IMPLEMENTING STATISTICAL PROCESS CONTROL: A CASE STUDY IN A HIGH-TECHNOLOGY CULTURE

by

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ABSTRACT

Ray Stata, Chairman of Analog Devices, asserts that the role of top management is to create systems to attain strategic objectives, as opposed to frequent intervention seeking short-term gains. This thesis investigates one initiative within the company's implementation of Total Quality Management, the introduction of Statistical Process Control (SPC) for processes in the test and assembly work areas of the Wilmington, MA plant. The objective is to test whether the subsystem established is viable, and simultaneously consistent with a culture promoting quality improvement.

Research for this thesis was conducted through interviews with the self-managed SPC group of facilitators at Wilmington and two experienced SPC team leaders. Additionally, reports from past SPC implementation projects and corporate/divisional guidance concerning SPC and quality were examined. The preparation of this thesis entailed the weaving of the collected information into a structure constructed from concepts on quality, group dynamics and organizational behavior.

For this thesis, success is defined as bringing a process under control and adding to the company's problem-solving skill base. Research indicated that the probability for success was improved by (1) limiting the scope of the task; (2) maximizing the contributions from all members of the team; (3) maintaining administrative control over the process by the team leader; and (4) providing managerial attention to support improvement of capabilities within the team.

Teams are established at Analog to accomplish breakthroughs, placing processes under control and improving process capability. The teams provide for the preservation of gains by establishing control charts for monitoring and Out-of-Control Action Plans. Performance of teams varies widely, significantly impacted by the conflict in the organizational culture and the behavior which would favor a team seeking breakthrough. Analog has prospered by focusing on rapid product and process innovation, while the SPC teams seek gains by establishing control over existing operations. The culture must adapt to accommodate this conflict by allowing different norms during team-based improvement activities.

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Chapter 1
Introduction

Statistical Process Control

Statistical Process Control (SPC) combines several quality improvement tools towards the goal of assessing and affecting variability of production processes. A list of the principle tools is shown as Exhibit 1-1. SPC is utilized for three purposes:

(1) improving productivity through reduction of defectives;

(2) maintaining efficiency gains through monitoring processes already under control; and

(3) increasing the capability of processes for yield with given product specifications.

Defectives are reduced by identifying causes, and reducing their impact. The SPC philosophy asserts that defectives result from variation: in materials, equipment condition, work methods and the environment. A logical methodology allows the quality improvement tools to be applied in a structured search for specific causes; e.g., unnecessary adjustments of process equipment. Once identified, these causes are attacked. Causes can be segregated into two categories: those common to all output and those unique (special) to a portion of the output.

A process is said to be "under control" when all apparent "special causes" are eliminated. But variation can never be totally eliminated; the possible causes are effectively infinite. However, the probability of producing defectives by a process under control is finite, a function of the amount of common variability present. The same improvement process can again be

List of Quality Improvement Tools Used in SPC

Seven Basic Quality Control Tools

1. Histogram
2. Checksheet
3. Pareto Diagram
4. Cause and Effect Diagram (also called Ishikawa or Fishbone diagrams)
5. Graphs
6. Scatter Plot
7. Control Charts
    a. X-Bar Chart
    b. Range Chart
    c. S-Chart
    d. Moving Average Run Chart
    e. Attribute Control Chart (p, np, c, u)

Others

8. Design of Experiments
9. Process Flow Diagram

Exhibit 1-1

applied to reduce the impact from the "common causes", thus improving the capability of process to consistently produce within specification limits.

Control Charts

The heart of SPC is the control chart concept, developed in the 1920's by Walter A. Shewhart of the Bell Telephone Laboratories. The many variations of control charts are able tools for monitoring a process under control, and alerting operators of the return of "special causes" (or the appearance of new factors) that interject extra variability into the output. The presence of "special causes" is observable because they create an out-of-control condition. Control charts use upper and lower control limits. Points that plot outside these limits indicate that the process is out-of-control, since such an occurrence is unlikely based upon calculations which account for the historical process variability. Additionally, improbable tendencies in the distribution of points may signal the process is out-of-control. The probability of erroneously assuming the process is out-of-control can be determined using statistical theory, as well as the average time period needed to detect a shift of some magnitude (termed average run length). The parameters chosen for a control chart limits represent the tradeoff between unwarranted corrective action and the loss experienced when defectives are produced unnecessarily.

Implementation of SPC

Implementation of SPC can be divided into three phases, corresponding to the three purposes of SPC listed earlier. First, one or more processes are brought under statistical control by eliminating the significance of any "special causes" initially present. Then, a system is established to maintain control of the process. Third, the process capability may be improved.

Only the first two elements are necessary to claim successful implementation of SPC. A sound methodology first requires understanding and simplifying the process. Then the variables that may impact the selected quality characteristic must be listed. Experimentation can uncover the degree of impact (and the most favorable setting) of each input. A trial control chart should then reveal if all the significant inputs have been identified and locked. Finally, a system to monitor the quality characteristic to ensure the process remains in control must be activated. This requires identifying departures from control and scientifically determining the "special cause".

But much of the potential gains can only be realized by successes in the third phase. Improvement is possible because of the principle that the probability of producing defectives from a process in control is determined by the common variability inherent in the system. After a structured search for the common causes, these are ranked by descending contribution to defectives. Then efforts can be made to reduce the variability by targeting the largest contributors and/or the simplest to remedy. Thus, the process yield will reach a new, higher level of performance.

Quality Frameworks

The modern concept of quality, a creeping revolution which has gained increasing importance in competitiveness over the past twenty years, requires objective evaluation rather than a vague notion of "goodness". Overall quality is a function of one or several observable quality attributes.

Still, several paradigms of quality exist, generally identified by their association with quality "gurus".

Exhibit 1-2 is a comparison (suggested by Fine, 1987) of three principle quality paradigms: (1) the Deming model; (2) the Juran model; and (3) the "Japanese" model. The Deming model is based on the writings of Dr. W. Edwards Deming and is epitomized by its definition of quality as "conformance to specifications". The Juran model is derived from the teachings of Dr. Joseph Juran, and is differentiated by the term "fitness for use". The Japanese model is a composite of several Japanese scholarly and industrial programs which are generally considered to represent Total Quality Management or Total Quality Control.

Professor Shoji Shiba of Tsukuba University rejects the notion that the various approaches to quality are distinct. Instead, they represent different stages along the evolution of the modern quality concept. The Juran model is an improvement of the Deming model, since Juran's "fitness for use" incorporates conformance to specifications, and goes further by including the necessity that the specifications adequately meet customer needs. The Japanese model defines quality as a means to delight the customer, by meeting both the basic and latent needs (met through features) of the customer. The evolution follows a path which shifts the determination of quality away from the producer to the consumer.

Although most definitions of quality are related, the approaches for ensuring quality vary in the combination of motivation, use of quality tools, and priorities for implementation.

Comparison of Quality Frameworks

	Deming Approach	Juran Approach	Japanese Apprach
Philosphy	Fitness to Standard Quality is Essential for Long-Term Survival	Fitness for Use Project prioritized by Cost of Quality	Continuous Improvement for Routine Projects prioritized with Strategic Objectives
Decision Rule	Direct (Physical) Measures of Quality (i.e., Defect Rate)	Cost of Quality: Failure, Apprasial, Prevention	Direct Physical Measures Increasing Cost of Variability
Focus	Improve conformance to specs (design and mfg)	Combine Design, Conformance, "Abilities", Field Service to Satisfy Customer	Continuous Improvement for Existing Products/Processes QFD for New Products
Process	Top management eliminates common problems, individuals solve own unique problems	Control--Control Sequence Improvement--Breakthrough Planning--Annual Program	Process Control, Performance Displays Self-Inspection and Correction Quality before Production
Cycle	Design-Manufacture-Test Sales-Market Surveys	Market Research-Development Design-Planning for Mfg Purchasing-Process Control Inspection-Test-Sales	Continuous Improvement Overlapping Plan-Do-Check-Act Cycles
People	Top Management Responsible Every Worker Accountable	Top Management sets Standard Workers Responsible if provided Self-Control	Total Participation Responsibility and Trust

Exhibit 1-2

Breakthrough vs. Control

Juran (1964) explores the difficulties faced by management when simultaneously accepting two distinct roles:

(1) Breakthrough, reaching improved levels of performance; and

(2) Control, maintaining existing levels of performance.

Individuals find the conflict even more stressful since they are unable to use the coping mechanism available to organizations, dividing responsibilities for the two functions.

Breakthroughs can be incorporated after discoveries found through systematic observation or experimentation, accidents, or through importation. Control is purchased with standardization of procedures and processes. SPC combines systematic investigation with standardization to achieve breakthrough/control cycles.

Thus, SPC initiatives must face this dichotomy. "Special causes" are eliminated and their undetected return prevented. A new level of performance is reached and its preservation ensured. But the requirement to switch roles between activities makes implementation of SPC challenging.

Chapter 2
Methodology

General Literature Research

Preparation of this thesis began with literature research in three areas: (1) the quality paradigms contrasted in Chapter 1; (2) instructional texts on statistical process control; and (3) discussions in the business press on implementation (primarily concerning the necessary training) of SPC.

Interviews

An extensive interview was conducted in a group setting with the SPC group (of facilitators) and Quality Manager at Analog Devices' Wilmington, MA plant. The crucial finding from this interview was the perception that success for teams implementing SPC was most significantly influenced by the team leaders' performances. Based on this hypothesis, interviews were conducted with two team leaders working with their second teams to uncover the key parameters that determine team leader performance. One leader's performance was considered above average by the SPC group, the other below average. The SPC group did not identify which leader they perceived as superior before the interviews to reduce the potential for interviewer bias. Since the perception of team leader performance and team success are correlated, I will differentiate the individuals as the "more successful" and "less successful" team leaders throughout this thesis. Additionally, I attended a team meeting conducted by a third team leader. This was an invaluable experience in viewing the different roles assumed by the participants in the team, including the team leader, supervisors, a technician, operators, and a middle manager who took part in the meeting.

Specific Literature Research

Specific literature related to Analog Devices was evaluated to understand the environment where SPC is being implemented and the strategic orientation (both past and present). This material included:

(1) corporate reports;

(2) SPC at ADI (a pamphlet standardizing SPC activities and terminology published in March, 1992);

(3) TQM at ADI (a pamphlet outlining the corporate quality improvement program published in July, 1991);

(4) SC-0150 Statistical Process Control Program (the specification which guides the semiconductor division's SPC program);

(5) Training presentation for technicians;

(6) Training presentation for operators; and

(7) four final reports from SPC teams.

Total Quality Management Seminar

Participating in a TQM seminar taught by Professor Shoji Shiba was extremely helpful in preparing this thesis. Beyond the many insights made manifest, Professor Shiba serves as the principal consultant on quality improvement for Analog Devices. Therefore, the quality model which precipitates ADI's quality improvement process is closely aligned with his teachings. Additionally, Ray Stata and Arthur Schneiderman, the Chairman and Vice President of Quality at Analog Devices respectively, gave lectures for the course concerning the history and current status of the implementation of Total Quality Management within the firm.

Limitations

Since the interviews used a small sample and findings were not collaborated with extended observation, any conclusion of this thesis requires validation before becoming a basis for action. Also, only a segment of the larger quality improvement effort was investigated; interactions, which should be expected to significant in a coordinated Total Quality Management environment, were not explored. However, the findings do form the basis for further examination.

Chapter 3
History and Culture of ADI

ADI: An Innovator

Analog Devices was established in 1965 as a manufacturer of components for real world signal processing. Early products were limited to simple circuits such as digital-analog converters. It experienced immediate and sustained rapid growth, averaging approximately 25% per year, powered by the pioneering of new circuit designs and production processes. The product line evolved with technology; now ADI considers itself the global leader for supplying data acquisition components used in precision applications.[1] The firm purposely created a culture which spawned technical innovation, "the cornerstone of customer satisfaction and business success".[2]

A Changing Environment

In the 1980's, the business environment changed. Technology allowed more elaborate combinations of distinct circuits to be placed on a single silicon wafer. The special purpose chip (actually a combination of standard circuits dedicated to a specific function) became a much more attractive market segment than the standard function chips, on which ADI had previcusly concentrated. The design and production of this new generation of products is immensely more complex. Managing this complexity, and the accompanying risk, became a central concern for management.

The shift from standard to special function chips also caused a significant change in relationships with customers. ADI's sales to its largest ten customers for standard function chips had traditionally

1 Ray Stata, Analog Devices Stockholders Meeting Address, 1988, p.2.
2 TQM at ADI, 1991, p. 1.

not exceeded 20% of its sales. Sales of special function chips, however, are highly concentrated and the supplier-customer interdependence is extremely pronounced. A design or yield problem can cause a customer of standard function chips to seek the item elsewhere. A similar problem on a special function chip results in armies of the customer's engineers descending to force elimination of the problem because a substitute is not immediately available from any other source. Problems may encourage the award of future business to a competitor. A reputation for reliable delivery is a critical for element in supplier selection.

In this environment, "customers will select vendors first and products second and they will limit their vendors to those who consistently meet escalating standards for quality and service".[3] Supplier evaluations involve:

(1) on-time delivery;

(2) parts per million defective;

(3) lead time requirements;

(4) responsive and open communications; and

(5) innovative solutions.

Conflict in Culture

ADI had followed its successful path guided by a goal of meeting the rational expectations of customers, employees and stockholders. Now, the expectations of customers needed to be raised to secure a competitive advantage even to satisfy the other two stakeholders.

Corporate tradition had rewarded managerial and technological breakthrough, assuming adequate control functions were established through product and process specifications unless a problem demanded

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3 Stata, p. 1.

attention. The focus on breakthrough allowed control problems to proliferate. The new environment brought a tremendous, and ironic, challenge: maintain the pace of breakthroughs while improving on the existing control structure. Control problems undermine the desired reputation as a reliable vendor, a problem against which technical excellence cannot compensate. Top management was convinced that long-term survival depended on not just tilting the balance towards parity, but progressing along both fronts.

Evolution of Quality Framework

Top management at Analog observed the change in the business environment in a disturbing manner, the tremendous annual growth rate that had been characteristic of the company since its inception began to moderate (In 1984, the growth rate fell below 10%). Recalling a report issued by Hewlett-Packard critical of quality offered by American semiconductor suppliers, Analog hypothesized that a quality focus may offer a solution. Senior executives traveled to the Crosby School of Quality.[4] But after being motivated to realize competitive advantage through quality, they paused as though inflicted with paralysis. Things were in some ways more uncomfortable; now the problem was apparent but solutions to dispatch it remained beyond their grasp.

A strategy consistent with Crosby's teachings (Crosby, 1979) prevailed. The executive committee resolved to bring in someone well-versed in quality tools. Arthur Schneiderman was appointed Vice President of Quality. Schneiderman brought tested quality methods, and with these began to

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[4] The Crosby philosophy was developed by Philip Crosby, once the Vice President of Quality for ITT. It stresses the costs of defects and sets an ultimate goal of "Zero Defects". The guidance provided by classes, lectures and books provides little direction to attain quality other than a policy to make products conform to requirements or change the requirement.

attack a myriad of problems. The resulting efforts provided considerable success, especially in improving yields and on-time-deliveries.

But top management remained concerned; improvements seemed isolated events rather than the desired epidemic infecting the entire organization. Assistance was sought to bring structure to the quality program using a Total Quality Management (TQM) philosophy.

In 1989, ADI began a relationship with Professor Shoji Shiba as a quality consultant, and became a founding member of the Center for Quality Management.[5] TQM became a central element of the company's business strategy.

TQM provides three tenets:

(1) Focus on customers;

(2) Continuous improvement; and

(3) Total company involvement.

ADI remains committed to these ideas, and actively seeks to spread the message on the importance of a quality management focus.

Ray Stata, the Chairman, has a deep conviction that the management of quality is a "critical technology" for the nation, a view is he has championed on the Council on Competitiveness. A related long-held principle espoused by the leading quality organization in Japan, the Japanese Union of Scientists and Engineers, that trade secrets do not hold within the realm of quality improvement, has been received with skepticism in America. For example, the SPC group's efforts to cooperate with other semiconductor manufacturers in SPC implementation methodology and training have been rebuffed. A recognition that cooperation is not a zero-sum game is lacking.

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[5] An association of high technology companies firmly committed to quality management and shared learning.

Chapter 4
SPC at ADI

Background

Analog Devices Semiconductor Division (ADS), the company's largest, is located at Wilmington, MA. Circuits are fabricated through chemical and photolithographic steps onto silicon slabs in a work area called "wafer fab". This area is locally referred to as the "front end". After fabrication, the wafers are passed into the "back end" for laser trimming, separating and assembly into integrated circuits. The chips are also tested and labeled in the back end before further processing a separate Analog plant.

The implementation of SPC in the back end began during the first quarter of 1989, after being used extensively in the front end operation since the early 1980's. This situation was not uncommon for the industry; wafer fabrication processes were well researched and scientific production methods widely applied. Due to resource limitations which prevent immediate and simultaneous action to place every process under statistical control, teams have been deployed to critical nodes, or priority processes. These teams consist of supervisors, technicians and operators led by a manufacturing engineer meeting one hour each week.

Because of the tremendous complexity involved in integrated circuits production, process and product specifications tightly control routine work tasks. Employees are trained to respect the guidelines. Therefore, breakthroughs needed to improve the processes are tasked to teams which operate with norms that differ from those of the formal organizational. Management attempts to include all those affected by the anticipated process changes in the team.

Role of SPC

Total Quality Management at ADI includes proactive, reactive and control problem-solving. Proactive problem-solving seeks to identify potential quality problems before they materialize, and take corrective action before the problem can surface. An example is Quality Function Deployment techniques to investigate and incorporate customer requirements for a proposed product during the design stage. Reactive problem-solving seeks to alleviate the losses from current problems. From the list of the "five evils" (waste, delays, mistakes, defects, and accidents), a multitude of problems must be prioritized and attacked. Control problem-solving creates systems that provide warnings to the appearance of expected problems.

The initial application of SPC falls in the reactive problem-solving category, since its goal is to assess and reduce existing levels of nonconformance. This breakthrough provides a new level of quality for customers. After ensuring a process is under statistical control, SPC techniques are also instrumental in recognizing control problems and directing quick remedial action. This enhances control by holding onto to previous gains, which protects customers against surprises. SPC is thus used as a tool to attack two types of quality problems, performing both breakthrough and control functions.

The SPC program has been strongly influenced by the adoption of Total Quality Management (Top management began exploring TQM in 1989, at the same time the division was implementing SPC into the back end). One team leader noticed the effort to merge SPC activities under the TQM umbrella. To the quality organization, this change was effected immediately. To attain consistency with TQM, the SPC program must reflect the three corners of the

TQM triangle: customer focus, continual improvement and total company involvement.

Customer focus demands that the critical quality characteristic chosen for control reflect needs of external or internal customers. Continual improvement argues against extensive projects to perfect a process, instead using quick drives against the "vital few" problems. Both of these issues are thoroughly investigated in Chapter 7 of this thesis.

Total participation calls for greater respect for the knowledge which comes from the lower reaches of the organization. Actually, SPC makes this knowledge apparent and concurrently communicates the top's interest in listening, creating the needed mutual respect. The SPC teams provide an excellent mechanism for opening communication, building a base for sustained quality improvement for the future.

SPC Group

After experiencing mixed results with the first two back end teams, a group of four engineers dedicated to quality improvement was established to:

(1) be a resource for teams (as experts in statistics, control charts, experimental design, and computer tools);

(2) guide teams along the 11-Step methodology;

(3) collate lessons learned needed to further improve the SPC implementation strategy and the standardized methodology; and

(4) assist in the automated collection of data for plotting control charts by providing software to calculate points.

One member of this SPC group (this term is used throughout this thesis to distinguish this resource group, formally called the SPC Development Team, from "SPC teams" which are created to implement SPC) is assigned as an advisor to each SPC team. The advisor's contribution to each respective team admittedly varies inversely with an assessment of the team leader's experience and effectiveness. The corporate guidance asserts that such facilitators are needed only until the organization becomes proficient with quality improvement tools, but will eventually be eliminated. It is apparent that the group still plays a valuable, though evolving role, weaning team leaders away from dependence as skills develop. The team has also taken steps to substitute formal guidance for ad hoc advice, as the increasing level of familiarization has allowed compilation of standard methods.

SPC Methodology at ADS

Before introduction of SPC into the back end, the operations manager and the quality manager of the semiconductor division jointly developed a 10-Step methodology, shown as Exhibit 4-1a, for bringing a process under statistical control. The standard methodology provides structure for the effort, makes measurement of progress possible, and allows quick digestion of Quality Improvement (QI) stories which take identical structured formats. Juran asserts that ". . . an organized approach can greatly increase the probability (of a) breakthrough."[1] Stipulating the path is beneficial, especially when dealing with processes that already provide a source of significant complexity.

The standard methodology has been altered (continually improved) since its adoption through the experience of the SPC group. The other divisions of ADI accepted this standard with only minor changes. The modifications resulted in an 11-Step methodology with an additional rung to highlight the

1 Joseph M. Juran, Managerial Breakthrough (New York: McGraw-Hill Book Company, 1964), p. 17.

10 Steps of a SPC Project

1. Identify and rank the critical nodes.
2. Form implementation teams.
3. Develop a detailed process flow chart.
4. List and prioritize the critical input parameters.
5. Lock the critical inputs that can be readily locked.
6. Choose the critical output parameters.
7. Determine and implement data collection plan.
8. Analyze data.
9. Set up control charts and determine preliminary Cpk.
10. Experiment to improve Cpk. Lock additional inputs as needed.

Exhibit 4-1a

11 Steps of a SPC Project

1. Identify and rank critical nodes.
2. Form implementation teams.
3. Develop a detailed process flow.
4. List and prioritize critical output parameters.
5. List and prioritize critical inputs.
6. Lock critical inputs to meet requirements.
7. Determine tool/measurement capability.
8. Determine target value and implement data collection.
9. Set up control chart format and perform short and long-term capability studies.
10. Develop and document Out-of-Control Action Plan (OCAP) and implement control chart.
11. Experiment to improve Cp and Cpk, lock additional inputs as needed.

Exhibit 4-1b

requirement for surveying measurement capability before designing the data collection plan. Furthermore, the wording has changed to add emphasis on critical elements including:

(1) deciding upon a target value for the critical output;

(2) including both long and short term capability studies;

(3) determining the tool measurement capability;

(4) establishing an Out-of-Control Action Plan; and

(5) highlighting the importance of implementing the control chart rather than just setting it up.

References to obvious actions such as "analyze data" and "determine preliminary Cpk" were dropped.

While the above changes can be classified as clarifications to the methodology (teams using before and after will follow the same path), recently (when establishing the corporate standard) a fundamental modification was made by reordering without altering the text. The change, which was proposed by the SPC group, allows teams to openly choose the critical output before listing the critical inputs. A debate, which preceding the change, centered around a tradeoff: the need to conserve resources by focusing on the "vital few" against the gains resulting from the prevention of myopia. The recognition of the limited marginal returns from an very comprehensive investigation of inputs, which may not affect the control of the critical output, carried the argument. Teams are still encouraged to review all potential process inputs while concentrating on those relevant to the critical output. Additionally, even inputs that do not contribute significantly to any critical output should be locked if this can be accomplished easily.

The current version of the 11-Step methodology is shown as Exhibit 4-1b. This methodology was published in March 1992 in a definitive guide entitled

SPC at ADI. The adoption by the entire corporation offers an excellent example of standardizing and diffusing quality tools.

Maintaining Control Charts

The display of control charts follows traditional guidelines: public and near the process. Charts in the test area are posted on bulletin boards in the middle of the test center. In the assembly area, charts are located above the equipment.

An interesting characteristic of the SPC program at the Wilmington facility is the manual plotting of control charts. When SPC was first used in the front end, the control charts were automatically displayed by the computer-aided manufacturing system upon logging onto a controlling terminal. Because of the dearth of interaction, the operators repeatedly failed to grasp the significance of trends or correlate cause and effect. A difficult decision to enact an exception to a "paperless fab" was made which forced operators to plot the points on the control chart. The points are still calculated automatically. This practice was copied when introducing SPC into the back end.

The interaction between the operator and the control chart is critical to both the operator's understanding of the process and development of insights about the process. One team leader remarked that just after the control chart was implemented, operators repeatedly made plotting errors (e.g., plotting +3 instead of -3). The errors disappeared with more training which stressed the meaning and significance of the points. This suggests that plotting errors can serve as a rough proxy for gauging operator comprehension of SPC concepts. Also, operators are more likely to associate changes in the setup or environment with out-of-control points while interacting with the process, rather than simply observing an out-of-control signal generated by the computer.

Reactions to Out-of-Control Signals

A key result from every SPC effort at Analog is an Out-Of-Control Action Plan (OCAP) which resides in its final form on the shop floor. It prompts the operator to take specific corrective action to regain control of the process based on the circumstances which characterized the departure.

As noted before, work tasks at Analog are tightly specified. One area of discretion that is significantly impacted by the introduction of SPC is the limitations imposed upon technicians in adjusting equipment. The control chart captures trends and relationships that dictate the required adjustment, avoiding frequent and unwarranted "tweaking". The sample OCAP, shown as Exhibit 4-2, shows that the technician is now allowed only to check locks on inputs and observe a new trial of the operation. SPC provides a new source of direction for the operators, but a fundamental change in the technicians' job. This is further explored in Chapter 5.

Enabling Software

The use of experimental design and creation of control charts is greatly improved by the availability of user-friendly software. Most team leaders utilize RS1[2], which is resident on the internal local area network. The SPC group supports this de facto standard, providing training and assistance to encourage adoption. Such a standard allows common training in data analysis, and makes the preparation of easy-to-follow guidelines possible.

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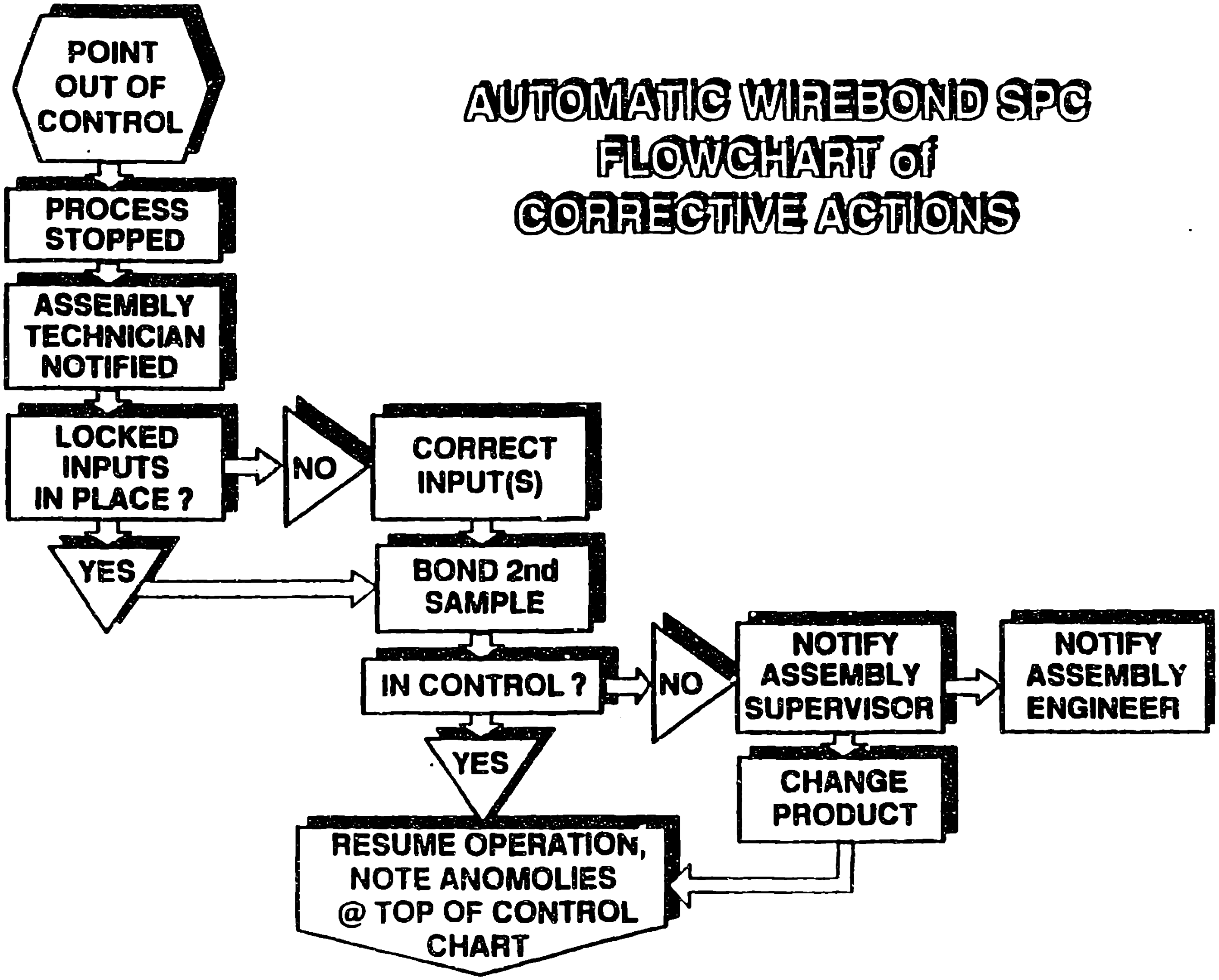
2 A statistical analyisis software package developed by Bolt Beranek And Newman Inc.

AUTOMATIC WIREBOND SPC FLOWCHART of CORRECTIVE ACTIONS



One team leader, who was not connected to the internal network, used another software package which did not support experimental design. The SPC group representative to the team assumed that responsibility. Operationally, this situation is not unsatisfactory, since the team leaders have not been extensively trained in the design of experiments, and the software provides ample opportunity for misunderstandings that could corrupt the data analysis. But the team leader missed an opportunity for learning, which should be a major objective of any quality improvement effort. With each pass through the improvement cycle, all participants should develop greater skills for attacking more daunting quality problems in the future.

Chapter 5
Team Dynamics

Importance of Team Dynamics

As stated in Chapter 4, a team approach is well-suited for breakthrough efforts, as Juran (1964) claims that a team with differentiated members is ideal because it provides coordination and cooperation.

Coordination is provided when:

(1) A definitive team charter allows different parties to work towards the same goal without rivalry.

(2) Greater participation enhances the quantity and quality of ideas to be tested.

(3) The granting of approval to experiment where agreement is needed is facilitated if all interested parties are represented.

(4) Requirements and justification for action to those directed to take action are automatically communicated if they are included.

Cooperation results if individual team members gain through inclusion because:

(1) Their rights in the situation are respected.

(2) Social needs are met through belonging.

(3) Egos are stroked by allowing an opportunity to demonstrate knowledge.

(4) Self-fulfillment is offered by allowing meaningful creative thought and identification with improvements.[1]

Thus a team approach is often used to achieve breakthroughs, but dysfunctional teams can preclude accomplishments. Team dynamics is a

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[1] Juran, p. 73.

significant variable in the "probability for success equation" for each SPC initiative. The SPC group rated the effective management by the team leader as one of the three most important prerequisites for success. Another critical element identified was the enthusiasm of the group, which is also clearly affected by team dynamics. The third element, the recognition of importance of the task, is discussed in the Chapter 7. But it is dependent on group communication as well as the choice mechanism, and certainly impacts on the enthusiasm of the group. The structure and interaction between members significantly impact project outcomes.

Structure of SPC Teams in the Back End

The teams are not cross-functional, but membership mixes the lower layers of the organization. Membership is almost without exception aligned with organizational structure. The team leader is the manufacturing engineer responsible for the operation where the target process resides. The technician may report directly to the manufacturing engineer or, as with the operators, be aligned with the team leader via group leaders and supervisors.

The more successful team leader suggested that having a member unfamiliar with the operation might be helpful, allowing an unhindered rethink of the process. With the exception of the representative from the SPC group, this suggestion has not been tested. This approach also offers an excellent opportunity to effectively train future team leaders.

The teams are not homogeneous, and clearly not as egalitarian as those described in Japanese literature on quality improvement. The teams use a common structure where each member plays a specified role which different members are best suited to assume. This team structure is consistent with management's view of extremely complex processes. Representatives provide different and important perspectives, which must be integrated to develop a sufficiently accurate image of the actual process. Exhibit 5-1, a model of the this concept, shows how interlocking circles of knowledge can combine to develop a thorough understanding of the process. A team unites the knowledge from different sources which enlarges the intersections, and creates a team capability to comprehend the process far greater than any single individual within the organization. Furthermore, the team assignment allows observation and experimentation to decrease the fraction of knowledge that remains undiscovered. Finally, the team is also tasked with recording its understanding of the process in a report, providing a headstart for future investigation.

Role and Importance of Manufacturing Engineers

All the team leaders have shouldered the accountability for the teams success, as demonstrated by the SPC group's assessment that team success is correlated with team leader performance. This is entirely fair. Among the team members, the team leaders are the most thoroughly versed (although a diversity of proficiency exists) in both SPC concepts and the 11-Step implementation methodology. They are also the experts concerning the process and the product, a position further heightened by their access to product engineers as peers. The organization operates with an assumption that only trained engineers can assimilate the tremendous complexity that is characteristic of the testing and assembly processes. This model was implicit in both the SPC group's and team leaders' justification of the key role the team leader assumes. They also personally attend to most of the

Mental Model of Team-Based Knowledge

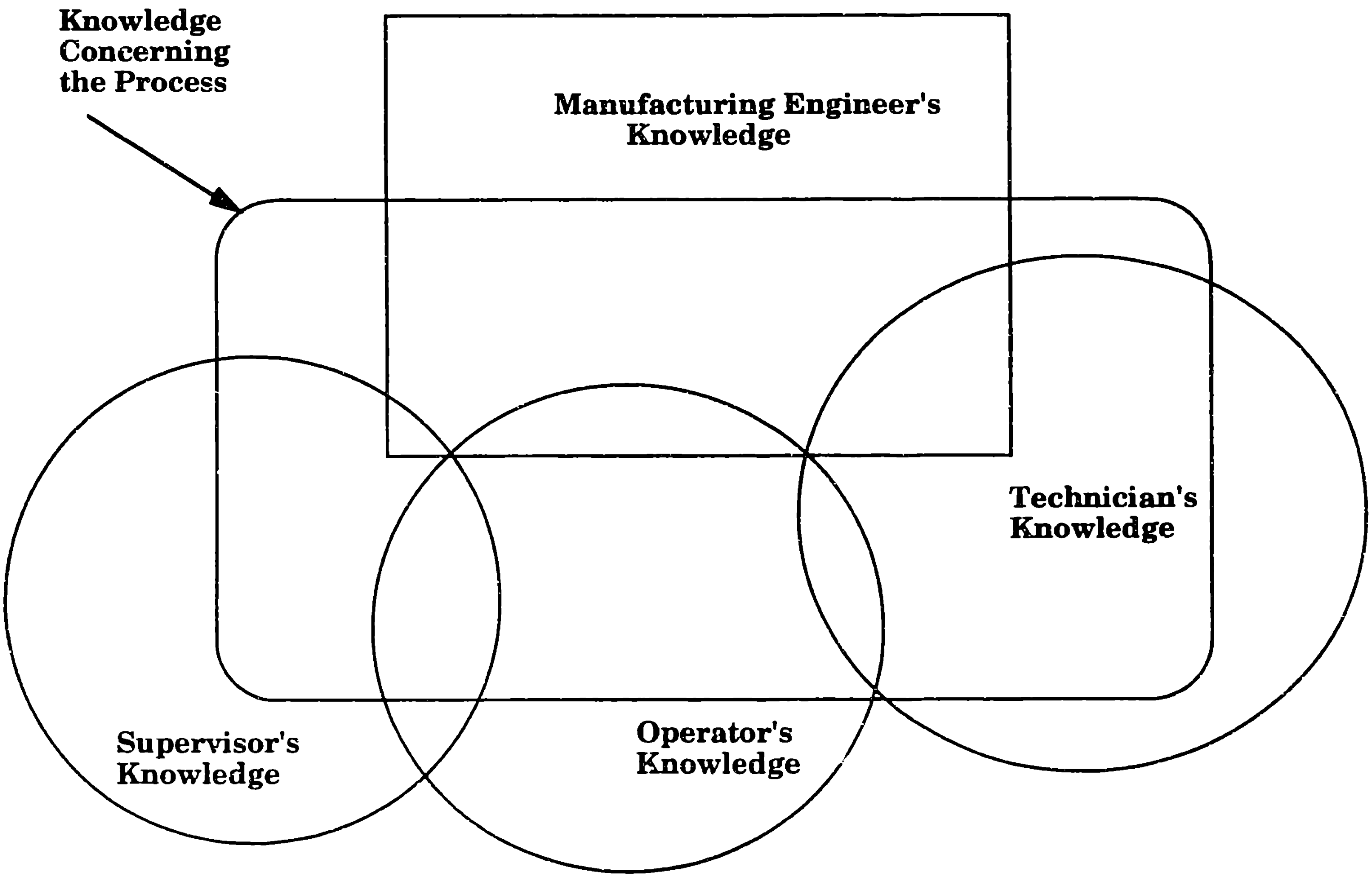

Exhibit 5-1

administrative and analysis work of teams, and assume a commanding role when presenting results to superiors.

Even if someone else is tasked with leading the team, the manufacturing engineer's presence is required. Besides the intimate knowledge of the process, inclusion is needed to ensure experimentation and implementation are supported.

The SPC group's representative to each team supplements the team leader. The group members intentionally vary their contribution inversely with the team leader's experience and effectiveness. The need for guidance decreases as the team progresses towards completion of the project and onto future tasks; eventually competent team leaders no longer require this assistance.

Role and Importance of Supervisors

The supervisors play a decisive role, providing familiarity for, while attempting not to stifle input from, the operators. Few supervisors in the back end have graduated up the ranks. Their presence can encourage operators to contribute, or alternately cause operators to fear lasting damage if proven ignorant. They can also help ensure the data collection is carried as planned and aid implementation of the control chart.

Inclusion confirms their right to control work in their area, ensuring approval to implement locks on inputs that must be effected through changes in work direction. Additionally, the supervisors are more knowledgeable concerning, and able to influence, actions of other shifts than the manufacturing engineers. This is essential when defining the process flow chart, collecting data, and implementing input locks, as well as the introduction of the control chart.

The supervisors also perform a important role in placing operators onto teams. Team leaders seeking members for a new team need input from supervisors. An understanding of operators' role and sound personnel judgment are critical to ensuring the team is properly staffed.

<u>Role and Importance of Technicians</u>

A technician provides familiarization with the equipment. This is especially critical to implementing locks on inputs.

<u>Role Importance of Operators</u>

The operators offer a dose of reality. Their knowledge of the process is independent of specifications or desired conditions. Both team leaders expressed their deep appreciation for the operators who pointed out discrepancies between the assumed process flow chart and what was actually occurring on the floor, important subtleties which could significant add to the process variability unless addressed. Work direction is almost always incomplete, and operators fill in the missing steps in cooperation with their workmates and supervisors.

Both team leaders emphasized that the timing for contributions from operators is often unanticipated. When I suggested that operators were only needed when the team was discussing the process flow and identifying and locking inputs, both team leaders reacted negatively. Operators concentrated on discrepancies between reality and plans that everyone else fails to even consider.

Motivation of Team Members

Juran cautions that managers often experience conflict between duties as an employee and drives as an individual.[2] With one caveat, this can be generalized to all employees. I believe the primary distinction between managers at all levels and workers is ambition. A manager is expected to tilt the balance, though not completely, towards company responsibilities. Workers retain greater independence in regard to the firm, but their personal drives include social needs which are often met through peer relationships. Workers are less willing to strive for the firm's benefit if their costs are significant. Therefore, I theorize that managers will support meaningful quality improvement efforts as priorities allow, unless the expected outcome clearly offers a significant threat. Workers' cooperation will depend upon their belief that the outcome will not be detrimental to them. Additionally, with workers a second conflict emerges. Potentially, the benefits from inclusion in the group could outweigh the expected effects on them personally, but pressure from peers who would realize only the impact without the benefits makes resistance the likely choice. The worker's presumed desire for good peer relationships may then cause the worker not to cooperate even if personal gain would result. This mental model is captured in Exhibit 5-2 by scales that weigh the impact of implementation of SPC. Note that both the magnitude of the impacts and the leverage arms combine to determine the balance.

The manufacturing engineers and supervisors clearly gain from SPC initiatives as long as their authority is respected. The goal is the reduction in complexity around a process that they are tasked with supervising. Hence, they both gain from any improvement.

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2 Ibid., p. 20.

Contrast of How Team Members View SPC

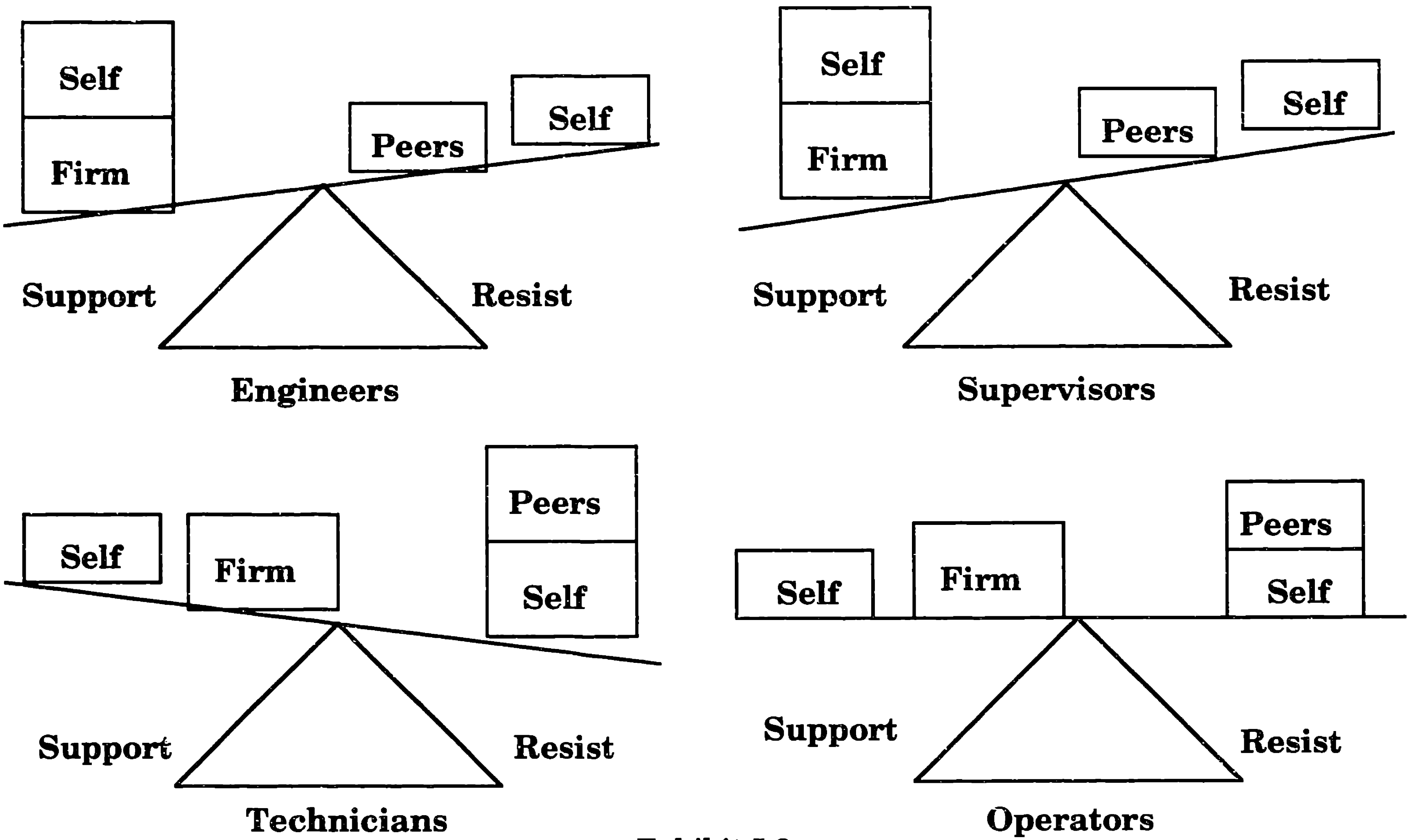

Exhibit 5-2

One member of the SPC group noted that the technician on one of the first projects expressed doubts about whether the process would function without "tweaking". Juran suggests that we "look behind the words of the objector to understand his situation. The maddening part of dealing with personal attitudes is that the reasons are seldom stated in words--they must be deduced from the situation."[3] Clearly, the technician's discretion in adjusting equipment is restricted with SPC. Both team leaders denied any resistance from technicians, asserting instead that technicians are overworked and welcome a relaxation of responsibilities. As Juran indicated, individuals will act to protect rights but probably not openly. It should be expected that technicians will not fully support SPC initiatives because their discretion is restricted by the implementation of SPC.

SPC requires standardization of process, limiting discretion available to workers. But operators, who initially possess little discretion over work content, cannot expect significant loss from SPC initiatives. In fact, participation in the redesign of the process provides some measure of power, or at least reduces the perception that work direction is arbitrary. The arguments before suggesting that belonging to the team will encourage participation should prevail if the expected loss of freedom is minimal.

The selection process may also constitute an informal recognition mechanism. If it is perceived that good performers are invited to participate, the cause-effect relationship can erode to where those invited assume the designation as a good performer.

Both team leaders also indicated that contribution from operators increased as the team progressed. They attributed this to an initial discomfort from feelings of inferiority. This observation would also be

3 Ibid., p. 40.

consistent with initial neutrality towards the team's success. Since appreciative feedback would make it evident that being an integral part of the team is rewarding, participation should act as a reinforcing cycle (a positive loop).

Implicit recogonition that the introduction of SPC affects technicians and operators differently is evident in the training given. Exhibit 5-3 compares the personal benefits that operators and technicians are shown during their respective SPC training. Note that a much greater attempt is made to convince technicians to support the program. Operator training is designed to efficiently communicate the quality improvement task; the technicians must be sold.

Also, with the exception of learning a new skill which makes an employee more valuable, all of the personal benefits assume that workers are motivated by the "removal of barriers and handicaps (that) rob the hourly worker of his birthright, the right to be proud of his work, the right to do a good job."[4] I believe this motivation is relatively weak, and only becomes operational if resistance to change is unjustified.

Types of Teams

Keidel (1985) identifies three different types of work organizations, best described with analogies to athletic teams. Analog, like many American companies, uses teams to augment its formal structure to divide routine and breakthrough activities. A football/basketball hybrid is best suited for this situation. A football team-type organization makes bounded complexity bearable through centralized control of operations. A basketball team-type

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[4] W. Edwards Deming, Quality, Productivity, and Competitive Position (Cambridge: MIT Center for Advanced Engineering Study, 1982), p. 17.

**Personal Benefits Presented to
Technicians at SPC Training**

SPC will . . .

- Lead to better running and better performing equipment.
  - -Reduce frustration.
  - -Eliminate firefighting.
  - -Make you look good.

- Reduce guess work, increase personal productivity and job satisfaction.

- Build on your present job knowledge.

- Provide a skill applicable in any job where reduced variation is a prime objective.

- Allow a way to express and use your ideas.

- Improve communication with operators and off-shift personnel.

**Personal Benefits Presented to
Operators at SPC Training**

SPC will . . .

- Provide a clearer on-the-job problem-solving method based on structured information.

- Reduce guess work, increasing personal productivity and job satisfaction.

- Build on your present job knowledge.

- Provides a skill applicable in any job where reduced variation is a prime objective.

Exhibit 5-3

organization offers the spontaneity and flexibility to overcome the unexpected, such as issues encountered during quality improvement projects. The two models are described in Exhibit 5-4.

In football, players accept specified roles, but success requires teammates to act concurrently in accordance with detailed plans. This requires tight control and effective (though not necessarily swift since actions are predetermined) communication for each member to fulfil their assignment. The organization can react quickly and effectively when confronted with opportunities and problems for which responses have been programmed, but pauses for direction when confronted with the unanticipated. Football organizations promote control while breakthrough is impeded by the frequent need for central approval before action.

Basketball teams are more flexible because players are assigned only nominal roles suited to a game which flows nearly continuously. Success requires instantaneous adjustments with many possible interactions that cannot be thoroughly rehearsed. These interactions must be coordinated with communication <u>between</u> members rather than <u>from</u> a mutual superior. But such cooperation cannot be easily enforced and often entails sacrifice from the individual. Therefore, the team is more versatile and requires less supervision, but is also less stable.

The SPC teams investigated showed difficulties in adopting new norms which are characteristic of a basketball team, instead retaining assumptions which gives order to routine activities. Participants take assigned roles consistent with positions held in the formal organization. The standard methodology and mid-course management briefings (which include corrective feedback) provide centralized direction.

Comparison of
Football and Basketball
Organizations

	Football	**Basketball**
Best Suited for	Reducing Complexity through Global Coordination	Innovating through Interaction
Coordination	Central Authority	Concensus
Leadership	Authoritarian	Facilitative
Strengthes	Efficiency, Risk Avoidance Coherent Response	Synergy
Weaknesses	Inflexible Reaction to Unanticipated	Role Confusion
Distance from Decision-Making	Distance from Top	Zero
Style	Systematic	Spontaneous

Exhibit 5-4

A football team-organization can still realize breakthrough, though not as efficiently as the basketball team. The football team can be explored in greater detail. During each play, two distinct types of teams compete whose very names reveal the difference: offense and defense. The distinctive characteristic of a great coach (a proxy for management) is the ability to judge the skill level of team members, then deploy to capitalize on the strengths and mitigate the weaknesses. On offense, this task is simpler since the effort is proactive. A defense must deploy to best thwart an uncertain advance. To bring the analogy to the point, management in a football team-type organization must act in the SPC arena as a defensive coach, prioritizing fuzzy control problems and then deploying available manpower in teams with skill mixes matched to problems. The team leader is the captain on the field, ensuring individual members clearly understand the task and their assigned roles. The leader must also assume a motivational role. This analogy demonstrates the foundation for directing a reactive problem-solving team:

(1) recognizing a "serious" problem;

(2) assigning people with the needed capabilities;

(3) communicating the task to the group;

(4) communicating individual action assignments; and

5) urging and providing oversight to ensure accomplishment of individual responsibilities for concerted action.

If SPC teams could demonstrate the flexibility attributed to the basketball team, they would be better prepared to independently face challenging obstacles. Keidel notes that a basketball coach (again a proxy for management) when developing strategy asks "How do I develop my team's ability to coordinate itself?"[5] Therefore, Analog's rigid deployment of teams may accomplish short-term objectives without preparing the team to meet more difficult challenges in the future.

The more successful team leader stated that he had not received training in team dynamics, but rather had relied on previous team experiences. This leads to an interesting question. Are teams used in a TQM framework sufficiently similar to other teams to use the same team dynamics concepts? The above analogy suggests the answer is no, and the collected evidence supports this position. The limited number of teams examined showed the characteristics of the football team with members performing assigned roles. Therefore, to shift to the more appropriate basketball team model requires that assumptions of how teams function must be reexamined.

Decision-Making Within Teams

The two team leaders interviewed utilized very different decision-making models for their teams. The leader deemed more successful admitted using, what I term, managed consensus. Openness and debate is strongly encouraged, but the leader attempts to steer the group towards consensus as the decision point nears. The leader acknowledged an explicit tradeoff which pitches efficiency against myopia and reducing future inputs.

The less successful leader believed in democratic decision-making. Decisions such as the identification of the critical output were made through voting. The leader purposely attempted to engage in the discussion without dominating.

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5 Robert W. Keidel, Game Plans: Sport Strategies for Business (New York: E. P. Dutton, 1985), p. 57.

During the first assignments for both leaders, the decision on which output characteristic to control were later found to be questionable. The team which had reached consensus continued; the team which had voted abandoned the first choice and returned. In a continuous improvement model, persevering is the correct choice as long as the choice offers some utility.

Management Participation

The SPC group noted that middle managers sometime choose to participate on a team. I witnessed a team meeting where the responsible manager arrived after the meeting had begun. The manager quickly assumed control from the team leader, asking informed and to-the-point questions. While clearly the meeting became more efficient (the team agreed on locks for the inputs, that had been previously identified, at a faster rate), the balance between direction and openness changed.

As stated earlier, management should seek to make the teams more capable through learning. The manager's assumption of power did not yield a more capable team and, therefore, was not warranted.

Rewarding Team Participation

Top management admits that participation is currently not being properly rewarded. It was suggested that operators enjoy taking an hour each week away from the normal routine. The more probable motivation for operators is that the teams serves as an informal recognition system. Team assignments for the remaining members are just another facet of their job description. The QA manager believed that participation was noted on performance reviews, but this was not a formal requirement.

Chapter 6
Training in Statistical Process Control

Managers

The initial step in the introduction of SPC into the back end was the training of middle managers and supervisors. Two-day seminars were conducted off-site by an external consultant with an emphasis on how statistical methods can solve problems by reducing complexity and managing by fact (using the language of reports rather than affection (Hawakawa, 1978)). An overview of SPC methods and a very limited theoretical statistical background were also presented.

Manufacturing Engineers

Next, manufacturing engineers received three days of instruction from the same consultant, with priority scheduling for those selected to lead the initial SPC teams. The emphasis shifted to mechanics of SPC as a problem-solving tool. The engineers learned about run and range charts, process capability plus a review of normal and non-normal distributions. The short duration of the training was somewhat overcome by the availability of the consultant to answer specific questions and give timely guidance as teams commence initial assignments.

Technicians and Operators

The technicians and operators are taught SPC mechanics during a one-day course before SPC is introduced into their work area or upon being assigned to an SPC team. The emphasis is placed on interpreting SPC charts for processes in control. The example for both groups is a common setting familiar to nearly everyone, gas mileage of a personal vehicle. Both courses were developed internally by the SPC group and are taught by the training department. The technician course is slightly more advanced mathematically than the operators, but both gloss quickly over the theoretical statistical foundation of SPC. Both also receive an overview of the 11-Step methodology for instituting control of a process at ADI and how process control benefits ADI.

Intentions to video the presentations or prepare condensed versions for refresher training have not come to fruition. Video capability would allow more flexible scheduling. Operators have often forgotten some of the concepts before control charts are instituted since coordination with the uncertain schedule of the SPC projects is difficult. The SPC group admitted that training of operators is one of the weak areas that requires greater attention.

An interactive video training course has been ordered which offers self-paced training. This will ease scheduling problems and make refresher training readily available.

Contrast in Training

Clearly, the levels of training described above, and in Exhibit 6-1, is commensurate with both the presumed mathematical background and the anticipated roles of each of the groups. Managers are expected to recognize critical nodes which are (1) amenable to control and (2) yield the greatest return from improvement. Mangers are also expected to follow the progress of SPC teams through the 11-Step process. Their knowledge of statistics and control charts provides the vocabulary base and allows active participation in quality improvement efforts.

Training Matrix for SPC

	Managers/ Supervisors	Engineers	Technicians	Operators
SPC Principles	Important Classroom	Important Classroom	Important Classroom	Important Classroom
Basic Statistics	Important Classroom	Important Classroom	Important Classroom or Video Disk	JIT Interactive Video Disk
Advanced Statisitics	Important Classroom	Important Classroom JIT Desirable	Important Classroom JIT Desirable	Not Essential
Control Charts	Important Classroom	Important Classroom	Important Classroom or Video Disk	JIT Interactive Video Disk
Design of Experiments	As Required Classroom	Important Classroom JIT Desirable	Important Classroom JIT Desirable	Not Essential

Exhibit 6-1

Manufacturing engineers play the principal role in SPC implementation and require a thorough understanding of the methodology with the advanced statistical background to prevent misapplication of the tools when the inherent assumptions (e.g., normality of underlying population) are not met. An engineer related that he first calculated the process capability index using the standard deviation of X-Bar rather than the standard deviation of the underlying population, introducing an error of magnitude equal to the square root of the number of measurements averaged into each X-Bar point. The software does not preclude, or warn, of such simple errors. This demonstrates that the initial level of training is insufficient for the engineers to assume their central role without the presence of experts like the SPC group. The engineers were also not well versed in experimental design and the SPC group gauged its support in this area inversely with the team leaders understanding.

Initially, I felt that the limited training offered to operators was inconsistent with SPC philosophy, but experts such as Deming assure management that "the production worker requires only a knowledge of simple arithmetic to plot a chart.[1] Obviously, a far greater body of knowledge is needed if the production worker is required to perform data analysis. The investment in training for the technicians and operators is insufficient to allow them to apply SPC techniques to solve problems without assistance, but corresponds with their role in the quality improvement program as established at ADS.

The training provides only the understanding necessary to contribute to team activities and to use a control chart to recognize (and react to) out-of-control conditions. Professor Shiba, the principal quality consultant to

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1 Deming, p. 126.

Analog, asserts that workers should be taught to work with a few quality tools initially. The essentials, shown back in Exhibit 1-1, are sufficient to face a majority of quality improvement problems. Training is required only to introduce these techniques. Then participation is needed to fully understand, building a foundation to receive further skills. Neither team leader had attempted to ensure participants exercised the training, assuming that the manufacturing engineers would always retain paramount responsibility for analysis.

Improvements for Training

The training value of participation on an SPC team cannot be overstated. Both team leaders emphasized that all team members became more familiar with the SPC tools as the effort progressed. Professor Shiba often argues that the tools can only be truly understood through use, and mastered through teaching others. The classroom training is barren without refresher opportunity available immediately preceding and during actual use. The team leaders specifically noted improvements in the operators' grasp of the concepts, attributed to a greater motivation to learn after recognizing that others are interested in their daily activities.

The motivational role of success stories would be enhanced by their utilization in later training. Personal knowledge of individuals involved in accomplishments makes the material more relevant and the goals less daunting. The vice president for quality for another member of the Center for Quality Management related that his small office is responsible for the training in quality improvement skills and publishing the internal newsletter, a combination that occurred by chance but is maintained through purpose. Both are fertile avenues for promoting quality programs.

Real case studies are also an excellent resource for team leaders, for both improving their management skills and spreading insights that may be transferable. No formal effort has been made to offer assistance in improving critical management skills. The SPC group admirably collects and transfers a valuable body of knowledge, but greater gains are possible. Writing case studies provides the opportunity to reflect and identify these gains, and the learning is certainly more enjoyable and efficient than reviewing final write-ups from previous SPC teams in archives.

The only criticism of the training program is that the overall program is admittedly disjointed. Each section complements the roles that the different groups assume in SPC initiatives, but the combination does not explicitly recognize the interactions. Both team leaders think the level of training received by all team members is appropriate. However, more relevant examples (from success stories), flexibility and timing would better support SPC efforts.

Chapter 7
Task Assignment

Choosing of Tasks

The first SPC projects in the back end were undertaken because of customer requirements to bring certain processes, such as wire bonding, under statistical control. Other early taskings offered even greater discretion by directing manufacturing engineers to form an SPC team to focus on any process in their respective areas.

The importance of clearly defining critical nodes is evident, but specific corporate guidance is not given. A manager identifying the critical node looks for "the process flow whose output has a significant impact on the total process".[1] Departments have formalized procedures to provide structure. The final test area evaluates processes using a matrix which accounts for such parameters as the expected growth rate of the product and whether the test equipment is used elsewhere in the company (to allow the multiplication of resulting gains).

Clarity of Task--Discretion vs. Direction

Both team leaders preferred to retain the team's prerogative to choose the critical output. The choice over the process to be controlled is also desired. However, discretion detracts from the appearance of importance. Management's recognition of a problem may automatically provide a presumption of criticality. A lack of direction foregoes this advantage, although failure to sufficiently justify an assignment from management may lead to an perception that the selection is arbitrary and unworthy of support.

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1 SPC at ADI, p. 8.

The selection process must balance the need for a perception of empowerment against the requirement that the problem be perceived as important. Furthermore, the following section questions whether the team is best positioned to ascertain the critical outputs. Professor Shiba suggests that this issue is best handled by allowing management to approve the team's choice. This provides: (1) assurance that the task is meaningful by testing it against the "big picture" and (2) provides an early check that the team does not set a target beyond their current skill level.

"Market-In" vs. "Product-Out"

There is no evidence of a "market-in" mindset in the development of tasking priorities. While the test center's matrix reflects market potential, the value of statistical control to individual or segments of consumers is not explicitly integrated into the choice.

SPC teams continue to enjoy broad discretion in designating the critical output, generally in accordance with product specifications. A Pareto chart for defectives and customer returns could be used to gauge importance, but the interviews revealed that professional judgment also plays a large role. A macro-method to inject customer focus is the mandating that objectives relate to overriding principles from a list of customer concerns identified in Chapter 3. For example, aim SPC efforts at controlling on-time delivery, reliability issues and cost containment.

Continual Improvement

Continual improvement is one of the three pillars upon which ADI's Total Quality Management program is built (the others being customer focus and total participation). Implicit in the Plan-Do-Check-Act (PDCA) cycle, taught by Deming, are the realities of competing priorities and diminishing returns. A believer in continual improvement seeks to remove the most serious impediments to quality during the first pass. For SPC, the "vital few" are the primary contributors to process variation. These should be identified and receive priority for corrective action. Once the process is under statistically control, management may choose between devoting the scarce resources improving the process capability by reducing the variation contaminating the system, or redeploying to place other processes under control.

Continual improvement calls for multiple passes to enhance process control, with each cycle expected to yield smaller marginal gains. The Vice President for Quality at ADI, Arthur Schneiderman, developed a concept for measuring the rate of improvement using defect "half-life" as a metric. "The half-life is the time (in months) it takes to cut a defect level in half. In terms of the PDCA cycle, the half-life represents a turn of the process. Our experiences have established several rules of thumb. A turn of the PDCA cycle will usually take 3-4 months and lead to a 20-40% improvement in a specific problem area. The multiple turns needed to achieve 50% improvement typically yield a half-life of 6-9 months."[2] The 11-Step methodology guides the teams through a single PDCA cycle. The last step can be interpreted to allow another pass to improve process capability. The teams examined understood their assignments to require an extremely thorough, single pass. This has led to an average time to completion of approximately 15 months.

Expectations should be examined. Management has been disappointed by the average project duration, but the results have received deserved praise.

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[2] TQM at ADI, p. 12.

Accordingly, a management that professes continual improvement should communicate that a single pass that yields a process under control is a successful outcome unless a review of priorities dictate further passes to improve process capability. Ray Stata noted the culture which honors technical innovation at Analog is often in conflict with a continual improvement philosophy.

This tradeoff has the almost dialectic nature of breakthrough versus control at its heart. A culture dedicated to breakthrough cannot affect the balance of managerial functions without a struggle. Management must alter systems to value control activities in the manufacturing area more fairly, without depreciating the worth of breakthrough efforts in both production and development.

Team Leaders' Assessment of Tasks

Both team leaders thought they were responsible to thoroughly analyze the process, and investigate all variables that could affect the outputs. The original 10-Step methodology confirmed this belief by ensuring teams performed a comprehensive investigation of inputs that may impact on the process even before deciding upon which output(s) should be controlled. Management should review this passive decision: Did the change in the methodology adequately signal a change in thinking?

A manager recently delivered an SPC tasking with a time limit of 6 months for completion. It was not evident that the tasking had a corresponding limited scope. The tradeoff should be confronted, and potential gains measured against other SPC projects that are being deferred.

Chapter 8
Probability of Success

Defining Success

A successful outcome is somewhat subjective, but must entail the accomplishment of measurable gains (e.g., defect reduction, productivity improvement) commensurate with the effort expended. This chapter sets forth some principles regarding the implementation of an SPC program to improve the success rate. Some of these were openly acknowledged by ADI, others were implicitly utilized.

Building on Early Successes

In the TQM infrastructure adopted by ADI, the recognition of successful quality initiatives feedbacks as motivation to enhance the probability of future quality improvements (See Exhibit 8-1 which is taught by Professor Shiba). This "snowball effect" can be ensured through two factors, the early projects should be both doable and meaningful. The probability of early successes can be artificially improved. Ensuring success can be accomplished by:

(1) choosing assignments with a level of complexity which will not overwhelm an inexperienced team;

(2) providing excess resources (e.g., a stacked team); or

(3) enlarging managerial oversight.

This is not simply sleight of hand; the enthusiasm and experience gained through early achievements will make future gains more assessable. The ability level rises quicker in an environment of cascading successes.

Seven Infrastructures for Total Quality Management

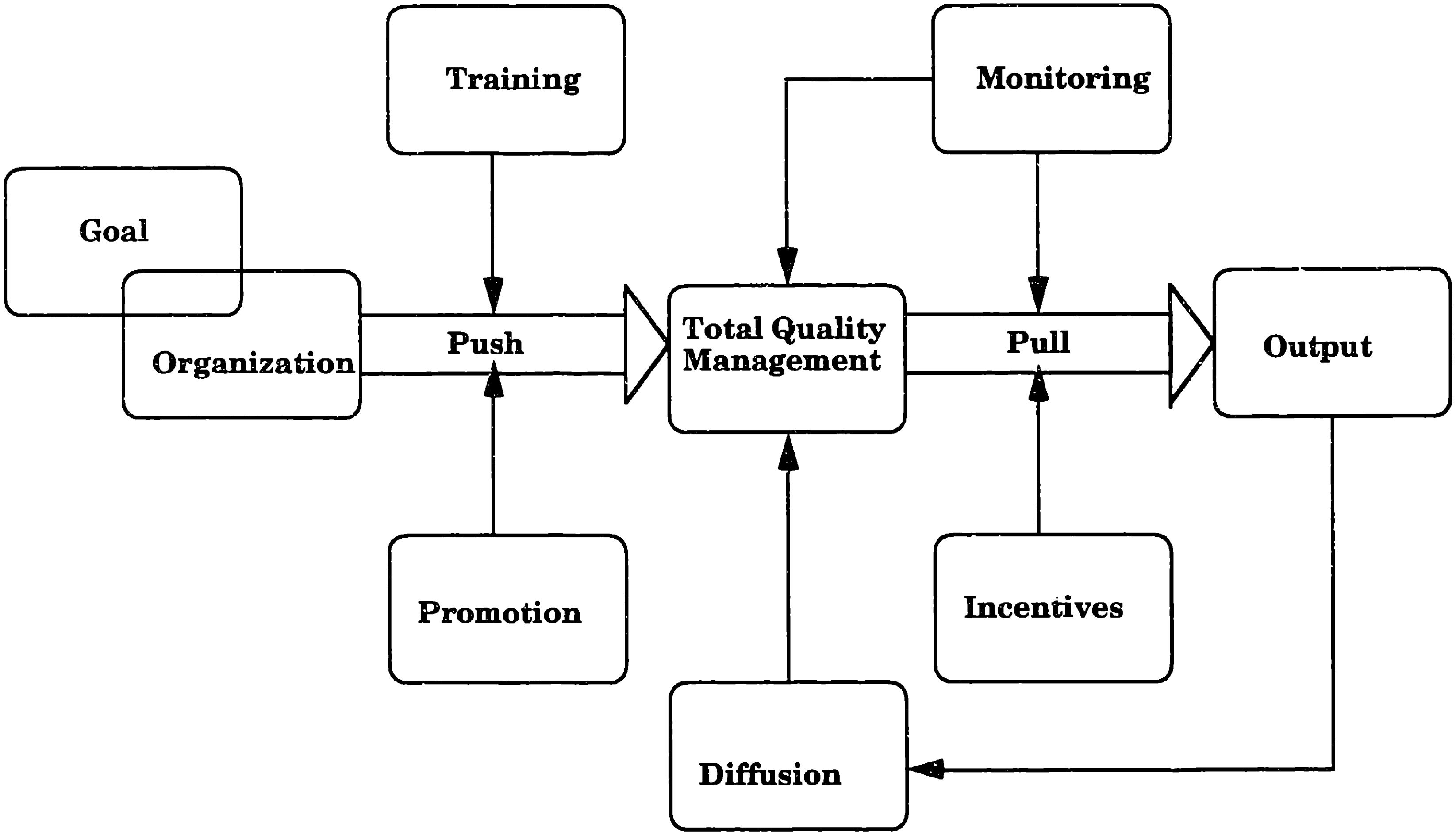

Exhibit 8-1

The two initial tasks assigned in the back end of the Wilmington plant were visible problems, and therefore accepted as meaningful, but little forethought was expended to ensure they were doable. One was an outstanding success, the second disbanded before a control chart could be effected. Although tremendous progress had been made towards simplifying a very complex process, the latter project was still perceived as a failure. No observable lasting damage came to the SPC program, but the perceived capabilities of individual team members were tarnished. Undoubtedly, their enthusiasm for taking part in further quality improvement efforts diminished. After review, management reformulated its deployment strategy, taking action to support teams with the establishment of the SPC group and to enhance oversight over the teams.

The feedback loop can be assisted through internal communication. Storyboards which recount a significant success are one avenue used by ADI. Publishing achievements in the company newsletter is another option.

Clarity of Task

Limiting the complexity of assignments must be done in consideration of the ability of the team and in recognition of diminishing returns and scarcity of human resources. The discussion in Chapter 7 of the continual improvement model asserts that teams should realistically be tasked to achieve gains reachable through a single pass of the PDCA cycle, unless the smaller gains available through additional passes exceed other potential accomplishments that the team could deliver if redeployed. ADS's recent SPC teams have a spectacular record for quality improvement but are often criticized for the long duration required to achieve these gains.

This problem is generally blamed on the competition with other job-related tasks for the manufacturing engineer's time. But the observation is totally consistent with a thoroughness (and recycling) needed to meet vague or exalted objectives. Determination and communication of a limited target would reduce project duration and more efficiently utilize valuable human resources.

Management's choice of the critical node narrows the scope slightly. But the scope could be further limited through assigning the critical output. Both team leaders objected to this invasion of their prerogative, defending a view that they are closer to the process and better able to recognize the relative importance of the options than management. This argument has significant merit, but is uncharacteristic of a firm engaging in TQM. Is this apparent product-out, as opposed to market-in, approach essential? A reasonable tradeoff allows management to approve proposed tasks submitted from the teams. This represents a minimum of interference required to provide oversight.[1]

Project Duration

Stoking the motivation of the team was a recognized responsibility by the more successful team leader. Motivation also seemed very dependent on the obviousness of need for the task by the SPC group. An imaginary problem cannot generate the needed spark and a team leader must be careful to ensure that slow progress does not allow the flame to be extinguished.

Project duration not only entails the inefficient deployment of resources; turnover within the group plays a increasingly detrimental role with

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[1] J. Richard Hackman, ed., Groups That Work (and Those That Don't) (San Francisco: Jossey-Bass Publishers, 1990), p.496.

extensions in the project schedule. New members have to be familiarized with what has be learned to date. Also, particularly for these early projects, the steps already accomplished have served as training assignments. The experience, both specific to the project and general to SPC, leaves with the departing member. The transfer of a team leader before completion caused one of the first two projects to be canceled without a control chart being realized.

The SPC group blamed the long run time on the commitment of team leaders. The conflict between routine and team responsibilities is explored further in a later section of this chapter. It is clear that the scope of the assignment also contributes to this problem.

The use of milestone scheduling based on the standard methodology steps was investigated. Both team leaders and the SPC group disapproved of this management tool because of the difficulty in forecasting progress. The SPC group preferred management attention to spur efforts rather than deadlines until quality improvement becomes internalized into the normal routine. This issue is explored further in the following section.

Time: A Scarce Resource

While the operators and technicians are relieved from their normal duties each week to participate in the team meetings, the supervisor and manufacturing engineer must accept the assignment without any compensating alleviation of other job tasks. The supervisor can at least justify the time personally invested since improvement in process control reduces their workload in the future (the SPC team is draining the swamp, instead of fighting the alligators).

However, the struggle for the team leader is evident. After it became perceived that progress was suffering due to this competition for time, mandatory team presentations to management were instituted to increase the perceived priority. The SPC group remarked that much of the analysis work has been accomplished in the two days preceding presentations. Recently, the SPC group ceded responsibility for scheduling presentations to the team leaders, and no presentations have since been scheduled. Is management attention essential to reasonable progression rate? The SPC group's concern is well founded, engineers take priority cues from management's attention. However, the observation on peaks of effort indicates that a even a loose milestone schedule could result in a speedier project run.

Still, it is important that management demonstrate its interest frequently to employees to alter the cultural assumptions on priorities. Ray Stata, the Chairman, insists that quality cannot be practiced during spare time. Instead, quality improvement must be integrated into nearly all routine activities. But he recognizes this is difficult initially, until the payoffs from quality relieves the strain by making the "alligator" an endangered species. Monitoring by management, which assumes a managerial commitment, is necessary until this hurdle is overcome. The presentations serve a dual role by advancing priorities and demonstrating managerial commitment.

The presentations also give the teams an opportunity to digest the assembled knowledge and critique the process. As taught by Professor Shiba, the quality improvement process becomes much clearer to the individual attempting to convey the knowledge to another. Public presentations completes the learning process.

Performance of Team Leader

The SPC group unanimously agreed that a superior performance by the team leader is the primary prerequisite of a successful team. Undoubtedly, some of the attributed accountability should reside elsewhere, but certainly the leader's role is crucial. As discussed in Chapter 5, the team leaders have assumed roles that they are uniquely qualified to fill. Their engineering knowledge and skills are essential to illuminating the problem, especially connecting cause and effect. Figure 8-2 contrasts the principles and circumstances that differentiate the more successful and less successful team leader.

The team leaders also serve as facilitators, helping those with only minimal exposure to the problem-solving tools. The more successful team leader believed one of his primary functions was to pull contributions from inhibited members, specifically exhorting operators to voice their opinions without fear in the presence of those higher in the formal company organization. This requires both private and public efforts to recognize the contributions of all members. Effectiveness during backroom talks is probably not evaluated on any engineer's performance review, but this skill is becoming increasingly significant. The more successful team leader was unsure of the motivation for operators to participate with an SPC team, but he strongly insisted it was his responsibility to provide positive feedback during discussions as one reward. This is a basic requirement for leading participatory teams. This informal system of rewards is critical when the formal system is insufficient.

The more successful team leader also twice referred to an informal subgroup, "my technician and I." Whether a purposeful effort or not, this honoring of the technician would help reduce the potential for resistance

Comparison of Team Leaders

	More Successful	Less Successful
Decision-making	Managed Concensus	Pure Democracy
What makes Good Team Leader	Details Follow-up Organization	Knowledge of Process, Methodology
Use of SPC Group	Technical Advice Methodology	Methodology
Area	Assembley	Test
Task	Process Specified	Area Specified

Exhibit 8-2

discussed in Chapter 5. The team leaders should actively attempt to increase the role of the technician in the analysis, substituting power for the discretion lost to the imposition of SPC.

But extensive process expertise and leadership skills do not guarantee success. Team leaders are also responsible for the necessary administration functions. The more successful team leader placed emphasis on these managerial responsibilities, both tracking details and planning ahead to keep progressing along the critical path. Publishing careful weekly minutes avoids reopening decided issues, and provides an opportunity to remind members of assignments to be accomplished before or at the next meeting. He even suggested that team leaders did not have to be the manufacturing engineer responsible for the specific area as long as the expertise was resident to the team. They only need an understanding of the process, and be details-oriented. This view is in opposition to the SPC group which listed the team leader's intimate knowledge of the process as critical for success.

The leaders have also, without fail, been forced to present progress reports to management with only minimal assistance from the remainder of the team. Public speaking fears and uneasiness in the presence of management are blamed for keeping other members from volunteering for this duty. As explored in Chapter 5, such blurring of roles would be uncharacteristic of the type of team observed. Rationalizations are not challenged because of the natural assumption that progress reporting is the responsibility of the manufacturing engineer.

The above argument on limiting the scope of tasks to allow deployment against other shortcomings is further strengthened by the SPC group's observation that team leaders improve during each assignment. Leaders leading their second team demonstrate more confidence and expertise.

Professional gains are realized by reaching an objective, reflecting on and digesting the lessons learned, and moving on. This is itself a PDCA cycle. The leader plans the first assignment with the aid of the standard methodology, accomplishes the task, reflects on the reasons for success and inefficiencies of the effort, then moves to improve themselves or the system before the next task. The less successful leader remarked that he volunteered for a corporate seminar on team dynamics after realizing his shortcomings in his first project. This training is not mandatory for newly-assigned team leaders, and its adequacy (and thus potential value) has not been determined.

Overcoming Skepticism: Widening the Base

Both team leaders expressed the assessment that top management at ADI is committed to improving quality, and the SPC teams are instrumental in this spreading this perception. One team leader and the SPC group believed that some of the workers were more skeptical.

This skepticism was anticipated by management. Ray Stata sees his role as creating a learning environment, termed the "New Analog". He also has observed that much correspondence prepared for his signature accurately reflects values he held years before, and has since discarded. Changing the assessments within an organization operates with a time delay dependent on the communication skills of the top and the organizational distance to the hearer. Management needs to continue to continue to demonstrate its commitment to quality improvement openly and often to reach the lower rungs of the ladder.

The SPC group and the team leaders noted that the quality improvement load has been shouldered by a dedicated, though significant, minority.

All noted that this group is enthusiastic to serve, with "persistence" a common descriptive. Cause and effect may be difficult to ascertain; are people motivated because their persistent nature was not overwhelmed by previous obstacles or persistent because their enthusiastic nature does not sanction retreat.

The proliferation of quality improvement teams has taxed this minority quite heavily, and potential members asked to participate are forced to decline because of their other commitments to quality improvement efforts. The availability of willing participants should be an observable variable that management uses to assess a sustainable number of quality improvement teams. As saturation nears, management must act to urge the majority into participation or review priorities to ensure limited human resources are being best utilized. Broadcasting the success stories should gradually overcome skepticism and help enlarge the pool enthusiastic to serve.

Communication Within the Team

The more successful team leader several times addressed the reluctance of some members, especially operators, to hold back information through fear of being proven ignorant. He repeatedly found it necessary to privately reassure operators that speaking out was important and riskless. A problem not surfaced cannot receive the proper attention.

The less successful team leader related that one difficulty with his first effort was communicating the importance and instructions for data collection. Designing the data experiment has in all cases been restricted to the team leader assisted by the SPC group representative. This is an activity where the team's input is severely limited. A danger exists that the exclusion of the other members results in poor implementation of the data collection plan. The supervisors, technicians and operators are well positioned to ensure the data is collected as designed, but can only truly fulfill this role if they understand the purpose of the experiment. Team leaders should be careful to brief the team before data collection begin. This assumes that the collection is not automatic and does require human intervention.

Preciseness of Information

The robustness of the measurement of the inputs and outputs is also critical to establishing process control. Often in the test area the quality characteristic is bias current, which is measured in microamps. The repeatability of floor measurements and the laboratory can be poor, making the data collected on the floor suspect. The potential for accurately measuring the inputs and outputs should be explicitly investigated by the team, since a random testing error could supply enough common variability to significantly detract from the control chart's usefulness.

Chapter 9
Conclusions

Simplifying Processes

The initial phase of SPC implementation produces a dramatic unveiling of the shrouds which make the process mysterious. For all the team members, the mapping of the process flow is enlightening. The SPC analysis requires this clear view of the process, which reconciles assumptions with reality. Thus, this investigation uncovers knowledge about the process, and reduces the complexity surrounding it.

The QA Manager emphasized that junior engineers and subordinates had accomplished amazing results in the testing area, confronting extremely complex problems which researchers still find daunting. SPC provides structure to the search by those most familiar with the process, yielding a clear superiority over conventional problem-solving for processes with significant complexity.

A Positive Loop: Growing Capabilities

The capability to tackle even more difficult assignments in the future is a secondary (at times the primary) gain from each success. Team members are trained hands-on. Success provides motivation to extend learning, and a better grasp of the concepts and vocabulary makes even greater knowledge assessable.

Altering organizational norms and structure to accomplish strategic objectives is the principle role of top management. Exhibit 8-1 suggests that this role in the quality improvement effort is analogous to a gardener developing a flower bed. The layout and planting sequence must be thoroughly planned to give the seeds have the fullest opportunity to flourish. But after the planning and planting, the biological functions of the plant and nature take the leading roles, and only monitoring and infrequent intervention (pruning and weeding) by the gardener is required. If faults are found in the planning, correction requires starting, at least the affected section, over. Management's efforts beforehand are most important.

The self-sustaining nature of a successful quality program occurs because the skill base increases when exercised combined with the snowball effect. In Chapter 8, success was judged by comparing accomplishments and effort. But a third factor should be included: the present value of future successes that each effort makes possible. Therefore, management's plans should provide the initial skill base and strengthen the feedback mechanism.

Managers should use their authority to control the task and provide the resources and oversight to assure success. Specifically, choices of the critical nodes and quality characteristic should be subject to review. Only a single pass of a PDCA cycle should occur without review. Oversight is adequately provided with the SPC group representative and the standard methodology. A presentation by all team members to management after reaching the goal will demonstrate management's commitment, deliver deserved praise, and ensure reflection on the process (to solidify learning).

Convincing the Masses

Success naturally overcomes skepticism. One member of the SPC group remarked that few participants in one of the first teams believed that input locks could be sustained. Most accepted the conventional thinking that equipment adjustments are needed to keep the output within specification.

Furthermore, whether the results from scientific problem-solving justifies the significant time investment was questioned. The SPC program was viewed as a "fuss about nothing".

Only after the first control charts were implemented was there acceptance that the previous frequency of adjustments was actually contributing to the variability. Such a basic concept of SPC could not be proved in the classroom; it requires a demonstration.

Technicians are the most likely participants to resist the introduction of SPC because it imposes rigidity on their craft. While the equipment may run better with SPC, the argument that a technician will have higher stature when acting in accordance with the out-of-control action plan is suspect. This situation can be abated by offering power in the breakthrough process to compensate for the loss of discretion in routine assignments. Team leaders should draw technicians to the center of team activities. Mastering the techniques of structured problem-solving would increase the technicians' skill level, and allow their position to continue to be respected.

Training Never Ends

Professor Shiba's assertion that knowledge requires use to be truly understood leads to a different perspective of training. Only an introduction of the quality tools is required before the first projects; true learning can then begin. Training includes both the classroom and meeting room experiences. Management must ensure the training resources remain available to continue the learning after the short course has been completed.

Team leaders should be given explicit instructions to create learning opportunities for all team members. The advantages from the snowball effect are restricted if only a few master the quality tools.

Intervention by Management

Centralized decision-making efficiently provides control, but flexibility and spontaneity are important for breakthrough activities. Management's principle role in the quality program should come at the beginning (or during major shifts), but monitoring and correction are still required. Corrections may have their intended consequence of avoiding a mistake, but they also dissipate the ability of the team to function independently. When is corrective action warranted? I suggest it is in approving the objectives offered by the teams. Action is justified if the team has chosen too difficult a task, which may result in failure. Management should also compare each proposed project to the business strategy, to ensure resources are being efficiently deployed. This represents a logical compromise between centralized and decentralized control, assuring both efficiency and effectiveness.

It is important to have the methodology lead the team through only a single PDCA cycle, if management must resolve to intercede only after the first step. This contains potential failures, limiting the risk while offering teams the freedom which contributes to breakthroughs.

Bibliography

Crosby, Philip B. Quality is Free. New York: McGraw-Hill Book Company, 1979.

Deming, W. Edwards. Quality, Productivity, and Competitive Position. Cambridge: MIT Center for Advanced Engineering Study, 1982.

Fine, Charles H. and David H. Bridge. Quest for Quality: Managing the Total System. Norcross, GA: Industrial Engineering and Management Press, 1987.

Hackman, J. Richard. Groups That Work (and Those That Don't). San Francisco: Jossey-Bass, 1990.

Hawakawa, S. I Language in Thought and Action. New York: Harcourt Brace Jovanovich, 1978.

Juran, J. M. Managerial Breakthrough. New York: McGraw-Hill Book Company, 1964.

Juran, J. M. Quality Control Handbook Third Edition. New York: McGraw-Hill Book Company, 1974.

Keidel, Robert W. Game Plans: Sports Strategies for Business. New York: E P. Dutton, 1985.

Kume, Hitoshi. Statistical Methods for Quality Improvement. Tokyo: The Association for Overseas Technical Scholarship, 1985.

Montgomery, Douglas C. Introduction to Statistical Quality Control. New York: John Wiley & Sons, 1985, 1991.

Steckler, Nicole A. Communication and Effective Leadership of Self-Managed Work Groups. Cambridge: Dissertation at Harvard, 1990.