

Comparison of Manufacturing Performance of Three Team Structures in Semiconductor Plants

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Abstract—Manufacturing programs aimed at improving performance often feature employee teams that address production problems at the shop-floor level. According to cognitive models of participation, performance under such programs is improved via the better utilization of skills and knowledge that occurs as employees are allowed greater decision making in their tasks. We examine the cognitive-model premise in a high-technology industry where improvement-team programs are on the rise. We study three types of improvement-team programs among a sample of eight manufacturing sites. The programs feature continuous improvement teams (CIT's), quality circles (QC's), or self-directed work teams (SDWT's) and vary in the amount of decision-making power, skill attainment via training, and skill use granted to employees. A quantitative analysis of performance reveals that CIT programs were associated with the highest direct and indirect productivity, two metrics that were available for each firm. QC and SDWT programs should not be dismissed, however, as they may lead to improvements in quality metrics, as we note in suggestions for future research. Qualitative data gathered in site visits suggest that poor implementation and failure to integrate production programs with engineering departments are two factors that inhibit program success.

Index Terms—Continuous improvement, employee participation, manufacturing, quality circles, semiconductor, teams, work groups.

I. INTRODUCTION

WITH THE rise in popularity of manufacturing programs aimed at continuous improvement, quality assurance, and preventive maintenance, many product manufacturers worldwide are enlisting teams and small groups of employees as vehicles for performance improvement efforts. Osterman [20] estimates that nearly half of all corporations in the United States have implemented some form of team-based work system. Groups and teams are valued in industries where competitive pressures and dynamic production systems require flexibility, adaptability, and skill diversity [12].

A common argument in support of employee-populated improvement-team programs is that their creation sets up a framework in which manufacturing problems can be addressed by lower level employees whose intimacy with the production process is greater than that of management's. This argument takes formal shape in cognitive models of employee participation [18]. Organizational theorists who support cognitive models claim that productivity increases as workers are allowed to participate in decisions [9]. By adding the workers'

pool of information to that of management, better decisions can be made, thus leading to better performance. Participation is expected to increase the flow of information within an organization and to better utilize all employees' skill and knowledge.

Implicit in cognitive models of participation are three necessary preconditions. First, employees must be participating in work decisions. We call the degree of decision-making power an employee group wields its level of autonomy [10], and we often measure it in terms of decisions related both to technical details of the production process and to administrative matters. Second, the models assume that participants possess knowledge and skills appropriate to the nature of the problem. Where employees are participating in production decisions, we can gauge their level of knowledge and skills in terms of the training that they have received. Third, the models assume that there is some substance to the autonomy held by employees, that participation exists not just in word but also in deed. To this end, we might observe how much employees' tasks have been transformed under the participation scheme as a measure of the intensity of the program. Cognitive models predict better performance in cases where these three preconditions are met, which leads to the hypothesis of this study.

Hypothesis: In accordance with the preconditions of the cognitive model, team programs emphasizing increased levels of autonomy, extended training, and modified tasks will lead to better performance.

Surveys and metaanalyses of participation research indicate that participation often has a significant, albeit small, relationship to performance [26] and give some support to cognitive models [18]. The individual studies included in these surveys, however, often include interventions lasting little more than a few hours or days and occur in diverse settings. A few empirical studies do exist in which the performance effects of group-based participation schemes in manufacturing settings were assessed. Marks *et al.* [17] found that participation in a quality circle (QC) program at an assembly plant led to improved individual-level productivity. Wall *et al.* [27] found no consequences on direct labor productivity in their quasi-experimental study of autonomous workgroups in a confectionery factory, but indirect labor productivity did improve with the resultant reduction in the number of supervisors. Pearson [22] reported that autonomous workgroups had significantly better productivity than traditional ones in an engineering workshop. The improvements resulted from new work practices that the autonomous groups adopted after discussion in weekly meetings. Pearson notes that the

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workers in these groups “made more efficient use of their manpower . . . eliminated some of the unnecessary work processes, and acquired more relevant work knowledge” [22, p. 926] than did their peers. Among autonomous groups at a dog-food plant, Walton [28] recorded significant savings due to group innovations, improved safety records, and lower absenteeism and turnover rates. Batt and Appelbaum [2] compared autonomous workgroups with off-line teams, such as quality of work life teams, among telecommunications and apparel manufacturing firms. They found that autonomous workgroups were positive predictors of an individual’s job satisfaction, organizational commitment, and perceptions of quality, while off-line teams largely were not. Overall, these studies reflect improved performance (or perceptions thereof) as a result of increased participation in work decisions and, as in the study by Pearson, seem to indicate support of the better utilization of employee skills and knowledge.

Single-site studies, which dominate the literature, face difficulties in generalizing their results to other sites or firms; for this, larger scale studies are required. In a review of literature covering both service and manufacturing groups with increased decision-making powers, Pearce and Ravlin [21] note that, overall, very few large-scale statistical studies of participation programs have been conducted. Furthermore, manufacturing group research has been conducted almost exclusively in low-technology settings, as seen in these examples, yet participation is expected by some researchers to have its most dramatic effects in work that is complex, nonroutine, and meaningful [21], [25].

This paper fills some of the gaps in our understanding of groups and teams by examining how differences in improvement-team program design affect manufacturing performance at eight high-technology production sites in the semiconductor industry. In the background section, we describe how manufacturing improvement-team programs have developed in this industry, drawing important distinctions between the teams in the programs and the traditional production workgroups. Special attention is paid to autonomy, training, and task content, as these variables reflect the level of decision-making power, skill attainment, and skill use permitted within each team program. We then employ a methodology that includes both quantitative and qualitative data to examine the premise of the cognitive model. A sample of 89 workgroups among the eight sites provides us with survey data, quantitative performance data from production records, and qualitative interview data.

II. BACKGROUND

In the mid-1980s, with the Japanese threat to American supremacy in the semiconductor industry fast becoming a reality, many domestic firms began to examine every aspect of Japanese manufacturing, looking for any factor that could explain their success. A number of U.S. firms began to adopt Japanese-style organizational innovations, such as the use of employee teams, in the hopes of gaining competitive advantage. Gustavson and Taylor [11] recorded the first instance of employee teams in a U.S. semiconductor fabrication facility

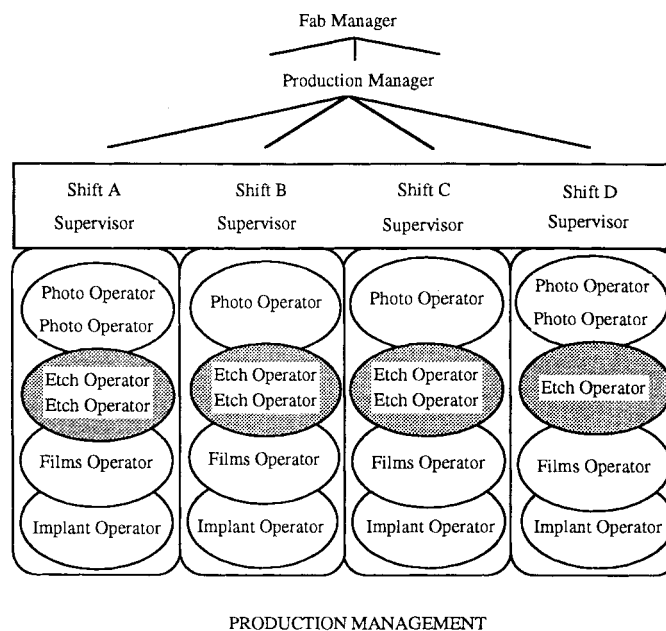


Fig. 1. Typical fab production hierarchy reflecting 16 workgroups. The etch workgroups are highlighted.

(fab) at Zilog, with later implementations reported at such firms as Harris [3], IBM [4], Motorola [8], and Xerox [19]. Recently, an ongoing large competitive manufacturing benchmarking study [14] has documented part of the spectrum of teams employed within the semiconductor industry [5]. Study researchers found teams composed of production operators who, after substantial training in group dynamics, statistical process control, and problem-solving techniques, were given considerable leeway in making administrative and production decisions for their work area. Other teams they observed garner members from a wide range of fab functions beyond and including the cleanroom (where processing is performed), whose purpose is simply to generate suggestions on topics ranging from employee morale to particle control to gain-sharing plans. In this section, we first define traditional workgroups, then describe three major types of team programs documented within the semiconductor industry [1]; it is from among these types of team programs that we will draw our sample.

A. Workgroups

The primary task of a semiconductor production operator workgroup is to process wafers in its area. Wafers are circular pieces of silicon on which small squares of circuitry are created; these squares are later separated into microcomputer chips. In the absence of an improvement-team program, the task of processing wafers consumes nearly all the working time of production operators. Workgroups are identifiable by their functional area and shift. An example of a workgroup would be the etch operators on the first or “A” shift, as indicated in Fig. 1. Most fabs run four shifts and physically divide the production process into four major functions: photo (where circuitry images are placed on wafers), etch (where selected layers of the wafer are removed), thin films (where new layers are deposited over the entire wafer), and diffusion/implant

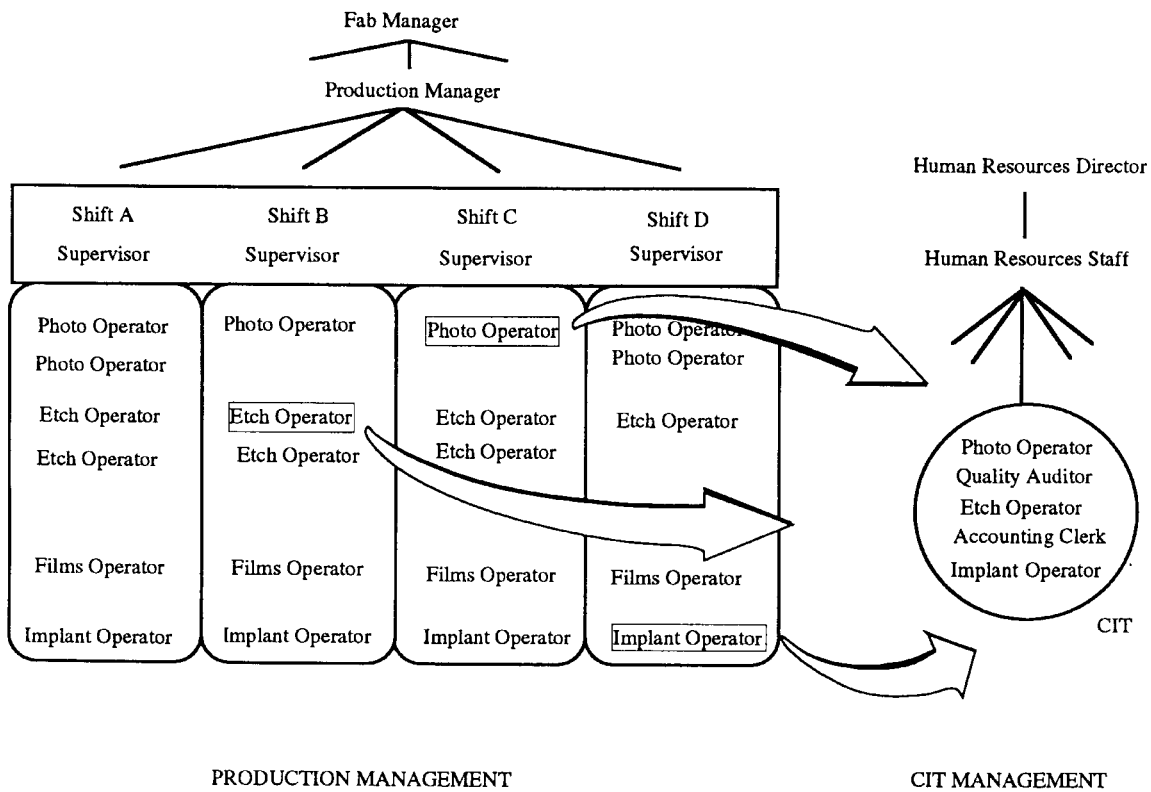


Fig. 2. Production organization in a fab with a CIT program. Indicated operators participate with other fab employees on one of the CIT's.

(where layers are added to selected portions of the wafer). This temporal and functional division results in 16 workgroups per fab, with five to ten members in each group. The workgroups described here fit Hackman's [12] description of a workgroup: an interdependent social system having clear boundaries and operating in an organizational context.

B. Improvement-Team Programs

Beyond their traditional workgroups, production operators often can participate on manufacturing improvement teams. We describe here three major types of team-based participation programs found in the industry: continuous improvement-team (CIT) programs, QC programs, and self-directed work team (SDWT) programs.

1) *CIT's*: In fabs employing CIT programs, small teams of operators work on selected projects, addressing problems ranging from employee morale to productivity issues to quality control. Employees from any number of workgroups from across the fab may voluntarily join together to work on a CIT; as a result, team membership is rarely from a single workgroup or functional area (see Fig. 2). This interspersing of members from various workgroups within each team serves as a key distinguishing feature of a CIT program. When comparing Fig. 2 to Fig. 1, note how the basic management structure remains unchanged, with CIT's existing in parallel to the traditional workgroups. CIT's typically meet once a week over the course of several months to a year. When its project is completed, the CIT disbands. CIT programs require no universal training of employees in technical problem solving (e.g., Pareto charts, fishbone diagrams, design of experiments),

as many teams do not work on technical problems. Those that do can be trained as needed. The CIT's also require no real training in group dynamics (e.g., conflict resolution, negotiation), as the teams tend to be short lived; teams that fail to work well together never need to meet again. Group autonomy is also typically low among CIT fabs; in the absence of increased skills and knowledge, decision-making responsibilities cannot be expanded. Typically, the program is managed by the human resources department, not the production department. Motorola's teams [8] are perhaps the most well-known CIT teams in the industry.

2) *QC's*: QC's constitute the second type of team program. Here, workgroup members from a single functional area may voluntarily join together to resolve quality and production problems unique to that area [15]. Unlike the CIT's, the QC's are permanent teams whose members are associated with a given equipment set; they do not represent a cross section of the entire fab, nor do they disband when a single project is completed. This fact is represented in Fig. 3, where we can see that QC's, unlike CIT's, can be overlaid across the traditional hierarchy in a manner akin to a matrix organizational structure. Single-area membership thus serves as a distinguishing characteristic of QC programs. At weekly meetings, QC members discuss their manufacturing performance and their efforts to improve it; administrative problems may also be addressed. Outside of meetings, members are allotted a few hours away from their regular production duties to work with engineers in designing experiments, collecting and analyzing data, and modifying equipment or procedures. Carrying out these new duties requires increased training in technical topics.

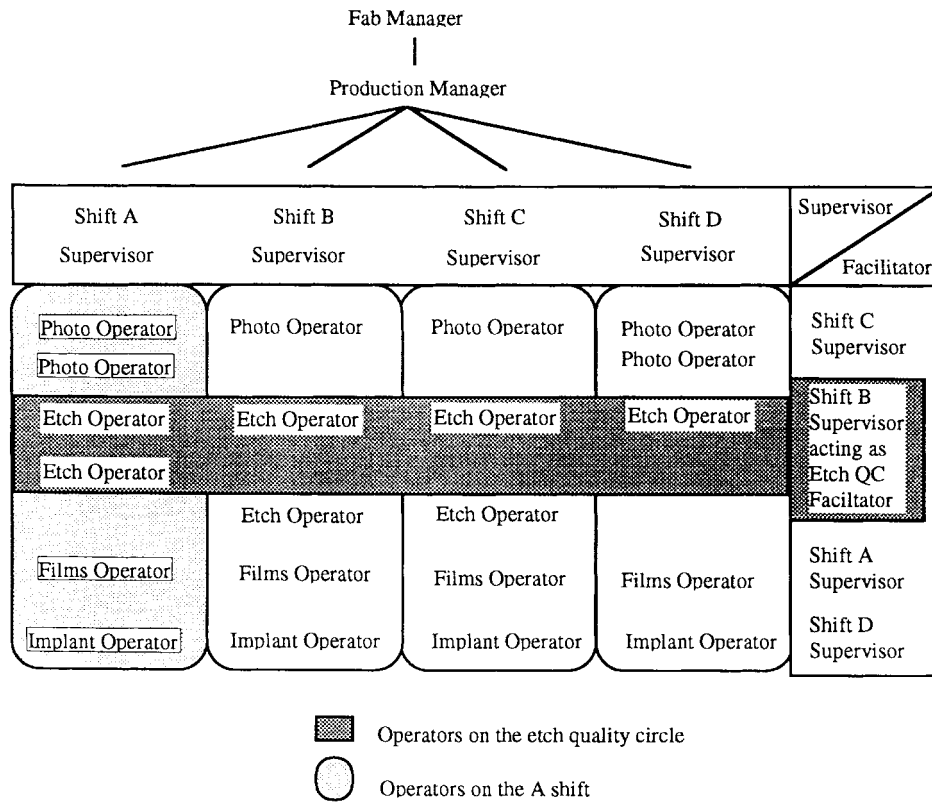


Fig. 3. Production organization in a fab with a QC program. Not every etch operator will participate on the etch QC (highlighted).

The increased training in turn permits the assumption of greater responsibilities over equipment and area functioning. In QC programs, production shift supervisors often take on the additional task of facilitating the QC's, as depicted in Fig. 3.

3) *SDWT's*: In the third type of team program, production operators participate on *SDWT's*¹ that replace the traditional workgroups (see Fig. 4). The new teams are formed along the same functional and shift lines as the old workgroups but now have greater responsibilities, enlarged duties, and increased skills through training. Thus, in Fig. 4, we now see that the *SDWT's* have supplanted the traditional workgroups; in other words, they are completely aligned with them. Teams are generally held responsible for monitoring and improving their own performance. They hold weekly meetings to review their status and to discuss problems and projects, both technical and administrative. Participation on an *SDWT* is not voluntary, as in the other two programs, but rather is determined by one's assignment upon employment or transfer to a functional area and shift. As a result, performance on the team can be and is considered in individual performance evaluations for pay purposes; mandatory participation and pay evaluation thus serve as key features of *SDWT* programs. Because *SDWT* members are held jointly responsible for their performance, the teams require mechanisms for modifying and regulating

member behavior. Thus, fabs that employ *SDWT's* often allow team members to help select new members, initiate disciplinary actions, write formal peer evaluations, coordinate daily production assignments, arrange training and cross-training sessions, and schedule vacations. In short, the *SDWT's* usurp duties previously performed by production supervisors. While job enlargement (e.g., the addition of technical decision-making responsibilities regarding equipment and functioning) is evident in the QC programs (and to a lesser extent among some *CIT's*), we see in the *SDWT* program the addition of job enrichment (e.g., the spreading of job duties up the production hierarchy) via the added dimension of administrative decision-making power. *SDWT's* are managed either by production supervisors or by cross-functional management teams. The first *SDWT's* in the semiconductor industry appeared at Zilog in the early 1980's [11].

III. SUMMARY

The descriptions of the three types of improvement-team programs indicate several trends in the variables that constitute the preconditions of cognitive models. First, autonomy over administrative matters (such as scheduling breaks, vacations, and training, handling disciplinary actions, etc.) seems to increase in progression from *CIT* to *QC* to *SDWT* programs. Decision-making authority in more technical realms appears higher in *QC* and *SDWT* programs than in *CIT* programs, as both of the former concentrate on production problem solving in their areas. It follows that training in technical matters should also be highest in *QC* and *SDWT* programs, while more

¹Various terms abound in the literature for teams that have increased autonomy, including "self-managing," "self-designing," "semiautonomous," and, more recently, "empowered" teams. While some authors do distinguish between the types, most use these terms interchangeably (e.g., [16, pp. 24-26]). For the purposes of this paper, the single term "self-directed" will be used to represent this class of teams.

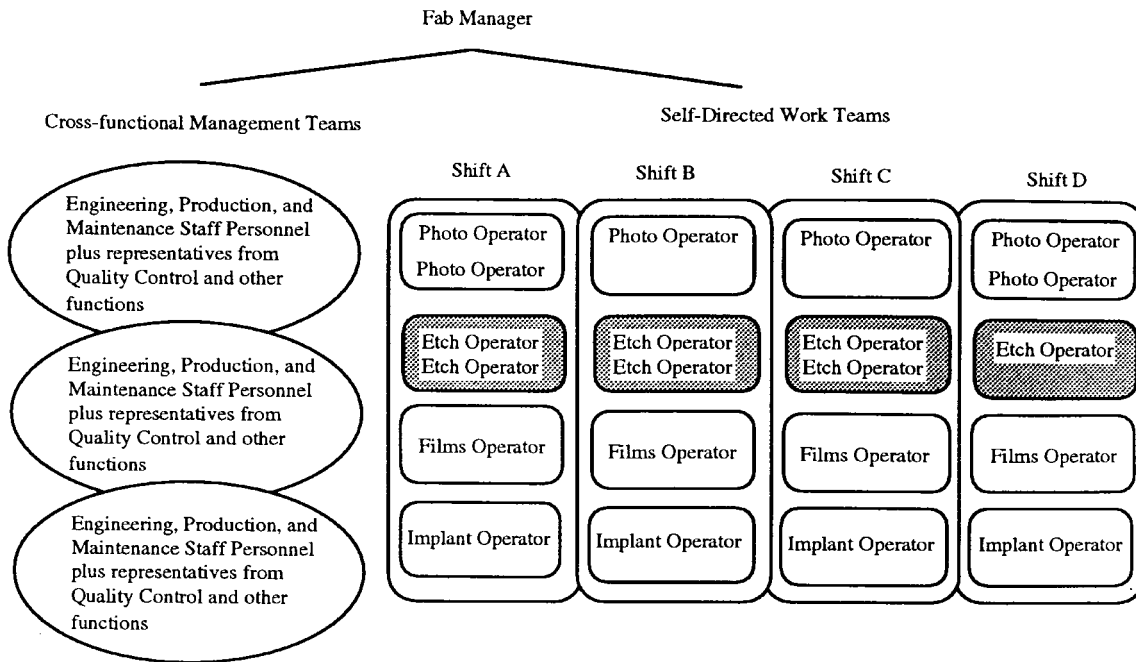


Fig. 4. Production organization in a fab with an SDWT program. The four etch SDWT's, which replace the traditional etch workgroups, are highlighted.

team-based training (i.e., in topics such as conflict resolution and negotiation) will again increase in progression from CIT's to QC's to SDWT's. The nature of the tasks performed by operators in CIT fabs remains largely wafer processing, with a limited amount of time spent in weekly CIT meetings. Tasks for QC operators are modified in that they become involved in experiments and data analysis as they track and improve their production performance. SDWT members experience the greatest change in their tasks; not only do they take on problem-solving tasks akin to those adopted in QC's but they also take on greater administrative duties.

All three programs feature teams, but these teams are of different types. In the terminology of Cutcher-Gershenfeld *et al.* [7], CIT's and QC's constitute off-line teams, while SDWT's constitute on-line teams. According to the categorization of Mankin *et al.* [16], CIT's and QC's are parallel teams, while SDWT's are self-managing work teams. Many types of teams commonly found in manufacturing environments can be classified according to the three programs described here (for example, a program featuring total preventive maintenance teams would most likely be structured as a QC program).

IV. METHOD

A. Research Design

An analysis of variance (ANOVA) design was employed to test our hypothesis in a high-technology industry. According to our hypothesis, we expect workgroups in SDWT programs to perform better than workgroups whose members participate in QC's or CIT's, as SDWT programs provide the highest degrees of autonomy, training, and modified task content (a fact that is confirmed below). In general, the question we are posing is: Do we see a difference in the performance of production

workgroups based on the type of team program their members may participate in? Thus, the unit of analysis is the production workgroup and the independent variable is the type of team program. It is important to note here that we cannot directly compare the performance of the teams themselves because they often lack a quantifiable end product, i.e., they often produce ideas and problem solutions whose benefits are not easily measured. We can, however, measure the performance of production workgroups, as they are present in each program and they produce a physical product: wafers. We assume that participation in a team program has ramifications for members that can be measured in terms of the performance of their workgroups.

B. Sample

We draw our sample from eight semiconductor fabs representing seven major firms. Three of the eight fabs were selected through their participation in a large bench-marking study of the industry [14]; the other five were identified through their membership in an industry association that helped to fund this work. Three fabs employed CIT's, two employed QC's, and three employed SDWT's. The determination of what program was employed at each fab was made during the site visit in conjunction with the fab manager and/or the heads of production and engineering. In each case, the author made a private determination first based on observation and interview data; then, the three types of programs were described to the manager, who was asked to categorize his teams. In each case, the manager's choice concurred with the author's, and when questioned, no manager reported that he had difficulty in choosing a category that fit his program. For fabs participating in the larger study, the categorization was confirmed against site visit notes taken by other researchers.

TABLE I
CHARACTERISTICS OF FABs IN THE SAMPLE

Characteristic	Fab Breakdown	
Type	merchant	6 fabs
	captive	2 fabs
Process Technology	CMOS	7 fabs
	bipolar	1 fab
Product	primarily logic devices	
Line Widths	0.8 to 1.3 microns	
Volume	high and at full capacity, all are volume producers for their firms	
Work Schedule	4 12-hr shifts	4 fabs
	3 shifts	2 fabs
	5 or more shifts	2 fabs
Age	~ 1 yr	2 fabs
	8-10 yrs	3 fabs
	14-16 yrs	2 fabs
	25 yrs +	1 fab
	older fabs had been renovated at least once	
Cleanroom Particle Count Levels	Class 1	2 fabs
	10	3 fabs
	100	2 fabs
	1000	1 fab

No fab employed more than one type of improvement-team program. Two fabs in the study belonged to the same firm: one fab employed CIT's and the other SDWT's. One additional fab employing QC's was originally included in the design but was dropped when it failed to produce performance data for its workgroups.

Fab characteristics are presented in Table I. Merchant fabs sell their product on the market; captive fabs produce for internal demand. There is some belief within the industry that captive status allows a fab to experiment more with job and organization design because the site is presumed to be more insulated from competition. However, the sample here reflects a complete range of types of team programs among its merchant fabs. Similar process technologies, products, and chip line widths (a smaller line width indicates a more advanced product; most fabs in this sample produced considerable volumes of submicrometer products) ensured a nearly identical equipment set among the sample, with production bottlenecks appearing in the same areas. This similarity, in addition to full-capacity production at each site, will serve to facilitate quantitative comparisons. Small line widths cause product quality to be very sensitive to airborne particles. Older fabs tend to have higher allowable particle count levels in the cleanroom; however, several of the older fabs had been renovated to accommodate lower particle levels and hence

more advanced products. The oldest fab in the sample was also the one with the highest particle count and the different (older) processing technology (bipolar junction isolated).

C. Pilot Fab

A pilot fab employing a QC program was incorporated in the study methodology to serve as a site where the author could familiarize herself with work organization and production aspects of semiconductor manufacturing. During a total of four weeks at the site, the author shadowed operators (observing them at their regular production tasks and in team meetings) and interviewed numerous engineers, technicians, human resource personnel, production supervisors, and fab management. The author also administered the written survey (described below) to operators at that site, using their responses to modify the survey as necessary. It would have been ideal to have three pilot fabs representing the three types of team programs employed in this study, but time and cost considerations precluded such an arrangement. However, frequent interactions with industry representatives during this phase served to broaden my understanding of fab organization beyond this pilot fab.

D. Data Collection

Data for the study was gathered during site visits, typically four to five days in duration, made to each of the eight fabs during the period 1992-1993. Quantitative performance data constituted the primary data source for the study and was collected at the workgroup level. The data covered one to three months, depending on availability, and was gathered from production records within six months of the visit. Raw data included the number of wafers processed per month, work schedules, headcount, scrapped wafer counts, cycle-time information, equipment utilization and availability, and other information specific to products and processes. Qualitative data was additionally gathered to provide understanding of the team programs. These data were gained in part via semistructured hour-long interviews with employees at every job level within the engineering, production, and equipment hierarchies at each fab. More than 100 interviews were held in total. At least three team meetings were also attended and observed during each visit, and four-hour unguided tours of the manufacturing areas were taken to permit informal discussions with operators. Last, employee surveys were distributed to two to four operators per workgroup at each fab. Due to heavy production demands, more operators at each plant could not be surveyed. Operators were selected by the supervisors, who were asked to select operators that they knew to be informed about and active in the team program. While selection bias exists as a result of this procedure, each program should be biased in the same direction (i.e., toward more involved operators). Multiple responses were averaged together to serve as the group response. This common procedure in the group literature has the disadvantage of masking extremes, but the alternative, asking groups to meet together to complete a single survey, was made impossible in this study due to production pressures. A group level of analysis of the surveys was chosen over an individual one

TABLE II
SUMMARY STATISTICS

Variable	mean	sd	1	2	3	4	5	6	7	8	9	10	11	12	13
Autonomy															
1 administrative autonomy	2.76	0.85	-												
2 technical autonomy	2.46	0.70	0.73	-											
Modified Task Content															
3 time in meetings	2.97	0.85	0.23	0.26	-										
4 time in preventive maintenance	2.80	1.19	0.38	0.38	0.21	-									
5 time in problem-solving	2.47	1.07	0.21	0.31	0.51	0.24	-								
Training															
6 task training	3.48	0.93	0.05	0.03	-0.04	-0.05	0.03	-							
7 team training	2.48	1.41	0.48	0.45	0.08	0.29	0.20	-0.12	-						
8 cross training	3.43	0.83	0.45	0.51	0.23	0.01	0.11	-0.09	0.33	-					
Workforce Characteristics															
9 education	2.54	0.66	0.10	0.07	0.12	0.09	0.12	0.09	-0.04	-0.20	-				
10 group tenure	2.51	0.80	-0.01	0.23	0.08	0.22	-0.02	0.01	0.30	0.19	-0.08	-			
11 organizational tenure	3.66	0.98	-0.11	0.06	0.06	-0.13	-0.02	-0.07	0.04	0.30	-0.33	0.45	-		
Outcomes															
12 direct labor productivity	33.47	17.26	-0.15	-0.16	-0.05	-0.21	-0.18	0.12	-0.09	-0.17	0.07	0.06	-0.01	-	
13 indirect labor productivity	24.02	12.16	-0.02	-0.01	-0.02	-0.07	-0.13	0.1	-0.03	-0.12	0.11	0.14	0.01	0.93	-

to be consistent with the productivity analysis, as production records are kept for workgroups, not individuals. Preaddressed, stamped envelopes were provided for direct return of the questionnaires to ensure confidentiality.

1) *Production Records and Workforce Data:* Adequate data from all eight sites was ultimately available for three outcome variables. Direct labor productivity was measured as the number of wafers processed per operator hour. Indirect labor productivity was calculated as the number of wafers processed per operator, supervisor, and technician hour combined. Both direct and indirect labor productivity were measured at the workgroup level of analysis. Wafer scrap percentage (calculated as the number of wafers scrapped per wafer processed) was also included in the study, but limited data records at the sites prohibited its calculation at the workgroup level of analysis. Instead, it was measured at the functional area level (i.e., no differentiation could be made between shifts) and was included in the analysis due to its industry importance.

2) *Interview Data:* Handwritten notes from each of the interviews were organized by fab and team program, then reviewed for general themes, interesting observations, and unique perspectives. In this process, the notes for each site were reduced to several pages each, with data organized under headings for every job title and for themes such as atmosphere and organizational support.

3) *Self-Report Measures:* It is necessary to ensure that the groups in the sample are representative of their programs. That is, we must verify that the levels of autonomy, training, and modified task content meet with the descriptions given for the CIT, QC, and SDWT programs, respectively. Self-report measures were thus gathered for these variables to confirm the author's assessments made through observations and interviews during the site visits. Survey items were measured on five-point Likert-type scales. Unless otherwise indicated, the questions in the survey were drawn from Van de Ven and Ferry's [24] instrument for measuring organizational effectiveness at the workgroup level. Correlations and summary statistics for all variables are given in Table II.

Group autonomy was separated according to technical or administrative decision making. Technical areas included task allocation, production quotas, work rules and procedures, external requests, and selection of monitored performance metrics and goal areas. Administrative areas included scheduling of breaks and lunches, scheduling of training, and selection of workgroup members. The questions were worded so that the operator would respond in reference to the degree of autonomy held by his workgroup as a whole, with the scales ranging from "none" to "very much." Alpha coefficients were 0.74 and 0.80 for administrative and technical autonomy, respectively. Three types of training were examined: technical, group dynamics, and cross training. The question asked how much training the operator had received; scales ranged from "a few hours or less" to "more than one month." Task content was measured in three questions gauging the amount of time spent in meetings, on equipment preventive maintenance, and on problem-solving tasks. The task content questions were created for this study and were based on indications from pilot fab interviews that the three areas covered the bulk of an operator's tasks beyond the regular processing of wafers. The scales ranged from "zero hours per week" to "six or more hours per week." Education and tenure (both organizational and group) were also captured to make sure differences in performance were not due to these workforce characteristics.

4) *Response Rates:* Eighty-nine workgroups (72% of the total 124) submitted self-report questionnaire data in addition to their production and interview data: 41 groups were in fabs employing CIT's, 19 in fabs employing QC's, and 29 in fabs employing SDWT's. Five operator surveys were discarded upon failing validity checks that were designed to flag random or incoherent responses. On average, just over one-quarter of the operator workforce was surveyed at each site.

E. Validity Check on the Independent Variable

The self-report measures are analyzed using ANOVA's to serve as a validity check on the independent variable: the type of team program. The results presented in Table III confirm that levels of autonomy, training, and modified task

TABLE III
STATISTICAL RESULTS FOR PERFORMANCE VARIABLES

Variable	Means			ANOVA		Tukey Contrast Test
	CITs	QCs	SDWTs	F	df	
Direct Labor Productivity (wafers processed per operator-hour)						
photo	39.5	27.0	26.9	1.4	23	-
etch	44.6	27.0	26.1	3.2	18	-
diffusion	60.4	24.6	32.3	18.1***	20	CITs > QCs, SDWTs
thin films	28.0	18.4	22.3	12.8***	24	CITs > QCs, SDWTs
Indirect Labor Productivity (wafers processed per employee-hour)						
photo	26.1	21.8	22.5	0.8	23	-
etch	32.0	16.7	22.4	2.0	18	-
diffusion	38.9	18.9	25.1	11.4***	20	CITs > QCs, SDWTs
thin films	20.3	11.6	17.2	7.3**	24	CITs > QCs
Scrap Percentage (wafers scrapped per wafer processed) (times 100)	0.10	0.11	0.16	1.1	31	-

* p < .05
** p < .01
*** p < .001

content are consistent with the type of program. Specifically, we see a significant difference in the degree of technical autonomy among workgroups in the three programs, with the Tukey contrast test indicating that SDWT's have the highest technical autonomy, followed by workgroups in fabs with QC's. Workgroups in CIT fabs trail significantly. Administrative autonomy is also strongest among SDWT's. The QC and CIT fabs have lower values for this variable, with no significant difference discerned between them. As for task content, workgroups in CIT fabs reveal the least degree of modification, with operators spending less time in off-line activities such as problem solving, meeting attendance, and preventive maintenance than their peers in the other two programs. SDWT's rank highest in team and cross training, but oddly lowest in task training. Their low rating in this latter category can perhaps be explained by their greater cross training: with their skills spread over more machines, their in-depth training on any single piece of equipment may be lower. Workgroups in CIT fabs reported statistically significant low levels of team and cross training, which is expected given the design of the CIT program. Workgroups in QC fabs reported high levels of technical training, as reflected in their scores for task and cross training, with lower values for team training. Although their team-training level was higher than that of the CIT fabs, the difference was not significant.

No workgroup-member tenure differences were expected, in relation to either the organization or the workgroup, based upon the type of team program; the ANOVA results support this assumption. Workgroup tenure averaged between two and three years, organizational tenure between six and seven years. Education levels were also nearly identical across team

programs; the average was about 2.5 on a five-point scale, with a "2" representing a high-school diploma and a "3" a two-year technical degree. These results rule out the possible confounding effect of these workforce characteristics on the performance results.

In summarizing the statistical results for the self-report measures, we see that in workgroups associated with CIT's, operators received more task training than they did team training, they spent little time performing problem-solving or preventive maintenance tasks or attending meetings, and they had relatively low levels of cross training on equipment. Group autonomy was quite low in both technical and administrative areas. Workgroups in fabs employing QC's displayed more team training, more administrative and technical autonomy, more time spent performing problem-solving and preventive maintenance tasks, more time spent in meetings, and more cross training than did their peers in groups associated with CIT's. Groups recast as SDWT's scored quite high in terms of task and team training, administrative and technical autonomy, time spent in problem-solving and preventive maintenance tasks, time spent in meetings, and level of cross training. Overall, they exhibited the greatest degrees of autonomy, training, and modified task content.

V. STUDY RESULTS

The results of this research are presented here in two sections: the first discusses statistical results for actual production performance; the second introduces qualitative data by team program to support, explain, or show contrary indications to the statistical findings.

TABLE IV
STATISTICAL RESULTS FOR SELF-REPORT VARIABLES

Variable	Means			ANOVA		Tukey Contrast Test
	CITs	QCs	SDWTs	F	DF	
Autonomy						
Administrative Autonomy	2.34	2.74	3.36	17.1***	88	SDWTs > QCs, CITs
Technical Autonomy	2.03	2.56	3.00	25.1***	88	SDWTs > QCs > CITs
Modified Task Content						
Time in Meetings	2.61	3.41	3.20	8.1***	87	QCs, SDWTs > CITs
Time in Preventive Maintenance	2.49	2.69	3.31	4.5*	88	SDWTs > CITs
Time in Problem-Solving	1.99	3.31	2.59	12.7***	87	QCs > SDWTs > CITs
Training						
Task Training	3.70	3.69	3.05	5.22**	88	CITs, QCs > SDWTs
Team Training	1.81	2.21	3.54	17.8***	86	SDWTs > QCs, CITs
Cross-Training	2.95	3.57	4.02	20.4***	88	SDWTs, QCs > CITs
Workforce Characteristics						
Education	2.55	2.48	2.54	0.1	88	-
Group Tenure	2.35	2.28	2.77	2.9	88	-
Organizational Tenure	3.58	3.57	3.84	0.7	88	-

* p < .05
 ** p < .01
 *** p < .001

A. Statistical Results

Overall, the basic proposition of this study is not supported: SDWT's were not found to be the best performers. Rather, these teams were outperformed by workgroups in fabs with CIT's. Means and ANOVA results for the quantitative performance metrics are displayed in Table IV. Because technological differences among functional areas were expected to influence productivity measures heavily (for example, a diffusion oven can be loaded with 200 wafers and left alone for hours, while a photostepper must be attended after processing every 24 wafers), an ANOVA is given for each area separately.

- Examination of the means for *direct labor productivity* reveals that in every functional area, the workgroups in fabs with CIT's had the highest performance, with the SDWT's generally following. Workgroups in fabs with QC's most often fared the worst. The ANOVA results indicate that this trend is significant at the 0.01 level or below for two of the four functional areas: diffusion and thin films.
- The performance trend continues under *indirect labor productivity*, with CIT's performing best and QC's worst.

However, the relative differences according to type of team program shrink as compared to direct labor productivity. The reduction in the size of the gap is not surprising given the design of the QC and SDWT programs. As operators take on more technical and administrative responsibilities, the number of supervisors and technicians directly involved in production can be reduced.

- The *scrap percentage* values were analyzed with workgroups aggregated at the functional level due to the manner in which this variable is tracked at the fabs (i.e., it is captured for 24-hour periods, thereby making shift discrimination impossible). The results of the analysis indicate that functions within CIT fabs have the lowest values, while those in SDWT fabs have the highest. Note that for the scrap metric, a lower value is better, as it signifies a higher percentage of good product. None of the scrap percentage differences were found to be statistically significant.
- The above results were maintained even when a possible outlier in the form of the oldest fab in the study was removed and the analysis repeated. This fab, which had a

CIT program, also had less advanced products and older technology, but these factors alone were not found to be driving the CIT results.

B. Qualitative Results

The qualitative results largely support the statistical results given above. The data were gathered during observations, interviews, meeting attendance, and fab tours conducted at each of the fabs and provide us with unique insights regarding program design and management. For the most part, we find that CIT programs have a loosely structured management in which supervision and guidance of teams is lackadaisical or poorly conceived. QC and SDWT programs fare better, but they face the problem of how to integrate engineering and maintenance functions better into the improvement programs. Details of the qualitative findings are presented here separately for each of the three types of team programs.

1) *CIT Programs:* The qualitative data gathered from the three fabs employing CIT's suggest that the low levels of training and autonomy revealed among their production workgroups are most appropriately viewed as a reflection of the low priority assigned to the team programs at those sites and of the low regard management has for the potential of operator teams to address problems of consequence. At each site, the team program was created more to please external agents, such as corporate headquarters or customers, than to take advantage of operator skills and capabilities. For instance, at one fab, the team program had been created by a shift production supervisor, not by a human resources department, a training department, or a quality department, as was the case at the other fabs. This supervisor was simply ordered by her manager to "go make teams," presumably because that is what the customers wanted; the supervisor was given no funds or assistance in doing so. Although the team program was by the time of my visit more than three years old, the teams had not progressed beyond cohesion-building projects such as coordinating fab-wide ice-cream socials. Operators complained that management took six months to approve of even the simplest of projects.

A similar situation prevailed at the second fab, where an organizational design team was considering transforming the CIT program into a more autonomous one. When pressed for their motivation in doing so, they responded, "Corporate headquarters will someday ask us to do this, so we want to get the jump on them." One of the team meetings that I observed at this fab strikingly symbolized the general disorganization surrounding the current team program. A four-person team was creating two posters for a presentation on their project, which involved changing the information system to support overrides of the Kanban scheduling policy. A solitary stencil set allowed only one operator to work at a time; thus, it was bound to take them more than three months to complete the posters. No manager was present, nor was anyone aware of how the team was spending its weekly hour-long meeting time. The team debated purchasing another stencil set, but decided against it upon realizing they might not be reimbursed for the \$4 expenditure.

The third fab employing CIT's was one of two fabs in this sample owned by the same firm; its sister fab on the same site employed SDWT's. Management at this fab was primarily concerned with creating a team program that would look as different as possible from that of the sister fab, simply because they were tired of hearing corporate headquarters tout the other team's successes. The fab assigned production supervisors, engineers, and technicians to each operator team. However, the supervisors were made team facilitators, who were to lead the teams initially and then gradually disengage, whereas the engineers were made full-scale permanent team members. Thus, engineers were placed in an inferior position in the teams relative to supervisors, who had a lower status in the overall organization. The assignment of team roles without regard to the existing status structure created a situation fraught with resentment. Like the other two CIT programs, the one at this third fab was neither run as efficiently nor designed as carefully as other programs in the study.

The disorganized management of the CIT programs makes all the more surprising the strong performance of workgroups in the fabs employing them, especially considering that the poor management did lead to frustration among the operators. For instance, at one fab, operators complained that their CIT program seemed mired in a cheerleading mode, and at another, operators were universally angry with a personally disagreeable team program director. But nowhere did operators seem to extend the target of their discontent to their regular production tasks. Regular production work was what it always was and what it was expected always to be: just work. The CIT programs, on the other hand, had been advertised as something new and special. Such promotion served to raise expectations and, judging by operators' comments, often ended in disappointment. However, given that operator participation in the programs was not universal and that the teams were not directly tied to specific workgroups, their mismanagement may have had little overall effect on the performance of production workgroups within the fabs. Rather, workgroups were able to perform their production tasks without major changes or modifications in their procedures, duties, or personnel relationships. Further, there was little confusion among employees about their roles as CIT members or the interplay of their CIT participation with their roles as workgroup members.

2) *QC Programs:* Site observations support the finding that QC programs gave higher technical autonomy to their operators than did CIT programs. I observed a particularly impressive QC discuss six months' worth of statistical process control charting in a 20-minute transparency presentation that took only one week to prepare. At the presentation's conclusion, a manager announced his intention to purchase an additional piece of equipment for the area. With barely a moment's pause, an operator in the circle swiftly and impressively explained why such an action would require certain other equipment purchases in order to balance the flow of work in the area. In addition to providing teams with opportunities to learn technical skills, the two fabs with QC's also provided them with technical support. Each operator and each QC had an electronic mail account; operators typically had access to all fab and workgroup metric performance information

via computer terminals on the shop floor. (However, several operators at one fab did complain that they had never been trained on the related software, so for them the information remained inaccessible.)

In contrast to the attention paid to technical autonomy, administrative autonomy was not emphasized at the QC fabs, nor did fab managers express any plans to increase it. They justified emphasizing technical autonomy by pointing out the predominance of females among the production operator workforce. Most of these women had only high-school degrees while working in environments where nearly all of the technicians and engineers were males with two- or four-year technical degrees. Technical skills and training were thus highly sought by the female operators, who were hoping to increase their status and to feel more confident in their exchanges with the support personnel. Administrative tasks, by contrast, were less appealing to the women; few operators wanted to evaluate their peers, many of whom were their close friends or neighbors. Also, given that no team program was accompanied by a direct increase in wages, the operators felt that by doing administrative tasks formerly performed by the supervisor, they were working harder for no extra benefit. The benefit they derived from increased technical skills and autonomy was immediate and also had the potential to affect their pay as it aided them in progressing along skill ladders.

Although by all appearances fabs with QC's provided much more structure, attention, guidance, and support to their teams than did fabs with CIT's, the design was not without its problems. Engineers and technicians served as resource people for the QC's, but because team meetings were often dominated by purely production-oriented problems between supervisors and operators, they believed their time was wasted. One engineer expressed concerns that teams at his fab were taking on projects that far exceeded their technical skills, increased though they were. It was perhaps this mismatch in project selection that hindered the quantitative performance of the workgroups associated with QC's. Alternatively, it may be that the benefits of QC programs are not appropriately captured in productivity measures; this idea is pursued further in the discussion section.

3) *SDWT Programs*: Visits to the fabs with SDWT's revealed striking differences relative to the other fabs that clearly support the ANOVA findings for the self-report measures. Here, management had given operator teams incredible administrative and technical autonomy in conjunction with increased skills stressing maintenance and teamwork. One operator felt so confident as a result of her technical training that she fixed her broken video cassette recorder at home. Another remarked, "Once I aligned an entire lot correctly except that I used the wrong mask. I didn't even know what a mask was. I would never go back [to the pre-SDWT organization]." One SDWT went through a painful grievance process to remove a poorly performing member who had been transferred from one site to another by managers unwilling to undergo the paperwork of her dismissal.

There were only a few indications at the three fabs employing SDWT's that the teams would not prove to be superior performers. At one fab, there was some problem in establishing

an information system that would provide real-time production performance data to the teams. These data were essential for team success in the opinion of operators, supervisors, and engineers, but the computer resources group had been requisitioned by the training department to complete a seemingly less urgent training database and thus could not provide the necessary team support. This situation typified the occasional misalignment of goals within the three fabs as they struggled to adapt traditional management structures to new forms of work organization. At the second fab, technicians were terrified of being replaced by technically trained operators. Most avoided speaking to the author informally; one who did ended up in tears as he contemplated his future. The technicians resented operators' gaining technical skills while they themselves were gaining no new skills from the people they considered to be their mentors: the engineers. One male technician remarked, "If I have to give up all of my knowledge [to operators, by teaching them equipment maintenance] to win back the semiconductor industry from the Japanese, then the engineers can do so too." Engineers at the fab expressed frustration at having to interact with entire teams instead of a single supervisor, a result of the shortening of the communication path that once traveled from operator to supervisor to engineer to technician and back but now typically went simply from SDWT to engineer. At the third fab, a raging debate was transpiring between operators and management over the extent of operator autonomy. For example, one team had taped paper over a window in their area so that management could not pass by and look in upon them; when confronted with the deed they retorted, "We're autonomous now, we can do what we want."

VI. DISCUSSION AND CONCLUSION

This research indicates that SDWT's did not perform as well as more traditionally organized and supervised workgroups whose members participate in QC's or CIT's. This finding belies the premise of the cognitive model of participation, which predicts that participation in decision making will better utilize worker skills and knowledge and thus improve performance. It also lies in contrast to research findings from a number of single-site studies [17], [22], [27], [28], in which workgroups with higher autonomy were found to have better performance. In fact, the finding of poorer performance among SDWT's in comparison to their peers in CIT programs proves an exception to the trend noted by Cotton *et al.* [6], in which better performance among participation schemes was found in programs that stress participation in work decisions.

A number of possible explanations emerge for the poorer performance of SDWT's. The first plausible reason is that work in semiconductor manufacturing is simply ill suited to participation, and most especially to autonomous teams. Vroom and Deci [25] have suggested that participation schemes are not appropriate among low-level workers, primarily because the problems they deal with are not of a complex enough nature. Preconditions necessary for successful autonomous teams similarly stipulate meaningful, nonrepetitive tasks; in addition, they call for a whole task for the group, interdependence among group members, and a

reward system based on group performance [21], [23]. Yet, three of these four conditions were met in nearly every fab in this study; the fourth (group rewards) was also found among those employing SDWT's. Workgroups were responsible for a functional area that performed a unique, complete step. Their work was organized so that a small group of operators jointly ran an equipment bank and in doing so coordinated their efforts. The tasks required judgment and awareness at all times, with even the automated procedures followed by visual inspections of the product. Among self-directed work teams, individual pay evaluations were based on peer review with components for group performance. The operator's job observed in these fabs mirrored that of the "systems controller" described by Kern and Schumann [13], who discovered systems controllers in automobile, machine manufacturing, electrical, and chemical industries in Germany. They described a systems controller as someone who ensures that a system functions properly in instances where the making of the product has been almost completely transferred to the technical system as the result of automation. They found that systems controllers required new skill-related knowledge in areas such as mechanics, electronics, quality control, and maintenance. Operators in the fabs in this study that employed QC's or SDWT's received training in three of these four topics (all but mechanics)—hardly the skill domain of workers in routinized, meaningless work. From all appearances, semiconductor manufacturing could thus support participation schemes, including those that incorporate an autonomous workgroup design.

A more convincing explanation for the low SDWT performance emerges from the qualitative data and lies in the long-time evolution and frequent poor design of team involvement at each site. The QC and SDWT programs that I observed were the result of years of managerial experimentation (which, coincidentally, rules out the further possibilities that the programs were short-term manifestations of participation or were still in nascent stages). Both of the fabs employing QC's first implemented CIT's, then transformed them into QC's. All three fabs with SDWT's first progressed through both CIT's and QC's. Along the path of organizational evolution, poor designs and half-hearted implementations often seemed to have eroded worker goodwill and to have reduced the chances of acceptance of new programs. In a number of cases, an information infrastructure (e.g., computer resources, data bases, tracking systems, etc.) necessary for team decision making was largely missing. In addition, the management structure above the workgroup level may not have been modified in ways that could fully support the teams. For example, ownership of the program may not have been made specific; thus, support personnel and resources may not have been provided to the degree needed by the teams.

While the evolving team programs that led up to SDWT's gave rise to disillusionment among some operators, they often proved even more frustrating to the engineers. Failure to involve engineers properly in improvement programs led to the failure of engineering personnel to support, understand, and commit themselves to the team program in a number of the fabs. Where engineers were instructed to attend team meetings

and to serve as resources or experts, they complained that no guidelines were developed or clear expectations described to aid them in understanding their role and the level of involvement they were to achieve. Some engineers did not know if they personally were being held responsible for the team's performance; fearing that they might be, they tended to perform most of the tasks associated with the team's projects to ensure that they were properly carried out. This often led to resentment among the operators, dissension within the team, and exhaustion and frustration among the engineers. In fact, at every fab in the study, far more attention was paid to production supervisors and their changing role than was paid to the engineers. In the semiconductor industry, engineers far outnumber supervisors and far exceed them in terms of the technical knowledge critical to the proper processing of wafers, suggesting that much more attention should be paid to the role of engineers in the team program. Without the engineers' support and involvement, it is quite conceivable that team progress, and ultimately group performance, would be impaired.

Another reasonable explanation for the poor SDWT performance is the choice of the outcome metric of productivity as a measure of effectiveness. This measure was chosen because of its importance in the industry, its traditional use in the literature, and its availability in terms of data. However, the argument that quality measures are far more significant than productivity measures in this capital-intensive industry with high product value is a strong one. The quality metric of scrap percentage showed no significant difference by type of team program. It is highly conceivable that other measures, such as the time to resolve production problems or the rate of reoccurrence of previously solved problems, might prove better measures of teams dedicated to improvements in manufacturing performance. One could argue that time spent by SDWT's and QC's on resolving quality problems would necessarily reduce productivity as measured here by the number of wafers produced, but that overall production of good chips would improve by increasing the percentage of good chips per wafer. This latter metric is referred to as die yield; unfortunately, the complexity of the production process precludes the tracking of die yield problems to individual functions, let alone workgroups, so that it could not be measured in this study.

Last, we must acknowledge the limitations of this study as we seek to interpret its results. Although this study focused on three very important aspects of the team programs—training, autonomy, and task—the programs also varied on other features, such as voluntary versus mandatory participation and temporary versus permanent team duration. Because our sample did not include teams with high autonomy but voluntary participation, for example, we cannot determine if the nature of membership is driving the results more than autonomy, training, and task variables.

One important distinction between this study and most others that have examined the effectiveness of SDWT's is that it was conducted in a high-technology industry. It may be that technology level can explain the results found here. This idea raises the question of the generalizability of the

study's findings. Eight sites within the semiconductor industry were included in the sample, in part to ensure generalizability beyond a single firm. The question remains if the findings can be generalized to other high-technology industries. It seems clear that they are not generalizable to industries with lower levels of production technology, given the trend of past findings indicating positive performance results for SDWT's in such environments.

Future research might look to improve upon the performance analysis conducted in this study by including a greater range of comparative metrics. The performance results presented here rest primarily upon a single measure, labor productivity, with the quality-based metric of percentage scrap analyzed at the functional level. A longitudinal research design would further aid in our understanding of manufacturing workgroups and improvement teams by assessing relative gains achieved under each type of program.

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