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Author(s): John Paul MacDuffie

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The Road to “Root Cause”: Shop-Floor Problem-Solving at Three Auto Assembly Plants

John Paul MacDuffie

The Wharton School, University of Pennsylvania, Philadelphia, Pennsylvania 19104

This paper uses case studies of shop-floor problem-solving at three automotive assembly plants to examine organizational influences on process quality improvement. Three complex quality problems—water leaks, paint defects, and electrical defects—were chosen because they are universally found in assembly plants, have multiple sources, and can only be resolved with high levels of interaction and coordination among individuals in multiple departments or functional groups. The case studies focus particularly on the early stages of the problem-solving process—problem definition, problem analysis, and the generation of solutions—emphasizing how each plant tries to identify the “root cause” of defects.

The paper then explores consistencies and contrasts within and across the three cases to analyze the factors underlying effective shop-floor problem-solving. Central to this analysis is the idea that successful process quality improvement depends heavily on how the organization influences the cognitive processes of its members. Problem-solving processes benefit from rich data that capture multiple perspectives on a problem; problem categories that are “fuzzy”; and organizational structures that facilitate the development of a common language for discussing problems. Also, when problems are framed as opportunities for learning, the combination of positive attributions that boost motivation and the suppression of threat effects can improve the effectiveness of improvement activities. Finally, when process standardization is understood as marking the beginning (and not the end) of further improvement efforts, the normal inertial tendencies of organizations with respect to adaptive learning can be partially overcome.

(Problem-Solving; Adaptive Learning; Quality; Knowledge; Organizational Capabilities)

Introduction

In this paper, I present the results of a study comparing problem-solving processes at three North American auto assembly plants.¹ I focus on production-related, in-plant problems affecting quality (and to some extent productivity) that are not traceable to one clear-cut source. Problems of this kind are common to all manufacturing plants, can-

not be easily resolved by applying a standard procedure or methodology, and require high levels of interaction and coordination across multiple departments or functional groups. As such, they reveal much about a plant’s capability for process quality improvement—a capability that many companies have worked to develop during the quality revolution of the past fifteen years (Cole 1990, 1992b; Fine 1986; Juran 1988).

I studied three problem categories that require collaborative problem-solving: water leaks, paint defects, and functional electrical defects. All are readily noticeable by customers and are measured in the J. D.

¹ The case material presented here is selected from a longer, more comprehensive version of this paper to conform to space limitations. The long version is available from the author upon request.

Power consumer surveys on vehicle quality. All are ubiquitous—no assembly plant in the world has succeeded in permanently eliminating these defects. Furthermore, all three problems have many possible sources.

For example, water leaks can result from gaps in the metal frame after it is welded in the body shop, which can be caused by poorly made or damaged stampings, misadjusted welding jigs or malfunctioning welding equipment. Or they can result if the sealer applied to the body before painting is either missing or inadequate—or if the rubber weatherstripping applied in the assembly department is poorly attached.

The paint process can be affected by small variations in the paint itself, the evenness of the spray from paint robots, or the temperature and humidity of the plant and the bake ovens. But the most elusive paint problems occur outside the paint booths. Painted bodies can be chipped or scratched by a worker's belt buckle, a tool set down in the wrong place, a misadjusted conveyer, or a redesigned jig. Misapplied sealer can prevent paint from adhering properly. Dirt can become embedded in paint because of inadequate cleaning after sanding, fibers coming off of gloves, unenclosed conveyer lines between stages of the paint process, paint ovens that are not cleaned often enough, and countless other reasons.

Functional electrical defects affect the operation of interior and exterior lights, instrument panel, wipers, radio, power doors and windows, and air conditioning. Many result from missing or faulty electrical connections. Two connectors may be pushed together without quite locking in place, and may subsequently vibrate loose. Certain option combinations may pack so much equipment in the dashboard that wires have difficulty reaching their connectors. If electrical wiring is misrouted, a subsequent operation attaching parts may put a screw through a wire, creating a short-circuit.

These three problem categories can also be interrelated. For example, while heavy applications of sealer can help prevent water leaks, this increases the odds of mistakenly sealing over holes needed for fastening electrical wire harnesses. Furthermore, while each problem can result from either technical difficulties with automated equipment, failures of organizational systems, or

human error, they most commonly result from a complex interaction of technical, organizational, and human factors.

I use my fieldwork observations here to develop, inductively, a set of insights about organizational influences on process quality improvement and the implications for how we think about problem-solving. Traditional models of problem-solving assume a structured process of problem identification and diagnosis, followed by solution generation and implementation (March and Simon 1957). Yet, as Simon (1973) has noted, "the problems presented to problem-solvers by the world are best regarded as ill-structured problems. They become well-structured problems only in the process of being prepared for the problem-solvers" (p. 186). Dealing with ill-structured problems, such as those studied here, requires "learning by doing" or "adaptive learning" (Adler and Clark 1991), in which the identification and diagnosis of problems emerges during the interaction among problem-solvers.

The adaptive learning required for process quality improvement draws increasing attention from both operations management and organizational researchers. Operations management researchers have investigated the outcomes of adaptive learning, particularly the tradeoff between the "cost of learning" and the "cost of failure" in pursuing defect prevention under different production conditions (Fine 1986, Marcellus and Dada 1991). Organizational researchers focus on the adaptive learning process, including the "sensemaking" arising from social interaction during problem-solving (Weick 1979, Argyris and Schon 1978) and how cues from the physical environment affect problem-solving (Tyre and von Hippel 1993).

The observations presented below will link these concerns about outcome and process. In certain organizational contexts, problem-solving for process quality improvement may result in the misidentification of problems, faulty diagnoses, and inadequate solutions. This not only drives up the "cost of learning" but may also produce new problems, driving up the "cost of failure." Yet the organizational context for problem-solving can also create positive conditions for effective learning and potentially eliminate the cost/quality tradeoff for the majority of process improvement activities.

Research Questions

My fieldwork emphasizes the first three stages of the problem-solving process, following a commonly used model (e.g. March and Simon 1958, Imai 1986, Tyre 1989) that includes:

1. Problem definition
2. Problem analysis
3. Generation and selection of solutions
4. Testing and evaluation of solutions
5. Routinization—Development of new routines

I characterize these stages in the following way:

1. Problem definition occurs when a problem situation is perceived by organizational actors in light of established routines and subsequently defined in relation to those routines (Tyre 1989). The definition chosen will affect all subsequent stages of the problem-solving process.

2. Problem analysis could also be described as “search activity.” March and Simon (1958) see search—“aimed at discovering alternatives or consequences of action”—as the key variable in problem-solving activity, and as differentiating routinized or programmed activity (involving little or no search) from problem-solving.

3. The generation and selection of solutions is heavily influenced by the skills and knowledge that individuals bring to problem analysis, by the variety of perspectives brought by different individuals (representing different groups), by the way individuals and groups interact during the problem-solving process, and by organizational reward and control systems.

Then, for each of these stages, I ask the following questions:

1. *Problem definition*—What counts as a problem? What information on problems is gathered and how is it used? What kinds of problems are considered legitimate for problem-solving and which are not? How do resource constraints affect problem definition and decisions about which problems to solve?

2. *Problem analysis*—Who is involved in problem analysis? How broad (and/or deep) is the conceptual knowledge they bring to the analytical task? What strategy guides the analysis? What search techniques and methodologies are used?

3. *Solution generation and selection*—Who is involved in generating and selecting solutions? Do they share a

common conception of the problem? What approach to generating solutions is used, in terms of techniques, group activities, boundary-spanning activities? What criteria are used for selection?

In addition to these stages of problem-solving, I will examine key attributes of the quality system within which problem-solving processes take place—in particular what organizational structure for quality improvement activities is chosen, what mix of people (with respect to functional or hierarchical position) is involved in such activities, and how the organization seeks to motivate problem-solving activities. I also briefly address issues of routinization and standardization.

Choice of Sites and Fieldwork Activities

My research sites for this study were three assembly plants in North America, one each from General Motors, Ford, and Honda.² I made inquiries about a total of nine sites at five companies (2 U.S.-owned and 3 Japanese-owned) and these companies were the ones that most quickly agreed to provide access. These three sites were chosen as most appropriate and most interested in the research after discussions at each company.

I spent one full week in the GM and Ford plants and five days, over two visits, at the Honda plant, all between January and October 1989. For reasons of confidentiality, I identify the plants only by company name; I have omitted or modified references that would indicate plant location, and have changed the names of any individuals who are mentioned in the case studies. At the GM plant, I carried out 23 interviews and attended four meetings—one work team meeting, two meetings of quality improvement groups, one informational meeting—as well as a daily quality audit meeting. At Ford, I carried out 19 interviews and attended three daily meetings—two meetings of quality improvement groups and one meeting

² My primary criteria for choosing the field sites were: 1) an agreement allowing extensive shop-floor access; 2) support for the project from corporate and plant-level management and, at GM and Ford, union officials (Honda is not unionized); 3) a readily observable level of problem-solving activity directed at quality improvement; 4) a reasonably high level of incidence for the three quality problems; 5) variation in company, production system (along a continuum from “mass production” to “lean production”), and quality performance; and 6) participation in the International Assembly Plant Study.

Table 1 Selected Characteristics of Plants in Problem-Solving Study

Characteristic	GM	Ford	Honda	Mean for US/NA	Mean for J/NA
Plant Age	Built in 1980s	Built pre-1940 Retrofitted in 1980s	Built in 1980s	–	–
Union status	Unionized	Unionized	Nonunion	–	–
Productivity (hours/vehicle)	20–25	15–20	20–25	24.9	20.9
Quality* (defects/100 vehicles)	200–220	120–140	100–120	159	112
Water leaks	4.9	7.0	3.1	6.3	3.0
Paint defects	31.8	16.7	10.1	18.0	11.2
Electrical defects	36.5	16.7	20.1	25.8	16.7
Total Automation (% automated prod. steps)	23%	35%	39%	30.6%	34.7%
Production Organization (0 = Mass Prod; 100 = Lean Prod)	64	43	69	42	75
Production Scale (vehicles per day)	700–900	900–1100	500–700	850	913

Source: International Assembly Plant Study, IMVP, M.I.T. except for * = J. D. Power Initial Quality Survey (unadjusted).

of department heads—as well as a single meeting of two Employee Involvement groups and one meeting with representatives from another plant. At Honda, I interviewed 20 people and attended one meeting of a quality improvement group.

At all of these plants, I sought and received permission to walk around the plant, to talk with workers, team leaders (where applicable), quality analysts, engineers, and production managers, to observe work processes, and to gather relevant documentation (e.g. statistical data gathered to document problems, daily quality audits, minutes of quality circle meetings). In each plant, I asked about the same production problems, talked to people in the same kinds of jobs, and observed the same production processes and quality-focused group activities.³

³ Many of these interviews were scheduled, semi-formal sessions, while others were extended conversations accompanying my shop floor observations. Besides these interviews, I spoke briefly with many other individuals. I tape-recorded interviews held in offices and meeting rooms and also took extensive notes, recording key phrases and comments verbatim as much as possible. I took notes but did not tape interviews on the shop floor or in the cafeteria. I supplemented my notes soon after each interview and typed up field notes each night. I did not transcribe the interview tapes but referred to them when writing the field notes.

Additional background information for these three plants is presented in Table 1, based on 1989 data from the International Assembly Plant Study,⁴ including plant characteristics not investigated during the field visits, productivity (in hours per vehicle), and J.D. Power consumer-reported quality data for overall defects (per 100 vehicles) and for the three problems studied here.⁵ Some variables are expressed as a range to preserve confidentiality. Averages for U.S.-owned and Japanese-owned plants in North America are included for comparison purposes.

The case summaries begin with background information about the plant and then describe the structure, composition, and motivational elements of the quality

⁴ The International Motor Vehicle Program at M.I.T. operated from 1985–90 and was sponsored by practically every automotive manufacturer in the world. The International Assembly Plant Study was carried out by John Krafcik and John Paul MacDuffie (see Krafcik 1988; Womack et al. 1990; MacDuffie and Krafcik 1992; MacDuffie 1991, 1995).

⁵ I first visited these plants in connection with data collection for the Assembly Plant Study. These visits, and similar trips to over thirty other assembly plants around the world, gave me a familiarity with automotive manufacturing, different types of production systems, and different approaches to quality that proved invaluable as a backdrop for the fieldwork on problem-solving.

system. The accounts of problem-solving activity are organized into sections on problem definition and problem analysis/generation of solutions.⁶ I then analyze the cases for evidence of consistency across stages within each case and of contrast across cases. The paper closes with a discussion of the implications, both theoretical and practical, for understanding process quality improvement as adaptive learning.

General Motors (GM) Plant

The GM plant is one of several built in the 1970s and 1980s using the team concept. All production workers are organized into teams of 15–20 members with an elected team coordinator. Unlike other GM plants that opened at the same time, the team concept has proved relatively successful, endorsed by a solid majority of the workforce in three local contract votes during the 80s. But this plant did not implement the manufacturing practices associated with lean production—reduced inventories, integrating quality inspection into production jobs—until the late 1980s. The technology in the plant is almost all of mid-1970s vintage, with little investment in new technology since that time.

Of the three problem categories, paint defects were viewed as the most significant by the plant, followed closely by electrical defects, with water leaks a minor concern. This matches the relative ranking of these problems in the J. D. Power data for this plant. Compared to the other two plants, the GM plant had 90–215% more paint defects reported by consumers—in part a function of its relatively old paint booths—and 80–220% more electrical defects. These defect levels are also considerably worse than the Big Three average.

Quality System

Structure and Composition. The plant has an elaborate structure of quality-related groups and roles. Each work team has a Quality Coordinator who samples a certain number of cars per day, keeps Statistical Process Control (SPC) charts, and attends the daily plant audit

meetings (see below). Most quality activities are organized by department. Each department (e.g. weld, paint, assembly) has a Quality Analyst (QA)—an hourly person jointly appointed by union and management for a one year term to support quality improvement activities—and a Quality Improvement Team (QIT) that meets monthly. QITs are headed by a member of the top management group and include shift superintendents, engineers, and first-line supervisors. Under the QITs are Quality Action Teams (QAT), short-term task forces set up to address specific problems, nominally with hourly and management members, although an inspection of QAT minutes revealed low attendance by managers. Most cross-departmental problems are referred to a Plant Quality Council made up of senior management and top union officials, although some are handled at meetings of departmental QITs. No design engineers were stationed at the plant.

Motivation/Incentives. At the corporate level, quality had certainly become a very important performance measure by the time of my visit. Plants were rated monthly on a GM corporate quality scale, based on a “surprise” audit, for internal comparisons. External comparisons with competitor’s products were based on consumer-perceived defects identified in a survey commissioned by GM. The results of both internal and external comparisons were printed up monthly on pocket-sized index cards and distributed to all managers at or above department level. Bonuses for the top level of plant management (but not below) were affected by quality performance.

Within the plant, for lower-level managers, staff, supervisors, and production workers, the quality incentives were less clear. Workers perceived that managers in charge of production, at all levels, still placed the highest priority on meeting daily production targets. With respect to quality, department-level managers seemed most concerned about being charged with the cost of fixing quality defects in terms of their budget performance. Production workers were covered at that time by a corporate profit-sharing program, but the tie between plant-level quality performance and the formula used to calculate corporate profitability was unclear. In any case, GM had not paid a bonus to any production workers for three years because of losses at the

⁶ On occasion, examples of problems outside the three primary categories are used to illustrate a particular point. Key themes in the cases are developed in parallel as much as possible, but themes unique to particular cases are also explicated when necessary.

corporate level (a period when top corporate officials continued to receive large bonuses—a fact pointed out to me by several employees). Thus while incentives to motivate the plant to achieve better quality performance certainly existed, they were unevenly distributed and not particularly strong in comparison with incentives to meet financial and production goals.

Problem Definition

Sources of Data. GM primarily uses internal quality audit data for identifying quality problems. The audits that “count” are carried out by corporate auditors who visit the plant unannounced once a week. They follow a standard methodology and assign weights for various defects to get an overall score, which is compared with other GM plants and with cars made by other companies but sold by GM. The plant replicates these audit procedures daily for its own internal problem identification purposes.

At the time of the study, customer-based warranty data were collected at dealerships on a “defects per thousand vehicles” (DPTV) basis, but these were only reported to the plant after a delay of several months, so they played little role in the plant’s problem-solving efforts. Also, the plant had established programs to emphasize that customers were the most important source of quality data. A few workers each night took a newly-built vehicle home for a thorough check and reported their findings at the next day’s audit. Groups of workers visited dealers in other states to see what quality problems were reported. But the internal quality audits remained the primary source for both the data and incentives guiding most problem-solving activity.

Deciding What Problems to Solve: “Avoiding Corporate” for Design-Related Problems. One consistent frustration for groups identifying quality problems is the difficulty in getting design-related changes made. This ultimately affects what is defined as a problem. There is a tendency to define problems in a way that allows the plant to deal with it independently, without lengthy and frustrating interactions with corporate designers.

The time involved in processing a design-related change, alone, is a disincentive. I was told that the typical engineering change involving parts design in this

GM division takes 210 days to process. QIT members told me that designers have refused to respond to several persistent quality problems pressed by the plant. For example, the routing of the tube carrying window washing fluid to the back windshield brought it so close to several fasteners for other parts that it frequently got pinched or blocked. The QIT suggested an alternate routing but the designer insisted that the original routing was adequate and that any problems were the fault of the plant.

As a result of such experiences, groups at the plant often focus on problems that can be addressed without involving the corporate level. For example, the plant has had a persistent problem with a bracket on the brake pedal subassembly to which cables for both the cruise control and power brakes are attached. The bracket often moves when the cruise control is used, resulting in misadjustment of the brakes. Engineers, supervisors, and operators I talked to agreed that the problem was a poor design—that the cruise control and brake cables shouldn’t be attached to the same bracket, and that the bracket was in a bad location.

But the problem was defined in terms of the design of the clip holding the cruise control cable to the bracket, and a new, stiffer clip with a longer flange was ordered from the supplier. Upon investigation, I learned that this latter solution involved a small enough change in clip specifications that it could be worked out directly between the plant and the supplier, a process that took only 3 weeks. To define the problem in broader terms would require, it was claimed, a long struggle with designers in Detroit.

Deciding What Problems to Solve: “Unidentifying” Problems Due to Cost Concerns. The dominance of cost concerns often effectively precludes the identification of certain problems—or can lead to problems being “unidentified.” One of the most common electrical problems serviced under warranty was the car horn either failing to operate or going off randomly—a highly visible problem for the consumer. The problem involved the wire connecting the horn button to the rest of the instrument panel wiring. First, this wire is connected and then the horn button is fastened to the steering wheel. The wire was generally cut long enough to allow a good connection to be made while the horn

button was not yet fastened to the steering wheel, but it would bend and often get pinched when the horn button was fastened on. When the wire was shortened to avoid this pinching, the connection would often be pulled loose before the horn button was in place.

This problem was first formally registered in the plant's "5 Phase Problem Resolution Process" in October 1988. The initial response was to ask the operators involved to take extra care and to experiment with some different installation methods. By November, the QIT for the Trim Department proposed the use of a coiled wire with "memory," designed to spring back to a shorter length after being stretched. By January 1989, the QIT worked with a supplier to test different "memory" wires, and found that it cut defects dramatically. That same month, a formal request for a design engineering change to the memory wire was sent to Detroit.

In April 1989, I was at the QIT meeting when the superintendent announced that their request would not be approved because the cost—94 cents per wire—was too much. An engineer at the meeting speculated that the design engineers might be examining wire with more "memory" capabilities than the plant needed—like the cord connected to a telephone handset which is stretched daily over several years—and said that such "overengineering" by designers was common. Unlike the superintendent of the department, who was angry about this outcome, most other QIT members seemed cynical, resigned, unsurprised by the lack of response. This horn problem persisted but it ceased being defined as a "resolvable" problem. The 5-Phase Problem Resolution sheet on this problem concludes the section on Problem Elimination with the statement "Re-design required for complete problem elimination."

Deciding What Problems to Solve: Striving for a Common Language. One prerequisite for problem definition is developing a common descriptive language that can be understood across departmental (and organizational) lines. I found two examples. I met with the Quality Analyst (QA) for the Paint Department while he was reviewing his daily audit of vehicles for paint "mutilations." I noted the highly picturesque language he used to describe these defects—boils, craters, bulls-eyes, sags, runs, orange peel, dings, mars, scratches, cracks, grind marks, powder bumps. He said the plant has been trying to make sure

everyone uses the same language for describing paint problems—in the plant but also the dealers when they file out a warranty form for a repair. The paint QIT developed a form, complete with diagrams, that lists this terminology. This attention to language had resulted in more consistency in the reporting of types of defects. It had not helped much in achieving consistency in the standards individuals used in determining whether or not to report a defect.

The Final Line Quality Analyst also referred to the use of language in defining problems. She checks with the in-plant auditors daily to find out which problems might affect her area. Then she would visit the supervisor or work team most likely, based on her experience, to know what had happened. Often they would point her to some upstream process. After investigation, she would write up a problem statement describing where the responsibility lay. Much of the process, she explained, involved interpreting how different departments defined the problem. "Different people in different departments use different words for the same problem. I change the language around some to be sure the guys on my line can tell what I mean." In this case, the QA handles the "translation" problems caused by different terminology on her own. But this does not help eliminate the issue of inconsistent standards for identifying what is a problem. Both common language and common standards for defining a defect seem critical to effective problem definition.

Problem Analysis/Generation of Solutions

"Placing the Blame" Through the Audit System. The in-plant audits are the basis for a twice-a-day ritual held in a special area in the front of the plant. The day's quality scores are announced by the Quality Analyst for each department, together with an explanation or defense of a bad score and applause for a good score. Several of the vehicles that were audited are parked around the speaker's podium and used to point out problems both during the audit meeting and throughout the day. All quality coordinators, supervisors, superintendents, and senior managers are expected to attend the meeting, and any visiting guests are invited.

The daily audit numbers are now perhaps the most important performance measure for the department, and the daily exposure of the departmental score only

intensifies the concern about what this number will be. The audit system requires that every problem be assigned to a department, both to tally the departmental score and to allocate the costs of repair. Since not every problem can be easily attributed to a single department, the assignment of problems is often the focus of intense negotiations among Quality Analysts, supervisors, and department heads.

The Quality Analysts play a key role in problem analysis, since they are supposed to “root cause” problems, i.e. find out the real source of problems. The QAs do try to track down whatever information they can about problems, but since they do not have the time or resources for a full investigation, they usually rely on one of two approaches: 1) An automatic assignment of a problem to the department that should have spotted it, i.e. the repair or inspection group that usually finds problems in that part of the vehicle; or 2) Negotiating with representatives from other departments about where to assign a particular defect.

One example of the former approach emerged when I observed one of the plant’s full-time auditors inspecting a vehicle. He found a paint defect—two small “dirt” spots on the hood (“dirt” refers to any foreign matter caught under the paint)—and, in checking the ticket, found they had been identified by inspectors at the end of the paint department but then “bought off” (i.e. passed through without repair) by the paint reprocess group at the end of the line. He told me this defect would be charged to the paint reprocess group that had failed to repair it.

When I asked how this would help with identifying the source of the dirt problem, he replied, “The reprocess guys are responsible. It’s their job to catch this.” This is a clear reflection of how the existing audit system still reinforces the “inspecting in” philosophy. Negotiating over where to assign the cost of defects is influenced partially by what is known about the problem, and partially by the number of defects already accruing to a given department that day (in the interests of insuring that no department looks too bad—or too good). In neither case is much effort made to identify the true source of a problem. Problem analysis, such as it is, is almost entirely concerned with assigning financial accountability, or as one QA called it, “placing the blame.” The plant’s production manager expressed his

concern about this, saying, “We spend too much time around here worrying about ‘Who shot John?’.”

Ford Plant

The Ford plant is the oldest I studied, built before World War II. It was completely retrofitted in the 1980s for a new product, and has been dedicated to that product ever since. It is in many ways a traditional mass production plant. There are no work teams. The number of job classifications, while reduced during the 80s, is still high—over 90 unskilled and over 20 skilled classifications. Relatively few employees are involved in Employee Involvement groups. The plant has made considerable efforts to reduce its use of buffers but inventories were large by lean production standards. But in the area of quality, the plant is closer to lean production policies.

Managers and workers alike spoke of a strong work ethic among employees, a “hands-on” attitude and high shop floor visibility from the management team, and a history of constructive (although not always cooperative) labor relations fostered by strong and long-serving plant managers and union officials. While employment has been stable for most of its history, the plant suffered massive layoffs in the early 1980s.

Of the three problems, electrical defects was viewed as the most serious, followed by paint chips and water leaks. These problems ranked first, third, and fourth, respectively, on the plant’s “Top Ten” list of problems during my visit. Interestingly, the J. D. Power data show paint and electrical defects at the same level, both better than the U.S. average (and for the latter, matching the Japanese transplant average), with the incidence of water leaks worse than the U.S. average (and more than twice as high as the transplant average).⁷

Quality System

Structure and Composition. Ford had recently reorganized the quality structure in all its plants,

⁷ This suggests, for electrical problems, that the plant was successful at repairing most defects before vehicles left the plant. Also, the incidence of water leaks, while high, was clearly not the plant’s top quality priority—suggesting that the plant was willing to accept that level of water leaks or that customers were less concerned about water leak defects than about electrical problems.

changing from department (e.g. weld, paint, assembly) to product "subsystem." Eleven subsystems were defined, with a group assigned to each. Among the subsystems were all three of the problem categories I chose: water leaks, electrical defects, and paint problems. This shows how much Ford had reoriented their quality system to emphasize the inter-departmental nature of many quality problems.

Each subsystem group meets daily, and is chaired by a member of the plant's operations committee, made up of the plant manager and all department heads. Other members include a "vertical slice" of the plant organization: design engineers (sent from Detroit for a 2-year stint in the plant under a new program called QPRESS), process engineers, supervisors, and hourly workers. A full-time "coordinator"—often a process engineer—is assigned to each subsystem group as staff.

Each subsystem group collects a tremendous amount of data, using Statistical Process Control and Pareto graphs and "8D" charts, named after an eight-stage problem-solving process developed by W. Edwards Deming, the quality control guru used extensively by Ford. These graphs and charts are reviewed at the daily meetings but also form the basis of the Production Operations Report (POR) presented semi-annually to corporate staff during an in-plant review.

Ford has also created a new liaison role for quality improvement activities: the Zone Improvement Person, or ZIP. A ZIP is assigned to a subsection of a department, and authorized to take a variety of actions to prevent a quality problem from leaving their zone. ZIPs are permanent positions, filled by production employees who are paid a small hourly bonus, and are said to be popular assignments. ZIPs, working with supervisors, either generate or oversee much of the data-gathering activity in the plant.

Motivation/Incentives. In many ways, the incentives to improve quality at Ford did not differ substantially from those at GM. Corporate-level audits were used to rank plants in terms of quality and performance on these audits, as well as the achievement of yearly quality improvement goals, factored into the calculation of yearly bonuses for top managers at the plant. Rivalries with other plants, either those who built the same product or who were consistent con-

tenders for divisional leadership, gave an extra competitive edge to these incentives. Production workers were subject to the same corporate-level profit-sharing as at GM, with the important distinction that Ford was paying out a substantial yearly bonus under this plan every year in the late 1980s. Another motivating factor was the memory of massive layoffs in the early 1980s, still vivid for many "old-timers" as a sobering break in the successful record of the plant from the time it opened. Both managers and workers attributed the commitment to both quality and productivity improvement in the plant to a strong desire to avoid such crises in the future.

Furthermore, Ford managers and workers alike seemed to perceive quality as central to their success in the mid-to-late 80s. Ford products were outscoring most GM and Chrysler products on quality during this time, although they still lagged Japanese companies. Finally, Ford's extensive reorganization of quality activities around vehicle subsystems meant that quality occupied more managerial attention here than at the GM plant.

Problem Definition

Sources of Data. Ford had gone farther than GM in switching from internal to customer-based data as its primary source for identifying quality problems. This includes not only warranty claims reported through dealers but verbatim comments from mailed surveys and phone calls to new owners. The plant also still collects its own internal audit data.

The plant is still adjusting to the increased reliance on customer-based measures. One department superintendent told me that the problems identified during internal plant audits correspond much more closely with their sense of current and persistent quality problems than any of the customer-based measures. But, he said, if they focus on "drying up" the problems listed high on the internal audit, the customer measures improve as well. This suggests that the internal and customer data are ultimately identifying the same problems, but that the plant cannot always see the underlying link. This hidden link is a function of the time lag for the customer data, the use of different language by customers, and the way that dealers assign warranty codes for repairs. But it also reflects the skepticism with which

manufacturing people view the quality perceptions of anyone outside the plant.

This skepticism is partially due to a common management reaction to the customer-identified problems—a nearly automatic acceptance of the customer definition of the problem, followed by an equally automatic data-gathering assignment. As one supervisor described this:

A hot item comes up on the NVQ (New Vehicle Quality) audit and management jumps on it, tells us to chart it. One time, we had some cars going to Taiwan and we had a report that the seat belts were rattling. So they told me to chart it ten times a day. But there's no way [at this point in the trim dept.] that you can tell if the belt will rattle, before the whole interior is in. But those are the charts that get started and continued. Problems that don't make the hit parade don't get charted.

Thus employees in this plant are often pulled between the customer-based data the corporation now wants them to rely on and the internal data that still makes more sense to them. As a result, problems are often “officially” defined, in reports of various kinds, in terms of the customer measures but people in the plant discuss them in terms of the internal measures.

Deciding What Problems to Solve: “Don’t Touch Metal”. As at the GM plant, problems are often defined—or left undefined—in terms of cost. In the sealer area, I heard about a persistent problem (since beginning production four years earlier) with the drip rail—the metal rim around the door opening that carries off rain water. A piece of weatherstripping over the outer lip of the drip rail prevents water from leaking into the car, but the lip is quite short, so that weatherstripping often will not seat well. The weatherstripping has been redesigned a few times, but the problem persists. It is made worse by the slightest variation in the thickness of the sealer placed along the drip rail—too thin and the result is leaks, corrosion, wind noise, but too thick and the weatherstripping will pop off. I asked what it would take to solve the problem, and was told, “a longer lip.” I asked if they had proposed this and was told, “No way—you don’t touch metal.”

This same response reportedly arose on other occasions too. Changes in the design of sheet metal parts is considered too expensive to change until a major model change—potentially eight years for this particular prod-

uct.⁸ The same is true for problems that would require a change of tooling to resolve. So the problem ceased to be defined in terms of the drip rail—instead, it was seen as a sealer or a parts (weatherstripping) problem. The shift here is subtle. “Water leak” is still the ultimate problem but the working definition—poor drip rail design vs. poor quality sealer or weatherstripping—frames the search for solutions powerfully. This may be one reason that water leaks continued to rank highest on the J. D. Power’s consumer-derived defect list but was third on Ford’s priority list (among these three problems) for in-plant improvement efforts.

At one subsystem meeting, someone remarked to me, “We just gather all the data and let Dearborn (corporate headquarters) decide what to do. Sometimes they decide it’s cheaper to let the customer find the problem than for us to fix it.” Clearly employees expect a certain percentage of the problems they identify to be ruled out-of-bounds for serious resolution because of cost concerns.

Deciding What Problems to Solve: The Role of Design Engineers. At the Ford plant, unlike GM, design engineers are stationed in the plant, through the QPRESS program. As a result, manufacturing people report less frustration with design, better communication, and more optimism that design-related problems they find will be addressed. Still, many signs of the functional divide between design and manufacturing remain.

The QPRESS engineers, assigned to the plant for a two-year term, are keenly aware of their pioneer status. While most were glad to have some hands-on experience in the plant, they worried about the effects on their careers. Would this time at an assembly plant really count in their favor at promotion time? How much was their lack of visibility in Dearborn hurting them?

They protect themselves, in part, in the way they define problems encountered in the plant. Their analytic procedures categorized all problems as design-related, vendor-related, or plant-related. One QPRESS engineer

⁸ I have no data on the actual costs of altering sheet metal design, but they may well be too high to justify a change in these circumstances. However, I saw no indication of any effort at Ford to assess the costs, in terms of customer perception, of quality problems that persist over the full life cycle of a product.

told me that he was really only responsible for design-related problems, but that on occasion, to preserve good relations with plant engineers, he would spend some time on a "plant" problem. On the whole, he was critical of the plant for their failure to make more progress with their assigned problems. Yet, as far as I could tell, many of the "plant" problems had some design implications. By confining themselves to problems they felt were appropriate to their expertise, the QPRESS engineers appeared to hinder rather than facilitate process improvement for complex problems that could not be easily categorized.

Problem Analysis/Generation of Solutions

Definition as Diagnosis. At first observation, the amount of attention to problem analysis at the Ford plant is very impressive. SPC and Pareto charts, the 8D problem-solving process sheets, and other data-based reports on quality are visible in profusion in meetings at all levels. But over the course of my visit, I began to notice that the data on quality problems were not treated very analytically. To define the problem in a certain category was, at the same time, to diagnose its cause. Based on past experience, most individuals, from production workers to management, seemed to feel that they understood the source of a problem immediately. Attention was therefore focused on choosing a solution.

My analysis of over fifty "8D" forms (the paper documentation for the Deming problem-solving process) proved revealing.⁹ The section on problem definition was typically brief and generic, using stock phrases from the various quality reports. The section identifying the "root cause" was typically a more detailed description of the problem, with the "root cause" often implicit but with no evidence of any direct attempt to test these assumptions. The section on "actions taken" varied in length but was typically haphazard, with no indication that solutions were systematically considered, tried out, and then either accepted or rejected for implementation. Unlike the "root cause" section, actions were described with many details, bristling with specification numbers,

name of new vendors or products that will be tried out, specialized terms for parts of the car. Occasionally, a general reference to some organizational action, such as an "operator awareness program" appeared as well. The section on verification was often scanty, listing "before" data only, or "before" and "after" data for the original problem—rather than "before" and "after" data for all the attempted solutions.

In general, the 8Ds appear to be used more to report on the activity level of the subsystem group, to show that the required processes are being fulfilled, rather than to diagnose, systematically, the "root cause" and possible solutions to a problem. When a problem recurs, seldom is it reanalyzed, and rarely are earlier actions reassessed. With past activities already documented and reported, the key is to generate new documentation, to provide proof of continued activity. Thus "continuous improvement" becomes less a process of incremental problem resolution than a process of energetic implementation of intuitively-selected solutions. Indeed, the profusion of data reports and charts, as a symbol for problem-solving activity, was a clear impediment to problem analysis, both because of the time spent generating them and because the sheer quantity tended to obscure rather than illuminate.

Accounting for Long-term Quality vs. Short-term Cost. A central, unresolved tension within the Ford system was apparent, between quality and cost. In my initial meeting, the comptroller said, "We can't continue to be all things to all people. We may need to spend more to keep improving our quality record." At first, I thought his comment reflected the traditional view of a tradeoff between cost and quality. But I came to understand his remark in another way—that the plant needs to be free to spend more money in some areas to make quality improvements that will, over time, save money in other areas. In other words, short-term cost concerns often constrain problem-solving activities that can lead, through defect reduction, to long-term quality and cost benefits.

I saw several examples during my visit. On the first day, I accompanied the electrical subsystem coordinator while he checked out a problem with wire harnesses in the instrument panel subassembly area. A supplier representative assigned to the plant joined us. The operator

⁹ The eight sections of the report include 1) team contact information; 2) problem definition; 3) root cause; 4) actions taken; 5) action dates; 6) verification; 7) prevention; and 8) congratulate your team.

showed us the problem. At one location on the wire harness, a plastic block where several wires connect was near a plastic locator pin, used to situate the wire harness in the instrument panel. The block and locator pin were supposed to be taped at a 180 degree angle to one another but instead were taped incorrectly, in parallel, directly adjacent to each other. The operator therefore had to break the tape in order to make the connection and insert the locator pin. Without the tape, the chance of broken wires or loose and rattling connectors increases, so, as a makeshift remedy, the operator was fastening the wires down with a "chicken strap" (a thin plastic strip designed to lock as it is tightened) to hold the wires together. This was virtually impossible to do in the required cycle time.

Much of what ensued was impressive. The operator gave up his lunch hour to help explain the problem. The electrical coordinator carefully checked the inventory to determine the incidence of the problem; a whole pallet was incorrectly taped. The supplier representative, clearly accepted by plant personnel as part of the "team," busily researched the problem that day and reported his findings at the electrical subsystem meeting the next day. A speedy resolution seemed imminent.

But I learned later in the week that the supplier had discovered nothing in the Ford specifications for the part about how the wires should be taped and that, according to the contract, the cost of remedying the problem fell to Ford. A decision was made, therefore, that the specification would be adjusted but that until then, the rest of the defective parts would be used, since it would cost too much to replace or rework them. So the problem did get fixed, but with Ford deciding that the loss of production time and the risk of loose wires in the instrument panel (both difficult to quantify) were easier to bear than the known cost of replacing the defective parts.

Here the effort to assign cost accountability took precedence over finding a way to minimize the quality impact of the problem. The accounting system was unable to balance the (measured) cost of replacing or reworking the faulty parts with the (unmeasured) cost of inspection, repair, and, potentially, a dissatisfied customer. These latter costs may be impossible to quantify. Nevertheless, decisions such as these send a powerful

message to employees that quality is important but only as long as no additional costs are incurred.

Honda Plant

The Honda plant was still increasing its production volume (and thus its employment), and building only a single product. Like the other Japanese "transplants" in North America, it transferred practically all of the elements of the lean production system used by its sister plants in Japan: minimal repair area and in-process inventories, work teams and problem-solving groups, job rotation, extensive training, minimal status barriers, and bonus pay based on plant performance. The workforce was mostly young, single men from the surrounding agricultural area with no previous manufacturing experience.

Managers told me that most workers arrived with utopian notions of what it would be like to work in a Japanese plant and went through a difficult adjustment process in the first six months. At the time of my visit, the level of production at the plant had recently risen without an increase in the workforce, which reconfigured all jobs and increased the work pace, and I saw signs of some tension between workers and managers as this change was being implemented. On the whole, however, I found the workforce quite enthusiastic about Honda as a company, proud of the success of its products, and quite committed to Honda's quality philosophy. Indeed, I heard complaints from workers that managers did not consistently follow Honda's quality principles—and this misalignment in expectations about quality standards was the source of growing pains for the plant.

Of the three problem categories, paint defects dominated plant attention, with less concern about electrical defects. Water leaks had been a major quality focus in the preceding year but were felt to be under control at the time of my visit. This varies from the J. D. Power data, where paint defects are better than the Japanese average but electrical defects are worse.¹⁰

¹⁰ This emphasis on paint defects was unsurprising, given the belief at Honda that their superior "fit and finish" had been a major factor in the company's major surge in market share during the 1980s. In contrast, nearly half of the Honda electrical defects reported to J. D. Power involved the radio-cassette unit (compared with only $\frac{1}{4}$ of the Ford and

Quality System

Structure and Composition. Most quality responsibilities are integrated into production jobs, with groups of coordinators responsible as liaisons for different aspects of quality, identified as Line Quality (LQ), Parts Quality (PQ), Vehicle Quality (VQ), and Quality Engineering (QE). LQ coordinators are assigned on the basis of the "zones" of 4–6 teams that make up departments. When problems are identified by team members, the team leader notifies the LQ coordinator, who then gather information about the problem. If it is a parts problem, s/he contacts the PQ coordinator. VQ coordinators work in the final repair area, and relay information about problems back to the LQ coordinators, although LQ may also alert VQ about a problem that will show up post-process. QE is the group responsible for research on warranty claims, handling quality problems between the plant and the customer, quality testing, and long-term quality planning. Small group activities related to quality are structured in three different ways, depending on the nature of the problem. A one-time or infrequent occurrence that arises from sources within a single department is typically handled by production workers and team leaders, in conjunction with LQ and PQ coordinators. A more complex or more frequent problem in one single work area may be assigned to a New Honda (NH) Circle—an off-line, after-shift quality circle group. A problem that potentially arises from sources in multiple departments can become a "project." A project requires a cross-departmental meeting—usually only one—typically organized by an LQ coordinator. A more serious or difficult-to-diagnose problem that spans departments may give rise to a "special project." These are assigned a leader and one or more "staff" members pulled off their regular jobs, and are time-limited—as soon as the project team presents an "action plan" to senior management, it disbands.

Motivation/Incentives. Honda uses various means to motivate its employees to be concerned about quality.

GM defects), a "stand-alone" component whose quality is mostly out of the control of the assembly plant. Thus paint defects were both more central in the company's self-definition of quality and seen as being more directly under assembly plant control than electrical defects.

Plant-wide bonuses administered semi-annually to all employees are based in part on the degree to which quality goals for the model year were being achieved. These bonuses, calculated as a percentage of base pay, do not differentiate among individual employees, except for a portion that is tied to attendance. Pay for production workers also increased as a function of length of employment but was not linked to individual performance. This Americanized "seniority pay" provided incentives for associates (all employees at Honda are called "associates," regardless of position) to work at the plant long-term so that returns on company investments in training and quality awareness could bear fruit. More individual incentives were supplied through programs known collectively as REACH (Recognizing the Efforts of Associates Contributing at Honda).¹¹

Problem Definition

Sources of Data. Like Ford, Honda uses a mixture of customer-based and internal measures of quality. Warranty information isn't coded at the dealers. Rather, each warranty claim contains a page of written information about the problem and its repair that are further researched by QE. The internal quality system is relatively simple. The Honda sales organization that "purchases" vehicles from the plant carries out unannounced audits to check "fit and finish"; monthly at the beginning of each new model production and then

¹¹ The Kaizen program rewarded associates for process improvement suggestions and for involvement in the implementation of approved solutions. The Hawkeye Award was given for spotting, recording, and notifying coordinators about unusual quality problems, particularly those originating in upstream processes. The Safety Award was given for identifying ongoing and unusual safety-related problems. Finally, the NH Circle award was given to the group with the most impressive problem-solving process, quality improvement impact, cost-savings, and presentation to senior management. For all these awards, associates would gain points that could eventually be redeemed for prizes of various kinds, including (at the high end) a Honda vehicle. While Honda management originally expected that it would take five or more years for any associates to win a car, they have found that the most active associates have accumulated enough points for a car in 2½ years. Special ceremonies for Milestone awards (i.e. lifetime point accumulation), Champion awards (i.e. most points during one calendar year), and Top Ten awards (i.e. ten associates with the most points in one calendar year) provided the additional incentive of social recognition and public praise.

every other month. During daily production, VQ coordinators keep track of problems by listing them on a flipchart near their final inspection area. All day long, a steady stream of LQ and PQ coordinators, QE engineers, managers and team leaders come by to find out what is listed. Each department has one central area where quality, production, and cost information is tracked over time. Otherwise, quality charts are much less visible than at the Ford plant, although a higher percentage of charts are current and in use than at Ford.

“See It”: Actual Part, Actual Situation. Honda emphasizes having people actually see quality defects directly. LQ, PQ, and VQ coordinators, team leaders, and, at times, production workers will often go to another part of the plant to see a car with a defect. Persistent quality problems that are under investigation by QE are documented with sketches and photos as well as testing data. For particularly puzzling problems, the quality coordinators are sent to visit dealers to examine them first-hand. Honda has a saying for this, the plant manager told me: “actual part, actual situation.” The philosophy is that when a person sees a quality problem, s/he is more likely to analyze it systemically, to communicate the problem more accurately to others in his/her team or work area, and to be motivated to find a preventive remedy.

Deciding What Problems to Solve: Too Much Quality? I heard many stories about Honda’s willingness to make strenuous efforts to prevent defects from reaching the consumer. Interwoven in the corporate culture and often repeated, these stories helped reinforce the powerful idea that for Honda, quality and responsiveness to customer needs are the top priority. But there were costs associated with this strong culture around quality.

According to one American engineer, Japanese managers had a clear view about priorities for quality problems. “They [Japanese managers] take the view that we should find and fix all major quality problems first, and then fix as many of the minor problems as time permits,” he said, noting that “major” and “minor” are defined in relation to how customers will react. In contrast, he said, “the Americans, once they buy in, tend to become zealots.” Showing me a barely visible spot of dirt under the paint on the roof, he said, “A Japanese manager would let this go—but most American work-

ers wouldn’t.” As a result, this plant was known as the “pickiest” Honda plant, regularly reporting the highest defect rates in the company. At the time of my visit, only 19% of vehicles were passed “first-time through” all departments without needing some kind of repair—compared with 40–50% at other Honda plants. As one worker told me, “We build the best quality cars in the world, but it’s only because we take so long on them.”

This state of affairs was viewed with some concern by plant managers.¹² Honda had the goal of training its associates over time to distinguish between defects that were “customer acceptable” and those that were not. Indeed, at one point during my stay, I saw the plant manager marching a group of young quality coordinators out to the parking lot to re-examine a set of vehicles that they had pulled aside for minor defects that he believed were “customer acceptable.” Yet managers feared that the effort to teach associates to calibrate precise levels of customer acceptability raised the risk of undermining their motivation and commitment to quality.

Deciding What Problems to Solve: Cost and Consistency Concerns. As at GM and Ford, there were clear cases at Honda in which cost concerns affected the choice of what problems to solve. For example, a VQ coordinator told me about water leak problems that could result from air bubbles getting into the white sealer used for body panel seams when changing from one sealer drum to another. A special project team had examined putting in a larger storage tank for sealer with a permanent piping system, so the supply could be replenished by adding sealer to the tank without disconnecting the sealer hoses. But their conclusion was that the one-time investment for this change would be too costly and that instead, sealer associates would be urged to watch carefully for bubbles with each sealer drum change. Management seemed to believe that the remedy of associate attentiveness would be effective, if less fool-proof than the more capital-intensive solution.

Coordination with the plant in Japan making the same product also affected Honda’s decisions about

¹² The tendency for American workers to become, at first, overzealous about quality was reported at nearly every Japanese transplant I visited.

which problems to solve. For the new 1989 model, the weatherstripping for the quarter window (known as the quarter seal) was 10 mm too long, posing occasional installation problems. But, according to the assembly department manager, "we couldn't get the parts change justified through Japan." When the 1989 model was first introduced, with a relatively slow line speed, associates were generally able to complete the installation successfully. With the recent line speed increase, noted the department manager, "it's a lot harder to get the seals on—if there's a metal burr around the opening, the guys have to force the seal on, even hit it with a hammer."

But the sister plant in Japan was not having any problems with the quarter seal, so Honda's design engineers were skeptical about the diagnosis of a too-long seal, believing the problem might have some other source more directly under the control of the American plant. These engineers were unwilling to change the parts specification for all plants, or to allow a different parts specification at each of the two plants. The American managers and engineers voiced some frustration about this pattern, saying that Honda Japan was unsympathetic to their arguments that certain unique conditions at their plants (e.g. larger American hands, lots of trainees due to rapid growth) required unique solutions. Honda Japan was insisting on a consistency across plants, they felt, that was unrealistic and which deprived them of the independent right to solve quality problems as they saw fit.

Assigning Responsibility, Not Blame. Quality problems are assigned to different departments, but with an important difference from the GM and Ford plants. One senior American manager told me, "The accounting system is deliberately designed to minimize the time spent figuring out who's to blame." Some Honda plants, he said, have a miscellaneous category for problems (such as water leaks) that can't easily be pinned to a specific department. But at this plant, the management team decided to assign defects to some department, e.g. all body "deforms" assigned to the body shop, all paint chips to paint, and all water leaks to assembly, in the interests of calling attention to problems. The costs for these repairs, however, are covered from a plant-wide fund rather than charged to individual departments. As this same manager explained:

The reason to want to fix the problem is so we don't lose a customer—not so costs won't accumulate. It doesn't really matter how it gets paid for . . . If I find a problem and then piss off Tom by not fixing it or trying to blame him for it, then I have two problems. Honda's philosophy is that a problem with our product is a problem for the whole company, not for an individual or department.

According to one department head, this system disturbs some Americans, who feel there is not enough accountability in the system. "It doesn't help the rapport between departments," he said. Despite the absence of any accounting penalty for a high defect rate, some feel it would be more fair for defects to be attributed to the department that caused them. So far, Honda has resisted taking this approach.

Problem Analysis/Generation of Solutions

Breaking Down Status Barriers: "Everyone Builds Cars". Honda attempts to encourage problem-solving across organizational boundaries by breaking down status barriers between organizational groups. Physically, the administrative and management offices have a completely open layout—rows of desks facing each other, without partitions or other physical dividers. All employees wear the same white overalls and often a Honda cap. There are no separate offices for managers, even the plant manager. The offices are generally empty; one manager called his desk "nothing but a giant inbasket." Most meetings take place in the cafeteria.

Managers and engineers also carry out a regular daily stint of work on the assembly line—30–60 minutes a day, four days a week, a reflection of the plant's philosophy that "everyone builds cars." I accompanied one QE engineer, who spent forty-five minutes filling in for an absent operator on the line where the engine is readied for installation. He looked over the Operation Standard for the job, asked a few questions of the adjacent worker, and began. The job involved inserting and tightening some bolts, slipping a metal sleeve over some locator pins, and doing "marker checks"—checking a previous operation and marking "no defect" parts with an orange, green, or yellow marker. He said he liked the chance for some "hands-on" work. "I feel like I'm close to the action."

Temporary and Permanent Countermeasures. A key role for LQs was overseeing problem analysis and

coming up with planned remedies—called “countermeasures” at Honda. The head LQ coordinator, Tom, in the Assembly Department told me how one problem—a fuel line pipe with a deform in it—had been handled earlier that week. A production worker in the assembly department spotted the problem and contacted the team leader, who found the LQ coordinator for that zone. The LQ wrote down the Vehicle Identification Number (VIN) of the vehicle, inspected the problem first-hand, decided that the defect probably came from the supplier of the pipe, and called the PQ coordinator. The PQ was also shown the problem directly before calling the vendor to find out how many bad parts were in inventory. The LQ quickly examined the parts beside the line to determine how many were defective and discussed temporary “countermeasures” with the assembled group. In this case, the decision was to have the LQ, team leader, and one operator do “marker checks” on all OK parts.

If the problem comes from an upstream process rather than from a part, the LQs must decide whether the situation warrants bringing in someone from the upstream department to examine it first-hand. Tom gave the example of a gas tank coming to the assembly department from the weld shop with a serious deform. “Since I hadn’t seen it before, I went to get the assistant manager and two associates from weld to come and see it. They were able to analyze the problem, which saved us from doing it. Also, they got the feedback at the same time.”

The LQs may request multiple countermeasures to deal with a problem. For one water leak problem involving an unsealed gap in the inner wheel arch, Tom asked the paint LQ to do a temporary 100% inspection of the seal for that gap and the weld LQ to check the specifications of the robot applying welds in that area. LQs can face “a fair amount of animosity” in these situations, according to Tom:

It’s very sensitive. We don’t want to tell them how to do their job or be too opinionated. We may not understand why they’re having a problem. You can’t assume you know the reason. If you don’t have good communication skills, you don’t don’t last too long in these jobs.

The “Five Whys”. Finding a permanent countermeasure involves the careful, iterative examination of possible sources and remedies of the problem—a pro-

cess known as the “five whys.” The answer to the first “why” is often based on the easily observable or familiar antecedents to its occurrence. An attempted solution based on this relatively automatic diagnosis is unlikely to be successful for long, because there are other “root” causes that are only uncovered with more “whys.”

I learned about one case where the brakes in a car didn’t work well during testing—a safety problem, ranked as the most serious of all quality problems. The first “why” revealed that a metal pin had fallen into a brake subassembly and was causing a jam. The second “why” led to an examination of the work stations where the subassembly was attached, to no avail. The next set of “whys” led to the supplier, and to material handling between the supplier and the plant.

Finally, a Japanese engineer, convinced that the pin looked familiar, successfully tracked it to an upstream machine, unrelated to the brake system. The pin had been replaced during routine maintenance, hadn’t been thrown out, had fallen into the engine compartment, and eventually into the brake subassembly. The documentation of this problem-solving process, covering several pages, was augmented by a plastic envelope containing the mangled pin.

Simple experiments to test potential solutions for quality problems could be seen when walking around the plant. The plant was, at the time of my visit, struggling with one water leak problem brought about by a design change that eliminated the use of sealer around one part of the door. The fixture holding the front seat belt was moved forward, in this new design, directly onto the door post. Sealer on the door post was eliminated to guard against getting any on the seat belt, and replaced by a self-adhesive tape that wasn’t sticking well. The LQ coordinator showed me an experiment involving the heating of this tape under a heat lamp to soften the adhesive before application. An SPC chart nearby showed the careful tracking of “before” and “after” data.

Many of the quality coordinators expressed the importance of having data to back up your proposed countermeasures. According to Philip, a VQ coordinator:

When you come up with a countermeasure, anybody can challenge it. A bullshit countermeasure isn’t worth a damn. You’ve got to have the data to show it is effective.

Spontaneous Meetings, and “Y-gaya”. When a problem is major, with no obvious countermeasure, the LQ can decide to designate it as a “project” and get VQ involved. The VQ typically calls an immediate cross-departmental meeting, paging whichever VQ, LQ, PQ, and QE coordinators s/he feels is appropriate; managers sometimes attend as well. “Meetings can get big,” said one VQ, “but we find that they’re a good way to let everyone know what’s going on.” Most meetings I saw were held in the audit area or in the break areas for teams near the line; some meetings are held right at the site of the problem. Honda has a term for these “spontaneous” meetings—‘y-gaya,’ which translates as “act forthrightly,” or as one American told me, “just do it.” A key element of a ‘y-gaya’ meeting is that anyone with relevant knowledge of a problem is included, regardless of rank. The norm for such meetings is that those closer to the problem speak first. “But the managers forget that sometimes,” said one associate who had recently attended such a meeting. The degree to which such meetings actually achieve the kind of open communication across levels that facilitates problem-solving is heavily dependent on the behavior modeled by the senior managers and coordinators in the group.

Operations Standards and Process Improvement: The Tension Between Standardization and Change. An approved countermeasure, to move from being temporary to being permanent, must be written into the operations standards for the relevant jobs. These standards are a key feature of Honda’s approach to quality, both in insuring uniformity of process and in the problem-solving process. Workers are expected to adhere to these standards strictly, both within a team while rotating across jobs, and across shifts. Concerned about variation across shifts, the department managers had begun to require meetings of the LQ coordinators on each shift during the brief time they overlapped in the afternoon. I heard several complaints about the “rigidity” of this approach from American managers and associates. To them, it was natural for workers on different shifts to find their own favorite way of doing a job.

But from the company’s perspective, each individual’s “favorite way” introduces variation into the production process that can potentially cause defects. The

tension between encouraging workers to find quality problems and suggest process improvements while also requiring that they adhere strictly to operations standards has been noted in studies of the Toyota Production System (e.g. Adler 1992, 1993). Managers and engineers at Honda often differentiated themselves from Toyota on this issue. One VQ coordinator, reacting to my comment about the high number of vehicles in repair one day, said, “we’re not as reliable as Toyota, and we don’t pin everything down as much, but that’s because we are always doing new things.” He felt that frequent process changes were an important component of Honda’s flexibility and quality improvement, but that more repair was inevitable in that situation.

Yet for Japanese managers at the plant, the fact that process changes were frequent was all the more reason to specify tasks carefully after each change and then follow operations standards precisely. Thus the mix of principles that govern Honda’s quality efforts—insure that no defect gets to the customer and follow operations standards precisely, but introduce frequent design changes and continually fine-tune the production process—fits the new quality paradigm but is also quite difficult to implement and vulnerable to disruption. Quality standards can be set too high, incurring unnecessary costs. On the other hand, too much process change with insufficient attention to revising (and following) operations standards can introduce variability that can boost defect levels. As motivated associates set out to solve complex problems, animosities can emerge between departments if communication is not handled carefully. Yet if associates decide that it isn’t worth the trouble to push for high levels of quality, the entire quality system can deteriorate. Given the down-side risks of slippage in the commitment to quality if employees perceive mixed messages from management, perhaps it is no surprise that the Honda plant seemed to err on the side of “too much quality.”

Contrasts and Consistency in Problem-Solving

The case studies reveal both similarities and differences in shop-floor problem-solving for process quality improvement at these three plants. I have analyzed the case study data by looking for evidence of consistency

within each case across stages of the problem-solving process and by contrasting pairs of cases for various themes (Eisenhardt 1989). (Table 2 summarizes this analysis.) In this section, I draw generalizable insights from the case material and demonstrate how the cases support certain propositions and prescriptions from the organizational behavior and quality improvement literature that are not often tested empirically.

Quality System—Structure-Composition and Incentives

The case studies reveal that different structural arrangements can be effective at promoting the boundary-spanning communication needed for problem-solving. The GM quality system was least effective because it was almost entirely organized by department. The one cross-cutting group, at the senior management level, addressed the most obvious cross-functional problems but ultimately ended up arbitrating between the competing claims of responsibility from the departments. This suggests that cross-functional integration must occur at both lower and upper organizational levels.

The Ford and Honda approaches each have strengths and weaknesses. The Ford matrix structure of “subsystem” task forces and the Honda structure of “problem-centered” task forces both draw their members

from “vertical” and “horizontal” slices of the organization. Both promote norms of allowing those with the expertise on a problem to speak. Both have “resident engineers” from the product design function available to participate in meetings and work on problems.

These two plants differ in the degree of permanence of their problem-solving groups and in the decision rules for group composition. The Ford approach gives the group a continuing focus (the subsystem) and a stable membership. The full range of problems related to a given subsystem is taken on, with problems that span subsystems handled on an ad-hoc basis. Core members are intended to remain the same over time, with guests invited for their expertise on a particular problem. This approach may be ideal for amassing both expertise and cumulative knowledge about subsystem problems over time. The repeated interaction across functional groups and hierarchical levels provides ample foundation for the development of a common language.

In contrast, the Honda approach establishes “spontaneous” groups that meet only until a problem is resolved, with members chosen for their relevance to that problem—potentially a quicker way to amass the right combination of resources for a given problem than the Ford approach. This may also avoid the stultifying group dynamics that can often accompany long-lasting

Table 2 Plant Case Studies—Contrast and Consistency Comparisons

Theme	GM	Ford	Honda
Quality System			
Structure	By department	By subsystem	By problem
Composition	Stable membership No design engineers	Core members plus Design engineers	As needed for problem Design engineers
Incentives	For managers only; no payout for workers from profit-sharing	For managers; plus large pay- outs for workers from profit-sharing	Plant-level performance bonuses for both managers and work- ers
Problem Definition			
Sources of Data	Internal	Internal and customer	Customer and internal
Categorization of Problems	Plant vs. corporate	Plant vs. design vs. vendor	Fuzzy, problem-centered
Problem Framing	“Avoid corporate”	“Don’t touch metal”	“See it”
Lens used	Cost	Cost/quality	Quality/cost
Problem Analysis/Generation of Solutions			
Purpose	Accountability	Documentation	Diagnosis
Process	“Who shot John?”	Definition as diagnosis	Root cause
Scope of Search	First-level cause	First-level cause	“Five Whys”
Experiments	No systematic data	“After” data	“Before” and “After” data

committees with fixed membership. However, such groups will not have any “memory” about the incidence of past problems or the value of previous remedies. Furthermore, the fluid membership and short time duration of these groups may only be possible in an organization with a strong culture and clear norms for communication processes (e.g. “those closest to the problem speak first”). Even with such a culture, it may take longer to develop a “common language” than in Ford’s approach, since any one individual has a relatively brief exposure to other members of a given problem-solving group.

It is worth noting the multiplicity of quality-related structures at these plants, e.g. organized by team, department, cross-department, subsystem, problem focus. This multiplicity seems deliberately chosen, despite the potential for redundancy, because of its benefits for quality. Clearly not all of these structures are equally effective, and there will be variation in the efficacy of any given activity. But the redundancy may help create a climate of attentiveness to quality problems, establish the conditions for “opportunity framing” (discussed further below), and assure that no problems fall through the cracks.

While all three plants provide managers with incentives to improve quality, they differ substantially in the incentives for production workers, supervisors, and other lower-level staff and clerical employees. GM’s profit-sharing plan was paying nothing to workers while corporate bonus plans continued to reward executives heavily. Ford’s similar profit-sharing plan had made large payouts (ranging from \$2500–7500) to workers, who tended to perceive the bonus as linked to quality improvement as much as (or more than) productivity. Honda had the most extensive set of incentive programs, applied to all employees and explicitly encouraging problem-solving. In contrast, the GM and Ford profit-sharing plans did not explicitly reward plant-level problem-solving, with bonuses that were tenuously linked (if at all) to plant performance in a given year.

Problem Definition/Analysis—Sources of Data

The case studies suggest that both customer data and internal data, as well as the direct observation of defects where they occur, can provide valuable clues for

problem-solving. The value of customer-based data is a function of how effectively it brings market-based information to bear on internal problem-solving processes—what Cole, Bacdayan, and White (1993) call the “market-in” principle—“bringing customer needs into every possible part of the organization, thereby heightening uncertainty.” Cole (1990) also emphasizes the value of quality as a superordinate goal able to unite groups typically in conflict—different departments, different functions, or management and labor. Customer-based data help communicate the overarching nature of the quality goal, and are arguably more powerful when they reach plant problem-solvers directly, e.g. worker visits to dealers at GM and Honda; verbatim comments on warranty reports at Ford and Honda.

In contrast, the value of internal data should be a function of the proximity they allow between processes of problem definition and problem analysis. Here the Honda case points to the value of direct physical observation of a problem situation. This is similar to Tyre and von Hippel’s work (1993) on the importance of the physical setting in prompting adaptive learning; and Leonard-Barton’s (1991) finding that the examination of a physical prototype during design facilitates cross-functional communication and the development of a common language. Dialogue about problems located at the “actual place, actual situation” may both yield a common language and a common understanding of what standards should be applied to deciding what will or won’t be defined as a problem—something that proved elusive at the GM plant, despite the attention to problem terminology.

While customer data and internal data can differ, combining both kinds of data may result in better problem-solving outcomes than when relying solely on one data source. The two sources of data reveal cognitive differences between the customer perspective and the plant perspective, and the effort to make sense of these differences can yield insights to guide problem definition and analysis. In each of the cases, there are examples of different sources of customer data being combined—written descriptions by customers of warranty problems (Ford and Honda); visits to dealers to talk with customers or see problems (GM and Honda); calls to new buyers (GM)—that offer more richness of information (Daft and Lengel 1986) and increase the

probability of successfully bridging the cognitive gap between the customer and plant perspectives.

Richness of information may also be related to the speed of problem resolution. The Honda approach of “see the actual part in the actual situation” is clearly more costly in employee time than a written defect report. Yet if it allows the early elimination of defects, the preventative benefits may outweigh the costs. While time-based measures of problem resolution were not explicitly gathered for this study, my observations suggest that Honda developed both temporary and permanent countermeasures fastest, followed by Ford and then GM. Where “market-in” principles boost uncertainty, the effectiveness of problem-solving may depend in part on its speed, consistent with Bourgeois and Eisenhardt’s findings (1988) about high-velocity decision-making.

Problem Definition: The Categorization of Problems

Recall that the problems investigated here were chosen because they commonly have multiple sources. This makes them particularly difficult to categorize—often important both for defining problems and establishing priorities for problem-solving. Yet the quality system at the GM and Ford plants emphasized the strict categorization of problems either by department (GM) or as “design, vendor, or plant” (Ford). One consequence, at Ford, was that the resident QPRESS engineers felt they should investigate only “design” problems and leave “plant” problems to plant engineers, even though many problems involved both design and manufacturing. In contrast, Honda tried to avoid the strict classification of problems in various ways: the simple list of daily problems in the final repair area, the emphasis on seeing a problem *in situ* rather than sending it back to its supposed source, problem-centered temporary task forces composed of anyone with relevant expertise, and an accounting system that did not attempt to determine which department should be assigned the costs of a problem. This suggests the value of putting problems into “fuzzy” categories, to use a term drawn from the psychology literature on categorization.

The strict classification of complex problems into one category and not another exemplifies the “classical” view of categorization (Gardner 1987)—categories have defining or critical attributes that determine what items

are members and what items are not; members possess these attributes, nonmembers do not, and there is no overlap between them (Smith and Medin 1981). In opposition to this view, Rosch and Lloyd (1978) have argued that the cognitive structure of categories is based not on “necessary and sufficient” criteria but rather on “prototypes”—objects that share the greatest number of attributes with other category members. Prototypes are mental representations that contain the most information about a category, are most easily learned, and are most quickly given as examples of a category. Other category members are located at varying distances from the prototype; their degree of similarity (or dissimilarity) to the prototype represents the degree to which they are members of the category. Thus categories and their boundaries are “fuzzy” rather than sharp. Many objects belong to more than one category, but are “better” members of the category in which they share the most attributes with the prototype.

The analogy to problem-solving is as follows. People can provide prototypical examples of certain problem categories, e.g. design or vendor, paint or electrical. When confronted with an actual problem, they compare its characteristics with these “prototypes” to decide how to classify it. Problems that resemble prototypes closely are easy to categorize, but others may be identified as “somewhere in between”—e.g. partly design and partly manufacturing, or partly electrical and partly water leak. This ambiguity about category is valuable information for finding the “root cause” of a problem. If quality systems force problems into one category or another, and problem-solving proceeds differently as a result, the benefits of rich, ambiguous data will be lost and the search for solutions may be misdirected. “Fuzzy” categories can help to preserve rich data about problems as they are communicated from one organizational member or group to another.

Problem Definition: Framing Problems as Opportunities

Problem analysis and solution generation, at both individual and organizational levels, are strongly affected, during problem definition, by whether problems are framed negatively, as liabilities or threats, or positively, as opportunities. For individuals, Dutton (1993) claims that an “opportunity frame” serves to give issues

a "positive gloss" and to suppress certain undesirable threat effects. "Issues that are wrapped in opportunity frames are almost irresistible because of the positive 'charge' or emotion and sense of control that such issues evoke" (Dutton 1993, p. 200). This positive emotion is associated with more creativity, speedier decision-making, and a search for more integrative solutions to negotiations tasks (Isen and Means 1983).

At the same time, at the organizational level, Jackson and Dutton (1988) found that individuals have a hard time seeing organizational events as "opportunities" unless they can rule out any sense of threat—since threat is strongly associated with reduced search for external information and an increased likelihood of resorting to dominant, well-learned responses that may not be appropriate to the situation (Staw, Sandelands, and Dutton 1981). When threat can be ruled out, framing issues as opportunities can signal and legitimize ideas of proactiveness and innovation. "Opportunities" create what Eisenberg calls "strategic ambiguity"—allowing for "multiple interpretations while at the same time promoting unity" (1984, p. 231). Opportunity framing also looks forward rather than backwards, "refocusing collective effort from past and present towards the future" (Dutton 1993, p. 203). However, the organizational context must both motivate individuals to frame issues as opportunities and convince them that it is feasible or reasonable to do so. Issues must be perceived as controllable, positive, and with potential gains.

There is ample evidence of both negative and positive framing in the three cases. Negative framing occurs when individuals or departments believe that they will be penalized if they are associated with a problem. The accounting system at GM, with its preoccupation with "Who shot John?," is a good example. The difficulty in getting a speedy and effective response from product designers in Detroit would also prevent GM plant personnel from believing that problems are "controllable" with high potential for "positive gain." Under these circumstances, the prospects of opportunity framing are low.

At Ford, the prospects are considerably higher. The cross-cutting subsystem structure, the creation of new lower-level liaison roles (ZIPs), the repeated use of quality as a superordinate goal capable of mustering

broad support across organizational boundaries should all support the view of problems as opportunities. However, as at GM, there are mixed messages about the gains from finding problems, particularly those where quality remedies have short-term cost implications. The message from managers at one subsystem meeting—try new things but try not to make mistakes—is unlikely to suppress the sense of threat if failures do occur.

Honda clearly works hard to create opportunity frames for problem-solving, both in its philosophy—"a problem with our product is a problem for the whole company, not for an individual or department"—and its systems—"the accounting system is deliberately designed to minimize the time spent figuring out who's to blame." Several people at the plant told me their paraphrase of a famous saying of Soichiro Honda, the company founder: "It's OK to fail 99 times as long as you succeed on the 100th time." The importance given to quality legitimizes the actions of low-level LQs who "drag managers" to their department to see a problem. Yet clearly this is not an easy process. Being confronted with a problem still can be an emotionally-charged event, particularly if accompanied by a quick categorization or smug diagnosis of cause.

Sitkin (1992) points out the difficulty, and the value, of changing the way an organization views failure. While successes have the benefit of positive reinforcement, the absence of failure (or the suppression of evidence of failure) can weaken organizational resilience when facing uncertainty and resource constraints and can increase managerial overconfidence. Large failures can be devastating, but "small failures" can be an important way to learn, because the experience of failure prompts experimentation. As expressed by Lounamaa and March, "performance improvements are confounded but performance decrements contain information" (1989, p. 116). The benefits of "small failures," according to Sitkin, include: closer attention to potential problems, ease of recognition and interpretation of problems, the stimulus of search processes, greater tolerance for vulnerability, and more efficient problem-solving through practice. "Intelligent failures" can be facilitated when the organization's culture legitimizes "learning through failure" and when management emphasizes "failure management systems" rather than individual failure.

The public presentations made by NH Circle or “special project” group members at Honda serve an important function in legitimizing “intelligent failure” by providing a template for how “learning through failure” occurs. Robert Cole makes a similar observation based on recent field research in Japan:

Typically, these problem-solving presentations include a history of the problem-solving activity, including a discussion of the blind alleys and failure modes that were pursued. Thus, they document a process by which failure and errors are overcome to produce success. In so doing, we see that errors and failures are treated as positive learning experiences. Top management officials, who often attend such sessions, associate themselves with an event in which learning from failure is a key theme (Cole 1992a, p. 12).

This is a good example of what Sitkin calls a “failure promotion system at the organizational level.” Organizational practices that frame problems as opportunities help counteract certain natural psychological and information-processing tendencies in human beings, increasing the effectiveness of process quality improvement.

Problem Definition, Problem Analysis, Solution Generation: Quality Lens vs. Cost Lens

In all three cases, the problem-solving process was heavily affected by whether quality or cost is used as the “lens” during the definition and analysis of problems and potential solutions. For example, “customer acceptability” is a criterion used by Honda to establish which defects should be addressed first (or at all). This quality lens generates a decision rule that defects which are unacceptable to customers should always be addressed. To use Juran’s terminology (1988), the “external costs of poor quality” are by definition too high if customers are unhappy, and thus from a cost-benefit perspective, it will always be worthwhile to incur some prevention costs. Similarly, minor defects that are acceptable to customers—more precisely, not unacceptable (or not noticed)—should not be addressed even if the cost of remedy is low. In this situation, the “costs of failure” are negligible and may exceed the “cost of prevention.”

When problems and solutions are evaluated first with a cost lens, decision makers may decide, based on short-term calculations, that the “cost of prevention” is greater than the “cost of failure.” Yet when managers

think about quality and cost in a “no tradeoff” way—another kind of “opportunity framing”—they are more likely to accept the short-term cost of defect prevention activities that will improve both quality and productivity in the long term (Cole 1992b).

The case studies support this hypothesis in several ways. At GM, managers worried about the amount of time and energy directed towards finding out “who shot John.” Pinning down cost responsibility interfered with using data about problems for careful “root cause” analysis and problem elimination. At Ford, cost concerns often justified the deferral or avoidance of actions that could reduce defects, in what employees often saw as a contradiction of the company’s overall commitment on quality. Honda worked to develop an organizational culture that emphasized “quality first” while adopting an accounting system that deemphasized departmental preoccupation with the “cost of failure.” Yet this did not mean that all quality defects were addressed immediately with no concerns for the cost of prevention. Cost was used not as a basis for deciding whether or not to fix a “customer unacceptable” defect but rather to determine the least costly remedy.

Problem Analysis/Generation of Solutions: The Standardization-Experimentation Cycle

Tyre (1989) and Tyre and Orlikowski (1994) have usefully challenged the notion of “continuous improvement” as an uninterrupted process of constant change. They note that most adaptive learning in the face of technological change follows a “punctuated equilibrium” model—rapid learning immediately after the change is made, followed by a longer period of routinization during which minimal (or no) changes are made. They cite ample literature, and their own findings, to suggest that this is a normal pattern of human and organizational behavior.

My observations confirm that adaptive learning alternates between periods of experimentation with process improvement and periods of relative stasis—if only because problem-solving activity is typically triggered by the appearance of a problem and stopped when a solution is found. However, these case studies also suggest the benefits for process quality improvement of organizational mechanisms that are “disequilibrating,” i.e. which limit the period of stasis by jarring

individuals out of their routines and prompting them to return to experimentation. Imai (1986), writing about "kaizen" (the Japanese term for continuous improvement), emphasizes the crucial role of standardization in process improvement, in which extremely detailed and careful specification of the process is undertaken, far beyond what is necessary to keep the process running routinely. This specification provides a crucial base line of data against which all future improvement efforts will be evaluated. It also codifies whatever gains have been made since prior improvement efforts.

Whereas routinization implies process stability until some unforeseen event disturbs existing routines, standardization has a different meaning in a "problems as opportunities" culture. Completion of the specification process signals that the search for problems or possible performance enhancements can (and should) begin again. The idea that standardization should be the beginning rather than the end of the learning process is analogous to the use of the term "commencement" to mark the graduation of students from high school or college. Similar to opportunity framing, it orients the individual and the organization towards the future rather than the past, and strives to overcome the inertia that can accompany the end of a long and difficult passage by providing a reason to look ahead to the next challenge.

Particularly relevant here is the prevalence of experimentation in the case studies and the use of "before" and "after" data. Experimentation at the GM plant was limited and the use of data haphazard. As noted previously, data collection was often used for accountability and not for problem analysis or the generation of solutions. At the Ford plant, the emphasis on problem analysis to report that action was being taken meant that data was typically gathered after some remedy was tried but not before. Thus there was often no base line to evaluate whether the remedy in question was effective or to compare the merits of different remedies. At Honda, documentation of process improvement efforts always included "before" and "after" data, experimentation with different solutions was common, and complete standardization of the process was required before further improvements could be pursued.

Even when standardization is taken as a signal to begin new process improvement efforts, it does not mean

that the same problem, job specification, or machine is addressed time after time. "Standardization as the beginning and not the end" should be understood as a goal that drives the constant *activity* of process improvement in some part of the plant's operations. Alternating cycles of experimentation and stasis are expected for any one process or step or piece of equipment. But across the plant, efforts are made to avoid any period of stasis through policies that promote constant search for the next opportunity for process improvement.

Conclusion

Problem-solving benefits from rich data that capture multiple perspectives on a problem and contain information about the physical context in which the problem occurs; problem categories that are "fuzzy," in the sense that problems are not forced into rigidly-defined groups but are perceived in terms of their degree of similarity (or dissimilarity) to complex problems observed previously; and organizational structures that facilitate communication across group boundaries and the development of a "common language" for discussing problems.

Also, when problems are framed as opportunities for learning and not liabilities to be avoided, problem-solving will benefit from the combination of positive attributions that boost motivation and the suppression of threat effects that can lead to reduced search and reflexive routine responses. Evaluating problems and potential solutions first in terms of quality criteria and only then in terms of cost creates a mindset that favors investments in process improvements, incurring short-term "costs of prevention" in order to reduce long-term "costs of failure"—the opposite effect from that of traditional accounting systems. Finally, when process standardization is understood as marking the beginning (and not the end) of further improvement efforts, the normal inertial tendencies of organizations with respect to adaptive learning can be partially overcome. These findings suggest the value of identifying and understanding the role of "disequilibrating" mechanisms and procedures used by an effective "learning organization" as a means of influencing the cognitive processes of its members.¹³

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