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The Role of Skill Upgrading in Manufacturing Performance

Melissa M. Appleyard
Portland State University, melissaa@sba.pdx.edu

3A. The Role of Skill Upgrading in Manufacturing Performance

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3A.1 Introduction

This section examines the industry-wide trend of upgrading the skills of production workers in the semiconductor industry. This analysis discusses the industry characteristics driving this trend, the human resource policies that support skill upgrades, and the payoffs associated with such upgrades. To provide a deeper understanding of the process of skill upgrading, two fabs from our sample are analyzed in detail. One fab is located in Japan (pseudonym Jfab) and the other fab is located in the U.S. (pseudonym USfab).

As a central part of their manufacturing strategy, these fabs have emphasized the upskilling of operators particularly for equipment maintenance activities. Through human resource policies, both fabs have extended the breadth and depth of their employees' skills (our definition of skill upgrading), particularly the skills of their operators and technicians. At the time of our visit, a manager at Jfab estimated that they were "95% self-sufficient" in maintaining their own equipment rather than using the vendor. He explained, "We don't use vendor maintenance because it is very expensive and because our people are better at it than the vendors' personnel. We end up teaching the employees of the vendors about their own equipment!" A manager at USfab echoed these sentiments regarding vendors: "Contracts are expensive and we can do better." USfab also has concentrated on upgrading the skills of its operators while it merged the operator and technician occupations into a "production specialist" position (a pseudonym). USfab's production specialists now perform 90% of the basic preventative maintenance (e.g., daily checks, chamber cleans, PMs). For equipment maintenance tasks, these two fabs have substituted participation by line workers for engineering time. Their operators rank at the top of our fifteen fab sample in terms of their intensity of participation in equipment maintenance activities, while their equipment engineers rank in the middle.[1]

In addition to equipment maintenance, another set of activities that affects manufacturing performance focuses on process-related problems and the manufacturing precision of the equipment. These activities can be grouped under the umbrella of statistical process control (SPC), which requires personnel to compare measures of processing outcomes (e.g., the height of a layer, the accuracy of alignment, processing time, particle generation,) against detailed specifications set by the process development group. For statistical process control (SPC) duties, Jfab and USfab do not emphasize the role of their line workers. Instead, Jfab has emphasized the role of the process engineer in conducting SPC, and its process engineers rank at the top of our fifteen fab sample in terms of the intensity with which they use SPC. Process engineers at USfab fall towards the bottom of our SPC rankings, and the fab's SPC capabilities are rudimentary with no automated SPC capabilities and no real time process adjustment. Engineers at USfab were plagued with fire-fighting responsibilities, since they committed approximately 80% of their time to fire-fighting. The engineers were anxious for the program of skill upgrading of operators to bear fruit so that operators could assume more trouble-shooting responsibilities. As one engineer put it, "We spend all of our time [taking care of] lots that went on hold. We want to train other people to do this, so we can have time for [more training and projects]." These findings suggest that both companies rely on their line workers for equipment performance, but not for process control. Jfab relies much more heavily on its process engineers, while USfab lags behind in establishing a focus for its process control efforts.

As described below, the two companies in this case study have established human resource policies consistent with deepening and broadening the skills of their manufacturing personnel in order to pursue their strategies for equipment maintenance and SPC. They have, however, experienced very different levels of success measured by our five manufacturing metrics (stepper throughput, cycle time, direct labor productivity, line yield, and defect density). Jfab scores consistently at the top of the fifteen fabs in our sample while USfab scores in the bottom half. Their divergent performance can be at least partially attributed to the different level of stability of their production environments. Jfab was operating in a relatively stable environment with few process flows and moderated process problems with an advanced SPC capability. In contrast, USfab was undergoing a reorganization of its operations, new process introductions, and adopting a new shop-floor work organization to better integrate its upskilled production specialists into problem-solving activities. We anticipate that with time, USfab will at least partially catch up to the level of manufacturing performance enjoyed by Jfab, as their aggressive skill upgrade program matures, and as they adjust to the changes to their organizational structure and manufacturing process technologies. This section concludes by considering the influences of automation and differences in employment systems on the pervasiveness of skill upgrade efforts across job categories.

3A.2 Technology Requirements Driving Skill Upgrading

Adopting New Technology

Contributing to its reputation as a fast-paced, technically-demanding industry, the semiconductor industry generally experiences a change in its major process technologies every two to three years. Furthermore, the results of the technically-advanced production steps are rarely visible to the naked eye whereas in the early days of the industry, operators performed visual inspections of their work. These factors contribute to the demands placed on manufacturing personnel. They must learn new process steps frequently and identify the subtleties associated with operating the new or modified equipment required by the new steps. To identify misprocessing, they must learn new methods of problem identification, whether it be the mastery of a new microscope or the basics of statistical process control. To properly stage and service equipment, they must understand the interactions between the equipment and the process. These demands on manufacturing personnel have encouraged the upgrade of skills across the industry, and Jfab and USfab have been particularly aggressive in improving the skills of their operators.

At the time of our visit, Jfab was in a relatively stable period both in terms of its organization and technology. However, this followed a turbulent period during which they reorganized their operations, opened the fab that we visited, and transferred in two new major production processes. These challenges were so great that they had to call on a long-time leader in their company to assume the managing director position on-site. Under his leadership, they had greatly stabilized their operations and achieved impressive manufacturing scores (as reported in section 3A.4). At the time of our visit approximately 1.5 years after the introduction of their two new processes, they were running three major process flows and manufacturing approximately 30 products, although eight to nine products dominated their output. When they do introduce new processes, training for both engineers and operators on the new process and associated new equipment is part of the ramp-to-volume plan. Not all companies have training planned into their production ramps.

In contrast to the relatively stable manufacturing environment of Jfab, USfab faced multiple changes in its organization and technology at the time of our visit. First, the company was consolidating its operations at the production site which entailed a number of personnel transfers and changes to the reporting channels in the organization. Second, at the time of our visit USfab was running four process flows producing 25 to 30 products and was starting the development and introduction of another four processes. One of the new processes will produce a shrink of an existing product, but the other processes are new technologies to the fab and will require the purchase of new equipment. Whereas engineering and hot lots are limited to approximately 3% of wafer starts at Jfab, engineering work constituted 10-15% of the work in progress at USfab. In addition, engineers and technicians from the process development group were on the shop floor laying the ground work for the introductions of the new processes further disrupting routine fab operations. Finally, USfab was in the midst of converting the size of their production wafers at the time of our visit. These types of changes are common in the semiconductor industry, although companies generally try to avoid instituting all of them simultaneously. To weather these changes, USfab stepped up their skill upgrade programs introduced a few years prior to our visit, and created a new work organization (described in section 3A.3).

Improving Manufacturing Performance in the Face of High Capital Costs

When we visited Jfab and USfab, management described a number of goals for the improvement of their manufacturing performance. As discussed in Chapter 4, annual capital expenditures range from 13-15% of sales in the semiconductor industry. These high capital costs have prompted firms to increase equipment uptime and eliminate bottlenecks in the process flow. Both fabs have recognized the importance of heightening the proficiency of their workers to improve equipment uptime and reduce out-of-control events. As part of their strategy, they were bringing equipment servicing in-house, which increased their need for a technically-advanced workforce. Although both fabs increased their self-sufficiency in terms of servicing their equipment, they still work closely with their vendors during advanced equipment improvement projects, which is common in the semiconductor industry. (See "The Role of Knowledge Spillovers in Buyer-Supplier Co-Development" under focus studies in this report).

At the time of our visit, Jfab was pursuing three main continuous improvement activities: statistical quality control (SQC), total productive maintenance (TPM), and cycle time reduction (CTR). All three programs required the operators and engineers to deepen their skill sets in terms of problem-identification, trouble-shooting, and preventive maintenance. Of the three programs, SQC was the oldest program of the three and had been in existence at the company since the early 1980s. The second oldest program was TPM, and the managing director joked that they were practicing TPM "before [they] knew what it was called." Part of their TPM program emphasized the need to become self-sufficient in terms of equipment maintenance activities. Jfab felt that their equipment vendors were not responsive enough and, therefore, the fab must assume full responsibility for cleaning and servicing equipment so as to further improve throughput and processing quality. Jfab rarely contracts for on-going regular service with their vendors and instead only have on-call service. The CTR program, a new initiative at the time of our visit, seeks to cut processing times, reduce the waiting time of wafers between manufacturing steps, and improve scheduling and the flow of information within the fab.

The primary goals at USfab were die yield improvement, line yield improvement, cycle time reduction, and the expansion of their TPM program. At the same time, they were converting to a new wafer size. Similar to Jfab, USfab wanted to reduce their dependence on their equipment vendors and bring all maintenance in-house as part of their TPM program. One of the primary goals of USfab under the TPM umbrella was to improve overall equipment efficiency (OEE). Teams consisting of a process engineer, equipment engineer, maintenance technician, and an operator were formed in certain equipment areas. These TPM teams focused on four primary determinants of OEE: equipment uptime, actual production time relative to theoretical production time, line yield loss at the machine, and adherence to production schedule. USfab determined that it must increase the involvement of operators in the OEE efforts, and this required an upgrade of the skills of those operators who had not participated in the TPM teams. Approximately three years before our visit, the fab decided to merge the operator and technician job category, provide training opportunities for the less experienced operators, and require an A.A. or A.S. degree for new hires into upper grades of the operator job category previously reserved for technicians. The few technicians on staff without a two-year degree retained their classification in the highest two job_grades of the production specialist occupation because they were very experienced.

The superior performance at Jfab measured by our five manufacturing metrics (discussed in section 3A.4) reflects the successful continuous improvement philosophy instituted by its management. The operators and engineers at Jfab were aware that their continuous improvement activities in quality circles, special project teams, and kaizen programs fed into the larger goals set by management. Through these activities, they sought to improve the quality of output as well as the efficiency of their manufacturing operations through long-term solutions to problems such as wafer breakage, machine set-up time, chemical usage, and particle generation.

In contrast, the workers at USfab voiced concern over a lack of leadership. Even though USfab's management targeted similar areas as Jfab for continuous improvement, when asked about the larger goals of the fab providing an umbrella for their projects, the workers at USfab could not articulate them. This provided evidence that poor communication between management and the manufacturing personnel prevented an alignment of their objectives and actions. Nevertheless, the management at USfab was committed to upgrading the skills of its operators, since the fab relied on its line workers to detect equipment and processing problems.

3A.3 Human Resource Policies Promoting Skill Upgrading

Work Organization

Common in Japan, Jfab only has one job category for line workers, the operator category. Operators at Jfab receive training and experience throughout their career that allows them to progress from material handling to responsibilities including statistical process control and equipment maintenance, which generally are assigned to technicians in the United States. As we found at a few U.S. companies, USfab is migrating towards a single operator classification (production specialist) similar to Jfab's and consistent with the goal of becoming self-sufficient in equipment maintenance.

Overall, Jfab is much more automated than USfab. At Jfab, the material handling is automated between equipment areas and within a few equipment areas and most production recipes are automatically downloaded after an operator scans his or her personal bar code, the bar code on the piece of equipment, and the bar code of the lot. The status and processing performance of most equipment is also automatically recorded in electronic form. In contrast to Jfab, most of the wafer handling and recipe entry is performed manually at USfab, which tends to heighten the chance of wafer breakage and misprocessing although it is much less expensive in terms of expenditures on capital equipment and information systems.

Despite the much higher level of automation in Jfab, operators manually tracked process and equipment status in a manner very similar to the operators at USfab. They recorded the lot ID, their own ID, various process measurements, and a 15-minute log of the equipment status, i.e., whether it was being set-up, processing, or down for maintenance. Although the operators at Jfab were duplicating the data collection done through automatic downloads to the company's electronic database, data logging activities require that the operators maintain close contact with the process and equipment to assist with prompt problem identification while supplying a check to the electronic information system.

Operators at both fabs have limited participation in identifying out-of-control events through statistical process control. At Jfab, the operators rarely view the control charts for the equipment or process. However, when there is an out-of-control event, the color of the data entry screen changes, an SPC alarm is triggered, and a list of actions comes up on the screen directing the operator how to proceed. At USfab, the production specialists record process data manually, and comment on out-of-control points on the back of their control charts. When they identify a processing problem, they investigate the cause, initiate corrective action, and note their actions on the control chart. If the operator is not experienced enough to solve the problem, the person will call for help. They are just beginning to construct out-of-control instructions.

In order to concentrate authority over lot dispatching and equipment issues, Jfab has constructed two special positions within the operator job category, the "leader" and the "key man," held by very experienced operators. The leader in each equipment area manages the product flow and is in charge of prioritizing the processing order of lots. Each machine at Jfab has what is called a key man on every shift. The key man is an operator who is considered the resident expert on the specific piece of equipment. The key man is particularly important during the night shift when engineers are not generally in the fab. The presence of the key man relieves equipment engineers from having to perform routine maintenance activities and permits them to focus on long-term equipment improvement projects. Jfab promotes people from the operator job category into these two high-skill positions, whereas other fabs, such as USfab, usually rely on people from other job categories (e.g., supervisors or engineers) to perform these duties.

To concentrate authority over wafer processing and equipment maintenance in the primary equipment areas, USfab instituted self-directed work teams approximately a year before our visit. Each self-directed work team comprises all of the production specialists, supervisors and engineers in a particular equipment area across all shifts and is responsible for goal setting, prioritizing work flow, specification changes, and performance reviews. All members of the team meet once a week. Depending on when the meeting is held, they may receive overtime or comp time.

USfab felt that cross-shift membership was required to guarantee knowledge transfer across all shifts. In the photolithography area, the team overcame major problems with misprocessing caused by the coat and develop tracks. Whereas previous problem-solving activities did not emphasize the role of the production specialists, USfab considers the involvement of the photo production specialists as a central reason for the success and wanted to make sure that the improvements would be well-understood by production specialists on all shifts. In addition to improving communication, production specialists welcomed the migration to self-directed work teams so that engineers would be more involved in supervision. During our visit, a few production specialists complained that their supervisors did not come from the operator ranks but were hired straight out of college or business school and had difficulty understanding the technical problems in their area. The production specialists anticipated that increased oversight by the engineers would off-set the lack of technical knowledge of their supervisors when coordinating trouble-shooting activities. Production specialists and engineers alike expressed optimism that this new organizational form would improve accountability and leadership throughout the fab.

Training

The amount of training and the topics covered are similar for line workers in the two fabs, but the method of training differs. For example, annual training in SPC at Jfab progresses through two stages. First the Quality Assurance department trains the leader in each equipment area on each shift, and then the leader trains the operators in his or her area. Similarly, for equipment maintenance training, the key man first receives three to twelve months of training from the equipment engineering group, is certified, and then conducts considerable on-the-job training of the other operators in his or her equipment area. As a testament to the quality of their key men, a manager at Jfab observed, "Several vendors have told us that our key men are the most knowledgeable about their equipment of all operators they have met in companies using their equipment." At USfab, most classroom training is conducted by corporate trainers, who do not have extensive experience on the manufacturing floor.

In anticipation of requiring a stronger skill base of its production specialists, USfab established an extensive educational program. The fab requires a high school degree for an entry level production specialist, but has increased the minimum level of education required to enter as a grade four production specialist (a grade formerly reserved for technicians) from a high school degree to a two-year A.A. or A.S. degree. USfab worked with a local community college to construct courses that would permit operators without their A.A. or A.S. degree to supplement their educational background through two programs. One program covers basic reading, writing, and analytical skills, while the advanced program includes science courses and courses specific to semiconductor manufacturing. Over 150 employees site-wide had completed each program at the time of our visit. Operators completing the advanced program can transfer some of the courses for credit towards an A.A. or A.S. degree. The company covers most of the out-of-pocket expenses for these programs in addition to releasing operators two hours per workday for classes in the basic program and four hours per workday to attend classes for the advanced program. Both programs are roughly one year long, and only operators with at least three years tenure can qualify to enroll.

Production specialists who concentrated on maintenance duties complained about the lack of vendor training on equipment and noted that they had to rely on the equipment engineers for on-the-job training. For members of the self-directed work teams, USfab has supplied eight hours of training covering the following topics: TPM, Just-in-Time manufacturing, problem-solving, and team dynamics. The fab also plans to provide additional training for the teams' production specialists so that they can work all jobs in their team's area (breadth training), as well as work without the assistance of a supervisor or technical expert (depth training).

Outside of USfab's special educational programs for upgrading its production specialists, Jfab and USfab provide similar levels of classroom and on-the-job training for their line workers. However, Jfab offers much more on-the-job training to engineers after the first year of employment than USfab . For example, during the first year of employment, operators spend roughly 50% of their time in on-the-job training at both fabs and 11-20% after the first year. For engineers, on-the-job training constitutes 21-30% of a Jfab engineer's time after the first year of employment versus no more than 5% of an engineer's time at USfab. Another difference in the training of engineers is that Jfab assigns senior engineers as mentors for newly-hired engineers during their first year of employment. At the end of the first year, the mentor provides a review of the new hire's performance.

When an operator is promoted at Jfab to first-line supervisor, the person will receive 20 days of training over a 10 month period at a local manufacturing college. Some of the training days are work days. This training may actually occur a number of years after the promotion. People promoted to the next level of supervisor are required to take a correspondence course administered by the corporate human resource group. This course requires two to three hours per day outside of work for six months. Supervisors at USfab are trained through a "buddy system" that lasts six to eight weeks on-the-job. They also attend a number of one to two day classes in supervisory skills such as facilitation, but the training does not appear to be as extensive as the training at Jfab.

Pay and Promotion

At both fabs, skill acquisition plays a role in an individual's compensation package. For promotion across certain job grades and particularly across job categories, USfab requires certain levels of education, whereas at Jfab performance and experience are the key determinants. As for actual pay levels (at the current exchange rate), operators at Jfab are paid more per hour than operators at each comparable job grade at USfab, whereas engineers at USfab are paid more than their counterparts at Jfab. For operators, promotion across the eight job grades at Jfab garners a much higher earnings premium: The highest grade pays 3.6 times the wage in the lowest grade compared to a ratio of 2.9 at USfab. Similarly for engineers, there is a higher ratio, 3.3, at Jfab between the monthly base pay for engineers in the highest job grade relative to the lowest versus a ratio of 2.3 at USfab. These differences reflect the pay structure common in Japan that lessens the pay disparity between occupations while rewarding its personnel for tenure and skill acquisition over the length of their careers (Brown *et al*., 1997). (See Chapter 5 for a detailed analysis of wage trends and inequality.)

At Jfab, two of the six primary performance criteria for each job and job grade are directly related to skill upgrading: knowledge, and quantity and quality of tasks. (The other criteria are: judgment, management creativity, negotiating skills, and attitude.) Division managers rank employees in each job category in each equipment area in terms of their proficiency, and these rankings in conjunction with the performance appraisals, which are conducted by their immediate supervisors, determine performance pay. Annual pay increases in a job grade usually varies ± 25% around the midpoint of the job grade depending on the performance evaluation. Performance evaluations not only determine bonus pay, but also affect the rate of promotion.

From the viewpoint of the production specialists whom we interviewed at USfab, skill acquisition did not seem to be closely tied to pay and promotion. However, a human resources manager explained that skill acquisition is now a necessary condition for a production specialist to be promoted up a job grade. USfab requires a production specialist to hold an A.A. or A.S. degree for promotion from level three to level four. (There are six total grades.) For promotion to engineer, a person must have a minimum four year degree (bachelor of science degrees are preferred); in the past, experienced technicians were promoted into engineering. USfab will cover 75% of the tuition if a production specialist wishes to attend college to earn his or her B.S. A human resource manager at USfab noted that they are moving away from forced rankings towards a system that emphasizes employee development and teamwork. They plan to establish an on-line tracking system for employees to check their training histories and devise a training plan based on the training required for promotion across job grades.

3A.4 Outcomes of Skill Upgrading

Overall Fab Performance

Even though our data show that the two fabs were experiencing divergent levels of success according to our five manufacturing performance metrics, their own goals overlapped in terms of reducing defects and cycle time and increasing their ability to trouble-shoot and service their equipment. In our sample of fifteen fabs, Jfab was a top performer across all five manufacturing performance metrics with a ranking no lower than fourth in any one metric. In contrast, in three of the five performance metrics for which we have data from USfab, USfab scored no higher than tenth. It is important to note that Jfab is a newer facility that opened in the early 1990s, two years prior to our visit. In contrast, USfab was opened in the mid-1980s and was in the midst of aggressively upgrading its process and equipment technologies at the time of our visit in the mid-1990s.

Line workers are a fab's first line of defense. Data reported in our previous human resources report found that high involvement in equipment maintenance by operators was positively correlated with one of our five performance metrics— line yield. (See Appleyard, 1996 for a complete discussion of this analysis; see "Innovation on the Shop Floor" in this report for a summary.) Scores constructed by weighting the intensity and complexity of equipment maintenance activities by operators placed Jfab and USfab in the top three out of our fifteen fabs. (See "Innovation on the Shop Floor" in this report for a discussion of the construction of these scores.) These high rankings reflect the focus and effectiveness of upgrading operators' skills.

Our findings in the last report also highlighted the importance of operator involvement in statistical process control: It was positively correlated with defect density and line yield, although negatively correlated with stepper throughput (see Chapter 2 of this report). SPC has not been the focus of either Jfab or USfab in terms of operator skill upgrade programs, and these fabs fall in the middle of the rankings for the extent of operator involvement in SPC. Jfab has successfully offset this deficiency by rigorously training its process engineers in SPC, and our data show that Jfab ranks at the top for process engineer involvement in SPC, while USfab ranks at the bottom. As documented in our previous study, a high level of involvement in SPC by process engineers was positively correlated with four of the five performance metrics—all except cycle time. These findings suggest that advanced problem-solving through SPC techniques has a profound influence on manufacturing performance, but some companies, like Jfab, can focus their skill upgrade programs for their line workers on equipment issues and still achieve top performance outcomes.

Perspective of the Individual Worker

Skill acquisition may affect an individual's compensation profile as well as daily work activities. At Jfab, increasing the breadth and depth of equipment and process knowledge increases an individual's bonus and rate of promotion. At both Jfab and USfab, the line workers have greater responsibility for machine uptime and processing precision relative to their counterparts at many other fabs. A few of the production specialists at USfab, however, expressed frustration that at the time of hiring they were promised that they would spend one-half of their time on production and one-half on maintenance. They contended that they spend nearly 99% of their time on production activities even after three years of working in the fab. Jfab avoided this situation, since it has been able to shift its more experienced operators into maintenance activities for two primary reasons. First, Jfab was expanding its operations, in contrast to the consolidation at the USfab site; and second, Jfab has a higher attrition rate, since its female workers typically "retire" after marriage or birth of the first child. As is true throughout large Japanese manufacturing companies, the attrition of female operators alleviates the pressure of too many operators vying for the more challenging job assignments. At Jfab, the approximate annual rate of resignation is 3% for men and 16% for women versus an estimate of 6% for USfab.

The push for self-sufficiency in equipment maintenance resulted in very high scores of operator participation in equipment maintenance activities for both fabs. This attests to the relatively high level of skill acquisition by operators at these two fabs at least in terms of equipment duties. From the individual worker's perspective, skill acquisition can broaden one's employment opportunities. In fact, a handful of production specialists were hired away from USfab by companies out-of-state. Their skills permitted their job market prospects to expand from a local to a national level.

3A.5 Conclusion

The two fabs in this case study have identified the central role of equipment in determining manufacturing performance in the semiconductor industry and have instituted programs for total productive maintenance. Their TPM programs strive to improve uptime and line yield while reducing defects caused both by particulates and parametric problems. Their TPM goals, in conjunction with other programs focusing on defect and cycle time reduction, prompted these companies to heighten the skill level of their manufacturing personnel. Both fabs examined in this case study have structured their human resource systems to promote skill acquisition, particularly by their operators in areas related to equipment maintenance, in order to improve their ability to service and trouble-shoot equipment.

Jfab had achieved superior manufacturing performance by the date of our visit, while USfab was in a state of transition regarding both its work organization and manufacturing process technology, and was experiencing relatively poor manufacturing performance. Gearing up for a number of changes to its technology and organization, USfab instituted an intensive classroom-based skills upgrade program for its operators. However, its engineers received little training after their first year of employment and scored in the lower half of the rankings across our fifteen fab sample for SPC and equipment maintenance usage. In contrast, Jfab promoted training for both operators and engineers as part of their aggressive continuous improvement activities rather than in response to implementing change. As the technology stabilizes and the new self-directed work team structure matures at USfab, we anticipate improvement in performance at USfab.

Long-run trends in employment and automation strategies have profound implications for the skill requirements of manufacturing personnel. At USfab, there was an increased preference to hire people with college degrees—operators with a two-year A.A. or A.S. degree and engineers with a four-year engineering degree. This suggests that demand may continue to fall for high school graduates in the United States in high-tech manufacturing. Rather than "dumbing down" the operator job, automation at Jfab and USfab resulted in operators being trained to assume *more* problem-solving responsibilities. A number of the operators at both fabs could be considered "junior" engineers and, especially at Jfab, receive a sizable wage premium over inexperienced operators. The ability of fabs to assign high-level tasks to operators depends on the degree of skill upgrading via on-the-job and classroom training.

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Brown, C., Y. Nakata, M. Reich, and L. Ulman. 1997. *Work and Pay in the United States and Japan*. New York: Oxford University Press.

[1] Data from fifteen of the sixteen fabs in the CSM-HR sample were used in the performance analysis conducted for this chapter. Data from the sixteenth fab arrived after the analysis had been completed.