

Manufacturing Improvement Team Programs in the Semiconductor Industry

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Abstract—Increasing numbers of semiconductor manufacturers are implementing improvement programs at their manufacturing sites (fabs). Yet despite their rising popularity, little attention has focused on the impact of a program's design on its overall effectiveness. This research examines the improvement programs established at ten fabs. A categorization scheme classifies programs according to their use of one of three types of teams: continuous improvement teams (CIT's), quality circles (QC's), and self-directed work teams (SDWT's). Results from 188 operator surveys and over 150 interviews with fab employees (including managers, engineers, technicians, supervisors, operators, and representatives from human resources and quality departments) indicate that a number of programs suffer from weak implementation and disorganized management. The failure to carefully design and implement a program is reflected in employee perceptions of the program's effectiveness. Perceptions of CIT programs are found to be significantly lower than those of QC or SDWT programs, both of which feature higher degrees of autonomy and training. Results also highlight a nearly universal failure to integrate production team programs with engineering and maintenance functions. To help improve future programs, design implications and aspects of effective team programs are noted. Special attention is paid to program selection, goal design, organizational support, engineering integration, information systems, and empowerment semantics.

Index Terms—Improvement teams, manufacturing, semiconductor, team design, work groups.

I. INTRODUCTION

IN THE MID-1980's, 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. While much of the interest was placed on manufacturing processes and equipment maintenance, organizational issues also became of interest. A number of United States firms began to adopt Japanese-style organizational innovations, such as the use of employee teams, in the hopes of gaining competitive advantage. In recent years, the use of improvement teams has rapidly expanded not only in the semiconductor industry but in many other organizations in both service and manufacturing industries. Osterman [11] estimates that nearly half of all corporations in the U.S. have implemented some form of team-based work system.

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In this paper, we explore how the various types of teams within the semiconductor industry are integrated into a fab's overall organization of work. We wish to unveil fundamental differences in team design and to assess team program effectiveness, both in the eyes of the employees who populate them and the managers who supervise them. The answers to these questions will yield insights into how an improvement program might best be designed in the semiconductor industry.

A. Teams in Semiconductor Firms

Table I lists a sample of team programs undertaken at semiconductor firms in recent years. The programs at each of these firms claim tremendous cost benefits as a result of great improvements in key manufacturing metrics, yet the program designs vary significantly. Differences in team autonomy exist, as do variations in the focus of team projects, level of training provided to operators, and integration with engineers and technicians. Thus, knowing that a fab "has teams" tells one very little specifically about the nature of the team program or its anticipated benefits.

B. On-Line Versus Off-Line Teams

Despite the study of industrial work groups since the early 1900's and the rising popularity of teams in recent years, we have surprisingly few schemes for categorizing teams. Cutcher-Gershenfeld *et al.* [5] offer a recent scheme tailored to manufacturing shop-floor team systems. They describe on-line and off-line teams, with the former having two categories: Japanese-style lean production teams and Scandinavian-style socio-technical systems teams.

On-line teams are transformations of traditional work groups in which team members gain decision-making power over production decisions due to increased skills and training. They are termed "on-line" teams because their members work side-by-side on the production floor. On-line teams of the lean production variety are frequently described in the automobile industry (e.g., [1], [14]). They differ from their socio-technical systems counterparts primarily in terms of their goals: lean production teams are concerned with continuous improvements in quality and productivity, while socio-technical systems on-line teams seek increased worker commitment and improved quality and safety. Off-line teams perform ad hoc reactive problem-solving separate from daily operations.

While the Cutcher-Gershenfeld *et al.* scheme helps clarify our thinking about manufacturing teams, its conceptualization

TABLE I
TEAM PROGRAMS IN SEMICONDUCTOR FIRMS

Company	Program Description	Results and Comments
Zilog [8]	autonomous work groups made decisions in areas of production scheduling, group membership, budget, and salaries	turnover < 6% (compared to Silicon Valley average of 55-60% at the time), product yields 25% higher than comparable fabs; plant was a greenfield site
IBM [7]	operators increased technical skills to gain ownership of mature processes and products	process uniformity improved by 50-80%, wafer yields at all-time highs, but gains were in part due to other work organization changes simultaneously enacted
Hewlett-Packard subsidiary [4]	photomask program included just-in-time concepts and total quality management	cycle time reduced 60%, WIP reduced 92%, yields up 15%; however, gains due to operator SPC skills could not be separated from effects of kanbans
Xerox [10]	employee involvement in process control coupled with new control methods and new functional project teams	probe yield up by as much as 74%, customer returns reduced by 7X, shipments up 114%, workforce down 24%, manufacturing costs down 25%; however, results reflect 5-yr program and are not controlled for improvements in technology
Harris Semiconductor [3]	self-directed teams of operators and technicians given training in technical and administrative skills then given responsibility for decisions in scheduling and other areas	cycle time reduced 70%, die yield up 30%, throughput yield up 10%; gains due to teams could not be separated from gain-sharing and other reward programs
Motorola [6]	employee teams address a wide range of quality issues, then compete in annual contest judged by corporate executives	estimated savings of \$2.2 billion annually through inventory reduction, increased productivity, streamlining processes, etc.; no indication of how savings are calculated

of team *programs* as composed solely of either off-line teams or on-line teams fails to capture the complexity of work organization. On-line teams have clear quantifiable manufacturing metrics (e.g., the number of wafers produced). In contrast, an off-line team typically has as its "product" an idea or a problem solution. Its members participate on a part-time basis, with their primary involvement remaining with their work group. We call fab off-line teams improvement teams; their goals typically are to improve fab performance by reducing costs, scrapped products, and cycle times. Due to the differences in product (goods versus ideas) and membership involvement (primary versus secondary), one cannot fairly compare the performance of on-line and off-line teams. Nor can one compare their design characteristics. For example, the consequences of granting decision-making power to an on-line team may be much more severe in the case of an operator error than to do so with an off-line team. What is needed is a scheme that can recognize the interdependence of work groups and teams within a manufacturing environment.

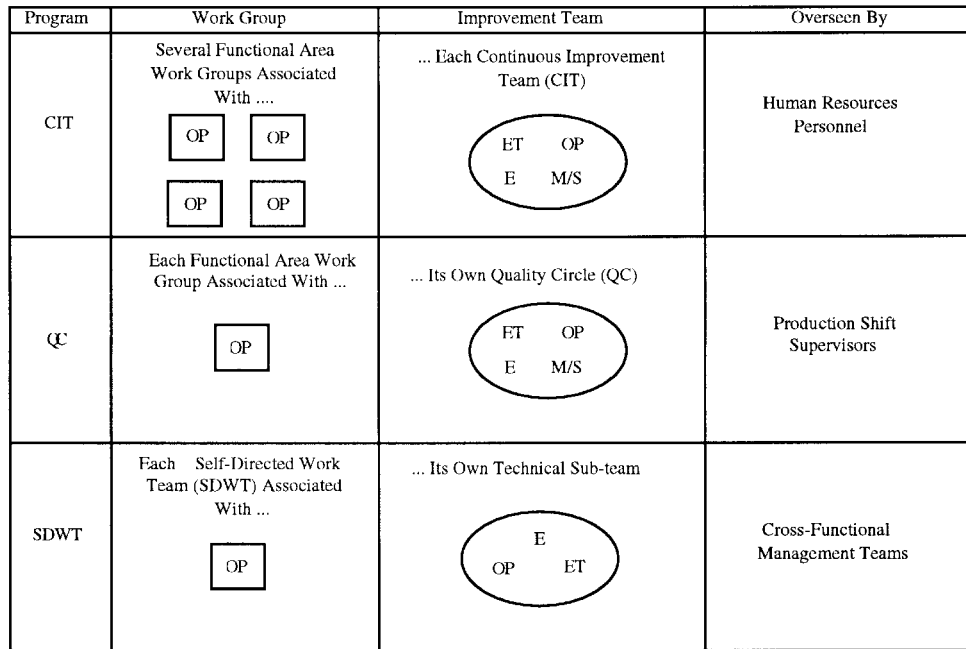
C. Types of Semiconductor Team Programs

A scheme for categorizing types of team programs in the semiconductor industry was developed in [2]. Each row in Fig. 1 depicts the components of a team program. The columns refer to organizational units within the program: work groups, improvement teams, and organizational support structures. Team characteristics are summarized in Table II; obviously,

some team programs will not match precisely the description of one of the three types of programs.

1) *Continuous Improvement Team (CIT) Programs*: CIT programs are characterized by functional area shift-based work groups composed of production operators, such as the etch operators on the "A" shift. Production operators in these on-line work groups have the opportunity of joining off-line continuous improvement teams (CIT's). They take on a project suggested by management or determined by the team, research it, analyze data, and develop a feasible solution to be presented for management approval. If approval is granted, the team or a third party implements the solution. At this point, the team disbands, having achieved its stated objective.

CIT programs are typical of American models of employee participation: they feature voluntary participation with no modification of job titles or reporting relationships. CIT programs exist in parallel with traditional hierarchies, as shown in Fig. 2. They require no universal training in problem-solving (e.g., Pareto charts, fishbone diagrams), as many teams will not work on technical problems. They require no training in group dynamics (e.g., conflict resolution), as teams that fail to work well together in short projects need never meet again. With training needs low, CIT programs can be relatively inexpensive and easy to implement. Their cross-functional design may serve to enhance overall cooperation. One hazard lies in the supervision of teams by human resources personnel with little authority over resources such as time or money. Support



OP operators ET equipment technicians E engineers M/S management/supervision

Fig. 1. Three major types of team programs in the semiconductor industry.

TABLE II
TEAM PROGRAM CHARACTERISTICS

Characteristic	CIT	QC	SDWT
type	off-line	off-line	on-line
lifespan	short-term	infinite	infinite
participation	voluntary	voluntary	mandatory
training	little needed	problem-solving, preventive maintenance, some group dynamics	problem-solving, preventive maintenance, group dynamics, administrative
evaluation of member performance	none	through subjective terms such as "teamwork" and "helpfulness" as determined by the supervisor	peer review, included in determination of pay and bonuses
membership	cross-functional	by functional area	by shift and functional area
job titles	mostly operators, but engineers, technicians, service personnel (e.g., payroll), etc. may also participate	operators	operators, sometimes merged with technicians
focus	fab-wide problem	functional area problem	functional area or area/shift problem
coordination/supervision	human resources representative	production supervisor	production supervisor or management team

from engineering and production staff also may be difficult to ensure, as they have no clear roles in the program.

2) *Quality Circle (QC) Programs:* Like CIT programs, a quality circle (QC) program has work groups primarily com-

posed of operators. Each work group or collection thereof (e.g., all etch work groups across all shifts) sponsors an off-line improvement team. While the term "quality circle" is not common among fabs, it is an appropriate label for

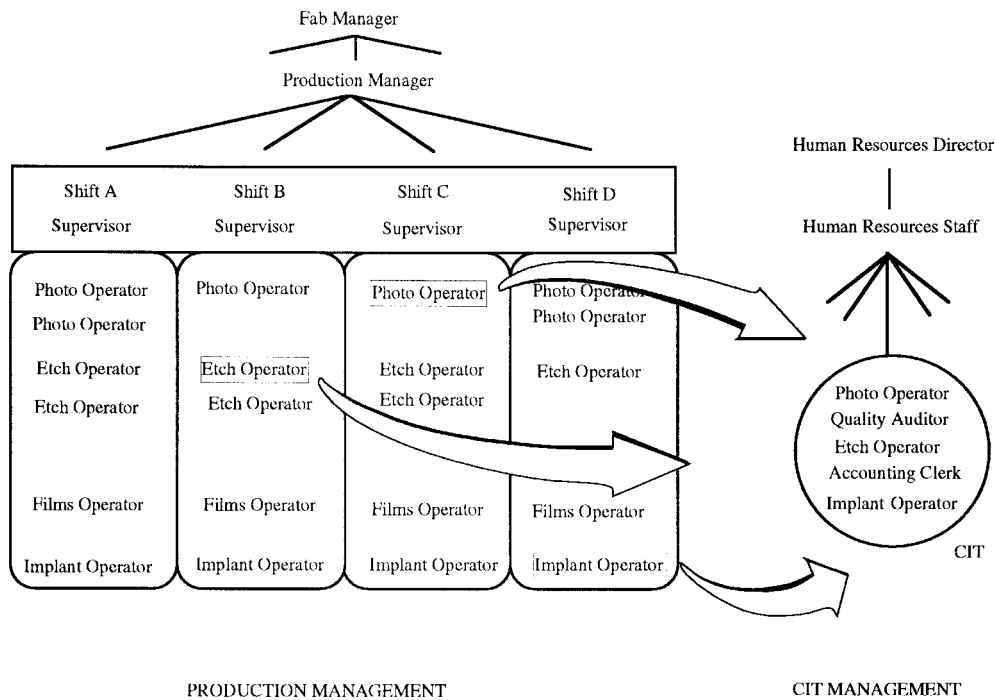


Fig. 2. Reporting hierarchy in a fab with a CIT program. Indicated operators participate with other fab employees on one of the CIT's.

these teams. Production supervisors serve as facilitators of the QC's (see Fig. 3), thereby initiating the transformation of the traditional hierarchy. Implementation of a QC program requires more training in technical problem-solving and team dynamics than does that of a CIT program. Thus, we expect its costs to be higher. If QC's are organized along work group lines, competition may arise among teams on different shifts, possibly leading to incentive conflicts. Further difficulties may arise as supervisors adjust to their new roles, in which they retain their shift leadership but must learn to guide rather than instruct QC's. The perceived benefit of a QC program over a CIT one lies in the direct and continual tackling of production problems by the operators closest to them, with help from their immediate supervisors.

3) *Self-Directed Work Team (SDWT) Programs*: The traditional hierarchy is transformed in significant ways under the third team program. Here, the work groups are organized as self-directed work teams (SDWT's). Thus, to be an etch operator on the "A" shift in a SDWT fab is by default to be a member of the "A"-shift etch SDWT. SDWT's are held directly responsible for improving their own performance, but often face problems that exceed their technical expertise. At such times, the teams may form technical sub-teams comprised mostly of engineers and technicians. Supporting the technical sub-teams and the SDWT's may be shift supervisors or management teams. The latter represent a further transformation, as boundaries between the engineering, production, and maintenance departments become blurred under the management teams (see Fig. 4).

Because SDWT members are held jointly responsible for their performance, they require mechanisms for regulating members. Thus, SDWT's might help select new members, initiate disciplinary actions, write peer evaluations, and ar-

TABLE III
CHARACTERISTICS OF FABS IN THE SAMPLE

Characteristic	Fab Breakdown	
Type	merchant	6 fabs
	captive	4 fabs
Process Technology	CMOS	9 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	6 fabs
	3 shifts	2 fabs
	5 or more shifts	2 fabs
Age	~ 1 yr	2 fabs
	8-10 yrs	4 fabs
	14-16 yrs	3 fabs
	25 yrs +	1 fab
Cleanroom Levels	Class 1	2 fabs
	10	4 fabs
	100	3 fabs
	1000	1 fab

range training. In short, SDWT's usurp duties performed by supervisors. While technical decision-making power leads to job enlargement (e.g., the spreading of operator duties into engineering and maintenance) in QC programs, SDWT programs add job enrichment (e.g., the spreading of job duties up the production hierarchy) via the dimension of administrative

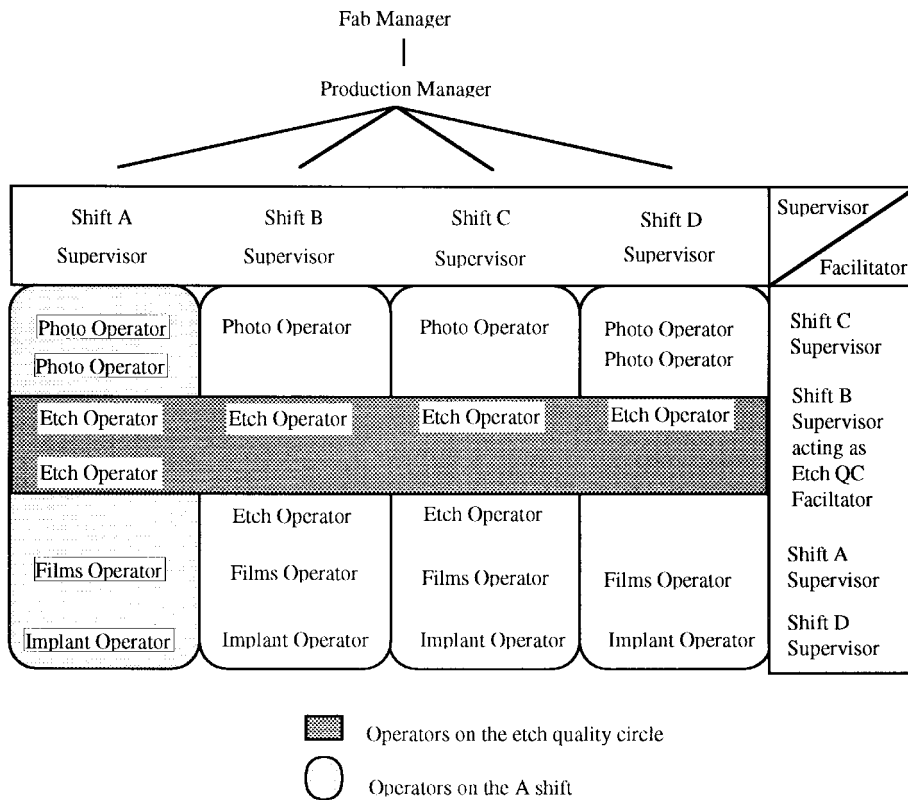


Fig. 3. Reporting structure in a fab with a QC program. Not every etch operator will participate on the etch QC.

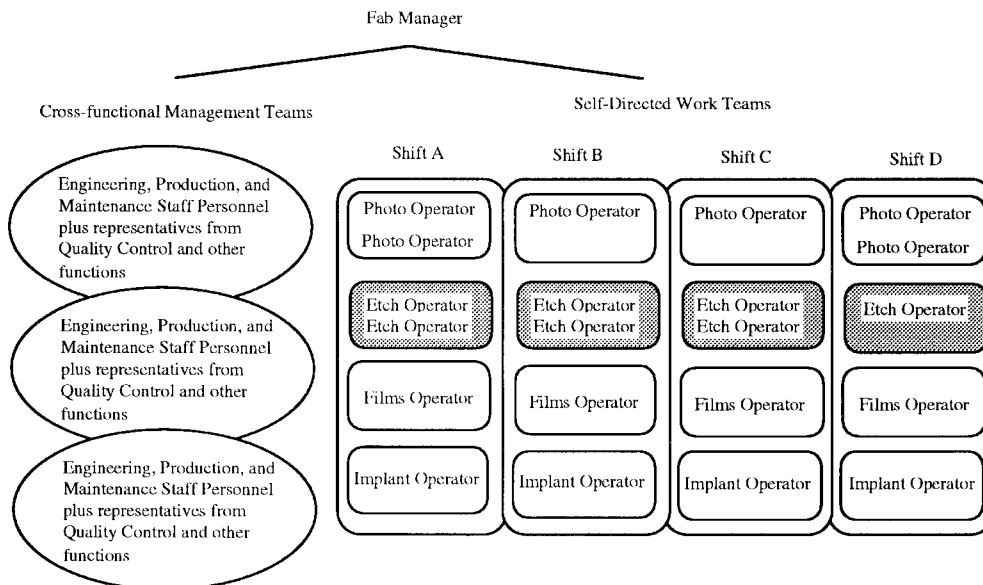


Fig. 4. Reporting hierarchy in a fab with an SDWT program. The traditional hierarchy has been replaced with a team structure. The four shift-based SDWT's are highlighted; each includes all etch operators on its shift.

decision-making. Team dynamics training requirements are therefore higher. As a result, we expect program implementation costs to increase. On the plus side, the enhanced flexibility of the design should facilitate employee learning. Like the QC programs, the SDWT programs should also benefit from the direct addressing of production problems by clean-room operators.

II. METHODS

A. Sample

This study was conducted as a focus study within a large-scale benchmarking study [9]. The sample consisted of ten fabs representing seven firms: AMD, Harris Semiconductor,

TABLE IV
SAMPLE QUESTIONS FROM THE WRITTEN OPERATOR SURVEY

1. <i>How supportive</i> have the following people been of team activities involving operators in your fab?					
	NOT AT ALL SUPPORTIVE	A LITTLE SUPPORTIVE	SOMEWHAT SUPPORTIVE	QUITE SUPPORTIVE	VERY SUPPORTIVE
a. Supervisors	1	2	3	4	5
b. Technicians	1	2	3	4	5
c. Engineers	1	2	3	4	5
d. Your fellow operators	1	2	3	4	5
2. How much does the <i>management</i> at your fab support teams in the following ways:					
	NOT AT ALL	A LITTLE	SOME	QUITE A BIT	VERY MUCH
a. Posting team news on bulletin boards, e-mail accounts, etc.	1	2	3	4	5
b. Supplying outside resources, training, and people as needed	1	2	3	4	5
c. Approving funds for implementation of team ideas	1	2	3	4	5
d. Rewarding teams for their achievements	1	2	3	4	5
e. Helping teams to formulate goals	1	2	3	4	5
3. <i>How much</i> do members of your work group try to get ahead at the expense of the next shift's work group?					
	NOT AT ALL	A LITTLE	SOMEWHAT	QUITE A BIT	VERY MUCH
	1	2	3	4	5
4. Overall, <i>how much</i> of an effect do you believe team activities in your fab have had in terms of <i>quality, efficiency, and other manufacturing performance goals</i> ?					
TEAMS HAVE HAD A NEGATIVE EFFECT ON THE FAB'S PERFORMANCE	TEAMS HAVE HAD NO EFFECT OR ONE WAY OR ANOTHER ON THE FAB'S PERFORMANCE	TEAMS HAVE HAD A SMALL POSITIVE EFFECT ON THE FAB'S PERFORMANCE	TEAMS HAVE HAD A SUBSTANTIAL POSITIVE EFFECT ON THE FAB'S PERFORMANCE	TEAMS ARE PRIMARILY RESPONSIBLE FOR CURRENT FAB PERFORMANCE	
1	2	3	4	5	

Hewlett-Packard, NCR, National Semiconductor, Silicon Systems, and Texas Instruments. Fabs were selected based on their implementation of a CIT (three fabs), QC (four fabs), or SDWT (three fabs) program. Half of the fabs participated in the larger benchmarking study; the other half were selected through phone interviews. Characteristics of the fabs are given in Table III. No fab had more than one type of team, but one firm with two fabs on one site had CIT's in one and SDWT's in the other.

B. Data Sources and Collection

This study made use of a broad range of data collection techniques to ensure a thoroughly representative evaluation of the team program at each fab. The data collection process began with a one-hour phone interview, usually with a fab or production manager. Following the interview, a site visit, typically four to five days in length, was conducted. Visits to the

ten fabs in the study were made during 1992–1993. During the site visit, interviews were held with operators, technicians, line supervisors, shift supervisors, engineers, department managers, and fab managers. Over 150 such interviews were held in total. Additional on-site interviews were held in training, personnel, and quality departments. At least three clean-room operator team meetings were attended. In addition, management “focus” meetings and shift passdown meetings were also attended. Unguided tours of the clean-room were taken to facilitate discussions with operators. Written surveys were successfully completed on company time by 188 operators (60.8% of those sampled), who returned them in pre-addressed envelopes.

C. Variables

The surveys contained items measuring perceptions of various aspects of team program effectiveness. Three variables were used to measure organizational support according to

TABLE V
CORRELATIONS

Variable	1	2	3	4	5	6	7	8
1 Management Support	--							
2 Technical & Supervisory Support	0.65	--						
3 Work Group Support	0.36	0.58	--					
4 Shift Competition	-0.04	-0.17	-0.34	--				
5 Extrinsic Job Satisfaction	0.22	0.25	0.12	-0.03	--			
6 Intrinsic Job Satisfaction	0.46	0.50	0.35	-0.12	0.47	--		
7 Knowledge and Skills	0.40	0.37	0.20	0.02	0.19	0.29	--	
8 Organizational Performance	0.35	0.45	0.37	-0.19	0.18	0.34	0.54	--

TABLE VI
STATISTICAL RESULTS

Variable	Means			ANOVA		Tukey-HSD Test
	CITs	QCs	SDWTs	F statistic	df	
Management Support	2.45	2.95	2.55	5.28**	182	QCs > SDWTs, CITs
Technical & Super. Support	2.91	3.62	3.39	11.28***	186	QCs, SDWTs > CITs
Work Group Support	3.35	3.45	4.00	7.50***	179	SDWTs > QCs, CITs
Shift Competition	1.94	1.77	1.69	0.91	185	--
Extrinsic Job Satisfaction	2.54	3.02	2.90	3.9704*	187	QCs > CITs
Intrinsic Job Satisfaction	3.47	3.65	3.61	1.39	187	--
Knowledge and Skills	2.22	3.07	3.43	18.12***	182	SDWTs, QCs > CITs
Organizational Performance	2.92	3.80	3.90	29.03***	182	SDWTs, QCs > CITs

df degrees of freedom

* p < 0.05

p probability that responses from the three programs
come from the same distribution

** p < 0.01

*** p < 0.001

job title: the first captured support from upper management (“management support”), the second from immediate technical and supervisory personnel (“technical support”), and the third from production work groups (“work group support”). Another variable examined the degree of competition among teams on opposing shifts. Both extrinsic job satisfaction (i.e., pay-related) and intrinsic satisfaction (i.e., nonmonetary aspects, such as relationships with supervisors) were also measured. Finally, operators were asked to assess the effect of the team program on their knowledge, skills, and overall fab performance. Items (based largely on [13]) were measured on 5-point scales. A subset of the survey instrument is presented in Table IV, with correlations given in Table V. The low correlations among the variables indicate that each variable represents a domain not captured by the others.

III. STUDY RESULTS

A. Statistical Results

Of the 188 survey responses, 68 came from CIT’s, 61 from QC’s, and 59 from SDWT’s. Results from a statistical analysis of the responses are summarized in Table VI. Two tests were performed: analysis of variance (ANOVA, see [12, p. 504]) and Tukey-HSD contrast test. While the ANOVA tests determine the existence of statistical differences in the

responses based on the type of program, the Tukey contrast tests indicate exactly where these differences can be found. For example, the ANOVA result indicates a significant difference in management support based on type of team, with the Tukey test revealing that the difference separates QC’s from SDWT’s and CIT’s (i.e., no difference can be established between SDWT’s and CIT’s for this variable). The values of the means reflect that the difference places QC fabs with the highest management support.

Perhaps the most striking finding in the ANOVA results is the poor overall rating of CIT programs. In each of the eight variables measuring program effectiveness, operators in fabs with CIT programs gave the worst ratings. Statistical significance (four times at the 0.001 level or below) was shown six times out of eight, with the responses of operators in CIT programs lower than those of their peers in at least one of the other two team programs. Operators in CIT fabs reported that their team programs enjoyed lower support than did operators in QC and SDWT programs at all levels of the organization: from upper management, engineers, equipment technicians, production supervisors, and work group members. CIT operators reported the greatest amount of competition between work groups on different shifts, although we note that the difference was not statistically significant. (Note that for shift competition a low score is deemed better than a high one if we believe competition across shifts to be unhealthy,

as the fabs in this study did. Thus, the high score by the CIT's is actually a worse rating than that of the others.) Their job satisfaction was also the lowest (significant for extrinsic job satisfaction). Finally, they were the least likely to believe that their personal knowledge and skills had increased or that their organization's performance had increased as a result of their team program (both results significant). All in all, their responses clearly separate them from operators in fabs employing QC or SDWT programs.

SDWT and QC programs appear evenly matched in terms of operator perceptions of effectiveness, with responses nearly evenly split among the eight variables. QC's rated highest in upper management support, technical and supervisory support, and job satisfaction (both extrinsic and intrinsic), while SDWT's did so in the areas of work group support, shift competition, knowledge and skills, and organizational performance. The differences between these two programs were statistically significant only twice, with QC programs showing greater upper management support while SDWT ones displayed greater work group support. This result may reflect the difference in program design: SDWT's are designed to be more self-reliant (i.e., less supervision by management), while QC's do not develop their internal structure as greatly as do SDWT's (e.g., no peer review, no group autonomy over decisions affecting members, such as training, discipline, etc.).

The responses of the operators largely serve to confirm the design implications highlighted by the team categories. Because CIT teams are not directly associated with a work group(s) and often are supervised by a human resources member who is distant from the clean-room floor, it is not surprising that operators perceive management support as being low. Support from technical and supervisory staff is also reported higher among QC and SDWT programs, a natural result of anchoring program management in production departments. Operator knowledge and skills are viewed as most improved by the team programs in the QC and SDWT fabs, as expected due to their training requirements. Thus, overall, the operators' perceptions of program effectiveness is in line with our expectations as generated by the team categorization scheme.

We note that the ANOVA tests only detect differences among samples; they do not confirm or refute causation. Thus, we cannot conclude, for example, that CIT's result in lower job satisfaction or that SDWT's and QC's result in higher job satisfaction. We can only say that, as a group, fabs with CIT's in this sample reflect lower job satisfaction than do fabs with QC's and SDWT's. The qualitative interview data in the next section are explored to add some depth to our understanding of causation.

B. Qualitative Results

1) *CIT Fabs*: Overall, management support of the team programs in CIT fabs appeared disorganized at best, in keeping with the operators' evaluation. At one fab, teams were created as a production supervisor's assigned project. The supervisor was not given funds for training or benchmarking visits, nor was she told the goals of the program. Another CIT fab tried

to support its teams by assigning supervisors, engineers, and technicians to each operator team. However, the supervisors were made facilitators who were to lead the teams initially then gradually disengage, whereas the engineers were made permanent full-scale members. Thus, engineers were placed in an inferior position relative to the supervisors, creating a situation fraught with resentment.

Integration of the improvement programs with the engineering departments was in fact a task seldom done at any of the CIT fabs. At one fab, no formal presentation was ever made to engineers regarding the teams and their purpose. It appeared that each fab had also failed in the very first step of integrating an improvement program into an existing work organization framework, in that it had not managed to coordinate program control between human resources and production personnel. The design problem made clear by the team categorization scheme—that of directing a program away from the clean-room floor—proved a major stumbling block for these fabs.

Although operator frustration was quite evident at the CIT fabs, there were participants who were pleased with the programs. These operators tended to be outspoken and active CIT leaders who were individually motivated to become involved in fab issues. Equally happy were operators who did not share such interests, in that they were not forced to participate. Frustrated operators tended to be those who participated on the teams as members but not leaders, whose expectations were not being met, and who increasingly came to view the programs as a management fad. Their experience points out another problem faced in CIT fabs: because costs are low and training needs small, a CIT program can be quickly implemented. Many design issues may be overlooked in a speedy implementation, causing problems that eventually lead to operator resentment. That CIT's in this sample are associated with lower job satisfaction didn't seem to be so much due to their inherent design as to their all too rapid implementation and the lack of supervision and direction thereafter.

2) *QC Fabs*: The QC fabs were observed to provide their operators with substantial technical support. Each operator and each QC had an electronic mail account; at three of the four fabs, operators had access to all fab and work group metric performance information via computer terminals in the clean-room. One QC fab was the most advanced fab in the study in terms of manufacturing improvement innovations; for example, each stepper computer screen was modified to display in real-time the machine's utilization rate, which the QC tracked over time.

Overall, the QC fabs provided much more guidance to their teams than did the CIT fabs, but the design was not without its problems. Engineers and technicians served as resource people for the teams, but believed their time was frequently wasted at meetings. One engineer expressed concerns that teams were taking on projects far exceeding their technical skills. Frustration was also high among maintenance technicians, who viewed the programs as vehicles for improving operator skills at their expense. However, when operators took over lower-level maintenance tasks, the technicians became free to tackle more complex and interesting projects. Nonetheless,

their initial fears seemed to be ill-addressed in most QC programs (as well as in SDWT ones).

3) *SDWT Fabs*: Visits to the SDWT fabs revealed striking differences in comparison to CIT and QC fabs that were not as noticeable in the ANOVA results. Here, management had given operator teams remarkable administrative and technical autonomy. Technical skills were so high at one fab that one work group had not seen its maintenance technician in two months and saw its supervisor only once per week. In interviews, operators expressed tremendous support of the programs, commenting that now they felt much more knowledgeable about their work.

The transfer of knowledge, skills, and power to operators was not without its problems. For example, a team at one fab blocked a clean-room window with paper to prevent passing management from peering in. When confronted with their deed, they retorted, "We're empowered now. We can do what we want." A few operators expressed reservations in evaluating their peers, many of whom were their friends and neighbors. Most operators resented the addition of tasks that added stress to their jobs without any increase in pay, but overall they preferred not to return to a supervisor-run system.

The SDWT fabs were striving to remove the traditional boundaries among engineering, production, and maintenance departments, but their efforts often faced resistance. Some engineers expressed frustration at having to interact with entire teams. Before, problems traveled from operator to supervisor to engineer to technician and back, so that the engineer often dealt only with a single individual (the technician). Nonetheless, the overall integration effort seems to have met with some success at each of the SDWT fabs.

IV. DESIGN IMPLICATIONS

The results indicate that of the three types of team programs, CIT programs suffer from the most problems in management and yield the lowest perceptions of effectiveness among operators. QC and SDWT programs fare much better in functioning and performance outcomes; little difference in the effectiveness of the two programs can be discerned. The results of this study may reflect confounding effects of fab, as no fab in the sample displayed more than one type of team. Thus, operators' perceptions may be a factor of some other aspect of work beyond the team program. However, the conclusions drawn here do hold true for the one firm with two types of teams at two fabs on the same site (one CIT, the other SDWT). Overall, the study results give rise to a number of implications for program design, implementation, and management.

A. Program Selection

The claim that SDWT or QC programs will not work in the semiconductor industry due to the complex nature of production, the high product value, and the limited education of operators does not seem to be true; opportunities exist for all three types of team programs. CIT programs might work best in plants with stable, mature processes and products where operator teams might tackle problems that arise in scheduling to meet volume demands. QC and SDWT programs may be

more suited to fabs with many new products and processes. Here, technical problems will abound; area-specific clean-room focus on them should prove very beneficial. SDWT programs feature greater operator autonomy, which comes at the price of increased training. These programs should only be attempted in fabs where management is ready to commit to training and guidance of teams over a period of many years.

B. Integration with Engineering

Failure to properly inform engineers about production department-sponsored improvement programs led to a lack of engineering support. Where engineers were instructed to attend team meetings and serve as a team resource, they complained that no guidelines were developed to aid them in understanding their role. 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 team's project tasks 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. It is not clear that an engineering presence is even required at most team meetings; successfully run programs were observed where engineers were contacted only as needed and updated through electronically sent team meeting minutes.

C. Goal Design

The difference between on-line and off-line teams should be kept in mind when determining team goals. On-line teams have clear quantitative performance metrics for which they can be held responsible. An off-line team should not be held responsible for improving the performance of a work group unless all members of the latter serve on the former. Otherwise, alternate incentives for the on-line team or its resentment of perceived outside interference may prevent the off-line team from achieving its goal. The easiest groups for which to set goals are SDWT's due to the direct embodiment of the improvement team in the work group.

D. Organizational Support

There is seemingly very little to be gained by creating and publicizing an improvement program without proper motivation for its existence clearly understood and conveyed by all levels of management. Lack of structure, lack of goals or the setting of inappropriate ones, and lack of supervision of group projects all were seen in this study to lend themselves to chaotic and disruptive situations that eventually led to frustration among operators and management alike. Poor designs and half-hearted implementations seemed to erode worker goodwill and to reduce the chances of acceptance of future programs.

E. Information Systems

Information systems that allow operators to learn of their performance as a work group should be installed and maintained. Such systems are critical in SDWT fabs, as work groups should be allowed continuous monitoring of their

performance if individual employee pay is to be based upon it. The most important information is that pertaining to the goals established for the groups, but other information, including fab-wide figures, is often found interesting by operators and adds to their understanding of overall fab performance. However, many managers balk at revealing measures of group performance for fear of sparking competition across shifts that may have detrimental effects overall. Thus, the information system should be designed with incentives for performance at the individual and work group levels.

F. Empowerment Semantics

Many of the fabs found themselves mired in semantic controversies concerning the difference between "empowerment" and "entitlement," with managers claiming the former and operators insisting on the latter. That such debates arose was largely the fault of management, who tended to introduce their programs as instruments that would "empower" workers. The term "empowerment" is easily interpreted as faddish; its use may undermine the seriousness of the program and set up an entire host of incorrect expectations. Management would be well-advised to take extreme care in choosing the terms by which to describe, define, and promote their programs in order to avoid common misconceptions. In doing so, they can make clear the boundaries of team authority and the limits to operator responsibilities at the program's very inception.

V. CONCLUSIONS

This research has pointed out a number of difficulties involved in designing, implementing, and managing a successful manufacturing improvement team program. The clearest findings came in relation to CIT programs, whose operators reported low program support and effectiveness in comparison to QC and SDWT operators. All three types of programs have potential for success in this industry, but it is clear that CIT programs face substantial design and implementation obstacles.

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REFERENCES

- [1] P. S. Adler, "Time and motion regained," *Harvard Bus. Rev.*, vol. 71, pp. 97–108, Jan. 1993.
- [2] D. Bailey, "Work groups and teams in semiconductor manufacturing: Structures, practices, and performance," in *The Competitive Semiconductor Manufacturing Human Resources Project: First Interim Report*, C. Brown, Ed. Berkeley, CA: Univ. California-Berkeley Engineering Systems Research Center, 1994, pp. 91–111.
- [3] L. S. Behnke, R. M. Hamlin, and B. C. Smoak, "The evolution of employee empowerment," *IEEE Trans. Semicond. Manufact.*, vol. 6, pp. 143–155, May 1993.
- [4] R. Berg and D. Smith, "The formula: World class manufacturing for hybrid thin-film component production," *IEEE/SEMI Int. Semiconductor Manufacturing Science Symp.*, May 1992, pp. 53–60.
- [5] J. Cutcher-Gershenfeld, M. Nitta, B. Barrett, N. Belhedi, J. Bullard, C. Coutchie, T. Inaba, I. Ishino, S. Lee, W. Lin, W. Mothersell, S. Rabine, S. Ramanand, M. Strolle, and A. Wheaton, "Japanese team-based work systems in North America: Explaining the diversity," *Calif. Manage. Rev.*, vol. 37, pp. 42–64, 1994.
- [6] B. J. Feder, "At Motorola, quality is a team sport," *New York Times*, Jan. 1, 1993, p. C1.
- [7] S. B. Fullerton and D. J. Pavlik, "Manufacturing integration through EBI," in *IEEE/SEMI Int. Semiconductor Manufacturing Science Symp.*, May 1992, pp. 48–52.
- [8] P. Gustavson and J. C. Taylor, "Case study—Socio-technical design and new forms of work organization: Integrated circuit fabrication," in *Automation and Work Design*, F. Butera and J. E. Thurman, Eds. Amsterdam, The Netherlands: Elsevier, 1984.
- [9] R. C. Leachman, D. A. Hodges, and V. Sohoni, Eds., *The Competitive Semiconductor Manufacturing Survey: First Report On Results Of The Main Phase*. Berkeley, CA: Univ. California-Berkeley Engineering Systems Research Center, 1993.
- [10] H. Naguib, "The implementation of total quality management in a semiconductor manufacturing operation," in *IEEE/SEMI Int. Semiconductor Manufacturing Science Symp.*, May 1992, pp. 63–67.
- [11] P. Osterman, "How common is workplace transformation and who adopts it?" *Ind. Labor Rel. Rev.*, vol. 47, pp. 173–188, 1994.
- [12] E. J. Pedhazur and L. P. Schmelkin, *Measurement, design, and analysis: An integrated approach*. Hillsdale, NJ: Lawrence Erlbaum, 1991.
- [13] A. H. Van de Ven and D. L. Ferry, *Measuring and Assessing Organizations*. New York: Wiley, 1980.
- [14] J. P. Womack, D. T. Jones, and D. Roos, *The Machine that Changed the World*. New York: Harper Collins, 1990.



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