Diffusion and Performance of Modular Production in the U.S. Apparel Industry

JOHN T. DUNLOP and DAVID WEIL*

This article examines the determinants of the diffusion of team production systems (modular assembly) and the impact of these systems on firm performance relative to traditional assembly systems in the apparel industry. The article draws on an extensive survey providing detailed information on a wide range of manufacturing practices and retail relationships in the U.S. apparel industry. We find that recent diffusion of modular practices is driven primarily by the product market. We also show that modular systems affect business-unit performance (particularly operating profits) where they are combined with complementary investments in information systems linking apparel suppliers with retail customers.

THE APPAREL INDUSTRY IS NO STRANGER to discussions of "high-performance work systems," team or "modular" assembly, and innovative human resource practices. Modular assembly alters the traditional method of production that relies on individual operators to perform one or two tasks repetitively by substituting teams of workers to sew and assemble parts or all of a garment. Throughout the 1980s, team-based assembly was heralded for reducing costs and enhancing workforce performance by the garment industry trade press, the major apparel manufacturing association, the major fiber and textile producers, the nonprofit Textile Clothing Technology Corporation (TC²), and the Amalgamated Clothing and Textile Workers Union (ACTWU).

Despite the advocacy for modular assembly, these practices have not

*The authors' affiliations are, respectively, Harvard University, and School of Management, Boston University This study was supported by funds from the Alfred P Sloan Foundation We are indebted to our colleagues on this project, Frederick Abernathy and Janice Hammond, for their comments. We are grateful to Catherine George and Igor Choodnovskiy for research assistance

INDUSTRIAL RELATIONS, Vol 35, No 3 (July 1996). © 1996 Regents of the University of California Published by Blackwell Publishers, 238 Main Street, Cambridge, MA 02142, USA, and 108 Cowley Road, Oxford, OX4 1JF, UK

diffused to a significant degree in the U.S. apparel industry. In 1992, about 80 percent of garments were sewn and assembled by the traditional Tayloristic progressive bundle system (PBS). Only 9 percent utilized the modular system.[1]

Drawing on a unique data set, this article examines the determinants of the diffusion of modular production systems and its impact on firm performance relative to traditional assembly systems in the apparel industry. The data set allows modeling of different classes of adoption determinants, particularly those related to the product market. The data also permit assessment of how modular systems affect firm performance relative to other managerial innovations.

Our empirical results demonstrate that adoption of modular systems arise from the same product market forces driving adoption of manufacturing practices related to new forms of apparel retailing. In particular, modular systems have been embraced by those business units that have adopted information systems increasingly required by apparel retailers. The impact of modular assembly on business-unit performance arises from modular assembly's interaction with these information systems, allowing adopting apparel suppliers to respond to more stringent retail delivery standards while reducing their own need to hold large work-in-process (WIP) and finished product inventories.

Data

This study draws from a larger data set providing comprehensive information on a wide range of apparel manufacturing practices in 1988 and 1992 at the business-unit level.[2] The sample consists of forty-two business units in the men's shirt, suit, and pants sectors, and in men's and women's jeans and undergarment product lines. These product categories rely on in-house manufacturing and have relatively large production runs.

The detail and confidential information requested in the sixty-page questionnaire meant that a random, stratified sample of the whole apparel industry was not feasible. Instead, to secure such detailed responses, the

[1] These results are taken from the industry data set underlying this article and described in detail in a later section of the article The estimates are consistent with those of the AAMA (1992).

[2] A business unit is defined as the lowest level of a firm with responsibilities for the formulation of annual policies dealing with merchandising, planning, manufacturing, distribution, and related activities for a product line or lines, and that collects financial data for those activities For some organizations, the business unit may be the overall corporation For others, a number of business units might operate within a single corporate umbrella A business unit may rely on one (or more) in-house plant(s) to manufacture its products and/or may rely on a network of contractors (with either domestic or foreign operations) to produce its products

survey effort required sponsorship and support from industry participants. This survey procedure was successful in assuring responses by major manufacturers in certain targeted product segments (particularly on the men's side of the industry). As a result, the sample is biased toward larger firms and business units.

The sample provides for considerable homogeneity in the product market characteristics and manufacturing practices among business units. The survey response rate for these product categories was about 50 percent, resulting in a sample that represents 30 percent of the total volume shipped by U.S. producers in 1992 for the five product categories. The findings presented here were also tested against a larger sample of business units that did in-house manufacturing regardless of product category.[3]

Apparel Assembly: PBS and Modular

Producing a garment in large quantities presents a set of operating problems. A typical jeans manufacturer for example can have upward of twenty thousand different items in its collection at any point in time (arising from different size, style, and fabric combinations). The manufacturer is faced with assembling each of these product variations from a large number of separate cut pieces. Individual sewing processes vary considerably for a given garment, from relatively simple operations requiring little skill to operations that can require over a year to learn. The limp character of fabric has thwarted attempts to automate the assembly process to any major extent. Even today, only a limited number of sewing operations have been successfully automated.

Thus apparel manufacture is labor intensive. For example, nearly three-quarters of all production workers in the dress shirt industry are involved in sewing room assembly.[4] Sewing room work[5] is currently undertaken by one of two major methods: progressive bundle and modular systems.[6]

[3] More detailed information on response rates and sample representativeness by product category is available from the authors Results from an analysis of this larger data set are also available from the authors

[4] The distribution of production workers in the men's shirt industry is indicative of overall patterns in the apparel industry In 1990, the distribution of production workers by department was cutting room 2,075 (5 5%), sewing room 27,303 (72 5%), finishing department 5,830 (15 5%), miscellaneous (e g , maintenance, shipping clerks) 2,463 (6 5%) See U S Department of Labor (1992), Table 7

[5] Organization of work in the cutting room raises fundamentally different questions from those in the sewing room concerning technology, investment, material costs, and access to skilled workers that are not addressed in this article

[6] The unit production system (UPS) is a third assembly method that has been widely discussed over the past decade UPS has a great degree of similarity to the progressive bundle system sewing operations are broken down to minimize direct labor content, and each operator works independently

Progressive bundle system. Since the emergence of mass markets for apparel, the dominant production method chosen for garment assembly has been the bundle system, which dates back before 1900. The progressive bundle system, which originated in the 1930s (Dunlop and Weil 1994), represents a refinement of the bundle system. In PBS, each individual sewing task is specified and then organized in a systematic fashion. PBS entails engineering-specific sewing tasks to reduce the amount of time required for each task. It also requires laying out shops to reduce the time required to shuttle a bin of garment bundles from operator to operator.

In PBS, each operation is done by a single worker operating at a stationary sewing machine. Each worker receives a bundle of unfinished garments. She (seldom he) then performs a single operation on each garment in the bundle. When the operator finishes a bundle, it is placed in a buffer with other bundles that have been completed to that point. The bundles in the buffer are then ready for the next operator in the sequence.

Each task in the assembly process has a target "standard allocated minutes" (SAM) that represents the total amount of direct labor time required for each task. SAM for an entire garment is therefore calculated as the sum of the number of minutes required for each operation in the garment production process, with adjustments for worker fatigue, break times, and related factors.[7] Compensation is based on the operator's rate of production relative to the SAM.

Refinement of PBS over time has led to high levels of pace and labor productivity in terms of direct labor content per assembled apparel product. Productivity measured as constant dollar value of shipments per worker rose consistently between 1963 and 1987. As a result, a typical men's dress shirt in 1992 required about eighteen minutes of direct labor, a pair of trousers twenty-four minutes, knit pants three minutes, and a T-shirt one and a half minutes. Given average hourly earnings in 1989 for these garments, the dollar value of direct labor for shirts was about $1.71; for pants $2.24; for knit pants $.33; and for a T-shirt $.17. Even the most complex garment among men's collections, suits, had only about $12.50 of direct labor inputs (Dunlop and Weil 1994).

A major by-product of PBS arises from its dependence on buffers between assembly operations to minimize downtime of workers given uneven

rather than in teams on her assembly step It differs from the progressive bundle system, however, in that work in process is transferred between operators through automated material handling systems rather than through the use of large buffers in the form of bundles

7 A SAM is based on rates of speed for a fully trained worker As a result, new workers in a production line will perform below the SAM estimate on their operation, while some experienced workers achieve rates of production far above the established SAM

assembly time requirements for different operations. Standard practice is a one-day buffer between operations. As a result, in a pair of pants with roughly forty operations, a large amount of in-process inventory is created. More important, a *given* pair of pants requires forty days or more to move from cut pieces to final product.

Modular system. Modular production is based on a fundamentally different notion than bundle assembly. Rather than breaking up sewing and assembly into a long series of small steps, modular production entails grouping tasks (e.g., the entire assembly of a collar) and assigning that task to members of a module (i.e., team of workers). A group (or "module"), ranging in size from five to thirty operators, works together to produce part or, in some cases, all of a garment (81 percent of the business units using modular assembly in our sample indicate that at least some modules in the business unit assemble an entire product). Although most operators in the module still spend the majority of their time on a single assembly task, operators do move to other tasks if work is building up at some other step in the module. Compensation is primarily based on the module's output (see below). Modules are partially self-directed in that operators determine task assignments, pace, and output targets in most cases based on the incentives provided by the group compensation system.[8]

Focusing production at the group level means that modular lines rely on far smaller buffers between assembly steps than under PBS.[9] Given that sewing operators are compensated at the group level, production activities are geared to ensure that the sequence of steps delegated to the module are completed, creating a disincentive to allow all work in process to accumulate in the module. By substantially reducing work-in-process buffers, throughput time for a given garment can be dramatically decreased: average throughput time for sewing operations on modular lines was 1.7 days versus 9.2 days for PBS lines.

As the above description would suggest, modular systems entail considerable modification to the human resource practices associated with assem-

[8] Manager descriptions of modular activities from our sample indicate that workers in modules focus primarily on these matters directly related to production as well as scheduling hours, breaks, and planned absenteeism for team members Modules on average report "some or little" influence on selection of team leaders and members, training, performance evaluation, and dispute resolution, while reporting "little or no" influence on the introduction of new technologies and capital investments. These results are available from the authors

[9] However, buffers are not usually eliminated even in modular assembly There is an average buffer of sixty apparel items between production steps in modular lines in the sample Only 30 percent of the business units using modular systems in the sample responded that workers directly hand off garments to other team members (implying a zero buffer) See Lowder (1991) and George (1995) for related discussions.

bly. The relation of assembly method to human resource practices can be seen in Table 1. By breaking down assembly operations into discrete operations undertaken by individual operators, PBS relies solely on piece-rate compensation and draws on line supervisors and—where present—union stewards to deal with problems and disputes on the line. The use of group assembly shifts the focus of incentive structure away from the individual and places it on the group. As a result, only one-third of assembly workers on modular lines are paid by piece rates, with the majority of operators receiving some type of group incentive. Training requirements differ as well, given the need for modular operators to be able to perform multiple assembly tasks. Table 1 suggests, however, that modular production relies on training for a more limited number of jobs (a median of two jobs versus one for PBS) than popular industry accounts might otherwise suggest.

The tight linkages between human resource practices and production systems indicate that the diffusion of innovative practices like group incentives, team-based supervision, and multiskilling will be fundamentally linked to the diffusion of the underlying production systems. In this sense, innovative human resource practices are more usefully described as a set of

TABLE 1

Human Resource Practices by Assembly System, 1992

	Percent of Business Units Drawing on Human Resource Practice		
	Overall[a]	PBS	Modular
Compensation Practices			
Individual piece rates	91 4	98 1	30 0
Straight hourly rate—target output	2 0	0 0	20 0
Straight hourly rate—skill or quality	3 5	0 0	20 0
Group incentive—target output	8 2	0 0	80.0
Group incentive—skill or quality	7 8	0 0	80 0
Split incentive (individual and group)	23 3	20 4	50 0
Penalty for rework	34.3	31 5	60 0
Other compensation system	1 7	1.9	0 0
Training Practices			
Workers are trained for one job only	54 1	58 9	10 0
Workers are trained for two jobs	31 7	28 6	60.0
Workers are trained for three jobs	6.8	5 4	20 0
Workers are trained for four jobs	7 4	7 1	10 0
Percentage of volume shipped by business unit using assembly system	88 9[b]	80 0	8 9

[a] Based on weighting reported incidence of practices by the overall percentage of volume shipped by business unit using each assembly system Overall incidence includes UPS

[b] Remaining volume shipped using UPS (2 2 percent), see text, and other systems related to PBS

complementary practices associated with an underlying manufacturing system rather than as separable decision variables for the firm.[10] The complementary relation between assembly method and human resource practices also illustrates why business units are often reluctant to innovate in the sewing room. Introducing modular production requires far more than rearranging plant layout; it requires changing the incentive system and training requirements for production workers along a number of dimensions.

Diffusion of Modular Production

Early modular advocates (such as the American Apparel Manufacturers Association [AAMA] and the Amalgamated Clothing and Textile Workers Union) argued for its widespread adoption because of its positive impacts on job characteristics, human resources, and in turn labor costs (e.g., AAMA 1988). In response to persistent problems regarding finding and retaining a skilled workforce, these advocates argued that modular assembly improves the desirability of apparel employment by increasing task variety and decreasing the isolation of individual operators in PBS. Given that more interesting work attracts a more stable and dedicated workforce, modular assembly is a response to labor shortages and can also decrease absenteeism and turnover.

An alternative argument for modular adoption relates to the "external fit" between larger competitive forces and assembly methods. Competitive dynamics in many segments of the apparel industry are being transformed as a result of technological innovations that allow the low-cost collection, processing, and dissemination of consumer sales data (Abernathy et al. 1995). These innovations set the foundation for a new retailing strategy directed at reducing a retailer's exposure to demand risk by adjusting the supply of products at retail outlets to match consumer demand on the basis of daily, point-of-sale information. These retailers require, in turn, that their suppliers compete not only on the historic basis of price, but also on the basis of their replenishment speed, flexibility, and services.

These industry changes have direct implications for the adoption of modular systems. A central advantage of modular systems over PBS is their impact on throughput times for garments (Cole 1992; Hill 1992). By reducing the amount of time required to assemble a given product, an apparel supplier can become more responsive to retail requirements for

---

[10] The link between work organization and human resource practices is particularly tight in apparel in this respect For a contrasting case, see Ichniowski, Shaw, and Prennushi (1995) for analysis of these linkages in steelmaking.

TABLE 2

CHARACTERISTICS OF MODULAR ADOPTERS AND NONADOPTERS

			Modular Users	
Business-Unit Characteristics	Overall	Nonadopters	Experimenters, Pre-1992[b]	Adopters, 1992[c]
Number of business units[a]	42	26	8	10
Replenishment pressure,[d] 1988	41 5	44 5	24 9	39.2
	(39 2)	(39 8)	(31 9)	(40 0)
Replenishment pressure,[d] 1992	44 6	44 0	30 4	53 2
	(36 2)	(37 6)	(32 4)	(32 0)
% of volume in basic product lines, 1988	54 3	56 2	57 5	44 6
	(30 3)	(32 8)	(25 2)	(23 2)
Work-in-process inventories held in sewing operations, 1988	3 6	3 3	5 0	3 1
	(2 3)	(1 6)	(3.6)	(2 3)
Size (1988 $million sales volume)	151 9	82 0	144 4	356 2
	(267 4)	(89 8)	(161 2)	(469 8)
Average length of modular trial (years)[e]	——	——	7	1 8
			(1 0)	(0 6)

[a] Two business units adopted, abandoned, and readopted modular systems and therefore are classified in both experimenters and adopters categories

[b] Business units that adopted and then abandoned modular systems before 1992

[c] Business units that adopted modular systems after 1988 and continued to have them in operation in 1992

[d] Percent of volume shipped to national chains/mass merchants

[e] Length for experimenters indicates the average reported time for those who abandoned modular assembly, length for adopters measures the average length of time between adoption and 1992

rapid product replenishment. Thus, the emergence of lean retailing in the late 1980s gave a competitive premium to systems that minimized throughput, much as PBS's impacts on direct labor content led it to dominate given price/cost-based competition.

In our sample, sixteen business units used modular systems at some point during the past decade. These business units can be broken up into two groups: "experimenters," that is, business units that tried but abandoned modular systems at some point *before* 1992, and "adopters" who adopted modules after 1988 and continued to use them up to 1992. Table 2 provides characteristics of both groups in addition to those business units that did not adopt modules throughout the entire period.[11]

The most commonly cited reason that modules were abandoned by experimenters (after an average eight-month trial period) concerns the perceived costs of modular systems in terms of lost labor productivity, and the consequent inability of modules to provide a sufficient payback to justify

[11] Two of the business units that abandoned modular systems reintroduced them by 1992 and therefore fall into both groups

continuing their use.[12] Given that the majority of experimenters adopted before or around 1988, these responses suggest that these business units adopted modules primarily because of their impact on direct internal costs, associated with the "job characteristic" arguments described above.

The adopter group of business units, in contrast, introduced modules in more recent years (no business units in our sample had modules in 1992 that had been in continuous operation before 1989).[13] Survey responses by business-unit managers suggest that "external fit" played a greater role in the adoption decisions of this group than for experimenters. Table 3 presents business-unit respondents' rankings of the reasons why they adopted modular assembly systems.

Improved ability to meet retailer standards on product delivery was cited as the most important reason for adoption. This was followed by reduction in work-in-process inventories, quality, and throughput time. Attributes related to the impact of modular production on human resource factors (e.g., impact on satisfaction, turnover, and safety and health[14]) are ranked next. Managers ranked at the bottom reasons related to modular's potential impact on reducing the number of support workers and supervisors, increasing space availability, reducing direct labor content, and improving the attractiveness of assembly jobs.

Modeling Modular Adoption

Tables 2 and 3 suggest that the motivations of recent modular adopters differ significantly from those of nonadopters and experimenters. To assess the comparative impact of these factors, business-unit adoption of modules between 1988 and 1992 can be expressed as a function of the degree of replenishment pressure and other product market factors previous to adoption (measured in 1988) as well as the other potential correlates discussed below.

Product market factors. If the adoption of modular systems is linked to the competitive pressures faced by adopting units, one would expect higher probability of adoption among those units facing the greatest de-

[12] These factors were cited by all eight of the business units that had dropped modular assembly Only two business units cited additional factors (such as workforce or management disruptions caused by modular systems) as reasons that modules were dropped

[13] Of the ten business units in the adopters group, one introduced modules in 1989, six in 1991, and three in 1992

[14] Repetitive motion injuries arising from PBS have been a major problem for business units in many apparel sectors Reducing these costs by increasing each operator's task variety can therefore be a motivation for introducing modular assembly

TABLE 3

REASONS FOR MODULAR ADOPTION BY BUSINESS UNITS

Reasons for Modular Adoption[a]	Ranking[b] Mean (standard deviation)
Improves ability to meet retailer standards on product delivery	2.8 (0.4)
Reduces work-in-process inventories	2.6 (0.7)
Improves first-pass product quality	2.5 (0.7)
Reduces throughput time for product assembly	2.5 (0.7)
Improves worker safety and health	2.3 (0.8)
Decreases turnover and absenteeism	2.2 (0.7)
Improves job satisfaction of workforce	2.2 (0.8)
Reduces number of material handlers and support workers	2.0 (0.7)
Reduces number of supervisors	1.7 (0.8)
Helps attract new workers	1.1 (0.9)
Reduces direct labor content required for garment assembly	0.9 (1.3)
Reduces amount of space needed for assembly operations	0.9 (1.0)
Number of business unit observations	10

[a] Based on business-unit managers responses for those business units that adopted modular systems between 1988 and 1992.

[b] Based on a scale of 1 to 3 where 0 = "not important", 1 = "somewhat important", 2 = "important", and 3 = "extremely important."

gree of pressure from retailers to provide products on a rapid replenishment basis. Retailer rapid replenishment programs emerged and remain concentrated in two retail segments: national chains and mass merchants.[15] Table 2 indicates that the recent modular adopters experienced the greatest increase in shipments to mass merchants and national chains between 1988 and 1992 (from 39 percent to 53 percent of total volume shipped) and

[15] Examples include Wal-Mart among mass merchants and Penny's in national chains. The link between these retail segments and rapid replenishment demands can be seen in the following. In 1992, daily or weekly replenishment shipments constituted less than 30 percent of total wholesale dollar volume shipped to department stores by business units. In contrast, 65 percent of total volume was shipped on a daily or weekly basis to mass merchants and 74 percent to national chains (Abernathy et al., 1995, pp. 187–188).

therefore replenishment pressure. The volume shipped to these retailers by both nonadopters and experimenters remained relatively flat. This would suggest a relation between the propensity to adopt modular systems and the volume shipped to this category of retailers.

Replenishment requirements also potentially change the cost of WIP inventories associated with PBS. Higher WIP levels imply a larger burden on business units facing a demand for rapid replenishment and therefore a greater incentive to introduce modules. As a result, business-unit WIP inventory in 1988 is used as a second product-market predictor of 1992 modular adoption.

Finally, rapid replenishment can be defined as the ability to restock products within a selling season. Basic (rather than fashion) products are therefore the focus of most replenishment programs. The percentage of basic products in a business unit's collection should therefore be related to the incentive to adopt modular systems.[16]

Other business-unit practices. The degree that business units were prepared to offer rapid replenishment may have also affected the rate of modular adoption. To test for this, we use the presence of information linkages with retailers in 1988 as a control variable (see later discussion). In addition, we control for the presence of previous experiments with modular systems.

Control variables. Business-unit size must be controlled because larger business units may also be more able to afford investments in modular systems. The ability of a business unit to manage efficiently its plant's assembly operations—independent of the factors described above—may also affect adoption. We employ estimated unit labor costs[17] for a typical garment item in the business unit as a proxy to control for these business-unit fixed effects. Mean values for all variables are found in the first column of Table 4.

Findings

Table 4 presents the results of logit regression models of the determinants of modular adoption. Since the shift toward rapid replenishment

[16] Rapid replenishment programs are still relatively uncommon for fashion products because of the difficulties of providing in-season replenishment for these goods. Even women's apparel retailers like The Limited that have incorporated replenishment principles have a narrow product line with lower level of product turnover than is typical for the fashion end of the women's apparel business

[17] Unit labor costs are calculated using the reported average number of minutes for a typical garment in the business unit's collection and their reported average hourly earning to calculate the direct costs of labor for a typical garment produced by the business unit

TABLE 4

LOGIT REGRESSION MODELS OF MODULAR ADOPTION DETERMINANTS, 1988 AND 1992
(CHANGE IN USE OF MODULES)

		Model (1)		Model (2)	
Adoption Determinants	Mean (standard error)	Coefficient (standard error)	Prob. Effects[a]	Coefficient (standard error)	Prob Effects[a]
Replenishment pressure, 1988 (% of volume shipped)[b]	41 45 (39 17)	.083* (.047)	12 3	——	——
Replenishment pressure, 1992 (% of volume shipped)[b]	44 62 (36 24)	——	——	127* (071)	14.4
Work-in-process inventories, 1988 (weeks of supply)	3 57 (2 26)	– 499 (439)	–5 2	076 (563)	0
% of volume in basic product lines, 1988	54.25 (30 26)	–.089* (.043)	–13 0 (018)	– 102* (057)	–10 9
Previous experiment with modular assembly (= 1 if yes)	19 (0 39)	3 11 (2 33)	1 9	2 68 (2 22)	1 3
Information system investments, 1988 (= 1 if present)	26 (.45)	– 711 (1 52)	0 7	–1 73 (2 07)	9
Size (ln 1988 $million sales volume)	4 09 (1 48)	2 93* (1 33)	9 7	3.60* (2.10)	6 8
Unit labor cost for typical garment (ln 1992$)	1 02 (1 33)	.968 (.925)	2 9	405 (961)	9
Log likelihood	——	22 55	——	24 51	——
Predicted modular adoption probability at means	——	31	——	22	——
Sample size	42	42	——	42	——

* Significant at the 05 level, ** significant at the 01 level T-tests are one-tailed

[a] Impact of a 10 percent increase in independent variable on probability of adoption, all other variables held constant at their mean values

[b] Percentage of volume shipped to mass merchants and national chains

occurred in the years between 1988 and 1992, Model (1) includes the variables described above and uses 1988 replenishment pressure as an independent variable, while Model (2) uses replenishment pressure in 1992. Chi-squared tests of the collective significance of the variables in both logit equations are significant at the .01 level.

The replenishment pressure coefficients in Models (1) and (2) confirm that firms shipping a high percentage to mass merchants and national chains are more likely to adopt modular systems than those with lower shipments. The coefficients imply that a 10 percent increase in shipments increases the probability of adoption by 12 percent in Model (1) and 14 percent in Model (2), all other factors held at their mean. The coefficients are significant in both models and imply that replenishment pressure raises adoption probabilities more than any other factor (except for percent basic in Model [1]).[18] While the level of WIP inventories in 1988 show a weak negative relation to adoption in Model (1) and virtually no relation in Model (2), the percentage of volume produced in basic product lines by the business unit is negatively (and significantly) associated with adoption.

The logistic results provide little evidence that previous experience with modular systems or the presence of information linkages in 1988 affect later adoption. The former result is consistent with the notion that the first group of modular adopters was motivated by factors very different from the more recent adopters. The lack of connection between 1988 information investments and recent adoption is more puzzling, but may arise from greater heterogeneity in the motives of early bar-code/electronic data interchange (EDI) adopters relative to those who adopted in the period after 1988 when rapid replenishment emerged as a major retail strategy.[19] The other major factor affecting adoption is business-unit size: the larger the business unit, the more likely it is to have adopted modular systems.

Performance Effects of Modular Assembly

Despite the strong association between module adoption and replenishment pressure, modular assembly is used by a small percentage of the industry. The ten business units classified as "adopters" in Table 2 draw on it for an average of 36 percent of total volume assembled (ranging from a low of 10 percent to a maximum of 70 percent). As a result, by 1992, only 8.6 percent of the volume shipped by business units in the sample was assembled via modular systems versus 80 percent by PBS.

The lack of more widespread use suggests several possible explanations. First, low levels of diffusion may reflect the fact that modular systems do not result in the expected impacts on throughput and replenishment speed. Second, modular systems may yield benefits, but high "switching costs" may inhibit their adoption (as found by Ichniowski and Shaw [1995] in the case of innovative human resource practices in the steel industry). Third, the benefits from modular assembly may accrue only given the presence of other business-unit investments also associated with lean retailing. Absent these investments, the comparative benefits of modules may be small (or unattainable). All three explanations require analyzing the relation of

[18] Among the ten business units using modules, the three units using the highest percentage of modular systems for assembly shipped about 52 percent of their products to mass merchants and national chains in 1988 In contrast, the three business units using modules least for assembly in 1992 had supplied only 26 percent to these retailers in 1988

[19] Lagged replenishment pressure is a strong determinant of bar code and EDI adoption in 1992, but is only weakly related to their adoption in 1988 (Abernathy et al 1995)

modular investments to other business-unit practices related to retail replenishment, and then measuring the impact of modular systems and other potentially complementary investments on performance.

Linking Modular Adoption to Information Investment

Retailer demand for rapid replenishment requires investment in information systems to transmit detailed sales and order information. Suppliers must adopt an electronic common language for identifying products and provide a means to transmit efficiently this information to and from retailers on a daily or weekly basis. Specifically, a business unit must invest in two basic information linkages with retail partners: (1) uniform bar codes for each of the products provided to the retailer, thereby allowing them to track sales at the individual product level; and (2) electronic data interchange which provides sales information in real time. Overall investments in the two basic components for information transfer increased dramatically between 1988 and 1992. In 1988, 26 percent of all business units were shipping at least some volume through the use of these systems, but by 1992, 81 percent utilized them.

Modular adoption therefore must be understood as part of a set of sequential decisions necessary to adapt to changing retailing requirements. Meaningful changes to the method of production make little sense if one has not made investments in information regarding product demand. Similarly, if one is unable to ship products efficiently to retail distribution centers, there will be little to gain from throughput reductions arising from modular assembly.

Case studies of sophisticated apparel manufacturers support this notion of sequential manufacturing investments. Levi Strauss and Haggar—two of the largest manufacturers of jeans and men's trousers—invested heavily in developing methods of uniquely identifying products and exchanging information electronically well in advance of any changes in design, cutting room, sewing, or relations with textile manufacturers. In contrast, two of the earliest adopters of modular assembly in the men's separate trouser and dress shirts sectors had abandoned their modular lines by 1992. Neither manufacturer had electronic data interchange with their retail customers at that time.

The relation between investments in information systems and adoption of modular systems can be seen in the sample. In 1992, *every* business unit that had modular manufacturing also had the basic information investments necessary to deal with lean retailers (versus an incidence of 75 percent for nonadopting business units). No such link existed between the presence of basic information investments and modular manufacturing previous to 1992. Only two of the eight "experimenter" business units that adopted and abandoned modular systems before 1992 also had information linkages with retailers in 1988. This corresponds to the overall incidence of information investments in 1988 (which composed about 26 percent of business units), once again suggesting that motivation for modular adoption in the pre-1988 period arose from other causes.

Modeling Performance Effects

Two types of business-unit performance outcomes will be examined. First, we look at the impact of modular adoption on lead times. Lead times are the total time required in the apparel production process from the time fabrics are ordered to the time finished products are ready for shipment by the business unit. They therefore represent a critical measure of the ability of a business unit to compete in a market increasingly dominated by rapid replenishment retailing principles.

Second, we look at the impact of modular systems on operating profits as a percentage of sales. If lead times capture a unit's external performance, operating profits are a key measure of its internal performance: A unit can reduce lead times by holding large inventories and be judged externally as successful, but this strategy could adversely affect its bottom line. A unit that engages in internal restructuring to reduce lead times (including the introduction of modular assembly) could both reduce leads and enhance profitability.

Given that our concern is with performance at the business-unit level, we do not consider here the direct impact of modules on unit labor costs in the sewing room per se. A comparison of labor costs in the subsample reveals that business units with modular lines have average unit labor costs about 4–5 percent lower than those with only PBS lines. Berg, et al. (1994) find that modules outperformed PBS lines in quality, costs, and responsiveness based on a case study of three apparel companies. A detailed study using direct comparisons of modular and nonmodular lines in a single company by George (1995) indicates that modular lines have slightly higher productivity levels, although neither type of lines dominates in regard to its ability to provide multiple products.

Performance is modeled as a function of the percent of volume assembled using modular systems as well as other factors associated with performance outcomes. Given that all business units that adopted modular assembly also had made basic information investments, we cannot measure the independent effect of modules on those outcomes. We can, however, mea-

TABLE 5

REGRESSIONS OF BUSINESS-UNIT PERFORMANCE, 1992

	Lead Time—Standard (days), 1992[a]		Lead Time—Shortest (days), 1992[b]		Operating Profit, 1992 (% of $ shipments)	
	(1)	(2)	(1)	(2)	(1)	(2)
Dependent variable mean / standard error	83 0	83 0	44.87	44 87	9 07	9 07
	(65 83)	(65 83)	(41 01)	(41 01)	(6 34)	(6.34)
Model						
Use of UPC bar-code standards and electronic data interchange, 1992 (= 1 if yes)	−92 52**	−89 06**	−53 47**	−50 26**	6 53**	6 06**
	(26 52)	(26 62)	(16 87)	(17 21)	(2 72)	(2 66)
Modular assembly (% of total volume assembled)[c]	—	− 630	—	− 700	—	098*
		(574)		(679)		(057)
Size (1988 $million sales volume)	− 022	004	040	051	002	− 002
	(036)	(043)	(054)	(055)	(004)	(004)
% of volume in basic product lines, 1988	.202	209	070	068	− 058*	− 056*
	(.351)	(350)	(226)	(226)	(033)	(032)
Adjusted R^2	0 31	0.336	0 276	0 304	0 196	0 261
Sample size	42	42	42	42	42	42

* Significant at the 05 level, ** significant at the 01 level T-tests are one-tailed
[a] Lead time measured in elapsed calendar days for "standard" or average product manufactured domestically
[b] Lead time for "shortest" or best performance for product manufactured domestically
[c] For business units that adopted modular assembly between 1988 and 1992 only

sure the degree to which modules improve performance above and beyond the benefit conferred by information investments by themselves.

Uniform Product Code (UPC) bar-code and electronic data interchange investments. The sequential investment discussed above suggests that the ability for a business unit to benefit from modular adoption would presumably be affected by the presence or absence of these investments.[20] Business-unit use of UPC bar codes *and* electronic data interchange is employed as the measure of information investment.

Modular assembly variables. Rather than using a dichotomous variable to capture modular effects, we use the percentage of business-unit volume assembled in modular lines. This provides a means of capturing the comparative impact of modular assembly in business units that rely heavily on it from those that use it for only a small percentage of assembly. Performance regressions using this variable are presented in Table 5.

[20] Analysis of the entire data set (including all 118 business units) has demonstrated large and positive relationships between these investments and apparel supplier performance (Abernathy et al., 1995, Hwang, 1995)

Control variables. The analysis controls for business-unit size and the percentage of basic products shipped to control for other factors correlated with performance and modular assembly practices.

Findings

The first four columns in Table 5 present the estimated impact of the percentage assembled via modular systems, information investments, and other factors on lead time performance (measured as standard and shortest reported lead times for a business unit). Model (1) (which excludes the modular variable) indicates pronounced and significant effects of information investments on both types of lead times. The negative coefficients (not significant) on the modular assembly variables in both standard and shortest lead times equations indicate that modular systems lower lead times as predicted. These coefficients imply relatively small modular effects for the sample as a whole: for standard lead times, Model (2) coefficients imply that a 1 percent increase in modular assembly leads to a .6-day decrease in lead time, which represents less than a 1 percent decrease in average lead times. However, for the typical modular adopter that draws on modules for 36 percent of assembly, these coefficients imply lead time reductions of about twenty-three (standard) and twenty-five days (shortest). These modular effects, however, diminish dramatically if the log values of lead times are employed as the dependent variable.[21]

The amount of performance variation accounted for by the models (as measured by adjusted R^2) changes little with inclusion of the modular assembly variable. A great deal of the variation in lead time performance is therefore explained by information investments, whereas relatively little of lead time performance can be attributed to variation in modular assembly volumes. The results in regard to shortest lead time performance are parallel to those discussed above.

Information investments are also associated with higher operating profits. Business units using bar codes and EDI in 1992 earned average operating profits as a percent of sales 6.5 percent higher than those business units lacking information investments.

Business-unit operating profits are raised further by modular production as shown in the final two columns of Table 5. The coefficient implies that a

[21] However, bar codes and EDI continue to have a large impact on the log value of both lead time measures The estimated coefficient on the information system variables for log (standard lead times) is − 85 (significant at a 01 level), implying that a 10 percent increase in the use of bar codes and EDI results in an 8 5 percent lead time decrease In contrast, the coefficient for modular assembly is − 009 (not significant) implying less than a 1 percent reduction in standard lead times for a 10 percent increase in modular assembly by business units See Table A1 for these regression results

one percentage increase in modular production would increase operating profits as a percentage of revenues by .098 percent. For a typical modular adopter, this estimate implies increased profits of 3.5 percent (or about a one-third increase in average operating profit levels). This effect is about one-half the size of the bar-code and EDI effect, and is also statistically significant at the .05 level.

The larger and more significant impact of modular assembly on operating profits versus lead times is consistent with the earlier distinction between "internal" and "external" performance. A business unit may improve lead times through a variety of means other than altering production strategies (most directly by simply holding more inventory for retail customers). However, production strategies (including modular assembly) that increase a supplier's responsiveness can allow that business unit to achieve lead time targets while decreasing its costs from holding more work-in-process and finished goods inventory. By reducing throughput times, this impact of modular systems may best explain the relatively large and significant profitability results found in Table 5.

The performance results are also consistent with the more general findings on complementarities in modern manufacturing (Milgrom and Roberts, 1990): Major performance effects arise from the investment in bundles of manufacturing practices, particularly those associated with information linkages. Having the set of practices required to send and receive sales and order information at this point in apparel industry development dramatically changes the external and internal performance of business units. The marginal impact of other manufacturing innovations in the cutting or sewing room or in distribution operations is small in comparison.[22] Although this dynamic may change as more and more apparel firms adopt baseline practices, the importance of understanding the sequential nature of investments in response to product-market changes are central to interpreting the potential impacts of human resource innovations specifically and other manufacturing changes more generally.

The foregoing analysis can be illustrated by recent developments at Levi Strauss Associates. The Partnership agreement reached between Levi Strauss and the Amalgamated Clothing and Textile Workers Union (now the Union of Needletrades, Industrial, and Textile Employees, UNITE) in 1994 represents a landmark in labor relations. It emphasizes the joint role of labor and management in developing, introducing, and refining modular

[22] Using the full data set, Hwang (1995) has found performance impacts arising from the use of sales information for production forecasting as a complement to the minimum standard practices described here

and other innovative workplace practices. In fact, the agreement provides UNITE a role in implementing these practices even in nonunion plants (and providing the union an open invitation to organize those plants). It would be inaccurate, however, to assess this innovative agreement without understanding the larger context of decisions by Levi Strauss over time.[23]

Levi Strauss was one of the first companies to invest in information linkages with retailers. In fact, it helped create one of the early systems for information exchange before an industry standard had been put in place. It also invested heavily in creating state-of-the-art logistic operations, consolidating a large number of traditional warehouses into four distribution centers that rapidly process shipments from plants to retail customers. The company's understanding of the critical nature of information and time to competitive performance has therefore motivated much of its strategy, including its most recent announcement of a program to provide customers with personally customized jeans.

In short, Levi Strauss's strategy is premised on providing customers with the right product, when they want it, without holding vast amounts of inventory in the process. The Partnership agreement is a necessary extension of this effort in making its union and nonunion production facilities capable of responding rapidly and flexibly to retailer and ultimately consumer demand.

Conclusion

Innovative human resource practices in the apparel industry—those primarily linked to modular assembly systems—have diffused slowly in the U.S. apparel industry. Modular systems, and the accompanying cluster of compensation, training, worker involvement, and supervisory practices, account for less than 10 percent of all assembly. These practices have been adopted in apparel workplaces with close relationships to retailers and inventory management, including investment in information technology. Where this suite of investments and relationships have occurred, business units have improved performance along a number of dimensions. To separate modular adoption as either the driver of change or, normatively, as the savior of the industry is to misunderstand fundamentally the dynamics of the channel and the benefits of those systems.

The modest impact of modular assembly suggests that the attention this innovation has received in the trade press is misplaced relative to other

[23] See "Partnership Agreement Levi Strauss & Co /Amalgamated Clothing and Textile Workers Union " For recent accounts, see Louis Uchitelle, "A New Labor Design at Levi Strauss " *New York Times* (10/13/94), pp D1, D6, Bureau of National Affairs, "Levi Strauss, ACTWU Announce New Partnership Arrangement " *Daily Labor Report* (10/14/94), pp A10–A11

TABLE A1

LOG LEAD TIME DETERMINANTS, 1992

	Log (lead time) Standard, 1992[a]		Log (lead time) Shortest, 1992[b]	
	(1)	(2)	(1)	(2)
Dependent variable: mean / standard error	4 39 (0 72)	4 39 (0 72)	3 76 (0 95)	3.76 (0 95)
Model				
Use of UPC bar-code standards and electronic data interchange, 1992	−0 90** (0.32)	−0 85** (0 32)	−0 92** (0 40)	−0 83* (0 40)
Modular assembly (% of total volume assembled)[c]	——	− 009 (007)	——	− 021 (016)
Size (1988 $million sales volume)	− 0002 (0004)	0002 (0005)	002 (001)	002 (001)
% of volume in basic product lines, 1988	0005 (004)	0006 (.004)	− 001 (005)	− 002 (005)
Adjusted R^2	0 23	0 272	0 175	0 227
Sample size	42	42	42	42

* Significant at the 05 level, ** significant at the 01 level T-tests are one-tailed
[a] Lead time measured in elapsed calendar days for "standard" or average product manufactured domestically
[b] Lead time for "shortest" or best performance for product manufactured domestically
[c] For business units that adopted modular assembly between 1988 and 1992 only

human resource changes arising from product market changes. For example, the advent of lean retailing is having more pervasive effects on the growing strategic role of distribution-center workers (who can powerfully affect time-based outcomes for retailers and their suppliers) in the retail-apparel-textile channel. Just as the skilled cutter was once the focal point of leverage in the industry, lean retailing implies significant leverage for distribution workers on wages and other labor-market outcomes. Lean retailing has also severely diminished the role of the traditional buyer whose "feel" for the market (and the compensation and career paths associated with that art) is being replaced by the merchandise manager with real-time sales data and advanced forecasting methods.

The growing importance of replenishment has also improved the viability of assembly operations closest to the U.S. consumer market. This implies shifts in employment away from the Far East and back to North America. In a related vein, replenishment requirements provide a partial explanation of the reemergence of the problem of sweatshops in some U.S. urban centers: such operations provide the twin advantages of low labor costs and proximity to the U.S. market.[24]

[24] The growth of sweatshops has received recent attention by the U.S Department of Labor The Department has attempted to increase the impact of its enforcement efforts by focusing on retailers who purchase goods that can be traced back to these workplaces

Our findings also have broader implications for the study of human resources. First, analysis of human resource systems must be embedded in an understanding of the environmental factors facing adopting business units, fundamentally those concerning product and labor markets (Dunlop, 1993; Kochan, Katz, and McKersie, 1986; Weil, 1994). Second, the underlying production technology constrains the degree of choice in alternative human resource practices. Third, human resource innovations made in response to evolving competitive dynamics cannot be separated from the larger set of choices undertaken by business units. In many sectors, the movement toward greater responsiveness to demand conditions fosters a need to innovate along dimensions described here for the retail-apparel channel. To regard human resource innovation separate from other practices necessary to adapt to new market conditions potentially overstates the impact of these innovations. From a policy and applied viewpoint, it may also distract decision makers (management and labor) from looking into the larger set of choices that must be made.

REFERENCES

AAMA (American Apparel Manufacturers Association) 1988 *Flexible Apparel Manufacturing The Coming Revolution* Report of the AAMA Technical Advisory Committee Arlington, VA American Apparel Manufacturers Association

——— 1992. "Survey of Apparel Manufacturing." Report of the AAMA Technical Advisory Committee Arlington, VA: American Apparel Manufacturers Association.

Abernathy, Frederick, John T Dunlop, Janice Hammond, and David Weil. 1995 "The Information-Integrated Channel A Study of the U S Apparel Industry in Transition " *Brookings Papers on Economic Activity Microeconomics* (Spring)·175–246

Bailey, Thomas 1993 "Organizational Innovation in the Apparel Industry " *Industrial Relations* 32 (Winter) 30–48

Berg, Peter, Eileen Appelbaum, Thomas Bailey, and Arne Kalleberg 1994 "The Performance Effects of Modular Production in the Apparel Industry " Economic Policy Institute Mimeo

Cole, William 1992 "Modular's True Colors " *Bobbin* (July)·64–67.

Dunlop, John T 1993 *Industrial Relations Systems,* rev ed Boston Harvard Business School Press

Dunlop, John T., and David Weil 1994 "Diffusion of Human Resource Innovations Historic and Current Lessons from the Apparel Industry " Working Paper Cambridge, MA: Harvard Center for Textile and Apparel Research

George, Catherine 1995 "Work Organization and the Cost of Product Variety." Unpublished paper. Harvard University

Hill, Ed 1992 "Flexible Manufacturing Systems " *Bobbin* (April).48–50

Hwang, Margaret 1995 "The Causal Effect of Innovation on Firm Performance." Working Paper. Cambridge, MA Harvard Center for Textile and Apparel Research

Ichniowski, Casey, and Kathryn Shaw 1995. "Old Dogs and New Tricks· Determinants of the Adoption of Productivity-Enhancing Work Practices " *Brookings Papers on Economic Activity Microeconomics* (Spring) 1–63

Ichniowski, Casey, Kathryn Shaw, and Giovanna Prennushi 1995 "The Effects of Human Resource Management Practices on Productivity " Working Paper No 5333 Cambridge, MA. National Bureau of Economic Research

Kochan, Thomas, Harry Katz, and Robert McKersıe 1986 *The Transformatıon of Amerıcan Industrıal Relatıons* New York: Basıc Books

Lowder, Robert 1991. "Balance A Delıcate Word ın Modular Manufacturing " *Bobbın* (November) 132–38.

Mılgrom, Paul, and John Roberts. 1990 "The Economıcs of Modern Manufacturıng· Technology, Strategy, and Organızatıon " *Amerıcan Economıc Revıew* 80 (June) 511–28

U S Department of Labor, Bureau of Labor Statıstıcs 1992 *Industry Wage Survey. Men's and Boy's Shırts (Except Work Shırts) and Nıghtwear, September 1990* Bulletın 2405 Washıngton, DC· U.S Government Prıntıng Office

Weıl, Davıd 1994. *Turnıng the Tıde Strategıc Plannıng for Labor Unıons* New York Lexıngton Books