Manufacturing flexibility: methods for measuring the impact of product variety on performance in process industries

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Abstract

Product variety is often assumed to yield competitive advantage by offering products or services tailored to specific market segments. This strategy should result in more total sales volume or higher prices, and presumed profit, gained by meeting more specialized demands. However, achieving competitive advantage through increased product variety is heavily dependent on the proper alignment of the marketing and manufacturing strategies. This paper shows that adding product variety can have adverse cost and margin implications when marketing and manufacturing strategies are mis-aligned. The critical strategic issues involve product pricing and manufacturing flexibility in product mix. We report methods that can be used to measure product mix flexibility and manufacturing performance in terms of costs and margins based on actual orders and production data. Such methods provide a means of empirically diagnosing the degree of strategic mis-match using actual operating data. These methods are general in nature, and have been tested in field research on high volume batch processes that are representative of many firms in process industries. The results show that gaining competitive advantage through increased product variety requires a clear understanding of the process choice required to support the contemplated range of product volumes, and the cost and profitability trade-offs involved. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Marketing managers, through strategies such as market segmentation and niche marketing, often suggest an increase in product variety and range to satisfy specific groups of customers’ needs or wants. These can involve differences in product features, packaging, or channels of distribution. Further, important consideration is being given to ‘mass customization’ strategies in many companies today (Pine, 1993; Kotha, 1995; McLaughlin and Victor, 1995). Additional impetus is coming from mass merchandisers expecting deliveries in small quantities directly to stores with extremely high service levels, specialized packaging, and unique promotion combinations (McDermott and O’Connor, 1995). These strategies should result in sales growth or higher prices, and presumed profit, gained by meeting more...
specialized demands. However, such decisions can have adverse implications for manufacturing and distribution systems that are not always captured in cost, margin and non-financial performance estimates for such strategies.

There is increasing evidence that achieving competitive advantage through increased product variety is heavily dependent on ensuring the proper alignment between the marketing and manufacturing strategies pursued by a company (Richardson et al., 1985; Leschke, 1995; Safizadeh et al., 1996). Failure to align marketing and manufacturing strategies in terms of product pricing and manufacturing flexibility in product mix can have serious financial consequences. What is not well-understood is how to determine whether a mis-match in strategy alignment will prevent a strategy of increased product variety from producing a sustained competitive advantage in terms of market share, sales growth and profitability.

This research presents general methods to empirically diagnose the degree of mis-match using a sample of company data. These methods are applicable in a wide variety of industries, and have been applied by the authors in such diverse industries as fiber glass, packaging materials, apparel, and furniture manufacturing. Our approach is to measure the cost and contribution margin per unit implications of strategic decisions regarding increased product variety. The results of field research are reported to test these methods and to demonstrate the major shortfalls in profitability which can occur when product pricing and manufacturing flexibility strategies are mis-aligned. The objectives of this research are to:

- provide a conceptual framework for understanding the pricing and process choice issues in addressing a marketing and manufacturing strategy of increased product variety,
- provide methods for examining the costs of adding product variety in manufacturing so that companies can make more informed strategic decisions concerning product variety,
- field test these methods by examining in depth the cost structure of a company that is addressing the issue of increased product variety.

2. Product variety—a strategic issue

There is an emerging literature concerning manufacturing flexibility that is directly related to the mis-alignment issue in supporting increased product variety. Although numerous dimensions of manufacturing flexibility have been defined, the work concerning product mix flexibility specifically relates to this research (Chen et al., 1992; Gerwin, 1993). Here product mix flexibility is defined as the capability of producing a number of product lines and/or numerous variations within a line (Gerwin, 1993). It represents the ability to produce a broad range of products or variants with presumed low changeover costs.

While substantial efforts have been made to define manufacturing flexibility in conceptual terms, a number of unexplored issues remain. Gerwin (1993) points to the need to show manufacturing managers how to evaluate and change the flexibility of their operations since little attention has been paid to developing procedures that fill this need. Further, he argues that special attention should be devoted to applied research on manufacturing flexibility since this area is not well-developed. Finally, Gerwin (1993) suggests that the need to develop operational measures of manufacturing flexibility and its value represent a critical research priority.

Related work by Ramasesh and Jayakumar (1991) and Watts et al. (1993) addresses the measurement of manufacturing flexibility. Research by Chen et al. (1992) explores the impact of the manufacturing flexibility provided by recent evolving computer and process technology including CAD, CAM, CAPP, FMSs, etc., upon the manufacturing/marketing interface within the new competitive environment.

Other research in manufacturing strategy has been concerned with determining the value of manufacturing flexibility. Swamidass and Newell (1987) report the results of an executive survey in the machinery and machine tools industries which indicate that manufacturing flexibility seems to contribute competitive advantage to a manufacturer regardless of the manufacturing process used. However, research by Hill and Chambers (1991) provides case exam-
3. Impact of mis-alignment of strategies to support increased variety

The experience of Plastech (Leschke, 1995) illustrates the drastic reduction in profitability that can result from the introduction of increased product variety without appropriate changes in manufacturing strategy and investment. When faced with a loss of major sales contracts, Plastech obtained a 20% increase in sales revenue by implementing a marketing strategy to increase product variety. As a consequence, batch sizes decreased by 50% and profits shrank by 83%. The costs associated with the firm’s high volume batch process could not maintain profits for the wide range of small volume products offered. Without new investment, the firm’s high volume batch process, having large changeover times (and costs), could not support the product mix flexibility needed to cope with the increased product variety required in the new markets targeted by the company.

Other examples of mis-alignment issues in supporting a strategy of increased product variety have been reported in the literature. Large mass retailers are recognizing this issue and ordering fewer product sizes and brands to achieve lower costs (Schiller et al., 1992). Toyota’s Shatai subsidiary reports that recent efforts to increase product variety in its Inabe plant have cut into productivity, requiring much more time to clean up paint lines and change tools (Moran, 1996). Recent research on mass customization in service industries notes the frequent lack of careful analysis of the investment required to support increased product variety strategies, resulting in excess costs (McLaughlin and Victor, 1995).

Such examples illustrate that the ‘flexible is free’ arguments in the literature do not always apply, particularly under high volume batch process settings. Suarez et al. (1996) report an empirical study of manufacturing flexibility in printed circuit board assembly plants in which they conclude that “achieving high-mix flexibility does not seem to involve a cost or quality penalty”. Likewise, Kekre and Srinivasan (1990) report an empirical study using the PIMS data base in which they report “the lack of any strong negative effect of broadening product line on operations”. Further, they note that “in industrial markets, product line breadth has a small but significant favorable impact on direct costs and manufacturing costs”, and “in consumer markets too, product line breadth does not have any direct impact on both relative costs and total inventory”.

Both of the previous studies used highly aggregated plant data. Suarez et al. (1996) discuss the problem of company data confidentiality. They note that they were unable to obtain a detailed account of each plant’s cost structure, and had to use a commonly reported aggregate industry measure (unit cost per component placed). The use of highly aggregated data can obscure the effect of sources of variation such as production run length on manufacturing cost. Furthermore, these studies do not identify the process choice decisions made in these plants, nor any investments in low volume batch processes that may have been made to support increased product variety. Neither do they address the degree of the price sensitivity in these markets, nor the ability of the companies to capture a price premium for added product variety.

Therefore, in order to show the effect of mis-alignment induced by increased product variety, we have taken a different approach in our analysis of product variety and manufacturing performance by developing a framework and general methodology to analyze a plant’s cost structure, using actual operating data.

4. Strategic framework for increased product variety

This paper examines the process choice and pricing implications of manufacturing and marketing
decisions to increase product variety. In shifting to a marketing strategy that targets low volume/high variety segments, it is often incorrectly assumed that the process choice for low volume products is the same as that for high volume products. The case of Plastech illustrates this point (Leschke, 1995). We are concerned with identifying the costs of increased product variety which result from mis-aligned process choice decisions, and the resulting impact on profits.

Early work by Blois (1980) provides the basis for a conceptual framework to understand the strategic issues concerning manufacturing flexibility. Blois (1980) proposed a Policy Interaction Grid which integrates product, manufacturing, and marketing policies. This framework is directly related to the issue of product variety as the three dimensions in the policy grid include: product type (custom/standard products), product volume (small batch/volume manufacturing), and marketing strategy (custom/mass marketing).

Further, Blois (1980) indicates the need for internal information concerning a firm’s process cost, capacity and delivery capabilities in order to achieve a marketing/manufacturing orientation. Such information includes customer and market profitability analyses, and cost estimates of supplying products in various volumes (including those outside the normal range). The contemporary work on Activity-Based Costing to determine cost drivers, and the Theory of Constraints to identify process bottlenecks and their impact on product profitability provides an excellent framework for contribution margin analysis (Spoede, 1996; Campbell et al., 1997). Such an approach ensures that marketing strategies are developed which take into account the organization’s capabilities and their customers’ contributions to profitability as distinct from their contributions to revenue.

We have extended the work of Blois (1980) by developing a framework in which the alignment of marketing and manufacturing strategies can be viewed when increased product variety is proposed. Two dimensions are critical in the strategic decision to increase product variety: the characteristics of buyer behavior measured in terms of price sensitivity for the targeted market segments, and the current process choice decisions in manufacturing. These dimensions, shown in Fig. 1, were motivated by the arguments of Blois concerning the critical role of pricing and the creation of value to the customer from more customized products.

The vertical dimension characterizes the degree of price sensitivity in the market segments targeted for increased product variety. The low market price sensitivity position represents segments in which customers are willing to pay a price premium for added product variety. This is caused by factors such as the value of the brand image, or the value of customized product features to the customer. The high market price sensitivity position represents market segments where it is difficult to obtain a price premium for product variety. This distinction in buyer behavior is critical in manufacturing because of the impact of pricing on profit margins.

The horizontal dimension characterizes the current and required investments in manufacturing capacity. While a number of process choice options are available, e.g., jobbing, batch, and line (Hayes and Wheelwright, 1984; Hill, 1992), this research is fo-
cused on batch manufacturing because of its prevalence in industry. The distinction between high and low volume batch processes is critical because of the important differences in capability and investment between these processes.

Typically, low volume batch processes are designed with features such as low changeover times and costs with high employee skill requirements that provide the flexibility needed to support a product variety strategy. High volume processes are normally designed with features such as short unit processing times, extensive process monitoring systems, and low employee skill requirements that enable low product costs to be achieved. Because of these differences in process design, significant investments in process and infrastructure are typically needed to shift the process choice from high to low volume batch and vice versa.

The framework shown in Fig. 1 suggests that a company contemplating a marketing strategy of increased product variety can face one of four possible general situations. In only one case, labeled (1), are the marketing and manufacturing strategies aligned. In case (1), the products can be priced to provide attractive margins, and the current process choice (investment) is low volume batch. This process choice provides the flexibility to economically produce a wide variety of low volume products in small batches. This case clearly provides an opportunity to gain competitive advantage through a strategy of increased product variety.

A mis-match between the marketing and manufacturing strategies occurs in all other cases, requiring resolution between the functions. Case (4) presents the most difficult challenge to the business because an increase in product variety is often achieved through low volume products. In this case, although the new products may have the advantage of retaining existing customers, or producing new sales growth, the customers are price-sensitive and it is difficult to capture margin through pricing increases for such products. The pressure by mega-retailers to reduce price and to make small quantity deliveries directly to stores is such an example. Although the current high volume batch process can physically produce the products, it is difficult to maintain profits in producing low volume products for price sensitive markets using those processes because of the changeover costs involved as illustrated in the Plastech case (Leschke, 1995).

Cases (2), (3), and (4) in Fig. 1 are illustrative of product variety situations requiring strategic resolution using both marketing and manufacturing perspectives. As is illustrated by the examples reported by Hill (1992), Leschke (1995), and Moran (1996), case (4) appears to be increasingly prevalent in practice as the pressure for the ‘mass customization’ of products increases. This framework is intended to help executives better articulate the actual flexibility of existing processes relative to market requirements. It focuses on the pricing and process choice issues in making strategic decisions concerning increased product variety. It clarifies the areas where: joint strategy resolution is required, business trade-offs are involved, and new process investments may be needed to support increased requirements for manufacturing flexibility. The opportunity for gaining competitive advantage through increased product variety depends on the joint resolution of these issues (Hill, 1992; Karmarkar, 1996).

5. Field research

The purpose of this research is to conduct an exploratory field test of the proposed framework and methodology. This involves the collection of actual operating data in order to construct a process profitability analysis, using statistical methods. The research is designed to test investigative techniques for determining the degree of alignment between marketing and manufacturing strategies in supporting increased product variety. Here we measure the relationship between contribution margin per scarce resource hour and production order size in order to test the degree of alignment between pricing and process choice strategies.

It is often assumed that the production of low volume products in batch processes is simply a matter of dealing with an increase in the number of changeovers. However, in many industrial processes, there are complex cost relationships dealing with changeover, process yields, and differences in run time productivity that can depend on product volume. We show that data measuring such relation-
ships can be obtained through special process studies, and these data can be used with the conceptual framework proposed in Fig. 1 to improve strategic debate concerning investments in manufacturing flexibility.

Previous research has demonstrated how investments in manufacturing flexibility can be made to support increased product variety, using computer and information technology in metalworking and assembly processes, e.g., with flexible manufacturing systems (FMS) (Chen et al., 1992). Further examples include Levi Strauss and Company make-to-order jeans which permit custom-fitted products (Goldhar and Lei, 1995), and Ingersoll Milling Machine Company use of a computer controlled manufacturing system to machine thousands of different prismatic parts in lot sizes of one (Goldhar and Lei, 1995).

This research extends the previous research in two ways. First, it tests general methods for examining the performance implications of increased product variety faced by executives. Second, it broadens the range of industries previously studied by applying these methods to the process industry. The methods proposed here were motivated by early pilot results which we obtained in manufacturing strategy analyses conducted in such diverse industries as fiber glass, packaging materials, apparel and furniture manufacturing.

The methods were tested in a process industry firm which is experiencing profit issues dealing with increased product variety, and which was willing to provide an extensive data base of operating data for the analysis. This company was selected because it provided an opportunity to conduct this research in a different type of industry than the metalworking and assembly manufacturing firms studied in previous research (Ramasesh and Jayakumar, 1991; Chen et al., 1992; Goldhar and Lei, 1995).

6. Company background

During the past 10 years, the company studied has introduced a large number of new products, and the total number of products has increased by a factor of six times. During the same period, no new investments were made to the firm’s existing high volume batch processes. This company is a leading chemical manufacturer with annual sales exceeding one billion dollars. Its branded products are sold in both consumer and industrial markets through a variety of channels, including mass merchandisers, independent retailers, and manufacturers’ representatives. In the portion of the business studied, it sells over 500 standard and special products in highly competitive markets which are characterized by substantial fluctuations in seasonal demand.

The product structure has four levels, consisting of packaged products, end product formulas (blends), manufactured chemicals, and purchased ingredients. Each family of packaged products is produced on a 7 day per week, high volume linked batch process which has three processing units: chemical manufacturing, formula blending, and packaging. Inventory is held for finished packaged products, and for raw material ingredients. Very little work-in-process inventory is held since materials are moved automatically in a linked batch process from chemical manufacturing to formula blending, and finally to packaging. Because demand exceeds the process capacity during the peak season, anticipation stock is held in finished goods inventory.

Formula blending is the bottleneck processing unit in this company. Its capacity is relatively expensive, the changeovers are longer than those for chemical manufacturing and packaging, and the blending changeovers are sequence dependent. In this company, blending changeover times are approximately 6 h, varying from 1 to 30 h. These changeovers involve substantial process cleanout time to avoid product contamination as well as the time needed to change ingredient materials and to adjust process control settings. Small changeover times are often explained by sequence dependencies, i.e., scheduling similar product blending orders in a sequence; thereby reducing process changeover time. The batch run time for production orders is approximately 70 h, and can vary from 4 to 210 h.

7. Hypotheses

Five hypotheses were tested using regression models to develop the process profitability analysis in the field research company. These hypotheses concern the effects on product yield, cost and contri-
bution margin of running low volume/high variety products on this firm’s high volume batch processes. The hypotheses were developed for the purpose of applying the process profitability methodology in the research company, and the specific results would not necessarily apply to all companies.

H1: Product yield and batch size are not related.  
H1A: Product yield decreases as batch size decreases.

H2: Process run time productivity (measured in terms of output/run time hour) is not related to batch size.  
H2A: Process run time productivity (measured in terms of output/run time hour) decreases as batch size decreases.

H3: Process productivity (measured in terms of output/changeover and run time) is not related to batch size.  
H3A: Process productivity (measured in terms of output/changeover and run time) decreases as batch size decreases.

H4: Total process productivity (measured in terms of output/total order processing time) is not related to batch size.  
H4A: Total process productivity (measured in terms of output/total order processing time) decreases as batch size decreases.

H5: Contribution margin per process hour is not related to batch size.  
H5A: Contribution margin per process hour decreases as batch size declines.

8. Statistical design

To test the hypotheses, regression models were specified concerning process productivity and product yield. These models were of the form:

\[ Y = B1 + B2 \times \ln(\text{Batch Size}) + B3 \times (\text{Seasonal Factor}) + B4 \times (\text{Natural Cycle Factor}). \]  

8.1. Regression model variables

Four dependent variables using three independent variables were studied in the regression analysis:

- Product yield (Saleable output/total input in units)
- Saleable output/run time (in hours)
- Saleable output/changeover plus run time (in hours)
- Saleable output/total time which consists of changeover plus run time plus downtime (in hours).

Product yield measures the total amount of product (in units) which meets the product specifications, i.e., saleable output, in relation to the total number of units consumed for the production batch. The next three dependent variables measure process productivity, i.e., output in units per process hour, considering process changeover time, run time, and down time.

These variables were selected in this company because they were thought to have the greatest impact on profitability in running low volume/high variety products on this firm’s high volume batch processes. Clearly, in other company applications of this methodology, other variables, such as absolute production volume, might be selected if they are considered to have a major impact in processing low volume/high variety products. The generality of this methodology is that it can be applied under a variety of business and process conditions.

The three independent variables studied in the regression analysis were:

- Production batch size
- Peak season/off-season factor
- Natural cycle sequence factor.

Experience with the production processes studied in this company suggests that the regression coefficients would differ between peak demand and off-season operation. Further, it was thought that both productivity and product yield would be affected depending on whether the natural product sequence is followed in scheduling the sequence dependent products. Running the products in the ‘natural sequence’ involves sequencing production batches so that the least process changeover time is incurred. The plant tries to follow these sequences unless customer priorities intervene. Dummy variables were initially included in the regression models to test the seasonal and natural cycle effects. In the case of the
natural cycle analysis, this approach was later modified as discussed in Section 9.

8.2. Data collection

Actual operating data were collected for 16 products that were considered by company executives to be representative of the types of products processed on two of the company’s high volume batch processes (referred to as processes A and B). These products represent a wide range of sales volumes and include products which are sold in both price sensitive and non-price sensitive market segments as evidenced by the marked differences observed in the unit contribution margins between segments. In the case of process A, the natural sequence is violated for approximately half of the production orders in both peak season and off-peak periods, and is a critical business issue. However, in process B, most orders are scheduled in the natural sequence since fewer end products are run in much higher volumes with production order sizes that are approximately 50% larger than those in process A.

In total, data for 95 production orders, covering a 13-month period, were collected for the products in the sample. Each production order covers the production for a single end product formula blend which is packaged in various product sizes SKU’s. These represent all of the production runs for the products involved during this period. The number of production orders/month in the sample was relatively constant in both the peak demand season and the off-peak period.

The specific data collected for each production order included: the end product type, blending formula, packaging specifications, raw material ingredient quantities, date the production order was processed, changeover time, run time, downtime, product yield, batch size, saleable product quantity, variable processing cost, raw material cost, and selling price. Fixed overhead cost allocations were not considered.

9. Regression results

Separate regression equations were developed for processes A and B using the four dependent variables and three independent variables defined above. These results are reported in Table 1. In all cases, the statistical significance level applied is alpha equals 0.05.

In the case of process A, a much more favorable level of performance was observed when the plant was scheduled to maintain the natural cycle. Therefore, the use of a dummy variable for the natural cycle factor in the original research design was modified, and two sets of regression equations were developed for process A. The first set of regression equations reflects the performance of process A when products are processed in the natural cycle sequence. The second set indicates the results when products are processed out of the natural cycle sequence.

9.1. Product yield

The results fail to reject the null hypothesis H1 for two of the three process conditions. When products are run in the natural cycle sequence in process A, and in process B as well, changes in product yield are less than 2%. The product yields for process A are adversely affected by batch size and seasonal factor only when the products are run out of the natural cycle sequence. In the case of running out of sequence in process A, the adjusted $R^2$ value is 0.65, the model is highly significant at 0.000, and all of the model coefficients are significant at the 0.01 level or less, rejecting H1. This is explained by the fact that when products are run out of the natural sequence, it often takes a longer time to achieve the product quality specifications during a process changeover because of process adjustments; thereby reducing product yield.

9.2. Saleable product / run time

The results fail to reject the null hypothesis H2 for one of the three process conditions. This occurs when products are run in the natural cycle sequence in process A. Run time productivity is significantly affected by batch size in process A when products are run out of their natural cycle sequence. The regression model is highly significant at the 0.0004 level, the adjusted $R^2$ value is 0.45, and the batch size coefficient is significant at the 0.0004 level. This can be explained by the fact that the operators
Table 1
Regression summary

|                      | Process A | | Process B | | | |
|----------------------|-----------|------------------|-----------|------------------|-----------|
|                      | In sequence | Out of sequence | | Value | Std. error | Significance | Value | Std. error | Significance |
| bc                   |            |                  | bc       |            |             |            |            |            |
| H1: yield            |            |                  |          |            |             |            |            |            |
| Saleable output/input|            |                  |          |            |             |            |            |            |
| Adjusted $R^2$       | 0.00       | 0.65             | 0.02     |            |             |            |            |            |
| $F$ value/significance | 0.68     | 0.260            | 22.77    | 0.0000*     | 1.65      | 0.1015     |            |            |
| LN (run size): coefficient | 0.005 | 0.016            | 0.350    | 0.0000*     | 0.012     | 0.1080     |            |            |
| Seasonal coefficient* | -0.020    | 0.022            | 0.151    | -0.16       | 0.06       | 0.0105*    |            |            |
| H2: Productivity     |            |                  |          |            |             |            |            |            |
| Saleable output/run time |          |                  |          |            |             |            |            |            |
| Adjusted $R^2$       | 0.09       | 0.45             | 0.47     |            |             |            |            |            |
| $F$ value/significance | 1.86     | 0.095            | 10.46    | 0.0004*     | 23.32     | 0.0000*    |            |            |
| LN (run size): coefficient | 2671    | 1951             | 6193     | 0.0004*     | 4387      | 778        | 0.0000*    |            |
| Seasonal coefficient* | -2977     | 2670             | 0.140    | -3782       | 3173       | 0.1235     | -3758      | 1405       | 0.0050*    |
| H3: Saleable output/CC + run time |          |                  |          |            |             |            |            |            |
| Adjusted $R^2$       | 0.36       | 0.55             | 0.53     |            |             |            |            |            |
| $F$ value/significance | 5.99     | 0.006*           | 14.85    | 0.0004*     | 30.11     | 0.0000*    |            |            |
| LN (run size): coefficient | 4635    | 1628             | 7121     | 0.0001*     | 5369      | 793        | 0.0000*    |            |
| Seasonal coefficient* | -3303     | 2229             | 0.080    | -4116       | 3039       | 0.0950     | -3432      | 1433       | 0.0100*    |
| H4: Saleable output/total time |          |                  |          |            |             |            |            |            |
| Adjusted $R^2$       | 0.45       | 0.47             | 0.46     |            |             |            |            |            |
| $F$ value/significance | 8.38     | 0.002*           | 11.12    | 0.0003*     | 22.68     | 0.0000*    |            |            |
| LN (run size): coefficient | 3164    | 1483             | 4505     | 0.0010*     | 4933      | 875        | 0.0000*    |            |
| Seasonal coefficient* | -6295     | 2029             | 0.004*   | -5634       | 2615       | 0.0215*    | -3971      | 1581       | 0.0075*    |

*1 = Peak season, O = other.
*2 Standard error of the regression coefficient.
*3 Values represent a one-tailed test of significance.
*4 Significant at the 0.05 level.
studied will frequently reduce process speeds when large differences in product characteristics occur between successive production batches in order to insure product quality specifications are achieved. Further, run time productivity was not affected by seasonality, although the sign of the coefficient is in the expected direction.

H2 is rejected for process B. Run time productivity is significantly affected by both batch size and seasonality. The regression model is highly significant at the 0.000 level, the adjusted $R^2$ value is 0.47, and all of the regression model coefficients are significant at the 0.005 level. Larger batches result in higher productivity, and lower productivity occurs during the peak season.

9.3. Saleable product / (changeover plus run time)

H3 is rejected for the overall models and batch size. The seasonal coefficient is only significant for process B. When products are run in the natural cycle sequence in process A the regression model is significant at the 0.006 level, the adjusted $R^2$ is 0.36, and the batch size coefficient is significant at the 0.005 level. Stronger results are observed when products are run out of the natural cycle sequence. In this case, the regression model is highly significant at the 0.000 level, the adjusted $R^2$ is 0.55, and the batch size coefficient is significant at the 0.001 level.

Similar results were observed for process B. The regression model is highly significant at the 0.000 level, the adjusted $R^2$ is 0.53, and all model coefficients are significant at the 0.01 level.

9.4. Saleable output / total time

H4 is rejected for the overall models and for batch size and season as well. The total time to process an order includes changeover, run time, and any non-scheduled process down time. Because of process conditions, downtime is especially prevalent during the peak season in the company studied. In this case, similar results were observed in both process A and B. When products are run in the natural cycle sequence in process A, the model is significant at the 0.002 level, the adjusted $R^2$ is 0.45, and the batch size and seasonal factor are significant at the 0.025 and 0.004 levels, respectively. When products are run out of the natural cycle, the model is highly significant at the 0.0003 level, the adjusted $R^2$ is 0.47, and all of the model coefficients are significant at the 0.022 level.

Stronger results are observed for process B. Here, the model is highly significant at the 0.000 level, the adjusted $R^2$ is 0.46, and all of the model coefficients are significant at the 0.0075 level.

9.5. Contribution margin / process hour

H5 is examined by constructing contribution margin curves under the theory of constraints accounting framework (Spoede, 1996; Campbell et al., 1997). The contribution margin per process hour curves plotted in Fig. 2 were derived using the regression models for productivity and product yield, and relevant variable cost factors for process A for the case when products are not run in the natural cycle sequence. This was accomplished using Eq. (2).

$\text{ Contribution Margin / Process Hour } = \frac{(p_2 - (ux/r) - cx)}{(x/r)} \quad (2)$

where $p$: unit price; $x$: saleable product quantity; $x$: production batch size; $z$: saleable product/product yield; $v$: variable process cost/process hour $^5$; $r$: process productivity (units/process hour); $c$: raw material cost per unit.

$^5$ Only costs which vary with process hours at the research company were considered in this analysis, e.g., crew labor, utilities, etc. No fixed or allocated costs were included in this model. This is consistent with recent work concerning Activity-Based Costing and the Theory of Constraints (Campbell et al., 1997; Spoede, 1996). In other applications of this methodology where such processing costs do not vary with process hours, this term should be omitted from the model.
calculate the $r$ value in the contribution margin per process hour function shown in Eq. (2).

The contribution margin per process hour curves shown in Fig. 2 reflect the regression model results for process A for different pricing strategies. These curves support the direction hypothesized in H5A. Similar results would be observed if other combinations of the regression equations shown in Table 1 were used to determine the contribution margin/hour for processes A and B.

10. Discussion of the results

In the research company, production batch size has a major impact on productivity in all but one case for both processes. The production of small batch sizes results in a decrease in overall process productivity. This is illustrated by the results shown in Fig. 3 for process B when changeover plus run time is considered. In this case, batch sizes smaller than 3 million units result in an important productivity decline in both peak and off seasons. The productivity loss for small batches is explained not only by process changeovers, but also by the loss of productivity during run time. This is illustrated in Fig. 4. Slower line speeds, process adjustments, and process down time can all affect process productivity when small runs are processed. These results demonstrate the difficulty that a process designed for high volume batch operation has in operating profitably under small batch sizes.

Likewise, the product yield results in Table 1 illustrate that the proposed methodology can indicate those process conditions where variables such as batch size do not affect manufacturing performance. For example, when products are run in the natural cycle sequence in process A, batch size does not significantly affect either product yield or run time productivity. This means that sufficient process flexibility exists (without adverse cost and margin effects) to accommodate market requirements for in-
creased product variety when quick customer response is not a critical factor, and products can be processed within the natural cycle.

The regression results from the research company also illustrate the utility of this methodology in measuring the performance impact of other types of process variables. The seasonality and natural cycle results illustrate this point. In process A, running product out of the natural cycle sequence during the peak season produces a marked decline in both

![Fig. 3. Process B productivity (output/CC + run time).](image)

![Fig. 4. Process B productivity (output/run time).](image)
overall productivity and product yield. Such results illustrate the lack of manufacturing flexibility in this company to run low volume products, or fill small Just-In-Time orders, on a high volume batch process.

All of these results demonstrate the utility of the proposed methodology in capturing relevant cost and contribution margin information for use in strategic decisions involving pricing and process choice in high variety/low volume markets. In the following discussion, we provide examples that illustrate the use of the proposed methodology in pricing and process choice decisions involving high variety/low volume products. These examples indicate the importance of understanding the cost and contribution margins for low volume products when a marketing strategy of high variety is contemplated.

The curves shown in Fig. 2 are plotted using an example from the field study in this research to illustrate the possible business consequences of increased product variety in case 4 of the framework shown in Fig. 1. Since the current process choice best supports the production of high volume products in long runs, the contribution margin per process hour is substantially reduced for batch sizes smaller than 2 million units. Products involving batch sizes less than 2 million units contribute low or negative margins.

This example illustrates the manner in which this methodology can be used in the analysis of pricing strategy. Consider the case when a price premium can be obtained on the basis of value added products in particular market segments as in the situation of case 2 of the framework in Fig. 1. This is illustrated by the proposed premium pricing, e.g., an increase of 40% in Fig. 2. Because of the premium pricing, the process is able to support new products having batch sizes as small as 1 million units with contribution margins approximating those at 4 million units under the alternative pricing strategy. When a price premium can be charged, the curve for case (4) in Fig. 2 moves upward and is labeled case (2). This shift in pricing strategy extends the range of batch sizes and product variety that can be supported at a given profit level by the high volume

![Fig. 5. Process A—investment effect.](image)
batch process. These two pricing strategies are used for illustrative purposes. In practice, many different pricing strategies could be considered using the proposed methodology.

This example can also be used to illustrate the type of analysis which could be developed when a new process investment is proposed that would provide the manufacturing flexibility needed to support a strategy of increased product variety. An example of this is shown for case (4) in Fig. 1. If an investment in a proposed low volume batch process were made, the contribution margin per hour curve would shift upward as indicated in Fig. 5. The proposed new investment provides an increase in the range of production order sizes (product variety) that would produce a given level of profit for the company. Under the proposed process investment, batch sizes as low as 1.5 million units provide approximately the same level of contribution margin per hour as batch sizes of 4 million units in the current process; thereby extending the range of product variety supported by the process.

Finally, the methodology could be extended to cover instances in which production batch sizes are run which exceed the customer order sizes. One way of incorporating this assumption in the analysis is by introducing an inventory carrying cost term in Eq. (2) to reflect the creation of cycle stock. Fig. 6 provides an example of such analysis, assuming a 25% inventory carrying cost and annual demand of 2,000,000 units. Comparing Figs. 2 and 6, order sizes smaller than 4,000,000 units produce low contribution margins, and the pricing policy has a major impact on profitability. However, in this case, production batch sizes larger than 4,000,000 units are also unattractive because of the magnitude of inventory carrying costs. In this example, the contribution margin/hour effect is most pronounced for small

\[ \text{inventory carrying cost term} = \frac{i}{r + cx/z} \]

where: 
- \( a \) = annual demand (in units); 
- \( i \) = inventory carrying cost rate (percent of item cost per year).
volume products under high inventory carrying cost percentages.

Likewise, the methodology proposed here could be extended to include cases involving the joint analysis of price discounts and production batch sizes. While there is a substantial literature on the issue of quantity discounts, very little of this work considers the detailed effects of process yields and productivity caused by changes in production order quantities, or the effect of differences in process choice (Weng, 1995). Process modeling of the type shown in Table 1 and Eq. (2) is needed in order to adapt the quantity discount analysis to reflect process effects.

11. Conclusions

The regression results demonstrate that the opportunity to gain competitive advantage through a strategy of increased product variety can be heavily dependent on achieving the proper alignment between marketing and manufacturing strategy. The key marketing and manufacturing strategy issues explored here using the proposed product variety framework and methodology involve: (1) process and infrastructure investments to improve the alignment between process choice options and market requirements, (2) pricing strategies to provide adequate margins for increased product variety, and (3) the use of inventory investment in cycle stock to enable longer production runs.

The methodology presented here provides a means of determining the unfavorable impact on business performance that can result from using an inappropriate process choice (high volume batch) to support a market characterized by low volume/high variety products without price enhancements, e.g., as in the Plastech case (Leschke, 1995). In the illustrations above, it is clear that products involving batch sizes smaller than 4,000,000 units can adversely affect process productivity, product yield, and contribution margin. While the specific results shown in this paper are only relevant to the firm studied, these results are intended to demonstrate the type of information needed in debating pricing and process investment decisions in market and product selection. This framework and methodology can provide the basis to determine appropriate pricing and process investment decisions, and to set achievable sales revenue and profit objectives for particular markets and products in many company settings.

It is important that debate concerning the strategy of increased product variety be based upon an accurate measure of the manufacturing flexibility requirements needed to support the contemplated range of product volumes. Further, it is critical that relevant process choice investment options, often involving new investment, be considered which would bring the marketing and manufacturing strategies into alignment. As an example, the processes studied here involved high volume flows of material that are difficult to change quickly. Thus, changeover time and cost are not trivial. The company had previously examined and installed improved methods for making changeovers efficiently. Even with these improvements, small order sizes produce adverse cost and margin results. This illustrates the need to evaluate changeover time and cost carefully in strategic decisions involving increased product variety and manufacturing flexibility. In many instances, new process investments are required to best support market requirements for increased product variety.

The methodology illustrated in Figs. 2 and 5 can provide important data to facilitate debate concerning the strategy of increased product variety. The proposed methods provide a way of determining the range of batch sizes that would produce a given level of profit. The impact of alternative pricing and process investment options on the range of profitable batch sizes can be tested using this type of analysis in assessing marketing and manufacturing strategic alternatives. Changes in pricing will shift the curves in Figs. 2 and 5 in a vertical direction while changes in process investment can change the shape of such curves. Likewise, a strategy of extending production order sizes to support a strategy of increased product variety, through investment in cycle stock, can also dramatically affect the range of production order sizes that produce a given level of profit.

The analytical framework and methodology presented in this paper provides a way of measuring manufacturing flexibility in terms of the complex cost relationships often encountered with process changeovers, product yields, and differences in run productivity that depend on product volume and
variety. This methodology and approach is general in nature and can be used in a wide variety of manufacturing processes to measure the impact of those factors which affect process productivity, product yield, and profitability. It is important that businesses contemplating a strategy of increased product variety employ such a methodology to provide relevant cost and contribution margin data. Further research in this area would include: testing the methodology in different industries, the analysis of different types of production processes, and the consideration of different types of investments to support a strategy of increased variety.

References

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