

IMPACT OF WORK TEAMS ON MANUFACTURING PERFORMANCE: A LONGITUDINAL FIELD STUDY

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We report the results of a longitudinal field study examining the impact of work teams on manufacturing performance. An electromechanical assembly plant was our research site from April 1992 through December 1993; work teams were formed on its four production lines in August 1992. Our results show that both quality and labor productivity improved over time after the formation of the teams. We offer qualitative insights into the functioning of these teams and their evolution over time, leading to workplace transformation.

The formation of work teams is a human resource management practice that is becoming commonplace in manufacturing plants (*Business Week*, 1994; Ichniowski & Shaw, 1995; *Manufacturing Studies Board*, 1986; *New York Times*, 1994; Osterman, 1994; Safizadeh, 1991). The popularity of work teams stems from the idea that by identifying and solving work-related problems, teams can contribute to improved performance. With an increasing emphasis on high-quality, fast product innovation and improved customer satisfaction, many companies now use team approaches to realize these goals in an environment characterized by functional and process interdependencies (Boyett & Conn, 1991). Work teams are considered to be "an integral tool aiding continuous improvement in work operations" (Cutcher-Gershenfeld and Associates, 1994: 42). Much of the evidence to date on the success of work teams, however, is in the form of anecdotes or descriptive case studies; stories of huge cost savings and quality improvements abound

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(Gupta & Ash, 1994; Hitchcock, 1993; Katzenbach & Smith, 1993; Schilder, 1992; Sheinkman, 1993; Tjosvold, 1991). In this article we empirically examine and document the impact of work teams on manufacturing performance over time in a natural setting.

THEORETICAL BACKGROUND

Our literature review focuses on studies that document (1) different types of work groups and teams in manufacturing environments and (2) teams' relationship to performance-related variables.

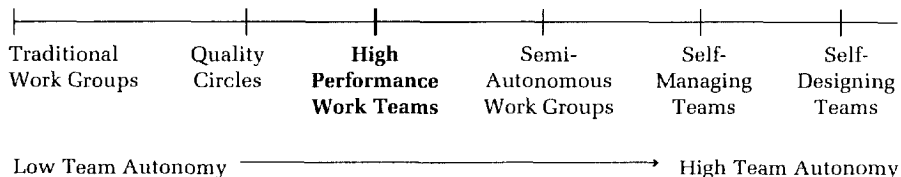
Types of Work Groups and Teams

A number of different types of work groups and teams are found in manufacturing environments today (cf. Goodman, Devadas, & Hughson, 1988; Hackman, 1987; Ledford, Lawler, & Mohrman, 1988). Teams can be classified on the team autonomy continuum depicted in Figure 1. Team types found on the far right have the most autonomy, and those on the far left have the least.

Traditional work groups. Workers perform core production activities, and other groups are responsible for support activities, such as receiving, quality control, and maintenance. Workers have no management responsibility or control. The first line manager controls planning, organizing, directing, staffing, and monitoring.

Quality circles. Membership is voluntary. Members are drawn from a particular work group or department. The group has the responsibility for making suggestions but does not have the authority to make decisions. The problem-solving domain is limited to quality- and productivity-related issues and cost reduction. Meetings are held on company time, usually weekly. A staff of specially trained facilitators helps team members with training and with group processes at meetings. No financial rewards are given for group suggestions. Typically, the group is not provided with systematic information on the firm's performance or strategic matters. The decision to install quality circles is made at the top of an organization, and the circles are created at the bottom of the organization. Although workers are organized to make suggestions within the defined domain, no changes are made in the day-to-day production hierarchy.

FIGURE 1
Team Autonomy Continuum



Semi-autonomous work groups. Workers manage and execute major production activities. Other groups perform support activities, such as quality control and maintenance, that are related to but outside the scope of major production activities.

Self-managing teams (or autonomous work groups). These are groups of individuals who can self-regulate work on their interdependent tasks. Group members have control over the management and execution of an entire set of tasks—from the acquisition of raw materials through the transformation process to shipping, including all support activities, such as quality control and maintenance, required to produce a definable product. The product could be a definable part of a production process rather than a completed product. The distinction between autonomous and semi-autonomous work groups is that the scope of the production tasks managed and executed by the autonomous type is narrower than that of the semi-autonomous type.

Self-designing teams. These groups have all the characteristics of self-managing teams. In addition, they have control over the design of the teams themselves and decide such issues as what tasks should be done and who should belong to the teams.

The work teams we investigated in this study are between quality circles and semi-autonomous work groups on the team-autonomy continuum depicted in Figure 1. Unlike quality circles, these work teams have some decision-making authority, but not to the extent characteristic of semi-autonomous work groups. Team membership is mandated by the management of the plant studied here and is not voluntary. Compared to quality circles, these teams have an expanded problem-solving domain, and they are provided with information on the plant's budget and competitors' products. Each team is composed of workers from the same production line. Hereafter, we shall refer to these teams as high performance work teams (HPWTs).

Work Teams and Manufacturing Performance

A common approach to measuring the impact of groups is to evaluate their effectiveness. Group effectiveness is defined as performance and employee satisfaction (Gladstein, 1984). More specifically, according to Hackman (1991), group effectiveness is the degree to which (1) a group's output meets requirements in terms of quantity, quality, and timeliness, (2) the group experience improves its members' ability to work as a group in the future, and (3) the group experience contributes to individual satisfaction. Our focus in this study was on the performance dimension.

In the quality management literature, experts advocate the use of teams as a means of improving quality. For example, Juran and Gryna (1980) suggested the use of "breakthrough" teams, and Deming (1986) emphasized the importance of worker input and management-worker cooperation for improving quality. It is also evident from our literature review that some theoreticians have tried to explain why participation in work teams is associated with performance improvement. For example, Mohrman and Novelli

(1985) discussed two models that relate participation in quality circles to improved productivity. The first model predicts that participation in quality circles leads to idea generation, which leads to idea implementation, which in turn leads to improved productivity. It is the implementation of the ideas themselves and the degree to which these ideas relate to productivity that contribute to productivity improvement. In the second model, participation in quality circles leads to favorable individual outcomes that improve job satisfaction, motivation, and task performance, leading to productivity improvement. This model incorporates many of the elements of the job characteristics model (Hackman & Oldham, 1980).

Several empirical studies in this domain focus on the effects of work teams on workers' attitudes and have some additional qualitative discussion on performance (see, for example, Wall, Kemp, Jackson, and Clegg [1986] and Ledford et al. [1988]). Some other studies have used cross-sectional research designs to examine the effects of quality circles on performance outcomes and to contrast the performance outcomes of participants and nonparticipants in quality circles (cf. Corbett & Harrison, 1992; Magjuka, 1991; Marks, Mirviss, Hackett, & Grady, 1986). Katz, Kochan, and Keefe (1987) surveyed plants of a major U.S. automobile manufacturer in 1979 and 1986 and found that work teams had a negative impact on plant productivity. Explaining their results, Katz and colleagues noted that "the negative impact of work teams on plant productivity in the company . . . resulted from problems associated with introducing the system . . . teams may yet help to improve productivity" (1987: 709). Griffin (1988) used a longitudinal and experimental research design to examine the impact of quality circles in an industrial setting and found positive impacts on perceptual measures of four individual-level dependent variables: job satisfaction, organizational commitment, performance, and intention to quit. Reviewing the empirical literature from economics, industrial relations, and organizational behavior on the effects of participation on performance, Levine and Tyson concluded that participation is more likely to have a positive impact on performance "when it involves decisions that extend to the shopfloor and when it involves *substantive* rather than consultative arrangements" (1990: 204).¹ Two more studies, Ichniowski, Shaw, and Prennushi (1994) and MacDuffie (1995), document the positive impact of a bundle of innovative human resource management practices on manufacturing performance. In both studies, work teams figured prominently in the bundle of innovative human resource management practices that positively impacted manufacturing performance. According to Osterman (1994), more than half of all U.S. firms are now exploring

¹ According to Levine and Tyson, "*substantive participation* in work and workplace decisions includes formal, direct participation schemes, such as work teams," whereas "*consultative participation* allows employees to give their opinions, but final decisions are still made by management . . . [Q]uality control circles are the most common form of consultative participation" (1990: 189). The difference between these two forms of participation "is not in the content of the decisions, but in the degree of worker influence" (1990: 190).

some form of team-based work system. In fact, teams have now become a topic of research investigation in their own right. For example, Cutcher-Gershenfeld and associates have been engaged in field research to derive insights into "the general nature of team-based work systems" (1994: 43). Consistent with such research efforts, our study examines the performance implications of a team-based work system over time in a manufacturing plant. In addition, the study provides qualitative insights into the transformation of a workplace with the formation of work teams.

RESEARCH SETTING

Our research site is a unionized plant operated by a division of a *Fortune* 500 firm. The plant has dedicated direct and indirect personnel, separate accountability, and separate record keeping. We conducted this study over a 21-month period, from April 1992 to December 1993. In August 1992, a separate HPWT was formed on each of the four production lines of the plant.

The family of products manufactured in this electro-mechanical assembly plant consists of a series of small motors used in industrial and residential applications. This family of motors has been designed using a modular strategy for increased manufacturing flexibility. All motors are built with component parts that have the same size and shape, but alternative combinations of the components result in numerous models. Consistent with this strategy, the manufacturing process used in the plant is a proven flexible automation technology. Although the extent of automation varies across the four production lines, the type of automation is the same—"pick and place" robots are interconnected by automated conveyor systems. A simultaneous engineering approach is used to coordinate product and process designs. Commercial production of the family of motors began in September 1990.² By the last quarter of 1991, the production on all four production lines of the plant was fully ramped up. Throughout our study period, the production of the family of motors continued at the fully ramped-up levels.

The Facility Layout and Work Organization

The plant is organized into three subassembly lines and one final assembly line and operates in a just-in-time (JIT) production environment. The three subassembly lines correspond to the three basic components of motors: submotor, gear train, and printed circuit board. On the final assembly line, these components are assembled into a motor. At the end of each of the four lines there is a quality inspection point where the products are functionally tested. The characteristics of products, capital and labor intensity, and labor skills vary across the four lines.

Submotor line. On this line, the product diversity is low since all submotors are identical except for the presence or absence of a mechanical spring-return device. The more complex process steps are done at the highly auto-

² Detailed production data for the period prior to April 1992 are not available.

mated upstream end of the submotor line that operates with very little human intervention. However, a number of workers are needed to manually complete the product. The number of production workers in the HPWT on the submotor line varied between 7 and 11 during the study period.

Gear train line. This line consists of two areas: machining and assembly. Some of the parts used in the gear train are machined on the line. Unlike elsewhere in the plant, workers in the machining area of the gear train line are trained machinists. The assembly area is highly automated, and there are very few production workers in this area. As a group, they have more seniority than workers on the other production lines. They tend to be a very cohesive group, and there is little turnover. The number of production workers in the HPWT on the gear train line varied between 4 and 6 during the study period.

Printed circuit board line. This is the most capital intensive line in the plant. Ideally, the printed circuit boards should not be touched by the workers after their assembly begins and until their assembly is complete. The workers on this line are primarily involved in inspecting the completed boards. The number of production workers in the HPWT on the printed circuit board line varied between 4 and 6 during the study period.

Final assembly line. This is the most labor-intensive line in the plant. Product diversity on this line is high, because the end product is assembled using alternative combinations of the more standard inputs from the three subassembly lines. Experienced workers handle assembly of the printed circuit board to the gear train because it is a delicate job. Also, many of the production workers are involved in final functional testing, a job that requires trouble-shooting skills. The number of production workers in the HPWT on the final assembly line varied between 14 and 18 during the study period.

The specific types of manual jobs performed on the four lines include wiring, subassembly, circuit testing, insertion, drop-in, operational checks, component preparation, and functional testing. Even though these jobs required different skills, they can be learned quickly without any kind of special training. Job rotation was not practiced either within or across the teams on the four production lines during the study period.

Each of the four HPWTs consists of production workers from the line as well as the production engineer assigned to the line, the production planner, and the plant manager. All four teams are assigned to a common facilitator, an individual who was brought in from the division's training department to organize and train the HPWTs. In team meetings, the role of the facilitator is that of a resource person and not a team member. The leader of the team is chosen from among the production workers.

All production workers in the HPWTs on the four lines are members of the same union. They are paid on an hourly wage rate basis. Neither company policies guiding wage rates or medical and retirement benefits changed during the study period. The contractual agreement between the union and the division did not contain any clause on employment security for production workers. The production workers in the four HPWTs were long-time employ-

ees with an average tenure of 18 years and an average age of 42 years. Variations observed here in the number of production workers in an HPWT are the result of individuals being laid off, retiring, or leaving for jobs with higher wage rates elsewhere in the division, and the vacancies not being filled immediately. There was no indication of any production worker leaving the plant owing to the introduction of work teams. During our study period, vacancies on the production lines were filled with either workers from other plants of the division or from the pool of previously laid-off workers.

The Evolution and Functioning of HPWTs

We developed insights into the evolution and functioning of work teams by collecting qualitative information for periods both before and after the formation of the high performance work teams, with a particular emphasis on the form of participative decision making. This included a detailed examination of the HPWTs' meeting logs and training documents and interviews and discussion with the team facilitator, team leaders, production engineers, plant manager, divisional labor relations manager, and the divisional director of manufacturing operations. We used the insights gained to specify models for empirically examining the impact of HPWTs on manufacturing performance.

Our research site was the first plant in the division to be selected for work team implementation. The primary reason for this choice was the enthusiastic response of the plant manager. Other plant managers in the division had initially expressed concerns about the feasibility and effectiveness of work teams in a unionized environment. According to the divisional director of manufacturing operations,

[the plant manager] firmly believed that work teams and turning over a portion of decision making to the work teams and running the factory that way was the wave of the future.

From management's standpoint, the primary objective for forming HPWTs on the four production lines was to institutionalize worker participation. The team facilitator observed:

one of the reasons we [the management] wanted the teaming was that we knew that if we went to the production workers they would give us some ideas about what we could do better to get our costs down and be more competitive.

The initial months following the introduction of work teams were spent in establishing trust between production workers and "management," which included all nonunion personnel. The facilitator believed that developing trust was important in overcoming the production workers' resistance to HPWT formation. Given the numerous instances in the past of programs being introduced and then abandoned, production workers were skeptical of management's commitment to team implementation. Further, being unionized, the plant did not have a history of cooperation between workers and management. Speaking for her co-workers, a team leader stated that she

was surprised that it [HPWTs] lasted the first year.

The facilitator played an important role in establishing trust between production workers and management by demonstrating that management was willing to implement the workers' ideas. She recalled the following incident in the early stages of team formation:

They [the production workers] tested me. [They said] "Well, if we are going to be work teams, then we want to get a new light on our bench." So, I'd go to the plant manager and give them a new light. . . . Now they'd say "Oh, the plant manager is really going to let us have this stuff."

Trust between the workers and management improved over time on all four teams. According to a team leader,

Some of the people [the skeptics] out there, they've changed their mind now. [They used to say] "It doesn't make any difference what I say, because they don't listen anyway." They have found that they do. Management does listen to what's said.

Another notable issue soon after the formation of HPWTs was conflict within the teams. The facilitator cited the submotor line, in particular, as one that had a high level of internal conflict among the team members after the formation of the HPWT. This conflict persisted throughout the study period. On the other hand, consistent with the preteam character of the working group on the gear train line, relations among the team members were especially harmonious. The conflict levels on the printed circuit board and final assembly teams were between these two extremes, and the facilitator did not identify any major issues related to conflict resolution among the team members. For the teams on the board and final assembly lines, the facilitator could not identify any major issues related to internal conflict between the team members.

After the initial months of trust building and conflict resolution, the facilitator made a concerted effort to get the HPWTs focused on solving problems. For the six months from January through June 1993, all members of the four HPWTs went through a "10-module toolkit training" intended to facilitate their ability to work as a team. The topics of the ten modules are: (1) vision of a competitive factory with a future, and values related to people, customer, quality, safety, and competitiveness, (2) mutual goals, interdependent working relationships, and commitment to the group effort, (3) organizing effective meetings, (4) defining team goals and purpose, (5) understanding self and others, (6) reviewing team processes, (7) listening effectively, (8) providing constructive feedback, (9) benefits of having conflicts and techniques for conflict resolution, and (10) the process of problem solving. This training program was mandatory, and any production worker who joined the plant had to go through it. Evaluating the impact of the training, the facilitator said

Actually, once you did some coaching and some training in the modules of the toolkit, they could relate to that . . . it [training] worked.

Examination of the meeting logs of the HPWTs on each of the four production lines suggested that after June 1993, the month in which the HPWT members on the four production lines completed their 10-module toolkit training, the orientation of the actionable entries in the log book began to shift from individual to group-level issues, such as revising the parts ordering system and increasing training on a specialized machine to reduce defects. Although some of the issues were still assigned by the team to the production engineer, others were increasingly being assigned to individual workers or the team as a whole. This was in contrast to the orientation of the actionable entries in the log book in the months immediately following the introduction of work teams, when they were mostly individual-oriented issues, such as the need for new chairs and tools for a particular workstation. Further, the responsibility of resolving these issues was usually given to a production engineer or the plant manager. Around mid-1993, the plant manager also authorized the HPWTs to implement suggestions for improvement costing less than \$200—an amount that covered a significant number of ideas for operational improvements. Expenditures above \$200 were handled by the plant's usual operating procedures.

Our discussion of the evolution of the HPWTs indicates that the form of participation in the teams was becoming increasingly substantive. We will now describe the functioning of teams to get further insights into mechanisms that support substantive participation.

The HPWTs meet separately once a week for about an hour in a conference room. Quality, the past week's accomplishments, customer delivery, and variances from budgets are the issues that are always discussed in the team meetings. The meetings also serve as a forum for sharing information on topics such as the division's budget, the financial performance of the plant compared to that of other plants in the division, competitors' products, changes in the customer base, and problems with the products in the field. Prior to the implementation of teams, such issues were seldom discussed with the production workers. On occasion customers and vendors attend the team meetings. Coordination and communication across the HPWTs is maintained by allowing one or more team members from another HPWT to attend the team meetings whenever it is required.

In all team meetings, ideas or problems that require action are recorded in a meeting log (known as the action log); the log notes who submitted the item, who is responsible for addressing it, and when it should be completed. In subsequent meetings the status of the item or its completion date is entered. At the end of each month the facilitator completes a team progress report that addresses progress on the seven primary team responsibilities: quality, customer satisfaction, training, action log and team meetings, cost awareness and management, safety and ergonomics, and housekeeping. HPWTs are encouraged to aggressively work toward resolution of action log items and are evaluated on their progress in resolving these items.

The plant manager used the following example to illustrate how ideas for operational improvement are generated during team meetings:

We have got that op check fixture that was built upstairs by the auto lab. This is a pretty expensive machine. Initially it was going to be a six-headed machine, and still is . . . three heads were going to be here [on one side], and three heads were going to be here [on the other side]. . . . As we met with the team, we decided to come up with a half round machine. Now the six heads are all here. . . . So that addressed some ergonomic issues.

According to a team leader,

We [production workers] get out of there [team meetings] feeling like we've accomplished something. I do. When I go to the team meetings, I feel that a lot of things have been accomplished, things that I couldn't have done on the floor without getting them [the team members] all together.

The above insights into the evolution and functioning of HPWTs suggest that group effectiveness, as defined earlier, continued to improve over the 21-month study period. Since the HPWTs were authorized to implement many ideas independent of management, the production workers' participation in decision making was largely substantive rather than consultative. As noted earlier, substantive participation involves formal and direct participation in work and workplace decisions and is likely to have a positive impact on performance. The trajectory of the HPWTs' evolution and their increasing effectiveness suggest that their performance impact should be modeled as a time-trend rather than as a one-time intervention. In the next section, we analyze panel data from the four production lines to see if there is quantitative evidence of the effectiveness of work teams measured in terms of improvement in manufacturing performance.

METHODS

Our study period, from April 1992 through December 1993, provides a window into a naturally occurring experiment of conversion to HPWTs. This was a period occurring well after the start-up of the plant. As noted earlier, production volume for all four lines in the plant was fully ramped up by the end of 1991. Besides the introduction of HPWTs in August 1992, no other intervention could potentially confound the impact of work teams on manufacturing performance. For example, no new product families or operational practices were introduced, nor were there any changes in process technologies or facility layout. Human resource management policies such as those related to compensation, recruitment and selection, employment security, job assignment, skills training, and communication (Ichniowski et al., 1994; MacDuffie, 1995) were the same across the four production lines and did not change during the study period.

Dependent Variables

We employed a longitudinal research design to examine the impact of HPWTs on manufacturing performance. The dependent variables for our study were quality and labor productivity. From a theoretical standpoint,

these measures correspond to the performance dimension of group effectiveness (Hackman, 1991) discussed earlier. These measures are also consistent with MacDuffie's (1995) study of automobile assembly plants, which examines the impact of clusters of innovative human resource management practices on manufacturing performance.

Quality (manufacturing defect rate). We measured quality as the percentage of total units produced that were defective. Since data on quality were available by the week, the study period for all quality-related analyses comprises 84 weeks.³

Labor productivity. Since HPWTs were not formed until the family of motors in the plant were more than 18 months into volume production, changes in process equipment, design, and raw materials had stabilized. The productivity issues that the HPWTs tend to focus on are the ones that allowed them to produce more units per worker. Thus, we focus on labor productivity, measured as a ratio of the number of units produced to total production hours. Since data on productivity are available by month, the study period for all productivity-related analyses comprises 21 months.

Independent Variable

Postteam time trend (abbreviated in equations as *TEAMTR*) represents the impact of HPWTs over time. It is measured as the number of weeks (for quality equations) or months (for labor productivity equations) since the formation of HPWTs and assumes the value 0 for the weeks and months before the formation of HPWTs.

Control Variables

To isolate the impact of HPWTs, we controlled for a number of other variables that are considered drivers of manufacturing performance. Following Hayes and Clark (1985), we identified the following four relevant groups of managerial policies: equipment policies, work-in-process (WIP) inventory policies, workforce policies, and policies affecting confusion in the factory. We did not consider equipment policies to be an important category of variables affecting performance since most of the plant's equipment and relevant policies (e.g., maintenance policies) were in place before April 1992, the beginning of the study period, and did not change appreciably during the period. Additionally, we did not include work-in-process inventory in the analysis because the plant has had a just-in-time (JIT) production environment since its inception and operates with minimal inventory. Our examination of the WIP data, available only at the plant level, suggested that the work-in-process level had been fairly constant throughout the study period. Defective units on all four lines were reworked and repaired on the same day they were detected.

³ Out of the 91 weeks in our study period, there are 7 weeks for which one or more observations were missing.

Following Hayes and Clark (1985), we identified variables that are representative of policies related to workforce and confusion in a plant. We operationally defined the variables related to workforce policies as follows: *Overtime* was measured as overtime hours per worker for each production line in a given period. *Headcount additions* was the number of workers who joined expressed as a percentage of the total number of workers on a production line in a given period. *Headcount deletions* was the number of workers who left expressed as a percentage of the total number of workers on a production line in a given period.

We operationally defined the variables related to the policies affecting confusion in the plant as follows: *Product diversity* was measured as a Herfindahl index (Gollop & Monahan, 1991) to reflect product heterogeneity on a production line in a given period. The Herfindahl index is of the form $1 - \sum s_j^2$, where s_j is the share of the j th distinct product in the total production. *Product complexity* was measured as the volume-weighted average of device complexity based on manufacturing difficulty (e.g., Cooper, Sinha, & Sullivan, 1992; Ittner, 1992) on each production line for a given period.⁴ The complexity index is of the form $c_j x_j / \sum x_j$, where c_j is the complexity value for product j and x_j is the volume of product j . *Capacity utilization* was the percent deviation from the planned production rate for a production line in a given period, which reflects approximate capacity for that period. We used two variables to distinguish between positive and negative deviations. Capacity overutilization (*VOLUP* in equations) was the percent positive deviation; it assumes the value 0 whenever the deviations are negative. Capacity underutilization (*VOLDN*) was the percent negative deviation; it assumes the value 0 whenever the deviations are positive. *Engineering change orders* was the total number of such orders issued on a production line in a given period that were not related to quality improvement. *Adhesive experiment period on the gear train line* derived from our discussion with the plant manager, who indicated that engineers experimented with alternative adhesives on the gear train line during the months April through September 1993. Such experimentation is considered to be outside the normal production process and is known to cause unusually high defect rates on a line. To indicate this period in the relevant model specifications, we used a dummy variable (*GTADH*) that assumes the value 1 for the adhesive experiment periods and 0 otherwise.

We also included a variable called *preteam time trend (PRTMTR)* to verify that there were no performance time trends, such as the learning curve

⁴ From the engineering department, we obtained ratings on the critical features of the products on the four production lines—namely, (1) control mechanism, (2) mechanical characteristics, and (3) electrical characteristics—in terms of their manufacturing difficulty. Each of these features was assigned a numerical value (the higher the number, the more complex it was). These features are coded in the model numbers assigned to the products. With information on the product model numbers and production volume for a given period, we calculated volume-weighted average complexity for the period.

effect, prior to the formation of HPWTs. It was measured as the number of weeks (for quality equations) or months (for productivity equations) since the beginning of the study and before the formation of HPWTs and as 0 after the formation of HPWTs.

Model Specifications

To examine the impact of HPWTs, we employed two statistical models—a fixed-effects model and a seemingly unrelated regressions (SUR) model—for each of the two measures of manufacturing performance, quality and labor productivity.

Fixed-effects model. This method involved pooling the observations from all four production lines of the plant. The formulation of the fixed-effects model was based on the assumption that differences across production lines can be captured by differences in the intercept term (Greene, 1993). We pooled the data from the production lines and added a dummy variable indicating each of three production lines to the model to estimate the differences in the intercept term from the fourth production line.⁵ The fixed-effects models were formulated as follows:

$$\begin{aligned} DEF_{ti} = & \lambda_0 + \lambda_1 PRTMTR_{ti} + \lambda_2 OT_{ti} + \lambda_3 ADDS_{ti} + \lambda_4 DELS_{ti} + \lambda_5 DIV_{ti} \\ & + \lambda_6 COMP_{ti} + \lambda_7 VOLUP_{ti} + \lambda_8 VOLDN_{ti} + \lambda_9 ECO_{ti} + \lambda_{10} TEAMTR_{ti} \\ & + \lambda_{11} GTADH_{ti} + \lambda_{12} SUBM_{ti} + \lambda_{13} GEAR_{ti} + \lambda_{14} BOARD_{ti} + \varphi_{ti}, \end{aligned} \quad (1)$$

and

$$\begin{aligned} PROD_{ti} = & \delta_0 + \delta_1 PRTMTR_{ti} + \delta_2 OT_{ti} + \delta_3 ADDS_{ti} + \delta_4 DELS_{ti} + \delta_5 DIV_{ti} \\ & + \delta_6 COMP_{ti} + \delta_7 VOLUP_{ti} + \delta_8 VOLDN_{ti} + \delta_9 ECO_{ti} + \delta_{10} TEAMTR_{ti} \\ & + \delta_{11} GTADH_{ti} + \delta_{12} SUBM_{ti} + \delta_{13} GEAR_{ti} + \delta_{14} BOARD_{ti} + \kappa_{ti}, \end{aligned} \quad (2)$$

where the variables in period t for production line i are defined as

- DEF_{ti} = quality (manufacturing defect rate),
- $PROD_{ti}$ = labor productivity,
- $PRTMTR_{ti}$ = preteam time trend,
- OT_{ti} = overtime,
- $ADDS_{ti}$ = addition of production workers,
- $DELS_{ti}$ = deletion of production workers,
- DIV_{ti} = product diversity,
- $COMP_{ti}$ = product complexity,
- $VOLUP_{ti}$ = capacity overutilization,
- $VOLDN_{ti}$ = capacity underutilization,
- ECO_{ti} = engineering change orders,
- $TEAMTR_{ti}$ = postteam time trend,

⁵ Specifically, in models 1 and 2 we included dummy variables for the submotor, gear train, and printed circuit board lines. The estimated coefficients of these dummy variables represent the average differences in the performance measure from the final assembly line.

- $GTADH_{it}$ = a dummy variable coded 1 for observations from the adhesive experiment period on the gear train line, 0 otherwise,
 $SUBM_{it}$ = a dummy variable coded 1 for observations from the submotor line, 0 otherwise,
 $GEAR_{it}$ = a dummy variable coded 1 for observations from the gear train line, 0 otherwise,
 $BOARD_{it}$ = a dummy variable coded 1 for observations from the printed circuit board line, 0 otherwise,

and

$\varphi_{it}, \kappa_{it}$ = random residual terms.

The time period t differs depending on whether a regression model involves defect rate or labor productivity as the dependent variable. Since the manufacturing defect rate data were available weekly, time period t is a week for the regressions with defect rate as the dependent variable. However, the production hours data used to estimate labor productivity were available only on a monthly basis. Hence, t is a month for regressions with labor productivity as the dependent variable.

Seemingly unrelated regressions (SUR) model. This method involves estimating separate equations for each production line while recognizing relationships across the production lines. Unlike the fixed-effects model, the SUR model allows the coefficients of the independent and control variables to differ by line (Greene, 1993). Although this procedure provides a less powerful statistical test than the fixed-effects model, it provides a check of the robustness of the more restrictive fixed-effects model. For each production line (i.e., submotor, gear train, board, and final assembly), we formulated the models as follows:

$$DEF_{it} = \alpha_{0i} + \alpha_{1i}PRTMTR_{it} + \alpha_{2i}OT_{it} + \alpha_{3i}ADDS_{it} + \alpha_{4i}DELS_{it} \\ + \alpha_{5i}DIV_{it} + \alpha_{6i}COMP_{it} + \alpha_{7i}VOLUP_{it} + \alpha_{8i}VOLDN_{it} + \alpha_{9i}ECO_{it} \\ + \alpha_{10i}TEAMTR_{it} + \alpha_{11i}GTADH_{itG} + \psi_{it}, \quad (3)$$

and

$$PROD_{it} = \beta_{0i} + \beta_{1i}PRTMTR_{it} + \beta_{2i}OT_{it} + \beta_{3i}ADDS_{it} + \beta_{4i}DELS_{it} \\ + \beta_{5i}DIV_{it} + \beta_{6i}COMP_{it} + \beta_{7i}VOLUP_{it} + \beta_{8i}VOLDN_{it} + \beta_{9i}ECO_{it} \\ + \beta_{10i}TEAMTR_{it} + \beta_{11i}GTADH_{itG} + \xi_{it}, \quad (4)$$

where each system consists of four equations—one each for $i = S$ (submotor line), G (gear train line), B (printed circuit board line), and F (final assembly line). Except for the random residual terms, ψ_{it} and ξ_{it} , the variable definitions in Equations 3 and 4 are identical to those presented after the fixed-effects models, Equations 1 and 2. The subscript i on the coefficients of the independent and control variables indicates that, unlike in the fixed-effects model, they are specific to production line i . The variable for the adhesive experimentation period ($GTADH$) is included only in the equations for the gear train line to represent April through September 1993, when the engineers experimented with alternative adhesives.

We considered the inclusion of lagged variables in the model formulation to be unnecessary because of the short average production cycle time in the plant (less than a day). Hence, most variables have either no lagged effect or a one-day lagged effect. However, since the length of the time period t was one week in the defect rate equations and one month in the labor productivity equations, the effects of a one-day lag were likely to be negligible.

Data Collection

The data for the study were collected from the plant's production, quality, personnel, and accounting records. The availability from April 1992 through December 1993 of a consistent set of data on the pertinent variables defined the period over which the study was conducted. As noted, data on all variables except actual production hours were available on a weekly basis, with production hours data available only monthly. Hence, as also noted above, the analyses involving labor productivity were conducted at a monthly level and those involving manufacturing defect rate were conducted at a weekly level. For all the variables except those measuring the positive and negative deviations from the planned production rates, data were available by production line. The significance of deviations from planned production rate is at the plant level, but the effect at the individual production line is similar because production volume is coordinated among the lines.

Diagnostics

We examined the data for collinearity and the residuals for outliers and violations of ordinary-least-squares (OLS) assumptions. With time series data and interconnected production lines, it is likely that the presence of serial and contemporaneous correlation and heteroscedasticity could result in inefficient estimates of the parameters, or biased and inconsistent estimates of their standard errors, or both.

Time series data are likely to require adjustments for serial correlation in the residuals. Where there was evidence of first-order autocorrelation, the data were transformed with the Prais-Winsten procedure (Park & Mitchell, 1980). Subsequent estimation with the transformed data showed that autocorrelation was insignificant. Also, after we had transformed the data for serial correlation, collinearity diagnostics (Belsley, Kuh, & Welsch, 1980) indicated that there were no collinearity problems.

Commonalties among the four production lines were likely to result in contemporaneous correlation between the residuals of the four separate regression equations. If ignored, the estimated coefficients of the separate regressions would be inefficient, with potentially biased standard errors. Thus, as noted earlier, we estimated the system of equations as a set of seemingly unrelated regressions (SUR). The correlations among residuals across production lines were as high as 0.37 in the defect rate equations. The correlations were as high as 0.55 in the labor productivity equations. However, in both cases conclusions drawn from the separate OLS and SUR models were very similar.

Heteroscedasticity and nonlinearity of the residuals were problems for both models. Transforming the dependent variables by taking natural logarithms (*DEF* and *PROD* became *LNDEF* and *LNPROD*, respectively) based on a Box-Cox analysis corrected these problems. White's (1980) test revealed no significant heteroscedasticity after the transformation.

Finally, on the basis of influence diagnostics (Belsley et al., 1980) observations corresponding to suspected outliers in the residuals were deleted, and the regression equations were then reestimated. Since the conclusions were essentially the same as the results using the full data set, we report the results based on the full data set.

RESULTS

Impact of HPWTs on Quality

Table 1 contains descriptive statistics and the correlation matrix for the weekly data set used for estimating the regression models related to quality (manufacturing defect rate). The correlation between the logarithm of manufacturing defect rate and the postteam time trend is negative and statistically significant at the 1 percent level. Table 2 summarizes the regression results for the fixed-effects model. Although the coefficient estimate for the preteam time trend is not significant, the coefficient estimate for the postteam team time trend is negative and significant at the 1 percent level. These results indicate that there is no time trend in the defect rate prior to the formation of the high performance work teams. However, in the weeks following the formation of the HPWTs there is a significant reduction in the defect rate. The coefficient estimate of -0.011 for the postteam time trend translates into a 38 percent reduction in the defect rate from the beginning to the end of the postteam period in our study. The coefficient estimate for the dummy variable for the period during which experiments were conducted with alternative adhesives on the gear train line is positive and statistically significant, suggesting that there was a significant increase in defect rate on the gear train line during the adhesive experiment period, April–September 1993.

Table 3 summarizes the results of the SUR estimation procedure. In the equations for the four production lines, none of the coefficient estimates for the preteam time trend is significant. In all four equations, the coefficients for the postteam time trend are negative; for the gear train and the final assembly lines they are also significant at the 1 percent level. These results are in agreement with the fixed-effects model results. Also, as in the case of fixed-effects model, the coefficient estimate for the dummy variable for the adhesive experiment period on the gear train line is positive and significant.

Impact of HPWTs on Labor Productivity

Table 1 also contains descriptive statistics and the correlation matrix for the monthly data set used for estimating the regression models related to labor productivity. The correlation between the logarithm of labor productivity and the postteam trend is positive and significant at the 5 percent

TABLE 1
Descriptive Statistics and Correlations^a

Variable	Monthly Data		Weekly Data																
	Mean	s.d.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1. Log of quality ^b		0.71																	
2. Log of labor productivity	1.80	0.65																	
3. Preteam time trend	0.71	1.46																	
4. Overtime	27.40	8.00																	
5. Headcount additions	0.02	0.05																	
6. Headcount deletions	0.03	0.04																	
7. Product diversity	2.05	0.70																	
8. Product complexity	1.00	0.05																	
9. Capacity overutilization	0.00	0.00																	
10. Capacity underutilization	0.10	0.09																	
11. Engineering change orders	2.14	2.43																	
12. Postteam time trend	6.48	5.45																	
13. Submotor line dummy	0.25	0.44																	
14. Gear train line dummy	0.25	0.44																	
15. Board line dummy	0.25	0.44																	
16. Adhesive experiment dummy	0.07	0.26																	

^a Correlations above the diagonal correspond to weekly data for manufacturing defect rate regressions; correlations below the diagonal correspond to monthly data for labor productivity regression. For monthly data, N = 84; for weekly data, N = 355.

^b Manufacturing defect rate.

* p < .05

** p < .01

TABLE 2
Results of Estimation of the Fixed-Effects Model^a

Variable	Coefficient Estimate	Standard Error
Intercept (λ_0)	-2.023**	0.297
Preteam time trend (λ_1)	0.004	0.007
Overtime (λ_2)	-0.004	0.010
Headcount additions (λ_3)	0.411	2.972
Headcount deletions (λ_4)	2.829	3.090
Product diversity (λ_5)	0.173	0.195
Product complexity (λ_6)	-0.144	0.426
Capacity overutilization (λ_7)	0.007	0.511
Capacity underutilization (λ_8)	-0.061	0.230
Engineering change orders (λ_9)	-0.045	0.073
Postteam time trend (λ_{10})	-0.011**	0.002
Adhesive experiment dummy (λ_{11})	1.034**	0.143
Submotor line dummy (λ_{12})	-0.218	0.114
Gear train line dummy (λ_{13})	-0.252*	0.123
Board line dummy (λ_{14})	1.010**	0.100
R^2	0.485	
Adjusted R^2	0.462	
F	21.071**	

^a The dependent variable is the logarithm of quality (manufacturing defect rate); $N = 328$.

* $p < .05$

** $p < .01$

level. Table 4 summarizes the regression results for the fixed-effects model. The coefficient estimate for the preteam time trend is not significant, but the coefficient estimate for the postteam time trend is significant at the 5 percent level. As in the case of quality, these results indicate no time trend in labor productivity prior to the formation of HPWTs. However, there is a significant improvement in labor productivity in the months following the formation of HPWTs. The coefficient estimate of 0.023 for the postteam time trend translates into a 20 percent improvement in labor productivity from the beginning to the end of the postteam period in our study. The statistically significant control variables suggest that the departure of production workers and capacity overutilization have negative impacts.⁶

Table 5 summarizes the results of the seemingly unrelated regressions estimation procedure. Since each production line has only 21 observations,

⁶ In Table 1 three pairwise correlations are greater than .50 for the monthly data: (1) between overtime and capacity overutilization, $r = .57$; (2) between overtime and capacity underutilization, $r = -.50$; and (3) between capacity underutilization and postteam time trend, $r = -.58$. Although the collinearity diagnostics indicated that we had no predictor collinearity problem, we confirmed this by deleting overtime, capacity overutilization, and capacity underutilization one at a time from the base model. The three separate sensitivity analyses showed that the estimated coefficients of the remaining variables, most importantly the team variable, were stable.

TABLE 3
Results of Estimation of the Seemingly Unrelated Regressions Model^a

Variable	Submotor Line	Gear Train Line	Board Line	Final Assembly Line
Intercept (α_{0i})	-1.725** (0.517)	-4.947** (1.405)	-0.603* (0.291)	-3.063** (0.733)
Preteam time trend (α_{1i})	0.014 (0.013)	-0.004 (0.013)	0.020 (0.016)	-0.006 (0.009)
Overtime (α_{2i})	-0.047 (0.034)	0.063 (0.045)	-0.085 (0.047)	0.031 (0.025)
Headcount additions (α_{3i})	-0.618 (4.010)	22.900 (11.599)	8.366 (11.650)	1.440 (3.901)
Headcount deletions (α_{4i})	1.499 (4.441)	-6.003 (7.066)	11.564 (13.180)	-3.043 (5.619)
Product diversity (α_{5i})	-0.898 (1.505)	1.250 (3.936)	0.130 (0.248)	0.014 (0.236)
Product complexity (α_{6i})	0.297 (1.305)	1.200 (4.768)	-0.284 (0.598)	0.629 (0.948)
Capacity overutilization (α_{7i})	1.060 (0.998)	0.767 (1.279)	-1.470 (0.863)	-0.668 (0.742)
Capacity underutilization (α_{8i})	0.526 (0.450)	-0.049 (0.555)	-1.239** (0.406)	0.025 (0.333)
Engineering change orders (α_{9i})	-0.049 (0.352)	-0.461 (0.234)	0.091 (0.140)	0.119 (0.078)
Postteam time trend (α_{10i})	-0.005 (0.004)	-0.022** (0.004)	-0.006 (0.006)	-0.011** (0.002)
Adhesive experiment dummy (α_{11i})		1.289** (0.175)		
R^2	0.219	0.560	0.204	0.351
Adjusted R^2	0.109	0.491	0.092	0.260
F	1.990*	8.105**	1.824	3.841**
N	82	82	82	82

^a The dependent variable is the logarithm of quality (manufacturing defect rate). Values in parentheses are standard errors.

* $p < .05$

** $p < .01$

and the regression has 10 variables (11 variables for the gear train line) plus an intercept term, the power of statistical tests is low. Hence, unlike the fixed-effects model, the SUR model does not permit us to draw sharp conclusions about the impact of HPWTs on labor productivity across the four production lines. In the equations for the four production lines, none of the coefficient estimates for the preteam time trend is significant. The coefficient estimates for the postteam time trend for the gear train and board lines are positive and significant at the 1 percent and 5 percent levels, respectively, which is consistent with the results of the fixed-effects model of labor productivity.

TABLE 4
Results of Estimation of the Fixed-Effects Model^a

Variable	Coefficient Estimate	Standard Error
Intercept (δ_0)	0.392**	0.122
Preteam time trend (δ_1)	0.010	0.023
Overtime (δ_2)	0.006	0.003
Headcount additions (δ_3)	0.486	0.507
Headcount deletions (δ_4)	-1.211**	0.448
Product diversity (δ_5)	0.222	0.222
Product complexity (δ_6)	-0.394	0.356
Capacity overutilization (δ_7)	-20.211**	5.208
Capacity underutilization (δ_8)	0.118	0.267
Engineering change orders (δ_9)	-0.010	0.012
Postteam time trend (δ_{10})	0.023*	0.010
Adhesive experiment dummy (δ_{11})	0.109	0.131
Submotor line dummy (δ_{12})	0.705**	0.124
Gear train line dummy (δ_{13})	1.382**	0.130
Board line dummy (δ_{14})	1.391**	0.118
R^2	0.794	
Adjusted R^2	0.752	
F	18.973**	

^a The dependent variable is the logarithm of labor productivity; $N = 84$.

* $p < .05$

** $p < .01$

Update on HPWTs

More than a year and a half after the end of our study period, we conducted follow-up meetings with plant personnel. We learned from these meetings that the teams were functioning effectively and continuing to contribute to manufacturing performance improvements for the four production lines at our research site. The divisional director of manufacturing operations and the plant manager believed that a key to sustaining the effectiveness of the teams was conducting their meetings regularly. According to the plant manager,

the main part of being a member of a team is to make sure that they [meetings] are happening all the time, consistently. It's something that is just really easy to sweep under the carpet. And once you do that a couple of times, pretty soon you lose the focus of the teams, and you don't have them any more . . . your teams will fail if you don't make it a point that they happen consistently and regularly.

We also learned during these meetings that in early 1995 job rotation was introduced within each team on the four production lines for ergonomic reasons and that all team members were going through a training program in total quality management. These developments are consistent with find-

TABLE 5
Results of Estimation of the Seemingly Unrelated Regressions Model^a

Variable	Submotor Line	Gear Train Line	Board Line	Final Assembly Line
Intercept (β_0)	1.447 (0.776)	4.816* (1.831)	1.588 (1.223)	1.426* (0.559)
Preteam time trend (β_{11})	-0.014 (0.048)	0.039 (0.053)	0.014 (0.055)	0.037 (0.029)
Overtime (β_2)	0.007 (0.010)	-0.006 (0.009)	0.005 (0.010)	0.003 (0.005)
Headcount additions (β_3)	1.018 (1.011)	2.141 (3.062)	-1.464 (1.722)	0.206 (0.611)
Headcount deletions (β_4)	-0.210 (1.083)	-0.934 (1.530)	-3.102 (1.904)	-1.990* (0.849)
Product diversity (β_5)	-0.335 (2.439)	-1.547 (8.390)	0.038 (0.463)	0.418 (0.358)
Product complexity (β_6)	-0.015 (2.331)	-1.223 (8.229)	0.157 (1.310)	-0.962 (0.655)
Capacity overutilization (β_7)	-5.005 (18.060)	-11.652 (20.914)	-19.527 (15.609)	-11.594 (9.057)
Capacity underutilization (β_8)	0.010 (0.780)	0.081 (0.847)	1.176 (0.743)	0.699 (0.470)
Engineering change orders (β_9)	-0.004 (0.067)	0.052 (0.048)	0.002 (0.027)	-0.013 (0.012)
Postteam time trend (β_{10})	-0.001 (0.016)	0.060** (0.016)	0.053* (0.018)	0.014 (0.009)
Adhesive experiment dummy (β_{11})		0.069 (0.124)		
R^2	0.291	0.809	0.827	0.783
Adjusted R^2	-0.418	0.574	0.654	0.566
F	0.410	3.455*	4.776*	3.609*
N	21	21	21	21

^a The dependent variable is the logarithm of labor productivity. Values in parentheses are standard errors.

* $p < .05$

** $p < .01$

ings of MacDuffie (1995), who observed a trend toward "bundling" innovative human resource practices in modern manufacturing plants.⁷

CONCLUSIONS

The purpose of this study was to empirically examine the impact of work teams on manufacturing performance. During the 21-month study period at our research site, there was a naturally occurring experiment of conversion to work teams. Using a longitudinal research design, and controlling for other variables that have the potential to affect manufacturing performance, we

⁷ We thank an anonymous reviewer for this insight.

obtained results indicating that quality and labor productivity improved over time after the introduction of work teams. We supplemented these quantitative results with qualitative insights into the functioning of work teams and their evolution over time, leading to workplace transformation.

We infer from the results of the fixed-effects models that for the plant as a whole there was improvement in both quality and labor productivity after high performance work teams were formed. However, for the individual production lines, the results of the SUR models suggest improvement in both quality and labor productivity after the formation of the HPWT on the gear train line only. This may be explained by the fact that the gear train line team was considered to be the most cohesive group. In contrast, there was no improvement in either quality or labor productivity on the submotor line after the formation of its HPWT. An explanation for this result is that there was conflict among the members of the submotor team in the months following the formation of the HPWT and persisting throughout the study period. On the board and final assembly lines, the signs of the estimated coefficients for the postteam time trend for both the quality and productivity regressions were in the predicted directions, but not always significant. The team dynamics of the board and final assembly teams suggest that they fell between the two extremes represented by the gear train and submotor lines, consistent with the regression results.

A limitation of this study is the absence of data from a control plant similar in all respects to our experimental plant but without formal work teams. The lack of such data prevents us from making a definitive causal attribution. However, by controlling for other variables that are known to affect manufacturing performance, our results provide evidence of the positive impact of work teams on manufacturing performance. Another limitation of this study, and in all fairness, of any field study, is the issue of the generalizability of findings. In some sense, we have tried to overcome this limitation by analyzing a panel data set that included longitudinal data from four production lines varying in terms of capital and labor intensity, tasks, skill mix, and the number of production workers in the work teams. Despite these caveats, we believe that it is important to advance human resource management research by systematically documenting the performance impact of work teams in real-world organizational settings.

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