy, manufacturing strategic choices, and manufacturing performance. Although the three clusters did not directly correspond to the process choice groupings of Hayes and Wheelwright, Miller and Roth found some evidence to support the characteristics of the product-process matrix. Our study is different in that we, first, directly examine whether a plant's process choice agrees with the emphasis placed on product customization. Then we investigate whether process choice supports the plant's other competitive priorities. Next, we assess the impact of such relationships on performance. Finally, we analyze off-diagonal plants in terms of other explanatory variables such as flexible automation and part commonality.

2.1. Process Choice Linked to Product Plans

Aside from the results of exploratory studies and those of Miller and Roth (1994), the descriptive and normative conclusions of the product-process matrix are yet to be systematically tested. Additionally, we need to know whether or not operating according to the prescriptions of the matrix results in superior performance. Indeed, the real test of operations strategy is its effect on performance (Adam and Swamidass 1989).

The product-process matrix divides process choices into four categories: job shop, batch, line flow, and continuous flow. Product plans, represented on the other axis, also have four categories ranging from low volume-low standardization to high volume-high standardization. These demand characteristics are the primary factors in making a process choice. Table 1 lists the extreme demand characteristics, their required competitive priorities, and the corresponding attributes of the two extreme process choices.

At one extreme, a manufacturing firm may decide to compete in a market characterized by uncertain demand for many low-volume product variants. At the other extreme, a firm may decide to compete in a market characterized by high-volume demand for a standardized product. Job shops and continuous flow shops have historically catered to the needs of these two extremes, respectively. A metal-working plant which produces metal parts for a host of companies is an example of a job shop. A beer manufacturing plant is an example of a continuous flow shop. When demand characteristics fall between these extremes, the process choice takes the form of a batch shop or a line flow shop. Plants producing clothing and automobiles represent batch and line flow shops, respectively.

Table 1 shows that customization and high-performance design are the principal competitive priorities for job shops. At the other extreme, high efficiency and consistent quality are the principal competitive priorities for continuous flow shops. The principal competitive priorities heavily influence the choice of production technology and the modus operandi of manufacturing plants. To accommodate the uncertainty in customers' requirements, job shops must choose a process that achieves flexibility at reasonable cost, and therefore use general-purpose machines and a multi-skilled work force. It would be too costly for a rigid, though more efficient, production process to switch over from one product variant to the next. To achieve low unit cost and consistent quality, continuous flow shops deploy highly automated, special-purpose equipment. The commodity nature of products and their high volumes justify investment in capital intensive technologies.

For product plans which fall between the extremes of standardized and customized products, competitive priorities vary based on the number of different products, their volumes, and the distinctive competencies of the firms competing in these markets. Generally speaking, however, as product plans move away from customization toward standardization, there seems to be less emphasis on flexibility and high-performance design quality and more emphasis on consistent quality and cost. How a manufacturing plant can most economically satisfy its competitive priorities determines its process choice.

The economics of production processes, in general, favor positions along the diagonal of the product-process matrix. Some firms, however, may decide to be different from their competitors by placing differing degrees of emphasis on one or more competitive priorities. For example, to place more emphasis on customization, a plant expected to operate as a batch shop may occupy a position above the diagonal to have more flexibility. Conversely, to compete on lower unit costs, it may occupy a position below the diagonal to achieve efficiency and consistent quality. Thus, firms operating in the near vicinity, but not exactly on the diagonal, can be niche players. Or these firms might be in the process of changing their diagonal position, but have only completed half of their move. They have either changed their product plans to be followed by a change in process choice or vice versa. As Hayes and Wheelwright (1979a) have noted, firms rarely change their product plans and process choices concurrently.

Although effective positions may be occupied in the vicinity of the diagonal, positions farther away from the diagonal are difficult to justify. Nevertheless, one may find plants that occupy positions far away from the diagonal. For example, companies which leave the operations function out of strategic planning process over time can find themselves in such mismatched positions. In other occasions it might be that business and operations strategy were compatible at earlier times, but gradual changes in products did not trigger concomitant adjustments to the process choice. For example, when product life cycle moves quickly toward standardization, the manufacturing process may not be able to move quickly toward a line flow process (Hayes and Wheelwright 1979a). There may also be occasions when a firm precociously anticipates standardization of the product and builds a line flow process but ends up using it for producing low volume-customized units.

While these reasons point to a temporary or ineffective occupation of positions far off the diagonal, advances in technology and methods of production are changing the economics of production. As a result, some manufacturing firms may deliberately choose more extreme off-diagonal positions. Specifically, the growing interest in modular designs, part commonality, group technology and flexible automation can make these positions profitable. These techniques may allow plants to achieve customized products in mass volumes or multiple standardized products in low volumes.

Leaving out this last scenario, we test the theory that positions either on or near the diagonal support the expected association between product plans and process choices. As such, we consider cells to the immediate right or left of the main diagonal to be "on-diagonal." Because manufacturing firms often operate multiple plants with different foci, and because their product plans vary across product lines (see Berry et al. 1991), testing the descriptive and normative implications of the product-process matrix with data aggregated across multiple plants for each firm in the sample can be misleading. In other words, it is at the plant level and with regard to the primary product line that one should expect a direct association between the four process choices and product plans. Other authors have also recognized the importance of conducting manufacturing research at the plant level (Flynn et al. 1990). We expect to find statistically significant support for the following proposition:

PROPOSITION 1. *Process choice of manufacturing firms with regard to the primary product line produced in a particular plant falls on or closely to the right or left of the diagonal.*

2.2. Process Choice Linked to Competitive Priorities

According to the strategic management literature, a firm may seek competitive advantage through generic strategies of cost leadership, differentiation, or focus (Porter 1980). The operations function translates these advantages into at least four generic groupings of competitive priorities: flexibility, quality, cost, and time (Skinner 1969; Wheelwright 1978, 1984; Hayes and Wheelwright 1984; Fine and Hax 1985; and Van Dierdonck and Miller 1980, among others). Innovativeness is sometimes included as a fifth priority grouping. Terms other than competitive priorities have also been used to represent the same factors (see Buffa 1984, Fine and Hax 1985, Kim and Miller 1990, Schroeder et al. 1986, Swamidass and Newell 1987, Miller and Roth 1988, Adam and Swamidass 1989, and Fitzsimmons et al. 1991).

Although surveys have shown that manufacturing firms consider all competitive priorities important regardless of positioning strategy (DeMeyer et al. 1989, Kim 1994, Kim and Miller 1990, and Wood 1991), they place stronger emphasis on those priorities that characterize their distinctive competence. As noted earlier, demand characteristics define the principal competitive priorities which, in turn, define a reasonable range for process choice. The degrees of emphases placed on the other competitive priorities then influence the selection of a specific process choice. Thus, the other competitive priorities are the additional factors for fine tuning the process choice.

In sum, the economics of production related to the degree of customization and volume coupled with the emphasis placed on various competitive priorities affect the decision on process choice. The association between competitive priorities and process choice has not been empirically tested. Again, because aggregate data of multi-product, multi-plant firms could mask the expected relationships, our "unit of analysis" is the primary product line produced in a particular plant.

PROPOSITION 2. *Competitive priorities of manufacturing firms with regard to the primary product line produced in a particular plant are consistent with the plant's process choice.*

2.3. Process Choice Decisions and Performance

There are clearly some normative implications behind the product-process matrix. Specifically, firms that follow the prescriptions of the matrix, i.e., operate on or close to the diagonal, are expected to outperform those choosing extreme off-diagonal positions. For example, deploying capital-intensive, special-purpose machines results in low unit variable cost, but high fixed cost. If customized products are produced in low volumes, the low unit variable cost cannot compensate for the higher fixed cost, and the position would not be sustainable.

Different measures are available for comparing performance. We measure the overall performance of operations in two ways. The first measure rates a plant's performance relative to corporate performance criteria. The second measure rates the performance of the operations function relative to plants owned by other companies in the same industry. While in §4 we show that

Table 2 Questions Dealing with Product Plans, Process Choice, and Performance

(Q1) The process and equipment can be organized in various ways. Please use the following definitions in answering the following question.

Job Shop:	Products are produced in small batches; similar equipment performing the same functions are grouped together.
Batch Shop:	Products are produced in moderately large batches; similar equipment performing the same functions are grouped together.
Production Line:	Products are produced in batches; work centers are laid out in the sequence in which the products are produced.
Continuous Shop:	Products are produced in large batches or in a continuous flow; work centers are laid out in the sequence in which the products are manufactured.

Which one of the following categories come closest to characterizing your dominant processes?

	Job Shop	Batch Shop	Production Line	Continuous Shop
Dominant Process	☐	☐	☐	☐

(Q2) Which one of the following descriptions most typify the production in your plant?

☐ Standard product with no options	☐ Standard product with standard options	☐ Standard product modified to customer specification	☐ Standard product with options modified to customer specification	☐ Customized product manufactured to customer specification

(Q3) How would you characterize the demand for your primary product line?

☐ Low Volume	☐ Moderate Volume	☐ High Volume	☐ Significantly High Volume	☐ Very High Volume

How would you rate the overall performance of manufacturing in your plant?

	Very Poor	Poor	Average	Good	Very Good
(Q4) Based on Corporate Performance Criteria	☐	☐	☐	☐	☐
(Q5) Based on the performance of manufacturing plants owned by other companies in the industry	☐	☐	☐	☐	☐

these two measures are highly correlated, they convey a quite different message in the evaluation of the operations function. Both measures are used to test the following proposition:

PROPOSITION 3. *Firms positioned on or close to the diagonal perform better than those choosing extreme off-diagonal positions.*

In the next section we will describe the instrument and data used for testing the three propositions.

3. Data

A sample of 400 companies from the *Harris Industrial and Manufacturing Directory* was selected. Half of these companies were subsequently contacted by telephone to request their participation in the study. A total of 175 firms agreed to participate, though only 110 firms returned their questionnaires. Questionnaires were also mailed to the remaining 200 firms, of which 34 responded. Subsequent analysis did not show nonrespondent bias.

Respondents were asked to fill out the questionnaire in relation to the primary product line at an individual manufacturing plant. The survey covered a wide range of issues including competitive priorities, process choice, and performance measures (Sharma 1987). Each plant in the sample was either a single-plant corporation, part of a division in a multi-division corporation, or a part of a multi-plant corporation. The questionnaire was filled out by the person with overall responsibility for manufacturing. The titles of the respondents, e.g., vice president of manufacturing and manufacturing manager, helped assure that they were knowledgeable about the array of strategic, design, and operating practices at the plant.

Respondents consisted of 22 percent job shops, 32 percent batch shops, 25 percent production lines, and 21 percent continuous shops. The average plant had an asset value of $103 million, annual sales of $84 million, and 450 employees. The sample consisted of 15 different industries at the two-digit SIC code level. With two exceptions, there was a close match between the distribution of our sample and that of population of manufacturing industries. Petroleum refining (SIC code 29) was under-represented and manufacturers of industrial and computer equipment (SIC code 35) were somewhat over-represented.

Five questions, shown in Table 2, directly asked respondents about product plans, process choice, corporate performance and manufacturing performance. Question 1 is our measure for process choice. In addition, 13 measured variables captured multiple dimensions of competitive priorities. Table 3 lists these variables and shows how each question was asked. Variables are measured on a scale from 1 to 5. With the exception of the cost priority, a higher value means more importance or greater achievement. In the case of the cost priority, a higher score means worse achievement. Note that 11 of 13 variables deal with actual achievement, rather than the importance attached to the priority.

Because many of the variables in the survey were perceptual measures, we were concerned about measurement errors. In order to assess the reliability of measured variables, we mailed a shorter version of the questionnaire to a sample of the original plants. The plant and the primary product line selected by the first respondent were shown on the short questionnaire so that the second respondent's answers were based on the same product. There were 67 questions on the follow-up questionnaire. All but one of the variables listed in Table 3, Q2, were collected on both versions. The inter-rater reliability turned out to be quite satisfactory for the sample (see Ward et al. 1994), albeit the correlations were below the levels achieved with objectively measured variables in the questionnaire.

To further assess the reliability of variables measuring competitive priorities, and to capture their latent dimensions, we factor analyzed the 13 measured variables. Specifically, we applied a maximum likelihood estimation procedure that allows the solutions to be systematically tested for different numbers of factors. Based on two tests—chi-square and Tucker and Lewis statistical reliability coefficients (Tucker and Lewis

Table 3 Questions Related to Competitive Priorities

Question Number	Description	Question Type
Q6	Product performance	4
Q7	Number of features on the product	4
Q8	Product quality consistency	4
Q9	Product quality as perceived by the customer	4
Q10	Ability to introduce new products into production quickly	2
Q11	Delivery time	4
Q12	Dependability on delivery	4
Q13	Product cost	4
Q14	Product price	4
Q15	Customizing product to customer specification	1
Q16	Ability to adjust capacity rapidly within a short time period	2
Q17	Ability to make design changes in the product after production has started	2
Q2	Degree of product standardization	3

Each question type was worded as follows:

1. Listed below are several alternatives for competing in an industry. Please indicate the importance that you attach to each alternative in selling the products in your primary product line (check one box for each item). [1 = not important, 2 = somewhat important, 3 = quite important, 4 = very important, 5 = extremely important]
2. Listed below are items that describe some management priorities in manufacturing. Please indicate the importance given to each item in your plant (check one box for each item). [the same as question type 1]
3. See Q2 in Table 2.
4. Relative to your significant competitors, please indicate your position on the following dimensions of performance (check one box for each item). [1 = significantly lower, 2 = somewhat lower, 3 = about the same, 4 = somewhat higher, 5 = significantly higher]

Table 4 Factor Loadings After a Promax Rotation

Variables	QUALITY	TIME	COST	PFLEX	DVSPEED	VFLEX
Product performance (Q6)	**0.80**	0.13	0.47	0.19	0.16	0.04
Number of features on the product (Q7)	**0.65**	−0.11	0.29	0.15	−0.03	0.40
Product quality consistency (Q8)	**0.84**	0.51	0.25	−0.05	0.10	−0.13
Prdt. quality as perceived by the cust. (Q9)	**0.81**	0.37	0.38	−0.07	−0.04	−0.08
Introduce new prdt. quickly (Q10)	0.10	0.29	−0.01	−0.03	**0.84**	0.38
Delivery time (Q11)	0.21	**0.92**	0.19	−0.05	0.10	0.08
Dependability on delivery (Q12)	0.36	**0.91**	0.12	−0.16	0.15	−0.06
Product cost (Q13)	0.42	0.11	**0.89**	0.10	−0.02	0.09
Product price (Q14)	0.40	0.19	**0.84**	0.10	0.13	−0.09
Customizing prdt. to customer spec. (Q15)	0.03	−0.13	0.08	**0.88**	−0.02	0.09
Adjust capacity rapidly (Q16)	0.01	0.10	−0.00	0.00	0.35	**0.90**
Ability to make design changes (Q17)	0.00	−0.09	0.12	0.30	**0.84**	0.17
Degree of product standardization (Q1)	0.11	−0.06	0.18	**0.89**	0.14	0.07
Eigenvalues	2.95	2.27	2.10	1.78	1.67	1.21

1973)—we reduced the 13 variables to six factors. Factor loadings after an oblique (Promax) rotation of the six factors are shown in Table 4.

A clear pattern of relationships in Table 4, commensurate for the most part with our expectations, lends further credibility to the six-factor solution. Four variables dealing with quality have high loadings on factor 1. We label this factor QUALITY. Two of the four variables deal with quality level and the physical aspects of product. In manufacturing terminology, these two variables make up "high-performance design quality." The other two variables, connoting "consistent quality," relate to the ability to conform to specifications and customer perceptions of quality. Merging both quality dimensions into one factor means that the plants which achieve high-performance quality in our study also tend to offer excellent quality consistency. Factor 2, labeled time (TIME), is made up of delivery time and dependability on delivery. Factor 3, labeled cost (COST), is composed of product cost and product price. There is a strong positive relationship between cost and price (Pearson $r = 0.50, p < 0.01$). In other words, plants with high cost in our sample also tend to charge higher prices. Higher cost related to enhanced performance on competitive priorities is passed on to the customer in a higher price. Factor 4, named product flexibility (PFLEX), corresponds to the ability to customize and respond to the unique needs of customers. Factor 5, called development speed (DVSPEED), deals with the speed of introducing new products. It connotes the priority that the literature has labeled innovativeness. Finally, factor 6, called volume flexibility (VFLEX), deals with the ability to adjust capacity rapidly.

Two of the priorities identified, PFLEX and VFLEX, are dimensions of a broadly defined flexibility priority (see Gerwin 1993). Product flexibility itself has been defined as the ability to make quick changeovers from one product to another, handle unique customer orders (customization), and frequent introduction of new products, as well as the presence of many standard products and options. PFLEX is primarily capturing the customization dimension of product flexibility. Our results should be interpreted with this limited view of flexibility in mind.

Thus the priorities identified through our analysis (quality, cost, time, flexibility, and innovativeness) closely correspond to those discussed in the literature. The next section examines the relationships between product plans, competitive priorities, process choice, and performance.

4. Analysis and Results

4.1. Proposition 1: Process Choice and Product Plans

Proposition 1, which deals with the association between product plans and process choice, may be initially tested via the Spearman correlation coefficient of variables (Q1) and (Q2). The null hypothesis would assume zero correlation between the two variables. This hypothesis was rejected with $r = -0.45$ ($p < 0.01$). The negative correlation is caused by the opposite direction of codes for (Q1) and (Q2), e.g., customized products = 5 and job shop = 1.

To gain additional insight, we examined the contingency table of the two variables. Table 5 shows the results.

Commensurate with our discussion in §2, the on-diagonal cells are shown as boldface in Table 5. In the case of job shops, the on-diagonal cells represent "customized product" and "standard product with options modified to customer orders." For batch shops, the on-diagonal cells correspond to the first three columns and for production lines, the on-diagonal cells correspond to columns two through four. The wider band for batch shops and production lines is consistent with the large spectrum of firms belonging to these two categories (Ward et al. 1992). Finally, for continuous flow shops the on-diagonal cells represent "standard product with standard options" and "standard product with no options." Given these on-diagonal specifications, the positions of the majority of firms (74.8%) in our sample follow the expected pattern of the product-process matrix. Batch shops and continuous flow shops have the largest number of off-diagonal players in the sample. To further evaluate Proposition 1, we examined the correlation between process choice (Q1) and volume (Q3). The Spearman correlation coefficient was 0.50 ($p < 0.01$). In short, the statistically significant correlation coefficients and the cell frequencies of Tables 5 strongly support Proposition 1.

4.2. Proposition 2: Process Choice and Competitive Priorities

To test the second proposition, which deals with the relationship between competitive priorities and process choice, we first used the SCORE option in SAS (1985) to obtain factor scores for the competitive priorities shown in Table 4. The means of the six factors across the four categories of process choice for on-diagonal plants are shown in Table 6. Table 6 also shows the statistical results of Tukey's HSD test (Kirk 1968). This test compared the means of each competitive priority across the four process choices.

Table 6 shows that, except for product flexibility in continuous flow shops and volume flexibility in batch shops, the mean scores for various priorities are greater than 3. Consistent with the results of past surveys, the plants in our sample emphasized more than a single priority. As expected, product flexibility and quality are the two most important competitive priorities for job shops. (Remember that the quality dimension incorporates both high-performance design and consistent quality.) Also the cost dimension, as we expected, is particularly unimportant for job shops. (Note that higher scores for COST mean inferior performance and lower priority.)

Quality is the top competitive priority for the other three process choices. In view of the composition of QUALITY, this finding is not surprising. Another contributing factor is the predominance of the quality crusade that began in the U.S. in the mid-1980s (Miller and Vollman 1985). As we hypothesized, the quality priority has its highest mean among job shops and batch processes. The contrast is particularly strong between batch shops and production lines. Further examinations show that process choice (Q1) has statistically significant negative correlations with both product performance (Q6) and product quality as perceived by the customer (Q9).

Although the mean of TIME for continuous flow shops is about ten percent higher than that of job shops, the difference is not statistically significant. Moreover, there were no statistically significant differences between the four process choices with respect to the means of delivery time and dependability on delivery. But TIME is the second most important priority for continuous flow shops and DVSPEED (which is also related to time) comes in a close third. Therefore, despite the fact that the results are not statistically significant, the means of this priority for job shops and continuous flow shops behave as expected.

Consistent with deductive arguments, product flexibility (PFLEX) loses its importance as process choice moves away from a job shop towards a continuous flow shop. Indeed, PFLEX is the priority with the strongest discriminating power among the four process choices. Because PFLEX represents the customization dimension of flexibility, this finding is not surprising. Although PFLEX does not measure all dimensions of product flexibility, it is still revealing that it has the highest mean

Table 5 Process Choices and Corresponding Degree of Customization*

	Degree of Customization (Q2)					
Process Choice (Q1)	Customized Product	Standard Product with Modified Options	Standard Product Modified to Customer Order	Standard Product with Standard Options	Standard Product with No Options	Number of Plants
Job Shop	**13** **(41.94)**	**14** **(45.96)**	3 (9.68)	1 (3.23)	0 (0.0)	31
Batch Shop	**13** **(28.26)**	**11** **(23.91)**	**6** **(13.04)**	12 (26.09)	4 (8.70)	46
Production Line	1 (2.78)	**13** **(36.11)**	**6** **(16.67)**	**13** **(36.11)**	3 (8.33)	36
Continuous Shop	4 (13.79)	2 (6.90)	6 (20.69)	**10** **(34.48)**	**7** **(24.14)**	29

* Frequency counts shown as cell values, with percentage of row totals given in parentheses. Numbers in boldface print represent on-diagonal positions.
Chi-Square = 41.60, $p < 0.001$.

among all the priorities for job shops. Surveys of American manufacturing firms in mid-1980s have shown that, in contrast to Japanese firms, quality was their top priority while product flexibility was ranked sixth (DeMeyer et al. 1989). According to our findings, national averages obscure the fact that flexibility is the top priority for a segment of manufacturing firms. Moreover, consistent with the results of several surveys, our findings show that U.S. producers of high-volume, standardized products do not consider product flexibility to be very important.

Because of the wording of our question, our finding on the cost priority must be interpreted with care. As stated earlier, "lower" averages for the cost and price questions imply "better" performance. Moving from the left to the right in Table 6, we expected the mean for COST to decrease. This decrease generally happened except for continuous flow shops. The mean for continu-

Table 6 Means and Rankings (in Parentheses) of Competitive Priorities for On-Diagonal Plants

	Process Choice			
Competitive Priority	Job Shop	Batch Shop	Production Line	Continuous Shop
QUALITY[1]	4.62 (2)	4.90 (1)	4.18 (1)	4.74 (1)
TIME	3.05 (4)	3.14 (4)	3.10 (5)	3.38 (2)
COST[2]	4.08 (6)	3.71 (6)	3.41 (6)	3.93 (5)
PFLEX[3]	4.74 (1)	4.24 (2)	3.24 (4)	2.07 (6)
DVSPEED	3.75 (3)	3.51 (3)	3.64 (2)	3.37 (3)
VFLEX	3.00 (5)	2.97 (5)	3.44 (3)	3.00 (4)
Number of Plants	23	26	29	11

Note: The numbers in the table are the means of factor scores after a promax (oblique) rotation and cannot directly be compared to original scales for the variables.
[1] Significant at $p < 0.01$, caused by the difference between batch shop and production line.
[2] Significant at $p < 0.01$, caused by the difference between job shop and production line.
[3] Significant at $p < 0.001$, caused by differences between all pairs except job shop and batch shop.

ous flow shops is not smaller than that of production lines, and it is slightly higher than that of batch shops. The only statistically significant result is noted between the means of job shops and production lines. Compared to job shops, production lines are expected to achieve lower cost.

We did not find statistically significant differences relative to process choice for the means of DVSPEED and VFLEX. DVSPEED is the second priority for production lines and the third priority for the other three process choices. The ability to make design changes and introduce new products quickly were considered important regardless of process choice. VFLEX is one of the higher priorities for production lines, but not so for the other three process choices. VFLEX represents primarily the ability to adjust capacity rapidly. That job shops and batch shops normally operate with a good deal of capacity cushion (Krajewski and Ritzman 1996) might help explain their low rankings of VFLEX.

We also explored the relationship between process choice and competitive priorities of the off-diagonal plants as defined in Table 5. Because off-diagonal positions are anomalies, not many firms fall in this category. Only 25 percent of the plants in our sample were off-diagonal players. In particular, job shops and production lines each had only four plants with extreme positions, thus preventing statistical analysis of their means. Table 7 shows the means of competitive priorities for the extreme players in batch and continuous flow shops.

Table 7 reveals a few interesting relationships. First, the same three competitive priorities found to have statistically significant relationships with process choice for on-diagonal plants—quality, product flexibility, and cost—are also statistically significant for the extreme plants. Second, off-diagonal continuous flow shops have high product flexibility, offering a high degree of customization to their customers. Conversely, off-diagonal batch shops offer much less product flexibility than on-diagonal batch shops or even off-diagonal continuous flow shops. Therefore, the flexibility priority for off-diagonal plants moves in the reverse direction of the same priority for on-diagonal plants. In addition, off-diagonal continuous flow shops do a better job on cost and time priorities than their on-diagonal counterparts. Finally, it appears that off-diagonal plants tend to be underachievers in terms of all competitive priorities except cost and time.

The final analysis of Proposition 2 compared the competitive priorities of various process choices which had the same product plan. For example, as shown in Table 5, "customized product" was the product plan of 13 job shops and 13 batch shops. For each column in Table 5, we compared the competitive priorities of different process choices. (The cells with few observations were excluded.) Going down in each column, we expected to see less emphasis on product flexibility and quality and more emphasis on cost. Our findings strongly supported the theoretical expectation. For the sake of brevity, we state the result only for the second column. The means for QUALITY, COST, and PFLEX for job shops were 4.79, 4.48, and 4.23. The corresponding means for production lines were 4.19, 3.76, and 3.34. These differences were statistically significant ($p < 0.01$). When compared to job shops, production lines placed more emphasis on cost and less emphasis on quality and product flexibility.

Our findings, in general, support the theoretical expectations in relation to competitive priorities for plants occupying both on- and off-diagonal positions. Moreover, product flexibility, which we measure as the degree of customization, is the only priority with statistically significant differences between the means of the four process choices. This priority seems to be the key discriminator between process choices, just as initially proposed by Hayes and Wheelwright.

4.3. Proposition 3: Process Choice Decisions and Performance

As discussed earlier, two measures were used to compare the performance of firms. The correlation between these two measures, Q4 and Q5, is highly significant ($r = 0.61$, $p < 0.001$), but each measure brings different insights to the evaluation of the operations function. The paucity of extreme players for job shops and production lines prevents performance comparisons for these two process choices. Table 8 instead shows the means of our two performance measures for the other two process choices, along with the results of t tests (Hoel and Jessen 1977).

Beginning with the first measure based on corporate-wide criteria (Q4), Table 8 shows that there is no statis-

Table 7 **Means and Rankings (in Parentheses) of Competitive Priorities for Off-Diagonal Plants**

	Process Choice	
Competitive Priority	Batch Shop	Continuous Shop
QUALITY[1]	4.67 (1)	4.24 (1)
TIME	3.31 (2)	3.47 (3)
COST[2]	3.81 (6)	3.26 (6)
PFLEX[3]	2.23 (5)	4.01 (2)
DVSPEED	3.07 (3)	3.06 (4)
VFLEX	2.74 (4)	2.80 (5)
Number of Plants	12	10

[1] Significant at $p < 0.01$.
[2] Significant at $p < 0.001$.
[3] Significant at $p < 0.001$.

tically significant difference between the performance of on- and off-diagonal batch shops. This finding does not support Proposition 3. On-diagonal continuous flow shops, however, do better than their off-diagonal counterparts. One reason for this finding is production volume. Our results show that the corporate-wide performance of on-diagonal plants improves steadily as they progress from job shops to continuous flow shops. High-volume operations get higher marks. Fiegenbaum and Karnani (1991) indirectly support this explanation by showing a positive relationship between firm size and financial performance. Additional analysis of our data also supports this explanation. The (Q4) performance measure is positively correlated with process choice ($r = 0.22, p < 0.01$). It is also positively associated with the firm's financial measures such as market share ($r = 0.24, p < 0.01$), sales growth ($r = 0.17, p < 0.05$), and earnings growth ($r = 0.24, p < 0.01$). While this performance bias is interesting, it is clear that (Q4) is not an appropriate measure for evaluating how well operations function performs for plants occupying on- or off-diagonal positions.

The second performance measure (Q5), on the other hand, seems to provide a much better test of Proposition 3. By comparing performance relative to plants owned by other companies in the same industry, it seems to "control for" the environment in which the operations function finds itself. More specifically, Q5 is not significantly correlated with process choice ($r = -0.02$). Given this reassurance, consider the second row in Table 8. It shows that on and off-diagonal batch shops have similar performances. However, on-diagonal continuous flow shops perform much better than their off-diagonal counterparts. Indeed, the performance of on- and off-diagonal continuous flow shops strongly support Proposition 3.

In §2.1 we discussed possible reasons for plants to select positions far below the diagonal of the product-process matrix. We examined the data for each of *the twelve off-diagonal continuous flow shops* to see what accounts for their selected process choice. Eight plants indicated that they used common parts or subassemblies across different products. With the use of modular designs, these continuous flow shops were able to place more emphasis on customization. Incidentally, two of

Table 8 **Means of Performance Measures for Firms Operating On and Off the Diagonal**

	Process Choice			
	Batch Shop		Continuous Shop	
Overall Performance of Operations	On Diagonal	Off Diagonal	On Diagonal	Off Diagonal
Based on Corporate Criteria (Q4)	3.73	4.19	4.65	3.67[1]
Based on Plants of Other Corporations (Q5)	3.90	3.87	4.41	3.50[2]

[1] Significant at $p < 0.001$.
[2] Significant at $p < 0.01$.

these eight plants also employed flexible manufacturing systems. We also reexamined the performance of the twelve off-diagonal continuous flow shops. Interestingly, there are significant differences between the performance of the eight plants which used modular designs and the four which did not. The means of the two performance measures for the eight plants are 4 and 3.87, respectively. The same means for the remaining four plants are 2.75 and 2.5, respectively. The long-term survival of these four plants which operate well below the diagonal and have poor performance is questionable. Follow-up interviews with manufacturing managers of these plants revealed subsequent developments that support this expectation in three of the four plants. One plant, an oil refinery, has gone bankrupt. The second plant, an automotive part supplier, seems to be facing problems and a new manufacturing manager has been appointed. The third plant originally produced automotive products. It has, however, changed ownership and now produces more environmental protection devices and less automotive products. The other plant, which had the best performance among the four, produced materials used by the food and beverage, pharmaceutical, and detergent industries. Because the plant does not have a discrete production process, it cannot take advantage of part commonality or flexible manufacturing systems. However, the production technology makes it possible to do customization at the very end of the continuous process, through blending and packaging operations.

The *sixteen off-diagonal batch shops* produced numerous standardized products with few options in moderate to high volumes. So while their product plans call for a production line or a continuous flow shop, the volumes were not high enough to warrant a move down the diagonal of the product-process matrix. For example, one of the shops produced fluid handling products and accessories. These standard products have stable designs, but their yearly volume varies considerably from only 200 units to 25,000 units. The plant has very recently moved in the direction of group technology. Grouping is first done by products, and then by production technology to form technology cells or "focused factories." In effect, the focused factory would allow more of a line flow than would be expected in a typical batch shop. Operating as a batch shop makes economic sense for this and the other off-diagonal batch shops. This finding helps explain why their performance is not worse than their on-diagonal counterparts.

5. Conclusion

Our study shows that manufacturing firms' choice of production process by and large agrees with the emphasis they place on product customization. Our findings support the expectation that firms with different process choices emphasize different competitive priorities. Moreover, we have uncovered some evidence that manufacturing performance suffers when there is a mismatch between product plans and process choices. Our findings show that some continuous flow shops use common parts and subassemblies to achieve customization. However, when customization in continuous flow shops is not supported by these programs, manufacturing performance suffers.

Although these findings have long been suspected, we have provided empirical support for deductive arguments. Our findings are subject to three limitations. First, the wording of the cost question was inconsistent with the rest of the questions and could have caused some interpretation difficulties. Second, the product flexibility dimension only captured the customization aspect of flexibility. Flexibility is a complex phenomenon and the literature has gradually uncovered its multiple dimensions and their strategic implications. Gerwin (1993) has recently discussed the difficulty of measuring and operationalizing flexibility. Third, our cross-sectional study did not test the dynamics of the product-process matrix covering plants with products and processes advancing through their life cycles.

These limitations do not, in our view, substantially detract from the significance of the findings. In addition to filling an important empirical gap, the study has four important implications for future research. First, the use of common parts and subassemblies and flexible manufacturing systems has allowed some continuous flow shops to achieve customization in mass quantities. Moreover, some batch shops use similar methods to produce standardized products in moderate to high volumes. As a result, in some situations positions far off the diagonal of the product-process matrix have become economically feasible. In fact, the coupling of volume and the degree of customization in the product-process matrix may not hold true for some manufacturing firms. Second, collecting data with regard to a dominant product line produced in a particular plant makes it possible to clearly investigate the differences between alternative process choices and their competitive priorities. Because firms with different process choices emphasize different competitive priorities, one would also expect them to make different decisions on how to design and operate the production system. Future surveys and empirical studies might benefit from separating their analyses for different process choices or including process choice as an explanatory variable in the model. Third, customization appears to be the competitive priority with the greatest discriminating power between different process choices. It has a particularly important impact on how the production system is organized. Our empirical results concur with the work of Ettlie and Penner-Hahn (1994) and Gerwin (1993) in showing the need for studying flexibility from a strategic perspective. Finally, batch shop and production lines operate along a fairly wide spectrum of product plans. This diversity calls for a more focused investigation of such plants. Finding a better way for discriminating between the practices in these plants appears to be a useful research initiative.[1]

[1] We are grateful to two anonymous reviewers for their valuable comments and suggestions.

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Accepted by Gabriel Bitran; received August 1994. This paper has been with the authors 7 months for 2 revisions.