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MEASURING MANUFACTURING FLEXIBILITY: THE IMPACT OF PRODUCT MIX ON MANUFACTURING OVERHEAD COST

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The Impact of Product Mix on Manufacturing Overhead Cost

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SYNOPSIS AND INTRODUCTION

Managers of manufacturing firms cite the ability to produce a wide range of continually changing products with minimal degradation of performance as the most critical manufacturing capability for future success (Slack 1987; De Meyer et. al. 1989; Stewart 1992). Operations researchers include this capability in myriad definitions[1] of manufacturing flexibility (Slack 1984,1987; Gerwin 1987; Gupta and Goyal 1989; Sethi and Sethi 1990). However, despite its salience as a management objective and its exhaustive categorization by researchers, consistent measures of flexibility do not exist. Measures that have been proposed by researchers (Sethi and Sethi 1990; Roll et. al. 1992) are not widely used by managers.

That product mix flexibility is an "invisible" objective is not surprising given the explosion of criticism levied at traditional performance measurement systems (Drucker 1990; Kaplan and Norton 1991; Eccles 1991; Eccles and Pyburn 1992; Nanni et. al. 1992). Moreover, Slack's (1987) finding that managers do not view flexibility as a goal in itself, but rather as a means to achieving objectives such as customer satisfaction, may explain why measures of flexibility are not among the "bottom drawer", nonfinancial measures used by operating managers (McKinnon and Bruns 1992). If so, it strengthens Eccles and Pyburn's (1992) criticisms that performance measures often are not grounded in an underlying model of the business process and frequently focus on process outcomes--- lagging indicators--- to the exclusion of intermediate results.

One approach to measuring flexibility is assessing the impact of realized demands on the performance of existing operations (Son and Park 1987; Gupta and Goyal 1989; Sethi and Sethi 1990; Roll et. al. 1992). Researchers in economics, operations management and management

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[1] In their comprehensive review, Sethi and Sethi (1990) identify 11 fundamental forms of flexibility from over 50 types of flexibility discussed in the operations literature. The four forms of flexibility examined in this study are: process flexibility, the ability to produce a wide range of products without major setups; product flexibility, the ability to add new products at low cost; volume flexibility, the ability to operate profitably at different volumes; and market flexibility, the ability to adapt to changing market conditions. The seven forms of flexibility: machine, material handling, operation, routing, expansion, program and production flexibility, are not relevant to this study. As Slack (1987) argues, all flexibilities are not equally important in all production environments. The nature of the textile weaving process and the longitudinal research design of this study mitigate variation on these dimensions.

accounting have developed theories that relate manufacturing cost and operating performance to product mix breadth and change (Skinner 1974; Panzar and Willig 1977; Willig 1979; Panzar and Willig 1981; Hayes and Wheelwright 1984; Hill 1985; Miller and Vollmann 1985; Johnson and Kaplan 1987; Cooper and Kaplan 1987; Karmarkar and Kekre 1987; Kekre 1987; Banker et. al. 1988). These theories typically predict that producing a broad, changing mix of heterogeneous products increases costs and reduces operating performance. Manufacturing overhead costs (all costs except direct material and, for some firms, direct labor) are hypothesized to increase disproportionately to other production costs as a result of transactions caused by complex material flows, balancing diverse demands with capacity, quality control, and change (Miller and Vollmann 1985).

Although theory predicts that product mix heterogeneity and change impair performance and increase manufacturing costs--- that plants typically are not flexible--- the empirical evidence is mixed (Hayes and Clark 1985; Foster and Gupta 1990; Kekre and Srinivasan 1990; Datar et. al. 1993; Banker et. al. 1990; Banker and Johnston 1993; Banker et. al. 1992; Cooper et. al. 1992). One explanation for why the hypothesized relation between product mix and performance is not discovered consistently may be that the variables used to capture product mix breadth and change are inadequate. Specifically, variables commonly used to capture the range of products produced (e.g. number of products produced), changes to existing products (e.g. number of engineering changes), and additions of products (e.g. number of product introductions) fail to distinguish similarities and differences among products. The prominence of product similarities and differences in theories of economies of scope, focused factories, and activity-based costing, suggests that this failure may lead to poorly specified tests of theory.

This paper uses an approach developed in the group technology field of operations management to create a measure of product mix heterogeneity that distinguishes products on the basis of similarity. The hypothesis that manufacturing overhead costs are related to product mix heterogeneity is tested using monthly data from 1986-90 for three weaving plants of a leading U.S. textile firm. The paper makes three contributions to the emerging literature on manufacturing flexibility. First, the paper develops a measure of product heterogeneity that incorporates product similarities and differences. Second, the paper estimates the longitudinal relation between product mix complexity and manufacturing overhead cost, and compares the

flexibility of three plants facing different levels of product mix complexity. Thus it complements papers that use cross-sectional or longitudinal analysis alone (Foster and Gupta 1990; Banker et. al. 1992; Cooper et. al. 1992). Finally, the paper provides evidence on sources of increased flexibility. Adler (1988, 51) claims that:

> For managers, flexibility is potentially advantageous--- and indeed, only becomes meaningful as a concept--- against a backdrop of stabilities. The managerial question is therefore not simply how to reduce rigidities, but how to find the right mix of stabilities and flexibilities.

By disaggregating products into the underlying characteristics that influence manufacturing, the paper identifies forms of product mix complexity that are costly--- product variety that generates differences in how the production process is operated and differences in quality requirements--- and that are not costly---product variety created by new combinations of existing material inputs. Moreover, the paper offers weak evidence of "variety-based learning"--- that experience producing a wide range of continually changing products mitigates the cost of product mix heterogeneity.

Key Words: Manufacturing Overhead Cost, Product Mix Complexity, Flexibility, Textile Industry

Data Availability: The author signed a confidentiality agreement with the firm that contributed data for this study that precludes revealing the firm's identity and disseminating data without the firm's written consent.

The paper is organized in five sections. Section 1 reviews previous efforts to measure the impact of product mix complexity on manufacturing costs and suggests an alternative approach for measuring product mix complexity. Section 2 describes the research sites and Section 3 outlines the research methodology. Tests of the relation between product mix heterogeneity and manufacturing overhead cost are provided in Section 4. Section 5 summarizes the paper's contributions.

I. PRODUCT MIX AND MANUFACTURING OVERHEAD COSTS

The Economics of Multi-product Production

Economies of scope exist when the cost of producing N products in a single facility is less than the sum of costs to produce the same products in N single-product facilities (Panzar and Willig 1977; Willig 1979; Panzar and Willig 1981). There are two sources of economies of scope: fixed costs that are common to many products and cost interactions among products. When large fixed costs accompany production, when individual product demand is insufficient to fully utilize these fixed resources, and when application-specific resources are not readily "rented" to an alternate user, shared fixed resources generate economies of scope in multi-product production (Teece 1980). While shared, application-specific fixed costs create economies of scope, cost interactions may increase (diseconomies) or decrease (economies) total production costs. Costs are minimized with joint production if cost interactions reduce production costs, or if cost interactions increase production costs by less than the amount of fixed costs required to operate multiple facilities (Gorman 1985).

Empirical efforts in economics (Baumol and Braunstein 1977; Pulley and Braunstein 1992) center on determining economies of scope by econometric estimation of the joint production cost function. This approach is fruitful when a limited number of products or product families are produced with few inputs for a lengthy period. However, in the more common production environment of several hundred products produced in ever changing combinations, data limitations typically cause the joint cost function to be under-identified. Accounting researchers circumvent this problem by adopting the more modest goal of estimating total interaction costs, rather than interactions between individual products. They identify probable interaction costs--- manufacturing overhead costs (MOHC) --- from firms' accounting records and relate these costs to product mix complexity (Foster and Gupta 1990; Banker et. al. 1992; Cooper et. al. 1992).

Empirical efforts to assess the costs of product mix complexity have yielded mixed results. Kekre and Srinivasan (1990) find no evidence that a broader product line is correlated with higher manufacturing costs and conclude that U.S. firms may be as flexible as needed given the market's demand for product variety. In the first plant-level study, Foster and Gupta (1990) find no relation between product mix complexity and manufacturing overhead costs in 37 plants of an electronics manufacturer after scale differences are removed. Banker et. al. (1992) find evidence of a relation between overhead costs and variables that indicate the presence of product mix complexity: engineering changes, batch sizes, and cycle times; but find no relation between costs and the number of products produced. Cooper et. al. (1992) estimate the cost function for an increasingly complex product and process by substituting a complexity-adjusted index of production output for unadjusted output measures. Complexity-adjusted output outperforms unadjusted output and they assert that the coefficient on complexity-adjusted output measures significant costs of product and process complexity.[2]

Product Mix Heterogeneity

Though circumventing the problem of estimating individual cost interactions, methods used by accounting and operations researchers to estimate the net effect of product interactions

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[2] Banker et. al. (1990) and Datar et. al. (1993) take a different approach of first assigning overhead costs to individual products and then estimating the relation of the revised product costs to product characteristics. By using revised product costs as the unit of analysis, they treat MOHC as separable in products and estimate costs of *product* complexity rather than joint costs of *product mix* complexity.

create the new empirical challenge of measuring product mix complexity. Typically two types of variables are used: those that are the result of product mix complexity (i.e. number of engineering changes and vendors); and, variables that are crude measures of product mix breadth (i.e. number of products, component parts, and production batches). None of these variables measure product similarities and differences, the hypothesized source of economies of scope and the proposed object of "factory focus" (Skinner 1974; Hill 1985).

The group technology literature of operations management offers an alternative method for directly assessing product mix heterogeneity. Developed as a means for classifying products on the basis of production and design similarities, group technology assumes that products are uniquely described by a well-defined but limited set of N attributes (Hyer and Wemmerlov 1984).[3] Wilson and Henry (1977) identify two categories of attributes used to assess similarity for purposes of group formation: "graphical" data describe the product in engineering terms, and "manufacturing" data describe process specifications for producing the product. The difficulty of implementing group technology is determining the relative importance of different attributes, and establishing the optimal number and composition of groups--- known in the operations research literature as the "cell formation problem" (Miltenburg and Zhang 1991). However, since the objective of this study is description of product attribute space and assessment of the breadth of attribute space occupied by a product mix, it is possible to use the conceptual strengths of group technology--- describing product attribute space--- without inheriting its implementation problems.

The relevant product attributes for determining the impact of product mix on manufacturing overhead costs include both "graphical" parameters that define the product, and process parameters that specify how the product is to be produced. If a product is defined by N attributes, product heterogeneity arises when the N-attribute vectors of two products differ.

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[3] One application of group technology is "cell manufacturing". Products are classified on the basis of manufacturing requirements and clusters of similar products are co-located in the plant. Aggregating groups of similar products simplifies material flows, reduces WIP inventories, and concentrates responsibility for individual products (Burbidge 1989).

Product-mix heterogeneity arises when heterogeneous products are produced by a plant in a specified time period.

Linking Product Mix Heterogeneity and Manufacturing Overhead Costs (MOHC)

The plants of this study operate many identical, parallel machines. Consequently, product mix heterogeneity arises with simultaneous and sequential production of different products. Relating simultaneous and sequential product mix heterogeneity to plant overhead costs yields a measure of flexibility: uniformity of performance.[4] A flexible manufacturing facility produces a wide range of continually changing products with consistent, low MOHC.

One avenue through which product interactions affect overhead costs is in simultaneous production of heterogeneous products. Skinner based his arguments for factory focus on the belief that product variety engenders confusion and goal incongruence among production workers and creates demands on management to resolve the ensuing conflicts. Proponents of cell manufacturing argue that co-locating similar products improves performance by reducing the need for coordination and by concentrating responsibility and authority at the point of production (Burbidge 1989).

The impact of sequential product heterogeneity on overhead costs is twofold: fixed effects and sequence dependent effects of setup. Sequential product mix heterogeneity requires machine setups between batches of different products. Although a "fixed" level of downtime is typically associated with all setups, an additional variable component of setup time may depend on the "origin" and "destination" products (Bitran and Gilbert 1990; Upton 1991). The minimum cost path of producing several products on a machine is a sequence that maximizes similarity of

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[4] This definition of flexibility is Upton's (1991) multi-product analog to Stigler's (1939) definition of flexible technologies. Stigler defines a flexible technology as one with a relatively flatter average cost curve over a wide range of output quantities. Though a less flexible technology might offer lower average costs at some particular output, X^*, in the presence of demand uncertainty that is resolved after the technology choice is made (Marschak and Nelson 1962) the more flexible technology offers lower expected costs for the distribution of expected demand.

adjacent products according to one or several critical attributes. If similar products are produced sequentially, performance is higher than if different products are produced.

MOHC is hypothesized to be lowest when products are tightly clustered in attribute space with little change from period to period--- products reflect a consistent set of manufacturing priorities, fixed and sequence dependent setup costs are minimized and cross-product learning is maximized.

II. RESEARCH SITES

The research sites are three weaving plants of a leading U.S. textile manufacturer, "Weaving Industries". During the period of this study, 1986-1990, the firm was recognized in the trade and business press as being well managed. Even so, like its U.S. competitors, Weaving Industries experienced declining demand for its high volume products. The erosion of commodity markets in combination with demands for greater customization accelerated product proliferation in Weaving Industries' product lines. The following section uses qualitative and quantitative data obtained during field visits to describe the plants and provide a context for interpreting subsequent results.

Plant Profiles[5]

The three plants, referred to as A, B, and C, are cost centers of the firm's Woven Fabric manufacturing division. The firm operates many plants with similar technical capabilities and limits each plant's product range through a facilities focus strategy. The focus strategy for the Woven Fabrics Division assigns each plant a raw material specialty. Plants A, B, and C specialize in products made of inputs 1, 2 and 3, respectively. In addition to its specialty, Plant C is a "swing" plant, used to balance capacity utilization across all three plants.

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[5] Technical terms used in subsequent discussions are typed in capital letters in their first use.

If management limits a plant's product range, its facilities focus strategy and its scheduling practices determine whether observed product mix variation is adequate to reveal the hypothesized relation between product heterogeneity and overhead costs. Weaving Industries' broad product offering does not limit the plant's product range; however, its facilities focus strategy and production scheduling practices do. Plants A and B, specialize in weaving products of inputs 1 and 2, respectively. Plant C which specializes in input 3 but frequently weaves products of inputs 1 and 2 promises the greatest range of observed variety. Production planning permits firm intervention in the composition and timing of demand; however, the scope of these interventions is limited. Fabric demand is heavily influenced by "fashion"; it is fleeting and if not quickly satisfied, evaporates. Thus, if demand is badly forecasted schedulers modify the schedule to align demand and production. Consequently, the plants experience significant product mix change even within the bounds of their assigned facilities focus.

Located in small towns in the textile intensive southeastern United States, the plants employ nonunion workers and pay identical wages for comparable job classifications. Self-sufficient production teams of four to five employees are responsible for approximately 100 looms each and with few exceptions the plants operated 24 hours a day seven days per week throughout the period. Absenteeism was less than one percent annually during 1986-90.

As a result of normal promotions, the plants have been marked by high management turnover; Plants A and B had four and Plant C three plant managers from 1986 to 1990. In contrast, the engineering and administrative staffs were stable. Consistent with industry averages, turnover among hourly employees was 20-25 percent annually for all three plants.

The plants were built within a decade of each other and there is little to distinguish the physical facilities or infrastructure. Finally, the production equipment is the same make and vintage, reflecting the firm's decision in the early 1980's to upgrade to an advanced weaving technology. The plants acquired the majority of their looms at the same time (mid-1984) from the same vendor. Plant B has the largest number of looms, L, followed by Plant C, with .91L and

Plant A with .83L.

The plants use the same advanced weaving technology. Weaving is the process of interlacing lengthwise WARP yarns and cross-wise FILL yarns at right angles.

[Insert Figure 1 here]

Warp yarns are wound onto a metal core, called a WARP BEAM, in an upstream process. During machine setup, the warp beam is mounted in the LOOM in an operation known as a DRAW setup. Alternatively, if a second batch of a product is produced on a machine, the threads of the new warp beam are tied to those of the exhausted beam and pulled through the loom. This minor form of setup is called a TIE. The loom raises and lowers alternate warp yarns and inserts the fill thread to form a panel of fabric. The finished fabric is wound onto a CLOTH BEAM. Next the woven fabric is visually inspected, packed and shipped.

In sum, the plants are virtually indistinguishable along dimensions known to affect operating performance and cost; specifically, employee skills and work practices, equipment age and type, and plant facilities and infrastructure. In contrast as the following section demonstrates, the plants have experienced different levels of product mix variety, caused in part by their different "focuses".

Product Mix Variety

From 1986 to 1990, the range of products that Plants A, B, and C produced each 4-week period increased and the stability of the product mix from period to period decreased.[6] Growth in the number of products produced over the five years provides a crude approximation of increasing product range. The different ways that product heterogeneity emerged are highlighted by examining the number of products produced using three definitions of "product": 1) a warp beam; 2) a unique combination of a warp beam and a fill thread; and, 3) warp beam and fill

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[6] Throughout the paper a production "period" is defined to be four weeks, or approximately 28 days. Each calendar year includes 13 periods and the study encompasses five years, or 65 periods.

thread combinations that exclude different generations of a product.

[Insert Table 1 here]

Controlling for minor differences in plant scale (number of looms), Panel A of Table 1 characterizes the growth of product variety, by treating as a single product all products that share common warp beams. Each plant experienced increased product mix breadth, with Plants B and C having the highest level of product variety by the end of the period.

Panel B characterizes product variety by treating unique warp-fill combinations as a different product. Again, product variety increased for all of the plants, although this increase took different forms. Comparing Panel A to Panel B, Plant B proliferated products by combining different fill threads with existing warp beams. The ratio of warp-fill combinations (Panel B) to warps (Panel A) indicates that on average warps are combined with two fills in Plant B, as compared to 1.5 for Plants A and C. In the language of manufacturing, Plant B proliferated products using common components.

Over time products undergo generational change. In theory the new generation replaces the old; in practice some customers are unwilling to adopt the new generation. As a result, generations of a product may coexist. Panel C characterizes product variety by treating generations of a unique warp-fill combination as one product. Comparing Panels B and C highlights differences between the plants in how product heterogeneity emerged. In 1986 one third of the products that Plant B produced were generations of existing products. This compares to one tenth and one seventh for Plants A and C, respectively. Differences are less pronounced but still present by 1990. Again, Plant B's product mix is substantially more homogeneous than either Plants A or C despite producing a large number of products.[7]

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[7] One facet of product variety not addressed by Table 1 is the distribution of products over operating capacity. Examining the share of operating machine hours dedicated to the highest volume product revealed no difference among the plants. Approximately 20 percent of capacity was devoted to producing the highest volume product in 1986, falling to 17 percent by 1990. Thus the plants concentrate a substantial share of machine hours on one product and concentration declined slightly with increased product variety.

Table 1 indicates growth in the range of products produced in a period. It does not address product mix change. A crude measure of product turnover, computed by dividing the number of products produced in five years by the average number produced each period, indicates the degree to which increasing product mix variety was accompanied by changing product mix composition (Table 2). Product mix change surfaces in all three plants; however, Plant C was marked by significantly more change than either A or B. Removing the effect of generational change, Plant C produced six entirely different product portfolios from 1986 to 1990. In contrast, Plants A and B produced 3.4 and 3.9 product portfolios in the same period.[8]

[Insert Table 2 here]

The plants experienced similar levels of growth in the number products produced; however, this similarity masks important differences in how product variety emerged. Plant A produced a small number of heterogeneous products that were rarely produced from common warps or generations of existing products. Plant B went from having the fewest to having the most products. However, despite dramatic growth in the number of products, product heterogeneity was minimized by proliferating through incremental change to existing products---combining new fills with existing warps and modifying products through generational changes. Plants A and B had similar low levels of product mix change. In contrast, Plant C experienced the same dramatic growth in the number of products as Plant B but was unable to contain product mix heterogeneity. Products produced in a period were dissimilar and changed substantially from period to period. This volatility is consistent with its role as the "swing" plant in the firm's focus strategy. Differences in the plants' level of simultaneous and sequential product

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[8] An empirical question is whether "change" reflects introductions of new products or production discontinuities that interrupt a product's lifecycle. For example, Panel B of Table 1 indicates that Plant C produced 404 products in five years, on average producing 53 different products each period. This might mean that products run for 8.6 periods (65 periods/7.6 turns) before being discontinued. Alternatively products might run one period every 7.6 months, a total of 8.6 periods over five years. Comparing the duration of continuous product runs, short product runs are prevalent for all three plants; approximately 10 percent of all production runs were completed in one period and 50 percent were completed in fewer than four periods. Thus erratic production schedules are as much to blame for product mix instability as new product introductions.

mix heterogeneity provides a powerful research design for testing the impact of product mix heterogeneity on MOHC.

[Insert Figure 2 here]

Manufacturing Overhead Costs (MOHC)

Weaving Industries defines manufacturing overhead costs as all costs except direct material and material waste.[9] Manufacturing overhead costs are classified as variable or fixed and (excluding depreciation and corporate allocations) typically account for 75 and 25 percent, respectively, of total manufacturing overhead charges for the three plants. Variable manufacturing overhead costs, the subject of this paper, are reported at two disaggregate levels: ledger accounts and consuming departments. Accounting ledgers segment costs by type; often distinguishing resources with different acquisition patterns. Departmental reports segment variable manufacturing overhead costs on the basis of reporting relationships among workers and supervisors. In the case of Plants A, B, and C, the departments correspond to stages of the production process. This paper examines the relation between product mix heterogeneity and variable manufacturing overhead costs at three levels: i) total MOHC, ii) ledger entries from eight major accounting classifications, and iii) departmental costs for four departments.

[Insert Table 3 here]

The MOHC data are the plants' historical accounting records from 1986-90. Table 3 links ledger classifications and departments and indicates the average relative magnitude of each for the plants during the period (Appendix A describes the ledgers and departments). An 'X' indicates that a department typically incurs costs of a particular type each production period. The plants exhibit similar spending patterns across departments and ledger categories. With the exception of the technical support department (an amalgam of three departments that together are consistently defined across plants), the plants use identical ledger categories and functional

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[9] The practice of treating even "direct" labor as manufacturing overhead is common among firms with advanced manufacturing technologies or high-commitment personnel strategies (Berlant et. al. 1990).

departments in accordance with definitions developed by corporate accounting. Consistent treatment of costs is assured through centralized accounting at the division level; the plants have little discretion in recording ledger entries.

Summary

The challenge of field-based research is finding research sites that differ in the variable being studied but are similar along other dimensions. As this section demonstrates, Plants A, B, and C are similar along dimensions previously shown to impact performance. At the same time the plants have experienced different levels and rates of growth of product variety. Similarities among the plants minimize confounding effects of variables that fall outside the research domain while differences provide the basis for measuring the impact of product variety on manufacturing overhead costs.

III. RESEARCH METHOD

Three preparatory steps are necessary to test the relation between MOHC and product mix heterogeneity: 1) Identifying product attributes; 2) Constructing measures of product mix heterogeneity; and, 3) Conducting time series analysis of MOH and product mix heterogeneity measures to remove predictable seasonality and persistence from the series. The following sections describe the methods and intermediate results of each step.

Identifying Product Attributes

Group technology uses engineering parameters and product-specific process specifications to assess product similarities and differences (Wilson and Henry 1977; Hyer and Wemmerlov 1984; Burbidge 1989). Interviews with engineers and production workers revealed that product specifications for woven fabrics fall into four categories: those describing 1) warp and fill threads 2) warp beam construction 3) how the warp and fill are combined, termed "fabric construction" and 4) product-specific process specifications (Appendix B). Each category includes several parameters. The problem, evident in employees' descriptions of woven fabric is that the specifications are not independent and are too numerous to incorporate simultaneously in tests of the impact of product mix on MOHC. Common factor analysis is used to reduce the product specifications to a parsimonious set of attributes that retain the information of the original data (Harmon 1976; Rummel 1970).

One test of whether a common factor model is reasonable is that partial correlations between pairs of variables controlling for all other variables are smaller than the original correlations between the variables. Kaiser's measure of sampling adequacy ($0 \leq \text{MSA} \leq 1$), measures the amount by which original correlations are reduced when additional variables are included. The product and process variables have a high overall MSA of .81, indicating that a common factor model is reasonable and that the variables adequately define product attribute space.

The maximum likelihood method[10] of extracting common factors is used to identify a smaller set of orthogonal product attributes from engineering specifications of products produced from 1986 to 1990 (Table 4). The maximum likelihood method was chosen because, if as in this study an entire population is analyzed, the data are not required to be multivariate normal and the factor solution obtained is invariant to the scale of the raw data. Moreover, "the appropriate number of factors will be those with eigenvalues greater than or equal to unity" (Rummel 1970, 122). The resulting factor solution is rotated using the varimax rotation criteria of minimizing the number of variables contributing to each factor.

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[10] Factor analysis is performed using the FACTOR (Method=ML, Priors=SMC) and SCORE procedures of the SAS software package (ver. 6.02). The maximum likelihood methodology "is equivalent to Rao's (1955) canonical factor solution" (SAS User's Guide: Statistics 1985, 340). Estimated communalities used to start the iterative procedure are squared multiple correlations, the best value when a population of cases is examined (Rummel 1970, 122). The iterative procedure weights individual variables by the reciprocal of unique variance; thus variables with the greatest portion of their variance in common factor space are most influential in defining factor space. Iteration stops when successive factor loadings agree to within .001 (Harmon 1976, 207-11).

[Insert Table 4 here]

Two criteria are used to evaluate goodness-of-fit of the factor model. One is the extent to which the model predicts actual correlations between variables. The square root of the mean squared difference between predicted and actual correlations of the variables with one another measures this aspect of fit. A value of .02 for the factor solution is evidence of a good fit between the estimated model and actual product data. A second test of goodness-of-fit is that correlations among variables, removing the effects of common factors, are approximately zero. The square root of the mean squared partial correlations for all variables with one another provides a measure of this aspect of fit. A value of .07 for the factor solution supports the model.

The correlation between variables and factors equals the variable's factor loading. Thus factor loadings are an appropriate basis for interpreting the seven factors. Factors are interpretted by examining the variables that weigh heavily in the factor solution and the patterns that emerge when scores of each product produced during 1986-90 are plotted for each plant.

The dominant factor that emerges to explain product variation distinguishes differences in products' raw material content. The factor is strongly influenced by whether the warp and fill threads of a fabric are made of input 1 or 2, the specialities of Plants A and B, respectively.

The second factor differentiates products on the basis of fabric weight. This factor is influenced by the weight of a linear yard of fabric, which in turn is correlated with the weight of constituent warp and fill threads, the density of fabric construction, and the warp contraction that results from intertwining warp and fill threads.

Factor 3 distinguishes products on the basis of expected machine downtime as reflected by the product-specific rated machine efficiency and expected machine stop level. A critical source of downtime and off-quality fabric is thread breakage, or the "machine stop level", expressed as breaks per 100,000 picks. Stop levels are statistically predictable given the thread thickness (denier); the thicker the thread the lower the expected downtime. Breakage rates may be reduced by adding extra sizing to strengthen the warp threads or by running the machine slower to reduce the force on the threads. Thus Factor 3 is positively related to the amount of size applied and negatively related to machine speed.

The fourth factor segments products based on warp beam construction. Warp beam length, machine speed and fabric density (picks per inch) determine the batch size and throughput time for a typical production run. The diameter of the full warp beam is limited by the loom's capacity. Given the permissible warp beam diameter, warp beam length is determined by the denier (thickness) of individual warp threads and the number of individual threads on the beam (as measured by the weight of warp threads in a linear yard of fabric). Thus Factor 4 is heavily influenced by warp length, warp denier, warp weight, and because warp thread comprise approximately half of fabric weight, by fabric weight.

Factors 5 and 7 distinguish differences in fill and warp thread constructions, respectively. Both factors are influenced by denier or thickness of individual fill and warp threads. In addition, Factor 5 depends on whether the fill is "finished" or treated to have a luster or shine and Factor 7 depends on how many individual warp filaments are twisted together to form a single, stronger warp thread.

Factor 6 distinguishes products based on their defect tolerance. Standards for acceptable quality depend on a product's eventual use. For example, fashion fabrics typically are produced to tighter tolerances than industrial fabrics. An artifact of the firm's product mix is that the highest quality standards are required by customers for high density (picks per inch) fabrics--- thus the relation of Factor 6 to fabric density.

[Insert Figure 3 here]

Figure 3.a-g illustrates differences in the plants' product mixes during 1986-90 for each of the seven product attributes. Each point represents the factor score of a single product that was produced in the plant during 1986-90. Consistent with the firm's facilities focus strategy, products produced in Plants A and B are tightly clustered in different segments of the raw material scale while products produced in Plant C span the scale and overlap the products of

Plants A and B (Fig. 3a). The remaining six factors suggest that the product mixes of Plants A and B are often as diverse that of Plant C (Fig. 3 b-g). The firm's use of raw material as the basis for defining facilities focus indicates that raw material variety is believed to be detrimental to operating performance. The question is whether raw material variety is the most costly form of product mix heterogeneity and whether the remaining six forms of product mix variety are accompanied by costs of complexity.

Factor analysis identifies systematic patterns of variation among products but leaves to the researcher the task of interpreting and linking the factor solution to meaningful constructs. Before the factor solution was calculated, engineers, schedulers and production workers were interviewed to discover anticipated sources of product variety. They were asked to describe the production process, to explain differences among products, and to discuss the impact of the these differences on performance. Confidence in the factor interpretation is provided by the extent to which the factors mirror the four categories that were consistently used to describe woven fabrics. Moreover, linkages between product specifications that were described are borne out in the factor loadings. Finally, the emergence of raw material as the dominant factor explaining between-plant product variation and the graph of raw material factor scores (Fig. 1.a) that illustrates minimal within-plant variation for the focused plants (A and B), link the factor solution to an independent assessment of critical sources of product mix complexity: the firm's facilities focus strategy.

Measuring Product Mix Heterogeneity

Two forms of product mix heterogeneity are present in textile weaving: simultaneous and sequential heterogeneity. Simultaneous product mix heterogeneity is hypothesized to increase MOHC when heterogeneous products are produced simultaneously on parallel machines. Sequential product mix heterogeneity is hypothesized to increase MOHC through two channels: fixed costs of setups and sequence dependent costs of producing heterogeneous products in sequence on a machine. These definitions suggest that MOHC is correlated with three measures of product mix heterogeneity: i) the average heterogeneity of products produced simultaneously, ii) the number of setups, and iii) the average heterogeneity of products produced in sequence.

In practice, the firm records output as it is shipped from the plant and maintains historical records for each 4-week period. Consequently, it is not possible to measure sequential heterogeneity at the machine-level or to unambiguously separate sequential and simultaneous product mix heterogeneity. The factor scores of products shipped in a 4-week period reflect both simultaneous and sequential product mix heterogeneity.[11] However, because the throughput time for producing a warp beam of fabric (two to four weeks) is long relative to the unit of analysis, simultaneous product mix heterogeneity is the dominant reason that different products are shipped in a period.

The measure of product mix heterogeneity used for each product attribute is the standard deviation of factor scores of products produced at time t, weighted by the number of machine hours devoted to the product in the four week period[12]. Scores are weighted to control for the distribution of production across machines[13]. The weighting scheme is consistent with the theory that performance declines when employees divide their efforts among a variety of activities.

[Insert Figure 4 here]

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[11] Production is "to order" and finished goods inventory is negligible. Consequently, period shipments are a good approximation of production in the previous period. The one period lag is caused by production throughput rates of 2-4 weeks that typically cause production of a batch to span two periods.

[12] An alternative measure of product mix heterogeneity is the Euclidean distance (in seven dimensional attribute space) between products (Rummel 1970, 490-513). However, this approach requires the restrictive assumption that equal changes in magnitude along each attribute scale have equal impact on performance. The common factor model extracts factors which explain variation among products. It does not follow, however, that the attribute which explains the greatest source of product variation is the primary determinant of cost. For this reason the multi-attribute distance measure is rejected and separate measures of product mix heterogeneity for each attribute are used.

[13] Machine hours differ from linear output because fabrics are produced at different rates. The actual number of machine hours by product was unavailable. Consequently, the number of hours devoted to a particular product are calculated from the actual yardage produced (including off-quality production), the fabric density and the rated machine speed.

Figure 4 a-g plots the longitudinal product mix heterogeneity series for the seven product attributes. Two insights emerge. Unlike the number of products produced, product mix heterogeneity did not increase steadily over the period; some forms of product mix heterogeneity changed very little while others decreased. Another insight concerns the relative product mix complexity of the three plants. While the number of products produced and the level of product mix change cause the plants to be ordered from most to least complex: C, B, A, during 1986-90, Figure 4 a-g indicates that the plant ranking is neither unambiguous nor constant.

The only available measures of sequential product mix heterogeneity are the number of major setups (DRAWS, that involve switching between products with different warp beams) and the number of minor setups (TIES, that reflect continuation of a warp beam). These variables are used to assess the fixed costs of sequential product mix heterogeneity.

Time Series Properties of MOHC and Product Mix Heterogeneity

There are several difficulties in establishing the relation between MOHC and product mix heterogeneity using time series data. First, it is likely that MOHC and product mix heterogeneity are nonstationary; specifically, both series are expected to exhibit an upward trend over the five year period. Accounting data, which record expenses in current dollars, are subject to inflation. The descriptive evidence suggests that product mix complexity also increased over the period. Second, MOHC and product mix heterogeneity are likely to persist. Persistence in MOHC is an artifact of acquiring resources in discrete, large quantities, of purchasing contracts that span production periods, and of managers' inability or unwillingness to reduce resource provision to the level of resource consumption in the short run (Cooper and Kaplan 1992) --- what economists term, the "lumpy" and "sticky" properties of resources. Persistence in product mix heterogeneity arises because production of a batch typically spans two periods and because demand for products typically reflect trends or fashions that persist for several periods. Nonstationarity and persistence increase the probability that regressions of MOHC and product mix variety will document spurious correlation between the variables (Harvey 1981; McCleary and Hay 1981).

To counter this possibility, the dependent and independent variables are first subjected to univariate time series modelling to remove variation that is predictable given the historical pattern of the variable itself (Box and Jenkins 1976; Fuller 1976). Then innovations in product heterogeneity variables --- the residual variation of the time series models--- are regressed against innovations in MOHC to determine whether heterogeneity is related to MOHC. Excluding as they do sources of overhead cost variation that are predictable without explicit knowledge of the product mix, the results provide strong tests of the relation between MOHC and product mix heterogeneity (Cook and Campbell 1979). The risk of this approach is that it may remove contemporaneous movements of MOHC and product mix heterogeneity that can not be irrefutably linked. Evidence of the magnitude of this problem is presented and discussed later.

Modelling product mix heterogeneity, total MOHC, and disaggregate ledger and departmental costs as output of ARIMA processes, most of the variables are found to be well represented by first order autoregressive processes.[14] In order to distinguish whether a variable is more accurately modelled as a random walk process or a first-order autoregressive process with a large value of ρ, equation 1 is estimated.

$$(Y_t - Y_{t-1}) = (\rho - 1)\, Y_{t-1} + a_t \qquad (1)$$

The t-statistic of the Y_{t-1} coefficient is used to test whether $\rho=1$. However, because the t-statistic obtained under the null hypothesis is not asymptotically normally distributed, modified critical t-values (τ-values) tabulated by Schmidt (1990) are used.[15] Small (insignificant) values of the Q-statistic for residuals of the specified ARIMA model indicated that sources of variation arising from predictable patterns in the variable itself were removed.

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[14] Power costs have a strong seasonal component that is well explained by a first order seasonal autoregressive process.

[15] This class of tests for a unit root are known as Dickey-Fuller tests. See Kennedy (1992). Results of the time series models are available from the author by request.

Accounting Data: an Imperfect Measure of Resource Consumption

Cooper and Kaplan (1992) argue that accounting records measure resource provision and that resource provision is the sum of actual resource consumption and excess capacity. Theory suggests that product mix heterogeneity is related to actual resource consumption. Since resource consumption is not measured, tests of the relation between resource provision (accounting records) and product mix heterogeneity must include a measure of excess resource capacity. Ideally this would be measured for each type of resource. In practice the only resource for which excess capacity is measured is production equipment. Consequently, excess production capacity, defined by the firm as the number of machine hours (including setup time) required to produce realized demand divided by the product of the number of machines and the number of hours in 4 weeks, is included in each regression.

Tests of the relation between accounting measures of MOHC and product mix heterogeneity will be most powerful when resource provision and consumption are highly correlated--- when no excess resource capacity exists. The degree of correlation differs across ledgers and departments. The extent to which contemporaneous product mix heterogeneity is significantly correlated with variable manufacturing overhead costs reflects: 1) external opportunities to acquire resources in discrete quantities, 2) internal opportunities to store resources in inventory, 3) a flexible workforce that may be deployed in a variety of departments or capacities, and/or 4) managers' willingness to eliminate costs of idle capacity during periods of depressed demand. These factors determine whether accounting records of resource acquisition are good proxies for resource consumption.

Accounting ledgers segment costs by type; distinguishing resources with different acquisition patterns. Resources that are acquired through long-term contracts or are purchased in bulk quantities and stored for later use provide weaker tests of the relation between cost and product mix. Thus, intuition about the nature of resource acquisition can be used to predict which ledger accounts will exhibit the strongest relationship to product mix heterogeneity. For example, overtime costs, which reflect unanticipated demand surges and operating difficulties, are more likely to vary with contemporaneous product mix complexity than straight time labor costs, which reflect the normal staffing of the plant in accordance with anticipated demand. Overhead labor costs, which include the skilled labor functions in the plant, will be less likely to respond to contemporaneous changes in product mix than operating labor costs because layoffs jeopardize retention of skilled employees. Operating supplies are likely to be purchased in economic order quantities; consequently, supply costs are likely to be imperfectly related to supply consumption and are expected to exhibit a weak relation to contemporaneous product mix. Power costs, which include operating machinery and general heating and lighting, vary with three factors: seasonal climate changes, capacity utilization and product mix complexity. Power will exhibit a stronger relation to product mix than other indirect materials such as operating supplies because it is acquired on an as-needed basis.

Differences among ledgers in the correlation between resource provision and consumption have implications for testing the relation between departmental MOHC and product mix heterogeneity as well. Table 3 indicates that the plants have similar spending patterns across departments and ledger categories. However, ledger costs are not uniformly distributed across departments. In particular, ledger entries that are expected to exhibit the highest correlation between resource acquisition and consumption, such as operating labor overtime are concentrated in the weaving, and technical support departments. The implication is that tests of the relation between overhead cost and product mix heterogeneity for departments in which resource provision and consumption are highly correlated will have greater statistical power than tests for departments in which this is not the case.

IV. EMPIRICAL RESULTS

This section reports the results of regressing innovations in MOHC on innovations in excess capacity and product mix heterogeneity using the method of seemingly unrelated regressions.[16] The relation between product mix heterogeneity and variable manufacturing overhead costs is estimated at three levels of cost aggregation: i) total MOHC; ii) ledger entries; and, iii) departmental costs. The models are estimated separately for contemporaneous and lagged (one period) measures of product mix heterogeneity. The use of one period lagged variables reflects the probability that on average half of production shipments in a period were produced in the preceeding period and the hypothesis that variable MOHC are influenced by contemporaneous production[17]. In general, both models yield similar results with the lagged models offering slightly better explananatory power. This may be an artifact of the throughput time of the production process or it may suggest that MOHCs are more related to preproduction activities (i.e. setups, establishing first run quality immediately following setup) which are more likely to occur in the preceeding period. The best models are presented for sake of parsimony and the caveat is that this choice reduces the reliability of inidividual t-statistics.

Product Mix Heterogeneity and Total Variable Manufacturing Overhead

The results of regressing total variable manufacturing overhead costs on excess capacity, major and minor setups (measures of sequential product mix heterogeneity), and measures of simultaneous product mix heterogeneity are presented in Table 5.

[Insert Table 5 here]

Excess capacity is not correlated with MOHC for Plants B or C. This could reflect reluctance on the part of managers to remove resources from the plant during periods of reduced demand. Alternatively it could point to the inadequacy of using machine capacity as a proxy for overhead capacity. The fact that Plant A is the only plant for which excess capacity enters

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[16] Since the plants produce similar products for similar markets it is likely that the vectors of disturbances of independently estimated OLS regressions are correlated between the plants (Kmenta 1986, 637). The method of seemingly unrelated regressions exploits this linkage to increase the efficiency of the coefficient estimates.

[17] The cross-correlation plots of the MOHC and the product mix heterogeneity variables support this assumption; there is no indication of longer lags in the relationship between the variables.

significantly to explain changes in MOHC supports the former explanation. Of all the plants, Plant A experienced the deepest, most persistent troughs of depressed market demand. If management anticipates sustained reductions in demand they will take more aggressive cost cutting measures than are warranted for the random demand fluctuations that characterize capacity utilization in Plants B and C.

Fixed effects of sequential product mix heterogeneity are indicated by the costs of major and minor setups. Plant B exhibits the expected relation of major setup costs greatly exceeding minor setup costs. In contrast, MOHC in Plants A and C are increased by minor setups, but indicate no discernable cost of major setups. The explanation of this puzzling result, which is explored in the next section, lies in offsetting effects of product mix heterogeneity on different ledgers.

Simultaneous product mix heterogeneity in expected downtime and customer defect tolerances[18] are significantly and materially related to increased manufacturing costs in Plant A. Variety in expected downtime is also correlated with manufacturing costs in Plant C, although a given change in downtime variety appears to be less costly in Plant C than in Plant A. Variety in fill thread construction reduces MOHC of Plant B. The strength of the result for Plant B, which had a history of using new combinations of existing warp beams with a variety of fill threads as a vehicle for product proliferation (Section II), suggests that this strategy is rewarded with lower manufacturing overhead costs. If bobbins of fill thread are exchanged mid-way through a beam of warp threads, a third relatively inexpensive form of "setup" emerges, and smaller minimum fabric batch size (heretofore the length of the warp beam) becomes economical.

Notably absent is a significant impact of raw material heterogeneity--- the factor believed by the firm to be most costly--- on Plant C, the plant that experienced the greatest level of raw

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[18] Investigating whether defect tolerance variety was proxying for average defect tolerance of the product mix, I found no instance where, when it was included in the models, *average* defect tolerance supplanted defect tolerance *variety* as an appropriate explanatory variable. In one instance (Plant C's Operating Supply Costs) average defect tolerance was significant while defect tolerance variety was not.

material variety. One explanation might be that costs to support the capability of producing a broad range of raw materials are not included in variable manufacturing overhead costs, the subject of this study; but rather, are classified as fixed manufacturing overhead costs. Evidence to counter this claim is found in a related paper (Anderson 1993), which examines the impact of product mix heterogeneity on measures of operating performance, including total factor productivity. The inclusion of "fixed" resources among inputs in the calculation of productivity is not accompanied by increased significance of raw material variety in explaining Plant C's performance.

Alternatively, costs of raw material complexity may be so persistent (because management is reluctant to reduce this "core" capability during brief downturns in demand for raw material variety) that they are removed with ARIMA modelling. To investigate this possibility the models were estimated for the untransformed variables. The overall results are summarized at the bottom of Table 5. While it is clear that substantial contemporaneous correlation is removed by time series modelling, even without taking these conservative measures to preclude reporting spurious correlation Raw Material Variety is not correlated with Plant C's MOHC.

Two observations emerged in comparing the results of Table 5 with results of a second regression (not reported) that substituted a commonly used measure of product mix heterogeneity --- the number of products produced--- for attribute-based measures of product mix heterogeneity. First, similarities and differences among products offer significantly greater explanatory power over the simpler representation of product mix breadth. The adjusted R^2 values improve for Plants A and C and are the same for Plant B. Second, omitting measures of product mix heterogeneity creates an omitted variables bias in the coefficients of excess capacity and setups. Specifically, the impact of setups is understated and the impact of capacity utilization is overstated because setups and capacity utilization are correlated with simultaneous product mix heterogeneity. As excess capacity increases marginally profitable business is accepted and product mix heterogeneity increases. Consequently, the omission of measures of simultaneous product mix heterogeneity creates a positive omitted variables bias in the coefficient of excess capacity. At the same time, because so many machines are idle, each machine can be dedicated to a different product; setup frequency is negatively correlated with capacity utilization and simultaneous product mix heterogeneity. Thus, omitting measures of simultaneous product mix heterogeneity causes a negative omitted variables bias in the coefficients for major and minor setups.

Product Mix Heterogeneity and Accounting Ledger MOHCs

For purposes of discussion, the ledger items are considered in three groups: operating wages (wages, overtime and shift premia), indirect materials (operating supplies and power), and overhead wages (wages, overtime and shift premia). The results of regressing each ledger on excess capacity, and measures of sequential and simultaneous product mix heterogeneity are presented in Tables 6-8. Before considering the specifics, three general results are considered.

First, lagged product mix heterogeneity is found to have greater explanatory power than contemporaneous product mix heterogeneity for overtime wages of operating employees, for indirect materials and for wages and overtime premia of overhead employees. This suggests that these costs are related to pre-production and early- production activities that typically occur in the period preceding product shipments. Overhead employees, who are responsible for machine setups, are more heavily employed in the early stages of production. The plant managers conjectured that operating overtime premia typically reflect "firefighting" activities related to poor setups to explain the correlation between operating overtime costs and early-production activities. Operating supplies include both pre-production (setup) and post production (packing materials) materials, but on balance pre-production costs dominate. The only counterintuitive relation is that overhead shift premia are better explained by contemporaneous product mix heterogeneity, while wages and overtime are better explained by lagged product mix heterogeneity. However, the incremental power of simultaneous product mix heterogeneity to explain shift premia is low and thus this result is unlikely to carry useful information.

A second general result is that correlations between MOHC and product mix heterogeneity (sequential and simultaneous) are strongest for costs predicted to have high correlations between resource provision and consumption (e.g., power, operating and overhead overtime wages).

Finally, the expected result that costs of major setups exceed costs of minor setups holds for virtually every ledger over all three plants. The exception is the Power ledger. Power costs decrease with major setups because machines are physically turned off for the lengthy process of a major setup, but are merely idled for a minor setup. This instance of costs of minor setups exceeding costs of major setups offsets the more common effect of sequential product mix heterogeneity and explains the anomalous results for total MOHC of Plants A and C. If the power "savings" of major setups is excluded, the average cost of major and minor setups for the three plants are:

	Major Setup	Minor Setup	Difference
Plant A	$520	$178	$342
Plant B	$350	$131	$219
Plant C	$284	$193	$ 91

An interesting pattern emerges: Plant C, which has the greatest experience doing major setups, has the lowest cost of major setups; Plant B, which has the greatest experience doing minor setups has the lowest cost of minor setups. These results are corroborated by the company's independent assessment that the difference in major and minor setup costs is $250.

Operating Labor Wages: Straight Time, and Overtime and Shift Premia

Table 6 reports the results of regressing operating wages and premia on excess capacity and measures of product mix heterogeneity.

[Insert Table 6 here]

Typically measures of product mix heterogeneity have greater correlation with overtime premia than with shift premia or wages. This is consistent with the argument that specification errors caused by differences between resource provision and consumption systematically limit the power of tests aimed at discovering correlations between consumption and production activities (Cooper and Kaplan 1992). Overtime is scheduled on as-needed while shift premia and wages reflect staffing for 24 hour, seven day a week operations. However, because the straight time portion of overtime and shift wages is included in the straight time wages ledger, the impact of product mix heterogeneity on overtime and shift work is understated and the impact on straight time wages is overstated.

As with total manufacturing overhead costs, excess capacity has the greatest impact on Plant A's operating labor overhead costs. A significant negative correlation between excess capacity and overtime for Plant B suggests that excess capacity creates fungible resources. Specifically, excess capacity frees resources and mitigates demand for overtime that might otherwise be required during periods of heightened product mix complexity.

Common sources of flexibility and inflexibility exist in operating labor wages. Consistent with the evidence of total manufacturing costs, the plants typically respond flexibly to product mix differences of warp beam, warp thread and fill thread construction but suffers increased costs when products differ in expected downtime. Defect tolerance variety is associated with increased overtime but decreased shift premia for Plant A. This may reflect managers' decision to substitute overtime hours on the first shift (no shift premia) when management supervision is high for shift premia-related hours during periods of increased product mix heterogeneity. Another possibility, revisited in the discussion of overhead, or "indirect" labor wages is that product mix heterogeneity may precipitate substitution between direct and indirect labor. Raw material continues to be insignificant for Plant C; however, labor costs in Plant B, which experienced relatively little raw material variety (Fig 4a), increased with raw material variety.

Indirect Materials: Power and Operating Supplies

Table 7 reports the relation between costs of indirect materials and measures of product mix heterogeneity. The explanatory power for power and operating supply costs of Plant B is too low to warrant serious consideration.

[Insert Table 7 here]

Considering power costs of Plants A and C, fill thread heterogeneity reduces costs in Plant C, while defect tolerance heterogeneity increases costs in Plant A. The former result has no clear interpretation; the latter result is a reflection of the fact that defects induce downtime that generates the need for overtime production (Table 6) and greater consumption of power. Plant C, with the lowest level of defect tolerance variety (Fig 4 g) throughout the period is little affected by it. More puzzling is the power savings conferred on Plant C by its consistently high level of raw material variety. One explanation is that raw material variety is inevitably correlated with major setups and is perhaps indicative of setup difficulty. Difficult setups take longer to complete and the machine is turned off for the duration. Thus power savings with raw material heterogeneity may be yet another perverse benefit of foregone production.

Measures of sequential product mix heterogeneity offer explanatory for operating supply costs of Plants A and C. This is reasonable since operating supplies include supplies used during machine setups. Measures of simultaneous product mix heterogeneity offer limited explanatory power for Plant C. This result is consistent with the prediction that operating supplies, which are typically purchased in economic order quantities, have little correlation with contemporaneous product mix. Another result that is consistent with intuition is that defect tolerance variety increases operating supply costs in Plant A. Operating supplies include packaging materials used to protect the fabric during shipment. Plant A experienced the highest levels of defect tolerance variety (Fig 4 g) and we expect this to translate into a wider variety of packaging materials and greater indirect material waste.

Overhead Wages: Straight time and Overtime and Shift Premia

As with operating wages, product mix heterogeneity offers the greatest explanatory power for overtime premia (Table 8) and, as expected, the overall explanatory power for indirect labor costs is substantially lower than that of direct labor. Fill thread variety reduces costs for Plants A and B, while warp thread variety reduces costs for Plants B and C. In sum, a strategy of proliferating products by using new combinations of existing materials is rewarded with lower costs of overhead wages.

[Insert Table 8 here]

Again, the possibility of substitution between shift work and overtime work emerges in the significant, but opposite signs of the coefficients of expected downtime for Plant A, and warp beam and raw material variety for Plant B. Returning to the issue of whether substitution between operating labor (Table 6) and overhead labor (Table 8) emerged with product mix heterogeneity, although some forms of product mix heterogeneity clearly had a greater impact on one or the other category of labor, the signs of the coefficients appear to move in tandem. Forms of product mix variety that are associated with increased operating overtime are also positively correlated with overhead overtime. This is consistent with the plants' work philosophy in which teams of production workers and dedicated skilled technicians jointly oversee approximately 100 machines.

Product Mix Heterogeneity and Departmental MOHCs

For purposes of discussion, the impact of product mix heterogeneity on departmental MOHC is considered on a plant by plant basis. The results of regressing each department's MOHC on excess capacity, and measures of sequential and simultaneous product mix heterogeneity are presented in Tables 9-11. Four general conclusions are worth noting before the specifics of each plants' departments are considered.

First, lagged product mix heterogeneity is found to have greater explanatory power than contemporaneous product mix heterogeneity for the inspection and administration departments. The administration department is dominated by power costs, discussed above. The inspection department includes costs of first run inspection (immediately following setup) and costs of final inspection. The greater correlation with lagged product mix heterogeneity suggests that first run inspection costs dominate final inspection costs.

Second, simultaneous product mix heterogeneity affects the departments differently. While a form of variety may be associated with lower costs in one department, these savings may be more than offset in another department. This result suggests that in the future departmental costs might be well represented as a system of simultaneous equations as in Datar et. al. (1993). These differences also have implications for managerial control systems. A cost-based reward system could potentially lead to divisive behavior at the departmental level if departments could influence product mix.

A third result is that sequential product mix heterogeneity affects departments differently. The original hypothesis was that major setups are more costly than minor setups. This result holds for the weaving and technical support departments of all three plants. It does not hold for the inspection or administration departments. The administration department result is well explained by the perverse power "savings" discussed earlier. However, the finding that for Plant C major setups are associated with savings in inspection costs while minor setups increase inspection costs is puzzling.

Finally, the results offer limited support for the hypothesis that product mix heterogeneity offers greater explanatory power for support department costs than for production department costs (Miller and Vollmann 1985). In the case of Plant A , measures of simultaneous product mix heterogeneity enter more significantly in the inspection and administration departments than for the weaving department. Similarly, explanatory power for the inspection and technical support department costs are greatly enhanced by including product mix heterogeneity for Plant B. Costs of Plant B's weaving and administration departments do not benefit from the same treatment. Plant C's weaving and administration department costs benefit from the inclusion of measures of product mix heterogeneity, while its inspection and technical support department costs are uninfluenced by product mix.

Plant A

In Plant A, defect tolerance variety reduces MOHC and warp thread variety increases MOHC in weaving. However, the savings associated with defect tolerance variety in weaving are offset by costs of inspection and administration. The apparent substitution between weaving and inspection costs when the product mix includes a wide variety of customer quality requirements suggests that customer requirements are "inspected in" rather than produced. Moreover, the increased overtime requirements precipitated by defect tolerance variety (Table 6) appear to be concentrated in the inspection area rather than in production. The results for the administrative department are driven by the impact of power costs which increase with overtime. Fill thread variety is correlated with increased costs in the technical support department of Plant A and warp thread variety is associated with increased costs of weaving.

[Insert Table 9 here]

Plant B

No measure of simultaneous product mix variety is significant for the weaving department of Plant B and regression on administrative costs offers poor explanatory power. Focusing on the remaining departments, expected downtime variety and fill thread variety reduce the costs of inspection. Economies of scope in fill thread variety are consistent with the recurrent theme that proliferation around common components is a cost effective means of achieving variety. Economies of scope in expected downtime are a perverse effect of weaving downtime; namely, no fabric is produced, so there is no output to inspect. On the positive side, the realization of these economies reflects management's explicit efforts to manage underutilized resources out of the system. Warp thread variety decreases the cost of technical support for Plant B. This result is contrary to anecdotal evidence that experience setting up a loom to run a particular thread decreased the setup time and the time required to repair a thread breakage, which would suggest increased costs of thread variety for setup tecnicians.

[Insert Table 10 here]

Plant C

Like Plant A, warp thread variety reduces weaving MOHC for Plant C. Fabric weight variety increases weaving MOHC. The only measure of product mix heterogeneity that enters significantly to explain inspection costs for Plant C is expected downtime variety, a source of reduced inspection costs. Unlike Plant B, which appears to manage its workforce to insure that inspector's hours are consistent with expected output levels, Plant C seems to employ a stable team of inspectors. Weaving downtime, is accompanied by idle inspectors. Depending upon the balance between weaving and inspection capacity, these inspectors are subsequently paid overtime wages to insure that delivery dates are met and to compensate for time wasted during weaving downtime.

[Insert Table 11 here]

No measure of product mix heterogeneity enters significantly in explaining Plant C's adminstration overhead costs. Although fixed costs of setups explain a substantial portion of cost variability, there is no evidence that support department costs vary with the specific products being setup. There are two possible explanations for this. First, because Plant C is unable to anticipate what it may be asked to do, it may maintain a stable team of employees to handle contingencies at all times. Significant idle capacity would arise during periods of low product mix heterogeneity; however, because accounting records capture resource provision rather than consumption, the empirical tests lack the power to resolve usage variation as a function of product mix heterogeneity. A second possibility is that as the "swing" plant, Plant C has learned to setup looms and is unaffected by product mix heterogeneity.

Fill thread variety reduces administrative costs while warp beam variety causes substantial increases in administrative costs. Warp beam variety is typically associated with a larger set of warp beam suppliers (both internal and external) and larger raw material inventories, both of which generate greater demands for coordination or administration. In sharp contrast to Plant A, Plant C appears to benefit from defect tolerance variety. This may reflect the fact that Plant A experienced the highest and Plant C the lowest level of defect tolerance variety throughout 1986-90. As was noted earlier, this is distinct from differences in the levels of *average* product mix defect tolerance, which when included do not enter significantly to explain department-level costs.

V. SUMMARY

This paper uses the attribute-based model of product mix heterogeneity developed in the group technology literature to test the relation between plant-level manufacturing overhead costs and product mix heterogeneity. Product mix heterogeneity is separated into two components: the sequential production of different products on a machine; and, the simultaneous production of different products on many parallel machines. Sequential product mix heterogeneity is measured as the number of major and minor setups. Simultaneous product mix heterogeneity is made operational by employing a framework developed in the group technology literature of operations in which products are defined as a unique set of product attributes. Product attributes are identified from engineering product and process specifications using factor analysis and measures of product mix heterogeneity are developed from the factor scores of products produced in a 4-week period. Multivariate regression is used to test the hypothesis that manufacturing overhead costs are related to product mix heterogeneity.

The results support the hypothesis that sequential product mix heterogeneity increases

MOHC through increased setup costs. Different forms of simultaneous product mix heterogeneity are associated with increases and decreases in variable overhead costs; Adler's (1988) claim that manufacturing flexibility requires identifying costly forms of variety is appropriate. In general, product mix variety that stems from new combinations of existing warp and fill threads --- what engineers call "modular" design and what researchers identify as proliferation around "common components"--- reduce overhead costs. Product mix variety that creates differences in process specifications (expected downtime) and generates diverse quality standards (defect tolerance variety) are associated with increased costs. In the few instances in which expected downtime variety and defect tolerance variety confer savings, they reflect perverse circumstances (i.e. power savings during downtime) or there is evidence of substitution between ledgers or departments (i.e. lower shift premia and higher overtime premia, lower weaving costs and higher inspection costs) where the net effect is to increase manufacturing overhead costs. Weak evidence that the cost of product mix complexity declines with experience in producing a broad product mix is provided by comparing the impact of setups and product mix heterogeneity on Plant C's costs with their impact on costs of the focused plants, Plants A and B. Moreover, the evidence that raw material variety increased direct and indirect labor costs for Plant B, a focused plant, but had no impact on costs of Plant C, the "swing" plant", suggests that experience producing fabrics from a variety of raw materials may decrease the costs of raw material variety.

Management accountants' role in supporting manufacturing's effort to become more responsive includes assessing the impact of product variety on plant performance, identifying channels through which variety undermines performance, and devising yardsticks for evaluating progress in achieving manufacturing flexibility. This paper is a first attempt to address these issues. There are many avenues for future research, but four seem most promising. In light of the small sample of this study, the most obvious opportunity for future studies is replication. Group technology, the basis for the measures of product mix heterogeneity, is in widespread use in a number of manufacturing settings. This suggests that the methods for developing measures of product mix heterogeneity may be generalizable as well. A second opportunity for extending this work lies in considering other sources of information to describe products. Although the basis for identifying product similarities and differences for this paper was engineering specifications, another possibility for discriminating among products is on the basis of resource usage. In particular, the second stage cost drivers used in activity-based costing to relate overhead costs to transactions caused by products could be useful for identifying underlying product mix heterogeneity. A third opportunity exists in considering whether accounting ledgers or departments should be modelled as a set of simultaneous equations with different forms of product mix heterogeneity yielding offsetting effects across ledgers/ departments (Datar et.al. 1993). Finally, this paper examines the impact of product mix heterogeneity on manufacturing overhead costs. The question that remains is whether costs of product mix complexity are recouped in the market. Future studies must reconcile the costs of product mix complexity with the value of product mix complexity, so that managers can determine "the right mix of stabilities and flexibilities" (Adler 1988, 51).

APPENDIX A: Description of Accounting Ledgers and Departments for Variable MOHC

ACCOUNTING LEDGER CATEGORIES

Operating Labor: (3 accounts: wages, overtime premia and shift premia)

Wages, overtime premia and shift premia of employees who monitor and perform minor adjustments to the looms. The straight time portion of overtime and shift wages is included in straight time wages. Wages exclude payroll taxes and benefits.

Overhead Labor: (3 accounts: wages, overtime premia and shift premia)

Wages, overtime premia and shift premia of skilled employees who perform loom maintenance and repair, inspection, and setups. The straight time portion of overtime and shift wages is included in wages. Wages exclude payroll taxes and benefits.

Operating Supplies:

Materials used in machine repair and setup (i.e. lubricants) and packing materials.

Power:

Electricity costs for operations and for general lighting and heating.

Other/ Miscellaneous:[19] Overhead (i.e. janitorial) and repair and maintenance supplies

DEPARTMENTS

Weaving:

The production department that includes looms and loom operators.

Inspection:

The first and last production stages in which inspectors test first-run quality immediately following loom setup and grade finished fabric.

Technical Support- Maintenance, Draw-in and Warp Replacement:

Between 1986 and 1990, each plant separated one or more of these departments for reporting purposes. To control for inconsistent definitions of departmental boundaries between the plants and within plants across time, these departments are treated as one technical support department. The Maintenance department is home to skilled electricians, pipefitters and welders who maintain and repair productive equipment and plant structure and infrastructure. The Draw-in department houses equipment used to set new fabric patterns before major setups and is staffed on an as-needed basis by draw-in operators. The Warp Replacement department is home to skilled technicians who specialize in loom setup operations.

Administration:

Includes costs of administration and support for which the plant manager is responsible. Excludes salaries of the plant manager and administrative associates that are classified as fixed manufacturing overhead.

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[19] This ledger is excluded; it includes miscellaneous supplies that are not expected to be influenced by product mix heterogeneity and are typically purchased in economic order quantities at regular intervals.

Appendix B: Product Diversity of Woven Fabrics

Heterogeneity of woven fabrics stems from unlimited combinations of different threads. In order to determine product attributes that contribute to product mix complexity and increased overhead cost and to identify relationships between product attributes, I conducted interviews with process and industrial engineers at each plant and at the manufacturing division. Though over 30 engineering parameters were mentioned in these interviews, they can be loosely organized into four categories: filament construction, warp beam construction, fabric construction. and the product-process interface.

Filament construction parameters describe the warp and fill threads that comprise a fabric. One aspect of filament construction is fiber specifications: fiber content, weight, and filament treatments. Fiber content refers to the raw fibers used (i.e. rayon, polyester). "Denier" is the industry's measure of weight per unit length. Chemicals used in the extrusion of manmade filaments may further differentiate filaments of the same fiber, changing their luster or shine, or imparting color. A second aspect of filament construction reflects upstream textile processes: spinning, twisting, dyeing and texturing.

The above discussion applies to warp and fill threads. Warp threads require additional description of the warp beam construction. The denier of the warp thread and the width of the warp beam indicates the density of the warp threads on the beam and the maximum width of the finished fabric. A related parameter is the length of each thread on the warp beam. Warp length determines the duration a loom runs before requiring set-up. Warp threads must be stronger than fill threads because they are under constant tension on the loom and are abraded with each pick. Consequently a chemical, called "size", is applied to warp threads during warp beam construction. There are two size-related specifications: size take-up, the absorption of size as a percent of warp weight, and slasher stretch, the extent to which warp contraction caused by sizing is reversed in weaving.

The third category of product specifications, fabric construction, describes the way that warp and fill threads are combined. The weave pattern describes designs on the fabric face. Common weave patterns are: satin, twill, and herringbone. Complex patterns are produced at slower machine speeds. Another aspect of fabric construction is the dimension of the finished product. Though largely governed by warp construction and raw material content, product dimensions are also determined by fabric density (picks per inch)--- how tightly the threads are packed together, and by warp contraction--- the percent of warp length lost in weaving as a result of inserting picks.

The most important feature of fabric, its uniformity, is largely a function of machine settings, or process specifications. The primary cause of fabric defects is loom stoppage. Process interruptions leave a perceptible line across the fabric. Loom stops occur with thread breakage, preventive maintenance or machine failures and are influenced by machine speeds, raw material uniformity and fabric construction complexity. Machine speeds are set to the fastest rate consistent with quality requirements of the customer. The machine speed chosen implies an expected operating efficiency, stop level, and quantity of off-quality production.

The following table summarizes the engineering parameters and process specifications:

	Variable	**Variable Measure**
I. Raw Material		
	1. Fiber content	Binary variable, 0-1 for each of 3 input types
	2. Denier or count	Weight per unit length
	3. Finish	Categorical variable, 1-5: 1=bright, 4=dull, 5=unfinished
*	4. Dye	Binary variable, 1=dyed
*	5. Texture	Binary variable, 1=textured
*	6. Twist Multiple	Twists per unit length
	7. Number of Filaments	Number of thread twisted to form one
II. Warp Beam Construction		
	1. Warp Length	Length of a warp thread
	2. Slasher Stretch	Percent warp length increase in weaving
	3. Size Take-up	Percent warp weight increase in sizing
	4. Reed Width	Fabric width
III. Fabric Construction		
*	1. Type Weave	Fabric pattern
	2. Picks per Inch	Fabric density
	3. Fabric Weight	Fabric weight/linear yd.
	4. Warp Contraction	Percent warp length reduction in weaving
	5. Filament Weight	Warp weight, fill weight/linear fabric yd
IV. Product-Process Interface		
	1. Picks per Minute	Machine speed
	2. Machine Stop Level	Thread breakage rate
	3. Expected Efficiency	Run time as a percent of machine throughput time (excludes setup time)
	4. Defect Tolerance	Categorical variable 1-5; 1=wide tolerance range, 5=narrow tolerance range

* Although these variables were mentioned in several interviews, upon further investigation they related to fewer than 10% of the approximately 600 products produced during 1986-90. Rummel (1970) advises against including categorical variables that are relevant for fewer than 10% of the observations in a factor solution. Thus these forms of product mix heterogeneity are excluded from the factor solution.

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Figure 1

Weaving Process Diagram

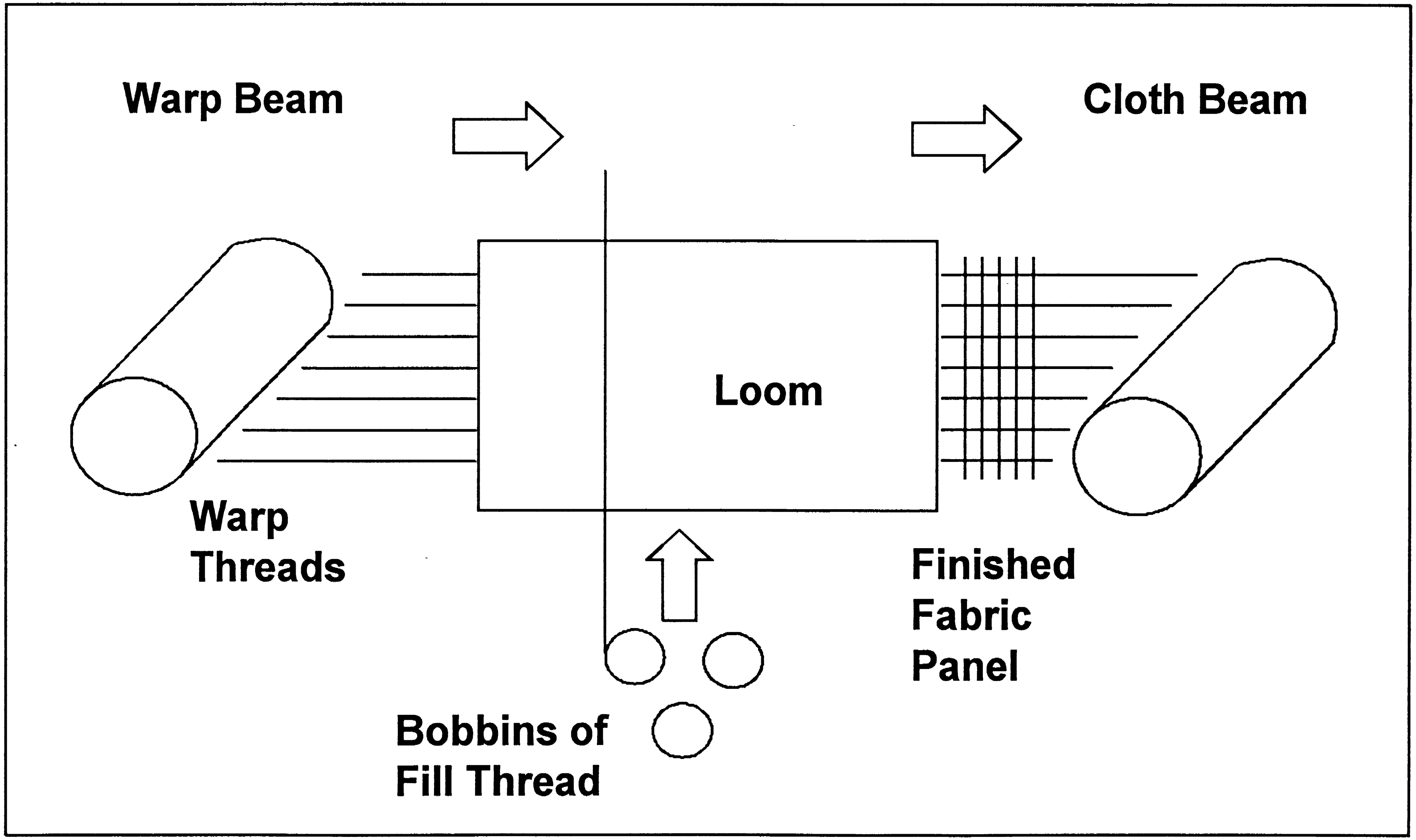


Figure 2

Research Design

Sequential Product Mix Heterogeneity:
Intertemporal Product Mix Change

Simultaneous Product Mix Heterogeneity:
Intratemporal Product Mix Breadth

	Low	High
Low	PLANT A	-----
High	PLANT B	PLANT C

Figure 3
Factor Scores of Products Produced, 1986-90

These figures plot the factor scores of products produced by the three plants between 1986 and 1990.

Figure 3.a

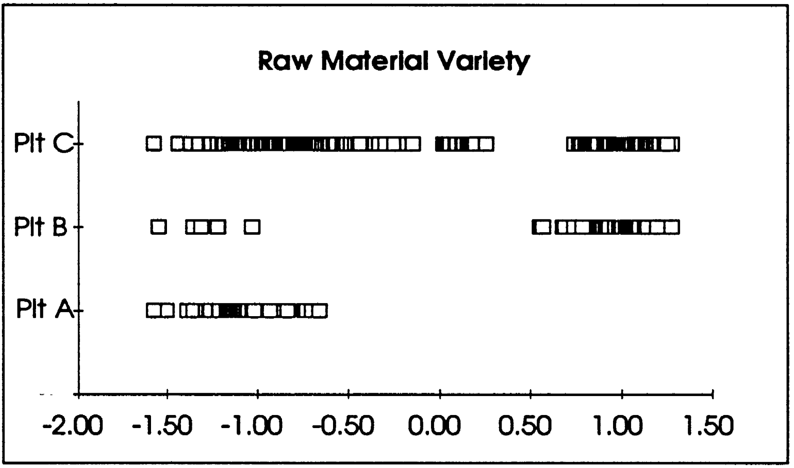


Figure 3.b

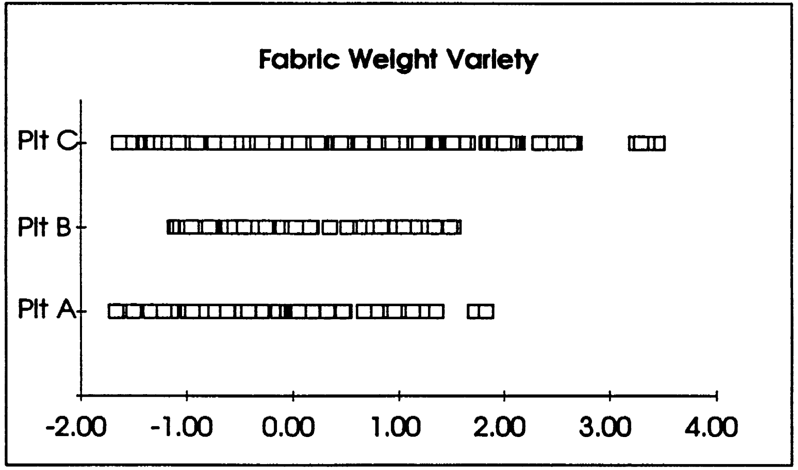


Figure 3.c

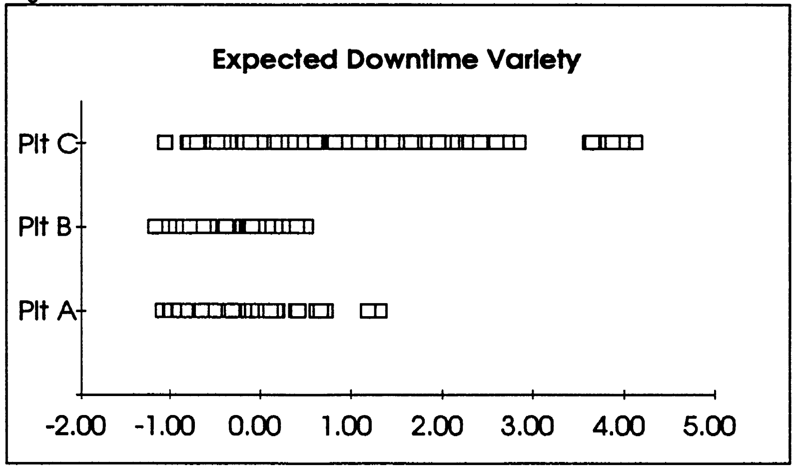


Figure 3.d

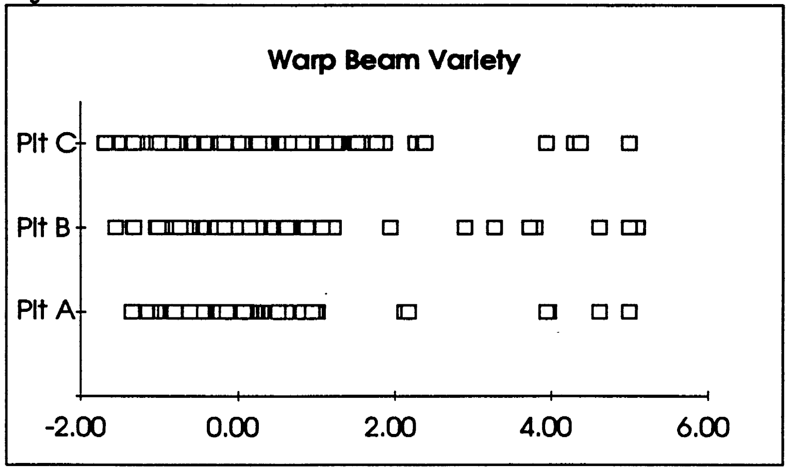
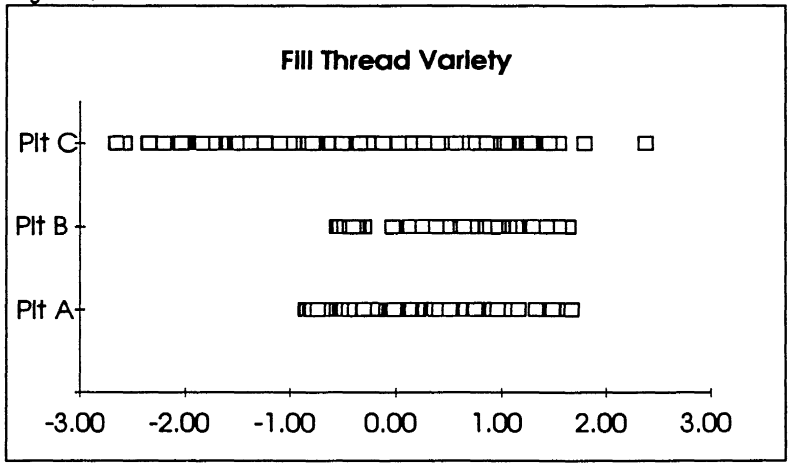


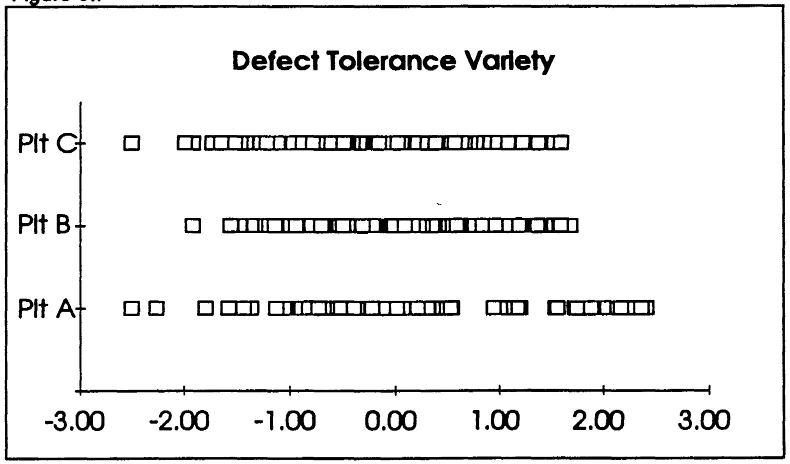
Figure 3 (continued)

Figure 3.e



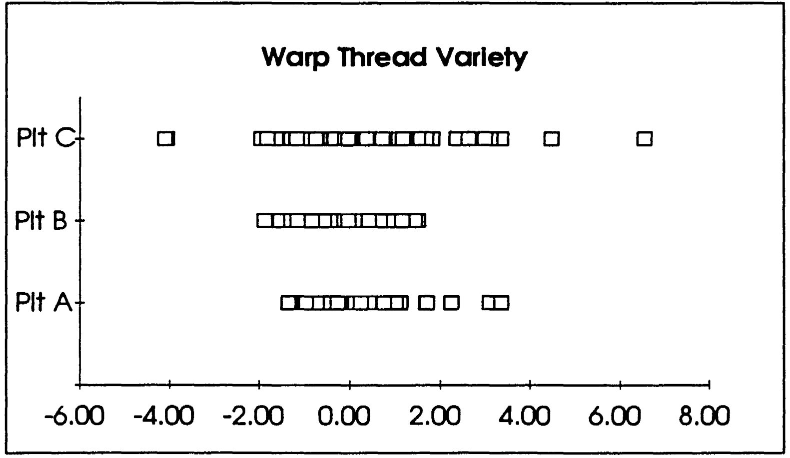
Fill Thread Variety

Figure 3.f



Defect Tolerance Variety

Figure 3.g



Warp Thread Variety

Figure 4
Seven Forms of Product Mix Heterogeneity, 1986-90

Plots of the standard deviation of factor scores for products produced at time t, from 1986 to 1990

Figure 4.a

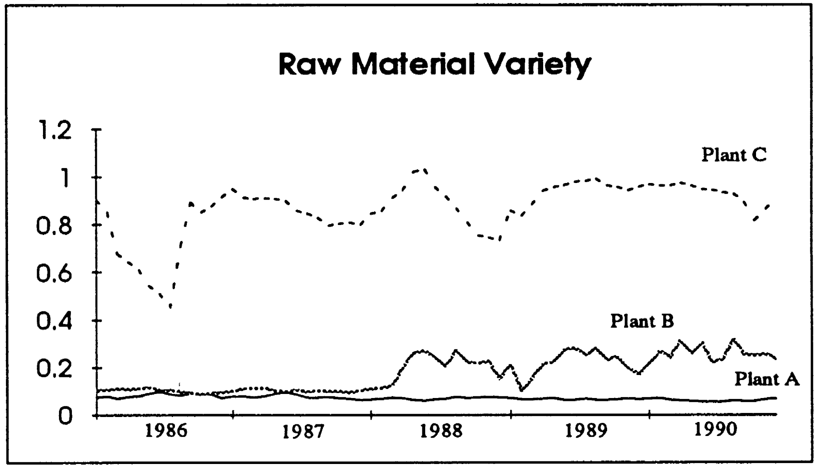

Raw Material Variety

Figure 4.b

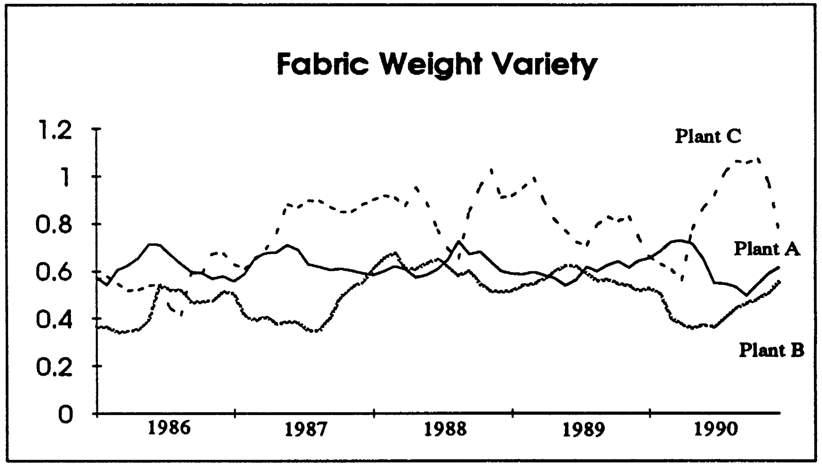

Fabric Weight Variety

Figure 4.c

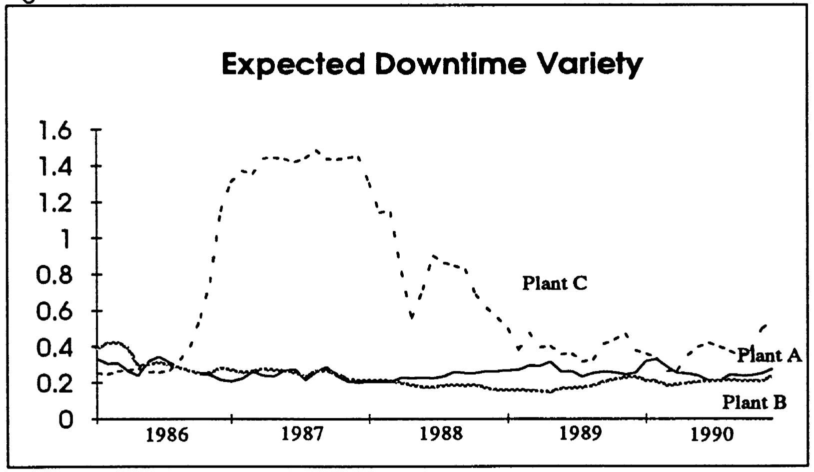

Expected Downtime Variety

Figure 4.d

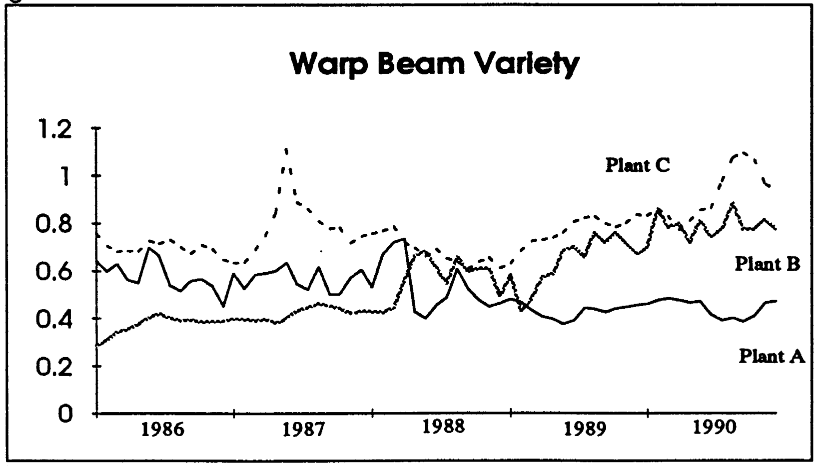

Warp Beam Variety

Figure 4 (continued)

Figure 4.e

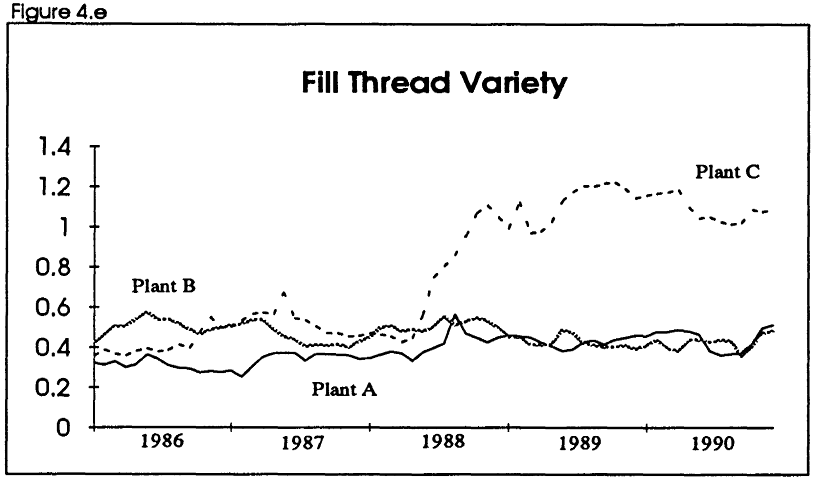


Figure 4.f

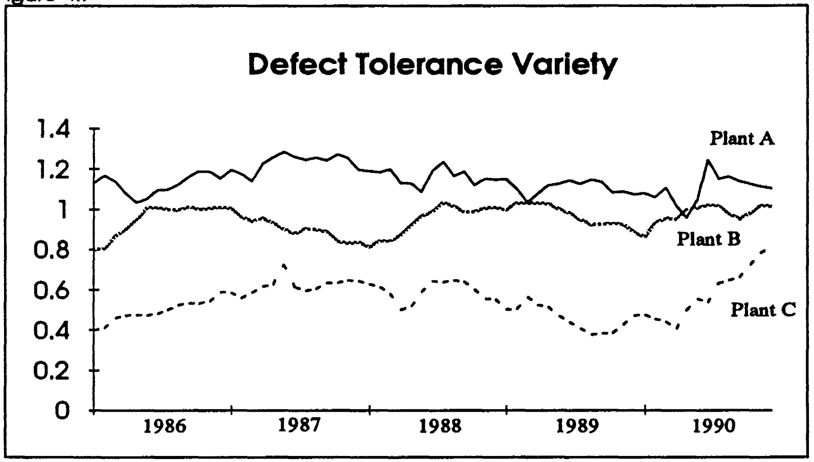


Figure 4.g

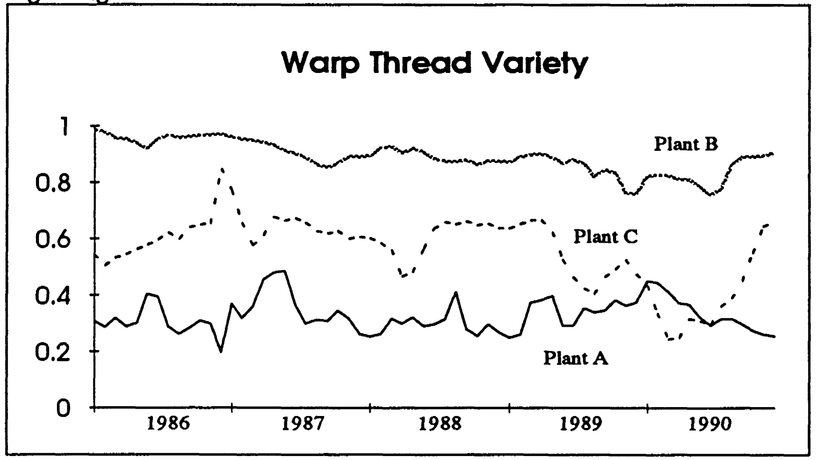


Table 1

Average Product Mix Breadth

The average number of products produced in the 13, 4-week production periods of 1986-1990 using three definitions of "product"

Panel A: Product= A unique Warp Beam, which may be combined with a variety of crosswise fill threads

	1986	1987	1988	1989	1990
Plant A	23	24	24	29	29
Plant B	14	15	22	25	35
Plant C	21	31	28	27	35

Panel B: Product= A unique combination of a lengthwise warp beam with a crosswise fill thread

	1986	1987	1988	1989	1990
Plant A	31	29	30	42	37
Plant B	30	30	42	51	67
Plant C	35	54	55	56	59

Panel C: Product= A unique combination of a lengthwise warp beam and a crosswise fill thread, treating generations of the same product as a single product

	1986	1987	1988	1989	1990
Plant A	28	28	28	34	33
Plant B	21	23	30	39	54
Plant C	30	45	45	46	51

Table 2

Product Mix Change

The average number of times the product mix changed during the five years, 1986-1990, calculated by dividing the total number of products produced during 1986-90 by the average number of products produced in a 4-week period for each of three definitions of a "product".

Product =	Number Products 1986-90	Avg. Number Products/ Period	Product Mix Turnover
Warp Plant A	77	25	3.0
Plant B	62	22	2.8
Plant C	155	29	5.3
Warp-Fill Plant A	162	34	4.8
Plant B	237	44	5.4
Plant C	404	53	7.6
Multi-Generation Warp-Fill Plant A	102	30	3.4
Plant B	128	33	3.9
Plant C	275	45	6.1

TABLE 3

Variable Manufacturing Overhead Costs (VMOHC): A Matrix Perspective of Accounting Ledgers and Functional Departments for Plants A, B, and C, 1986-90

Functional Dept.: Accounting Ledger:	Weaving Department	Inspection Department	Technical Support Department	Administration	% of Total VMOHC by Ledger
Operating Labor:					
Straight Time Wage	X		X		A: 37%
Overtime Premia	X		X		B: 44%
Shift Premia	X		X		C: 46%
Power				X	A: 34% B: 28% C: 27%
Operating Supplies	X	X	X		A: 14% B: 11% C: 10%
Overhead Labor:					
Straight Time Wages		X	X	X	A: 10%
Overtime Premia		X	X	X	B: 10%
Shift Premia		X	X	X	C: 10%
Other/ Miscellaneous*					A: 5% B: 7% C: 7%
Percent of Total VMOHC, by Department	A: 45% B: 36% C: 42%	A: 6% B: 10% C: 11%	A: 10% B: 11% C: 13%	A: 38% B: 43% C: 34%	

* This ledger is not included for empirical analysis for three reasons: 1) it includes supplies that bear no evident relation to product mix, 2) the supplies are typically purchased in economic order quantities, and 3) they are treated as a special plant manager's account and are not included in any department's budget.

Table 4

Rotated Factor Pattern

The results of using the maximum likelihood method of factor extraction and the varimax rotation criteria to identify independent sources of product variation from product engineering specifications.

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	C(1)
Slasher Stretch	.95	-.09	-.24	.10	-.05	-.01	.03	.87
Input 2 Warp	.95	-.09	-.26	.08	-.03	-.02	.04	.67
Input 2 Fill	.68	-.18	-.18	-.14	.52	-.09	-.07	.98
Reed Width	-.55	.05	.19	.07	-.18	.26	-.06	.88
Input 1 Fill	-.67	-.22	-.22	-.15	-.04	.19	-.11	.55
Input 1 Warp	-.84	.11	-.22	-.32	-.08	.06	-.01	.96
Fill Weight	-.08	.85	.23	.24	-.13	-.15	.07	.63
Warp Contraction	-.23	.78	-.15	.08	-.25	-.11	.07	.69
Fabric Weight	.11	.66	.16	.56	-.08	-.10	.05	.84
Fill Finish	-.06	.52	.39	.08	-.40	-.16	.08	.63
Size Pick up	-.06	-.03	.80	-.13	.06	.23	-.11	.69
Machine Stop Level	-.14	.25	.72	.18	-.40	-.01	-.13	.81
Rated Efficiency	.14	-.14	-.76	-.30	.26	.12	.20	.88
Warp Weight	.23	.26	-.05	.91	.03	-.07	.07	.46
Rated Machine Speed	.18	-.20	-.12	-.34	.22	-.13	-.20	.77
Warp Length	-.11	-.08	-.12	-.70	-.05	.02	-.17	.98
Fill Denier	.30	-.12	-.27	.14	.70	-.10	-.06	.73
Input 3 Fill	.18	.42	-.01	.04	-.66	-.20	.08	.31
Defect Tolerance	-.22	-.26	.16	-.01	.08	.79	.06	.83
Picks Per Inch	-.42	-.43	-.29	-.29	-.07	.52	-.12	.81
No. Warp Filaments	.03	.13	-.24	.19	-.08	.06	.75	.78
Warp Denier	.44	.04	-.17	.51	-.09	-.19	.58	.80
% Common Product Variation Explained	27%	17%	16%	15%	11%	7%	7%	
NAME:	Raw Material Content	Fabric Weight	Expected Downtime	Warp Beam	Fill Thread	Defect Tolerance	Warp Thread	
Squared Multiple Correlation of Variables with Factors	.98	.88	.90	.94	.85	.80	.80	

(1) C= Variable Communality

Table 5
Product Mix Heterogeneity and Total Variable Manufacturing Overhead Costs
Seemingly Unrelated Regression Results

	PLANT A: Total Manufacturing Overhead Cost	PLANT B: Total Manufacturing Overhead Cost	PLANT C: Total Manufacturing Overhead Cost
c	304 (.15)	-2351 (.62)	-284 (.10)
1) Excess capacity	-129089 (4.09)**	-73049 (.77)	2739 (.04)
2) Major Setup	170 (.72)	973 (2.91)**	78.2 (.37)
3) Minor Setup	167 (3.04)**	228 (3.47)**	240 (5.37)**
Product Variety:	---(-1)---	---(-1)---	---(-1)---
4) Raw Material	NA	11083 (.78)	-19456 (.39)
5) Fabric Weight	19780 (.23)	154187 (1.34)	-2015 (.04)
6) Expected Downtime	173266 (1.91)*	-80236 (.37)	105346 (2.85)**
7) Warp Beam	-15054 (.38)	-149096 (1.63)	7499 (1.29)
8) Fill Thread	-38526 (.43)	-306468 (2.22)*	19727 (.38)
9) Defect Tolerance	184250 (3.83)**	155122 (1.02)	-114781 (1.18)
10) Warp Thread	-30356 (.61)	-223640 (1.22)	-105660 (1.58)
Adjusted R^2	.39	.17	.33
F-statistic	5.5 **	2.3	4.0 *

Results Without Pre-whitening Variables using ARIMA models

Adjusted R^2	0.57	0.56	0.80
F-statistic	10.1	9.1	26.9
Significant Variables (# above)	1,2,3,7,9	all	1,3,6,8,10

N=63, Absolute t-statistics in parentheses
** = significant at 1%, one-tail * = significant at 5%, one-tail

Table 6 Product Mix Heterogeneity and Operating Labor Wages

Seemingly Unrelated Regression Results [a]

COST:	Plant A: Operating Wages: Straight Time	Plant A: Operating Wages: Overtime Premia	Plant A: Operating Wages: Shift Premia	Plant B: Operating Wages: Straight Time	Plant B: Operating Wages: Overtime Premia	Plant B: Operating Wages: Shift Premia	Plant C: Operating Wages: Straight Time	Plant C: Operating Wages: Overtime Premia	Plant C: Operating Wages: Shift Premia
c	-2.61 (.00)	.83 (.01)	12.7 (.34)	-401 (.30)	-121 (.52)	-2.6 (.03)	-418 (.30)	-54.3 (.29)	34 (.53)
excess capacity	-47319 (4.39)**	-7443 (4.88)**	-2176 (3.40)**	-36722 (1.12)	-16363 (2.99)**	-3373 (1.85)*	24113 (.84)	-4769 (1.26)	1100 (.89)
Major Setup	262 (3.54)**	28.5 (2.50)**	9.23 (2.07)*	157 (1.43)	35.1 (1.84)*	7.13 (1.18)	148 (1.45)	34.4 (2.71)**	3.86 (.86)
Minor Setup	99.0 (5.67)**	13.2 (4.96)**	6.21 (5.93)**	81.5 (3.70)**	12.3 (3.31)**	3.99 (3.30)**	114 (5.74)**	19 (7.15)**	7.36 (8.40)**
Product Variety: Raw Material	NA	---(-1)--- NA	NA	8654 (1.81)*	---(-1)--- 1291 (1.82)*	-179 (.77)	-8073 (.34)	---(-1)--- -406 (.16)	303 (.34)
Fabric Weight	27169 (1.03)	3706 (1.02)	1842 (1.39)	11674 (.32)	685 (.12)	-997 (.56)	1960 (.10)	3496 (1.50)	273 (.39)
Expected Downtime	-33911 (1.15)	10209 (2.76)**	-1696 (1.13)	34315 (.46)	7319 (.68)	56.3 (.02)	3610 (.21)	6515 (3.51)**	887 (1.39)
Warp Beam	-22643 (1.87)*	-668 (.42)	-411 (.66)	-69120 (2.23)*	-8500 (1.84)*	360 (.23)	33716 (1.22)	772 (.26)	1121 (1.10)
Fill Thread	-4126 (.15)	-7722 (2.15)*	-3750 (2.65)**	14558 (.31)	-14811 (2.18)*	1289 (.55)	-20561 (.84)	1428 (.54)	-734 (.81)
Defect Tolerance	-4847 (.32)	4097 (2.06)*	-1515 (1.94)*	-35096 (.67)	11191 (1.46)	-1745 (.67)	-24648 (.53)	-2757 (.56)	194 (.11)
Warp Thread	-2339 (.15)	4218 (2.10)*	-571 (.72)	-18236 (.30)	-11300 (1.23)	5159 (1.72)	-19671 (.62)	-9075 (2.64)**	-2409 (2.05)*
Adjusted R^2	.55	.54	.53	.13	.25	.10	.34	.49	.47
F-statistic	9.6 **	9.2 **	9.0 **	2.0	3.0 *	1.7	4.2 *	7.0 **	6.6 **

N=63, Absolute t-statistics in parentheses; ** = significant at 1%, one-tail * = significant at 5%, one-tail

[a] A system of 3 equations for straight time labor in 3 plants. A system of 6 equations for shift and overtime premia in the 3 plants.

Table 7 **Product Mix Heterogeneity and Indirect Material**

Seemingly Unrelated Regression Results [a]

COST:	Plant A: Power	Plant A: Operating Supplies	Plant B: Power	Plant B: Operating Supplies	Plant C: Power	Plant C: Operating Supplies
c	-346 (.19)	-35.2 (.05)	118998 (45)	48771 (62)**	4071 (2.26)*	128 (.22)
excess capacity	-58785 (2.31)*	-23009 (2.00)*	-37354 (.53)	16695 (.83)	20093 (.48)	-40218 (3.08)**
Major Setup	-476 (2.37)*	145 (1.68)*	399 (1.44)	89.0 (1.27)	-408 (3.16)**	96.4 (2.25)*
Minor Setup	108 (2.39)**	36.5 (1.83)*	60.4 (1.34)	25.9 (1.88)*	49.6 (1.79)*	39.4 (4.31)**
Product Variety: Raw Material	---(-1)--- NA	---(-1)--- NA	---(-1)--- 3038 (.26)	---(-1)--- 760 (.26)	---(-1)--- -209962 (3.85)**	---(-1)--- -2186 (.21)
Fabric Weight	106154 (1.45)	21026 (.67)	164264 (1.83)*	-2831 (.12)	-24303 (.80)	-13944 (1.49)
Expected Downtime	-9845 (.12)	31147 (.94)	-407161 (1.70)*	40867 (.89)	25727 (1.17)	10381 (1.37)
Warp Beam	20781 (.63)	-25513 (1.79)*	-65680 (.66)	-10377 (.54)	45875 (1.22)	4358 (.37)
Fill Thread	-61874 (.83)	21009 (.65)	-72128 (.73)	-61493 (2.12)*	-92948 (2.72)**	7222 (.69)
Defect Tolerance	160297 (4.17)**	51420 (2.94)**	45433 (.45)	38626 (1.21)	-69981 (1.17)	-5295 (.27)
Warp Thread	-33489 (.84)	-2420 (.13)	-172471 (1.38)	-46442 (1.21)	-43771 (1.09)	-25130 (1.83)*
Adjusted R^2	.30	.18	.04	.01	.24	.30
F-statistic	3.4 *	2.5	1.2	1.0	2.6	3.6 *

N=63, Absolute t-statistics in parentheses; ** = significant at 1%, one-tail * = significant at 5%, one-tail

[a] A system of 3 equations each for power and operating supplies in the 3 plants.

Table 8 Product Mix Heterogeneity and Overhead Wages

Seemingly Unrelated Regression Results [a]

COST:	Plant A: Overhead Wages: Straight Time	Plant A: Overhead Wages: Overtime Premia	Plant A: Overhead Wages: Shift Premia	Plant B: Overhead Wages: Straight Time	Plant B: Overhead Wages: Overtime Premia	Plant B: Overhead Wages: Shift Premia	Plant C: Overhead Wages: Straight Time	Plant C: Overhead Wages: Overtime Premia	Plant C: Overhead Wages: Shift Premia
c	55.6 (.32)	6.13 (.27)	1.34 (.10)	36651 (131)**	-40.9 (1.00)	5.28 (.27)	32582 (147)	3.67 (.11)	2.11 (.17)
excess capacity	4218 (1.52)	-832 (2.31)**	-224 (.92)	222 (.03)	-1073 (1.03)	-456 (.89)	3319 (.71)	-2142 (3.04)**	-202 (.77)
Major Setup	61.9 (2.98)**	8.15 (3.03)**	.24 (.14)	46.5 (1.98)*	6.50 (1.79)*	2.61 (1.53)	-21.8 (1.41)	2.29 (.98)	.40 (.43)
Minor Setup	20.7 (4.29)**	1.28 (2.04)*	.37 (.92)	3.26 (.70)	2.32 (3.24)**	.39 (1.14)	11.0 (3.31)**	2.14 (4.30)**	.54 (2.98)**
Product Variety: Raw Material	---(-1)--- NA	---(-1)--- NA	NA	---(-1)--- 1274 (1.28)	---(-1)--- 252 (1.70)*	-135 (1.88)*	---(-1)--- 1311 (.35)	---(-1)--- -873 (1.62)	-94 (.44)
Fabric Weight	1412 (.19)	1590 (1.64)	241 (.41)	9245 (1.14)	1422 (1.18)	130 (.23)	-999 (.30)	-335 (.69)	382 (2.29)*
Expected Downtime	6713 (.84)	1660 (1.63)*	-1159 (1.76)*	-10276 (.67)	-1608 (.70)	1671 (1.49)	387 (.14)	-120 (.31)	122 (.80)
Warp Beam	1782 (.52)	-169 (.39)	-241 (.79)	-9361 (1.45)	-2491 (2.59)**	948 (2.03)*	6029 (1.41)	511 (.82)	-69.5 (.29)
Fill Thread	-17040 (2.19)*	-2877 (2.91)**	-497 (.79)	-5308 (.54)	-2756 (1.90)*	708 (.99)	29.6 (.01)	-179 (.33)	78.3 (.36)
Defect Tolerance	-2062 (.49)	852 (1.58)	-745 (2.17)*	12780 (1.19)	2425 (1.51)	767 (.96)	-9056 (1.26)	757 (.73)	-490 (1.20)
Warp Thread	3094 (.70)	-43.1 (.08)	163 (.47)	-33533 (2.60)**	-2676 (1.39)	1825 (1.96)	-3794 (.77)	-2466 (3.44)**	49 (.17)
Adjusted R^2	.24	.22	.00	.02	.17	.04	.11	.35	.13
F-statistic	3.2 *	3.0 *	1.0	1.1	2.3	1.3	1.8	4.3 **	2.0

N=63, Absolute t-statistics in parentheses; ** = significant at 1%, one-tail * = significant at 5%, one-tail

[a] A system of 3 equations for straight time labor in the 3 plants. A system of 6 equations for shift and overtime premia in the 3 plants.

Table 9

Plant A: Product Mix Heterogeneity and Variable Manufacturing Costs, A Departmental Perspective

Seemingly Unrelated Regression Results

	Weaving	Inspection	Technical Support	Administration
c	-1991 (1.28)	-249 (.68)	-556 (1.55)	128472 (51.4) **
Excess Capacity	-90129 (3.57)**	-6152 (1.13)	-18726 (3.27)**	-52281 (1.46)
Major Setups	393 (2.18)*	-39.1 (.91)	102 (2.50)**	-714 (2.53)**
Minor Setups	197 (4.67)**	25.8 (2.68)**	38.5 (4.04)**	103 (1.62)
Product Variety: Raw Material		---(-1)---		---(-1)---
Fabric Weight	14697 (.23)	21525 (1.37)	-21534 (1.46)	74128 (.72)
Expected Downtime	-65985 (.87)	-11667 (.66)	3573 (.21)	104725 (.90)
Warp Beam	-41896 (1.40)	-6030 (.85)	-1735 (.26)	53811 (1.15)
Fill Thread	-72323 (1.05)	-2318 (.15)	34223 (2.19)*	2970 (.03)
Defect Tolerance	-82012 (2.28)*	29442 (3.55)**	-6725 (.83)	203999 (3.75)**
Warp Thread	75287 (2.03)*	1488 (.17)	6386 (.76)	39920 (.71)
Adjusted R^2	.46	.20	.38	.23
F-statistic	6.01 **	2.41	4.47 **	2.75 *

Absolute t-statistic in parentheses, N=53

** = significant at 1%, one tail; * = significant at 5%, one tail

Table 10

Plant B: Product Mix Heterogeneity and Variable Manufacturing Costs, A Departmental Perspective

Seemingly Unrelated Regression Results

	Weaving	Inspection	Technical Support	Administration
c	-180 (.12)	-493 (1.03)	51.4 (.11)	186128 (47.5)**
Excess Capacity	31732 (.85)	-2283 (.19)	-14961 (1.31)	-10878 (.11)
Major Setups	187 (1.50)	93.4 (2.23)*	84.0 (2.20)*	602 (1.76)*
Minor Setups	75.6 (3.01)**	28.6 (3.46)**	25.6 (3.33)*	29.5 (.44)
Product Variety:		---(-1)---		---(-1)---
Raw Material	6389 (1.18)	280 (.16)	814 (.49)	14041 (.97)
Fabric Weight	-2853 (.07)	8383 (.58)	-2982 (.23)	165980 (1.41)
Expected Downtime	136087 (1.60)	-61633 (2.26)*	28792 (1.10)	-5561 (.02)
Warp Beam	-34288 (.97)	-15379 (1.34)	-1338 (.12)	-116543 (1.24)
Fill Thread	33176 (.62)	-47163 (2.71)**	-13002 (.78)	-297694 (2.10)*
Defect Tolerance	26154 (.43)	1285 (.07)	-28681 (1.55)	37701 (.24)
Warp Thread	-42055 (.60)	-15511 (.67)	-47735 (2.20)*	-311506 (1.67)*
Adjusted R^2	.06	.21	.24	-.03
F-statistic	1.42	2.61	2.98 *	.80

Absolute t-statistic in parentheses, N=63
** = significant at 1%, one tail; * = significant at 5%, one tail

Table 11

Plant C: Product Mix Heterogeneity and Variable Manufacturing Costs, A Departmental Perspective

Seemingly Unrelated Regression Results

	Weaving	Inspection	Technical Support	Administration
c	832 (.49)	-116 (.27)	536 (1.03)	133415 (56.1)**
Excess Capacity	-98231 (2.73)**	-7920 (.83)	-1097 (.10)	104998 (2.04)*
Major Setups	28.5 (.23)	-71.1 (2.23)*	97.4 (2.53)**	45.2 (.26)
Minor Setups	199 (8.04)**	50.1 (7.38)**	45.7 (6.01)**	15.1 (.41)
Product Variety:		---(-1)---		---(-1)---
Raw Material	9386 (.32)	7738 (1.03)	-301 (.03)	-8917 (.22)
Fabric Weight	46226 (1.68)*	-2598 (.33)	3043 (.36)	-2823 (.06)
Expected Downtime	31221 (1.42)	9820 (1.67)*	-1609 (.24)	20907 (.66)
Warp Beam	22465 (.62)	-1250 (.14)	-6709 (.60)	153219 (3.14)**
Fill Thread	-56067 (1.59)	-1640 (.17)	-8123 (.75)	-123752 (2.41)**
Defect Tolerance	-32540 (.56)	8129 (.53)	-6948 (.39)	-240920 (2.93)**
Warp Thread	-105601 (2.67)**	-12148 (1.19)	-13427 (1.10)	-8150 (.15)
Adjusted R^2	.59	.48	.43	.09
F-statistic	8.81 **	6.16 **	5.07 **	1.51

Absolute t-statistic in parentheses, N=56
** = significant at 1%, one tail; * = significant at 5%, one tail