ABSTRACT

Following the successful implementation of the Alcoa Production System in 1998, Alcoa Shanghai Aluminum Products shifted its focus in 1999 to Quality. Excess supply among domestic aluminum foil producers had intensified price competition, and the company was finding it increasingly more difficult to attract and keep customers. High quality was seen as the only viable competitive advantage, as it would differentiate Alcoa Shanghai from its competitors and increase the company’s production efficiency. Alcoa Shanghai thus realized it needed an internal strategy to control and improve quality.

A new quality strategy was developed for Alcoa Shanghai, one that deeply affects the culture of the organization, requiring employees to think about and see things in a new way. The organization at Alcoa Shanghai is unlike any encountered in Western or Japanese companies, due to the vastly different economic, social, and political conditions present in China. Thus, while elements of the strategy were borrowed from common quality programs such as Total Quality Management and Statistical Process Control, the strategy itself is tailored to the specific needs and skill sets of Alcoa Shanghai. On the other hand, because other Chinese companies are likely to have similar organizational issues, the quality strategy developed for Alcoa Shanghai can be seen as one that is applicable to Chinese manufacturing in general.

Implementation of the new quality strategy has begun at Alcoa Shanghai, with a high level of employee involvement. The organization has been trained in modern quality concepts and has achieved significant results through small team efforts. The implementation is a continual effort, and Alcoa Shanghai is well poised to reap further benefits from their new way of doing things.

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Chapter 1: Introduction and Overview

Here in the United States, most manufacturing companies recognize quality as a critical component of their factory operations. American manufacturers learned their lesson in the 1980’s, when domestic market share in nearly every industry was being lost to Japanese products at an alarming rate. After some initial panic, it was quickly realized that the strength of the Japanese manufacturers lay in their emphasis on quality. American companies thus began to adopt quality concepts from the Japanese, and even invented several quality programs of their own. Their renewed interest in quality has no doubt played a significant role in the rebound of American manufacturers as potent competitors to the Japanese once again. Today, nearly every large American manufacturing company stresses quality as a major component of its competitive strategy.

In some sense, a similar pattern of events is beginning to unfold among manufacturing companies in China. As the country shifts from a planned to a market economy, domestic manufacturers begin to face competition that was previously not present. After decades of isolation from the outside world, many Chinese factories now realize that they lag behind foreign competitors in both technology and operations management. To survive, they must learn and adopt the methods of their foreign competitors, perhaps even improving upon them. One particularly critical area of learning, as expected, is quality. Having operated in a protected environment for so long, these Chinese companies previously never had to focus on the quality of their products.

Alcoa Shanghai Aluminum Products is one company that has worked and is working very hard to catch up with international standards, particularly the standards of its American parent company, Alcoa. Prior to 1995, this company had operated for a decade as a traditional Chinese state-owned enterprise. In that year, Alcoa bought a controlling interest in the plant, establishing it as a joint venture. Since then, Alcoa Shanghai has been systematically modernizing its own production capabilities. Most recently, in 1998, the company began the implementation of the Alcoa Production System (APS), a variant of the Toyota Production System. The success of APS has helped raise the competitiveness of the company significantly.
With APS in place, Alcoa Shanghai realized in 1999 that quality was the key to further increasing its competitive edge. APS already enabled the company to provide faster response with lower inventories; to also offer high quality product would truly delight customers. More importantly, Alcoa Shanghai management recognized the importance of quality to internal operations. For example, effective quality control would complement the mechanics of APS, allowing the production system to be even more streamlined. The role that quality programs had played in the turnaround of American manufacturers was well known to the company.

Alcoa Shanghai was thus interested in bringing quality into its organization. Between June 1999 and December 1999, the company hosted an internship project, in conjunction with the MIT Leaders for Manufacturing (LFM) program, to help develop a new quality strategy for its organization. This thesis is one of the results of that internship project.

1.1 Project Goals

The primary goal of the project was to develop a quality strategy that complements Alcoa Shanghai’s implementation of the Alcoa Production System. The strategy would introduce modern quality concepts to the company, ultimately enabling it to operate more competitively. Most of the individual components of the quality strategy would be borrowed from well known quality programs, but they would be tailored to the organization. As a previously state-owned enterprise, Alcoa Shanghai’s organization had a set of skills and needs that is not encountered in either the West or Japan. To some extent, the quality strategy developed for Alcoa Shanghai would be broadly applicable to many other Chinese companies, since they have similar organizational issues. Thus, the project goal can be considered to be a quality strategy for any typical Chinese company facing similar pressures.

In addition to a new quality strategy for Alcoa Shanghai, a rough implementation plan would also be defined, and implementation of the strategy would have begun before the end of the internship. It was not expected that the strategy could be fully developed and implemented within the six-month timeframe, but key components would be tested and proven. Furthermore, certain individuals within the company would be prepared to continue the implementation after the termination of the internship.
1.2 Approach to the Problem

Because culture was expected to have a significant influence on the definition of the quality strategy, it was decided that the first and most critical step in the project would be a careful assessment of the company’s organization and environment. A rough outline of the approach taken is as follows:

1. Understand the business and political environment within which Alcoa Shanghai operates. The political environment is important because business in China is always inevitably influenced by politics. Assess the organizational culture of Alcoa Shanghai, including the people’s skills, interests, and motivations. Learn about the production and non-production processes of the plant.

2. Define the importance of quality to Alcoa Shanghai. Assess the company’s initial condition, including any gaps, opportunities, and barriers to quality improvement.

3. Review common quality programs that have proven to be effective in Japanese and Western companies. Consider their relevance to Alcoa Shanghai’s case.

4. Articulate the quality goals of the company, then design a strategy that is capable of meeting these goals and is suited to the organization. Define a rough plan for implementing this strategy.

5. Begin implementation of certain selected components of the strategy. Provide for the implementation to continue after the internship has ended.

1.3 Layout and Purpose of this Document

The layout of this thesis roughly follows the approach described above. Chapter 2 describes the project setting and background, including general information on Shanghai and a detailed description of the company’s organization and production process. Chapter 3 discusses the role of quality at Alcoa Shanghai, including the company’s initial condition. Some perceived gaps, opportunities, and barriers are also discussed. Chapter 4 takes a brief look at several well-known quality programs: ISO 9000, Total Quality, Quality Circles, and Statistical Quality Control. This chapter is intended to give the reader some ideas of what kinds of quality initiatives have worked.
for other companies. Chapter 5 presents the quality strategy that was created for Alcoa Shanghai, called ‘Excellence through Quality.’ The chapter begins by articulating the goals of the strategy, then presents a framework that was designed to help the company think about quality. It closes with a description of the implementation plan. Chapters 6, 7, and 8 describe the implementation of three key components of the strategy. Finally, Chapter 9 closes this thesis by describing some of the conclusions and learnings gained by the author from performing this project.

This thesis is to be interpreted as a case study on the topic described by its title: bringing quality into a Chinese organization. Because organizational culture was a major influence in the design of the quality strategy, and because most Chinese companies have similar organizational structures, it is believed that the process documented in this thesis would be effective for most Chinese companies. In fact, the quality strategy designed for Alcoa Shanghai should be directly applicable to other Chinese manufacturing companies, with perhaps a few minor modifications.

Because this thesis is a case study, it includes a large number of appendices that present the actual output of the work done at Alcoa Shanghai. The author has provided these materials in both English and Chinese wherever possible.
Chapter 2: Project Setting and Background

The work detailed in this thesis was performed by the author during a six-month assignment at Alcoa Shanghai Aluminum Products Company. While the focus of the project was on quality improvement in a manufacturing environment, the author found that cultural issues played a very strong role in defining the nature and scope of the work. In fact, understanding and appreciation of the Chinese work and life culture constituted at least 50% of the learning experience. It is therefore necessary, when reading this thesis, to consider the work in the proper context. This chapter begins to build the context by describing the setting of the project in some detail. It must be emphasized, however, that no amount of detail can ever come close to truly representing the experience of living and working in modern China.

2.1 Overview of Shanghai, China

While not an expert of any kind on the social and economic conditions of Shanghai, the author wishes to share some of his perspectives on living and working in the largest city of the world’s most populous country. It should be noted that this section is not intended to be an exact account of Chinese history and politics, but is merely intended to provide a context and setting for the work described in the rest of this document.

2.1.1 China: political and business environment

As of the late 1990’s, the People’s Republic of China had a population over 1.2 billion, or roughly one-fifth of all the world’s people. Since October 1, 1949, the country has been governed by the Chinese Communist Party (CCP), the largest Communist party in the world with 54 million official members. Membership into the CCP is extremely coveted (and difficult to attain), as it is often the key to both power and wealth. For example, it is no coincidence that managers at domestic companies (including Alcoa Shanghai) are almost always CCP members. The country’s constitution allows for other political parties, but these parties must be under the supervision and guidance of the CCP, and may never hold office. The constitution also permits certain freedoms (religion, speech, assembly, etc.), but they are very closely monitored.
China’s large population, combined with its relatively undeveloped economy, presents huge growth prospects for businesses of all kinds. The country has been a favorite target of multinational companies around the world, who wish to capture even a small fraction of the potential market in everything from commodities to high-tech services. “If we could just make a dollar off every Chinese,” goes the common adage among executives of these companies. Unfortunately, many companies are finding that even one dollar is a lot to spend for the typical Chinese citizen. Furthermore, despite recent measures to move from a planned to market economy, the government has a history of meddling with business dealings. Most recently, for example, the government has outlawed foreign investment in Internet businesses and delayed the deployment of CDMA wireless technology. These announcements came only after significant amounts of foreign money had already been invested in Chinese Internet companies, and after an agreement had already been reached between Qualcomm and China Unicom to build CDMA infrastructure. Such uncertainty on the part of the government clearly makes doing business in China extremely difficult.

2.1.2 Shanghai: economic condition

With a population over 16 million in its metropolitan area, Shanghai is China’s largest city, as well as its most important industrial, commercial, and financial center. Located on the east coast at the convergence of the Yangtze and Huangpu Rivers, this port city has virtually no natural resources yet produces five percent of China’s industrial output, and contributes one-sixth of the national budget. Its importance is evidenced by the fact that it is one of few cities (others include Beijing and Chongqing) governed at the same level as a province. Shanghai is also regarded as the most modern and Western of Chinese cities (excluding Hong Kong), famous for its shopping and architecture.

Shanghai has long been the economic center of China, though it experienced a decline in the 1980’s due in part to Beijing’s drastic reform policies. Beijing was reluctant to allow Shanghai the same extent of economic freedom that was being experimented with in Shenzhen, causing the

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1 Most of the information presented in this section was obtained from the US Embassy website: http://www.usembassy-china.org.cn/consulates/shanghai/epcss.htm
latter to take over the lead in foreign trade. In 1992, President Deng Xiaoping finally gave approval for Shanghai to engage in free market practices on par with Shenzhen and other designated ‘Special Economic Zones.’ Starting then, the city aggressively attracted foreign investment by designating its own development zones that offered tax and other benefits. In five years’ time, more than 17,000 foreign enterprises had contracted to invest about $32 billion in Shanghai. Most of these investments were in the form of joint ventures.

Today, foreign-invested enterprises (FIE’s) account for about one-fourth of Shanghai’s economic output and over 35% of the city’s exports. They are a major source of employment; indeed, jobs at foreign or joint venture companies are the most desirable. Overall, however, the success of these ventures has been mixed. At the end of 1998, the city government estimated that roughly half of all FIE’s were unprofitable. Included in this group was Alcoa Shanghai.

Shanghai’s economic reforms have been a mixed blessing to the city’s residents, who have had to bear the stresses and burdens of shifting conditions. The entry of foreign enterprises has put pressure on state-owned enterprises (SOE’s) to become more competitive. In 1996, it was estimated that 30% of Shanghai’s SOE’s were losing money. To reverse this trend, many SOE’s began to abandon some of the social benefits they have traditionally provided, such as housing, medical care, and education. Many of these burdens were shifted to individuals, creating problems of unemployment and poverty. These problems are compounded by a general lack of skills, such as English, sought after by the new foreign-invested enterprises.

In summary, economic reform in China during the last decade can be credited with the rapid growth the country is seeing now. The reforms have come at significant cost to the people, who are only now beginning to adapt to the conditions of a free market. Despite the difficulties, however, Shanghai’s outlook for continued growth remains very positive.

2.2 Overview of Alcoa and Alcoa Shanghai

Alcoa Shanghai Aluminum Products (Alcoa Shanghai, or ASAP) is one of several manufacturing facilities overseen by Hong Kong-based Alcoa Asia Limited. The company is located at 855 Jiang Chuan Road, in the Minhang Economic Development Zone of Shanghai. It is established
as a joint venture, with 60% ownership by Alcoa and 40% ownership by Shanghai Light Industry, which represents the Chinese government.

2.2.1 Alcoa

As of 1999, Alcoa is the world’s largest producer of primary aluminum, fabricated aluminum, and alumina. Headquartered in Pittsburgh, Pennsylvania, the company is active in all major segments of the industry, including mining, refining, smelting, fabricating, and recycling. Major customers come from the packaging, automotive, aerospace, construction, and other industries. In addition to aluminum products, Alcoa is also a player in other businesses such as alumina chemicals, plastic bottle closures, packaging machinery, vinyl siding, and electrical distribution systems for cars and trucks.

With 25 business units, 228 locations, and more than 100,000 employees worldwide, Alcoa generated $15.3 billion in revenues in 1998. In late 1999, the company announced a stock merger with Reynolds, then the number three player in the industry. This announcement followed a similar one by Alcan, the Canadian company in the number two spot, that it was merging with two large European aluminum producers to become the top player. With this major reorganization, the aluminum industry is poised to see significant changes in its business environment in the coming years.

2.2.2 Alcoa Shanghai

Alcoa Shanghai Aluminum Products Company was established in May 1995 when Alcoa purchased a 60% interest in the aluminum foil production facility of the Shanghai Aluminum Fabrication Plant, which operates under the control of Shanghai Light Industry. The foil plant was built the mid-1980’s, and had operated as an entirely state-owned enterprise. Today, it is run as a joint venture between Alcoa and Shanghai Light Industry, representing the Chinese government. Until late 1999, the plant had never been profitable. Figure 2.1 shows the front entrance to the facility.

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2 Alcoa company website: http://www.alcoa.com/
Alcoa Shanghai produces aluminum foil ranging in thickness from six to 400 microns (one micron, or 1\(\mu\)m, equals one-thousandth of a millimeter), offered in several alloys and numerous widths. Major product applications include packaging (food, pharmaceutical, and cigarette), adhesive tape, decorative sheet, and fin stock (for automobile radiators). Customers are domestic, varying in size from large state-owned enterprises to single person operations. Orders are defined by final gauge (thickness), alloy, width, temper (hardness), and weight.

One particularly important class of product made by Alcoa Shanghai is thin-gauge foil. This is aluminum foil with thickness in the range of 6 to 7 microns (6 \(\mu\)m – 7 \(\mu\)m), which customers laminate onto paper for use as packaging material. Per ton, thin-gauge is the most expensive, and thus most profitable, foil sold by Alcoa Shanghai. However, because it is so thin, the coverage area per ton is also the highest, and this more than makes up for its higher price. Therefore, customers actually save money by using thin-gauge foil. On the other hand, thin-gauge foil is difficult to produce – its thinness makes it more susceptible to pinholes, breaks, and
other quality problems. Thin-gauge production technology was transferred to Shanghai several years ago from Alcoa’s Itapissuma foil plant in Brazil, one of the most advanced in the world. Alcoa Shanghai leads other Chinese producers in thin-gauge foil, and it is considered the company’s key strategic product.

Business Environment

Competition within the Chinese market is intense, driven by capacity surplus among domestic aluminum foil producers. In order to position itself as the supplier of choice, Alcoa Shanghai strives to offer low cost, high quality, and rapid response to extremely variable demand. Management believes the key to reaching these ambitious goals is superior manufacturing. Thus, the company has put in place a number of initiatives designed to improve its manufacturing capability. The most significant of these is the Alcoa Production System (APS), described later in this chapter.

Because of the intense competition among foil suppliers, customers have become extremely demanding. For most of them, price is the primary factor affecting their purchasing decision; at the same time, however, they expect high quality and fast delivery. To make matters worse, it is a common business practice in China for customers to constantly renegotiate pricing terms, even after orders have been confirmed. For example, a customer may place an order at a specified price, to be picked up two weeks later. In the two weeks that follow, Alcoa Shanghai’s sales department will contact the customer several times to reconfirm the order; each time reconfirmation is given without any problems. However, on the agreed pickup date, the customer will arrive at the plant, claim to have run out of money, and demand a deep discount. As a matter of principle, the sales manager often refuses to grant this type of last-minute discount, and the sale is not completed. Alcoa Shanghai is then left with a large amount of idle finished goods, which it must eventually sell (usually at a discount) or scrap.³

Alcoa Shanghai’s competitive position is compromised by the practice of smuggling among its competitors. While the company purchases aluminum ingot from domestic Chinese suppliers, its

³ Interview with Shi Muchao, Sales Manager, Alcoa Shanghai Aluminum Products Co., July 1999.
competitors are believed to routinely smuggle aluminum stock from Korean suppliers, avoiding the heavy import duties levied by the government. The materials from Korea are usually of higher quality than what is available domestically, primarily due to the higher quality alumina available there. Recently, the Chinese government has vowed to crack down on all smuggling activities, but policy enforcement is very difficult. It is not difficult to understand why when one considers that most of Alcoa Shanghai’s competitors are state-run enterprises, with very close ties to the government.

To operate profitably in this difficult business environment, top management has undertaken a number of initiatives aimed at achieving greater competitiveness. For example, the Alcoa Production System has been successful in reducing inventories and cycle times, allowing faster response to orders. More recent initiatives have focused on quality control and improvement.

Organizational Structure and Employee Demographics

In any manufacturing environment, quality is closely tied to people’s attitudes, behaviors, and actions. Therefore, a critical element of any quality improvement process must be cultural change. Proper cultural change, in turn, relies on an accurate assessment of the current situation, including an understanding of people’s backgrounds and capabilities. To begin to develop this type of understanding, this section describes the organizational structure and employee demographics at Alcoa Shanghai.

The organization chart for Alcoa Shanghai is presented in Figure 2.2. The structure is largely functional, with managers from Environmental Health and Safety (EHS), Human Resources, Purchasing, Alcoa Production System (APS), Manufacturing, Process, Quality, Finance, Engineering, and Sales and Marketing reporting to either the Plant Manager or the General Manager. During the author’s assignment, Albert Wang was the Plant Manager, while Benny King served as the General Manager.

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4 Interview with Albert Wang, Plant Manager, Alcoa Shanghai Aluminum Products Co., June 1999.

5 Peter Senge, in his book The Fifth Discipline, argues that these are three levels of explanation for any complex situation. Chapter 3 revisits this conceptual framework.
The manufacturing organization includes the casting shop, foil shop, maintenance, process development, planning, and quality departments. The foil shop is further separated into the rolling, finishing, and packing areas, each overseen by its respective supervisor. The plant operates 24 hours a day, seven days a week, utilizing four rotating shifts of operators, each shift coordinated by a foreman (lead operator). The rotation schedule calls for operators to work two days on first shift (7:00 A.M. – 3:00 P.M.), two days on second shift (3:00 P.M. – 11:00 P.M.), and two days on third shift (11:00 P.M. – 7:00 A.M.), followed by two days of rest. Schedule swapping is kept to a minimum, so that each shift is staffed by a team of operators that are experienced in working with each other.

The Minhang area was one of the first to be designated by the Shanghai government as an Economic Development Zone. Prior to the designation, the area was largely agricultural, with

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6 Much of Shanghai and its surrounding areas today is divided into special regions, such as economic and technology development zones.
most of its residents employed as communal farmers. When manufacturing plants began to
displace the farms, the government offered farmers the opportunity to seek work as production
personnel. (Policies like this are easily effected in the Communist environment of China, where
most factories are state-run, and citizens’ jobs are designated by the government anyhow.) The
Shanghai Aluminum Fabrication Plant was no exception; indeed, many of its original operators
were previously farmers who worked in the area. In the early years of the company, the plant
invested significantly in training these new operators. When the joint venture commenced more
than ten years later, Alcoa invested in even more training to bring their skills closer to Alcoa
standards.

As with operators, non-production personnel also do not represent the level of education and
skills that one typically expects to find at a Western company. Due to certain past policies of the
Chinese Communist (discussion of which is outside the scope of this paper), there is a
widespread shortage of well-educated professionals in the country. This is clearly evident at
Alcoa Shanghai, where only 8% of the employees (including production staff) have bachelor’s
degrees or higher. Indeed, many of the company’s engineers never attended college, though they
may have received relevant specialized training.

The original agreement establishing the joint venture between Alcoa and Shanghai Light
Industry provides for the retention of all original employees and stipulates that Alcoa Shanghai
may not terminate anyone’s employment. In addition, the Shanghai partner oversees the
company’s human resources management. As a result, Alcoa has very little freedom in defining
the cross-section of employees at the plant. At present, about 90% of the company’s workforce
has been with the plant since the state-run times. The rest have been hired domestically since the
joint venture began.

Figure 2.3 illustrates the employee educational levels at Alcoa Shanghai at the time of the
author’s assignment.7 The company employs a total of 328 employees, of which just under half
are production staff (mainly operators and maintenance staff). The general manager and plant

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7 Actually, the data represent the demographics as of September 30, 1999.
manager are American expatriates; all other employees are Chinese, mostly from Shanghai and surrounding areas. Roughly one-third of the workforce, including a number of managers, are female. The pie chart shows that the level of education is generally quite low, with about 50% of the employees having never attended high school.

![Pie chart showing educational levels of Alcoa Shanghai employees.]

**Figure 2.3: Distribution of educational levels of Alcoa Shanghai employees.**

*The Aluminum Foil Production Process*

The Alcoa Shanghai plant has casting, rolling, annealing, trimming, and packaging capabilities. The foil production process begins with aluminum ingot obtained from local suppliers and ends with packaged coils of specified alloy, hardness, thickness, width, and weight. Figure 2.4 illustrates some simplified process flow paths, Figure 2.5 gives the plant layout, and Figure 2.6 shows photographs of some of the process areas.

![Diagram of the aluminum foil production process.]

**Figure 2.4: The aluminum foil production process.**
Figure 2.5: Alcoa Shanghai Aluminum Products facility layout.
Aluminum ingot warehouse.

Casting line.

Intermediate mill (rolling).

Rough anneal furnace.

Heavy slitter (trimming).

Packing area.

Figure 2.6: Aluminum foil production process steps.
At the start of the production process, pure aluminum ingot is melted, combined with other metals (according to alloy requirements), and cast into large coils at one of two lines in the casting shop. Each coil contains about nine tons of six-millimeter-thick sheet, 1.3 to 1.6 meters wide. After casting, the coils are allowed to cool for approximately 24 hours, aided by large fans blowing in the axial direction.\(^8\)

In the rolling area, three large mills reduce the thickness of the coil through a series of successive passes. The breakdown mill (BDM) is capable of reducing coils from 6 millimeters (the cast thickness) down to as low as 180 microns. The intermediate mill (IM) takes output from the BDM and produces final thicknesses in the range of 22 to 270 microns, while the finishing mill (FM) takes output from the IM and produces final thicknesses down to 6 microns. The number of passes required at each mill depends on the final thickness of the product. Many thicker products (22 microns and above) do not need to go through the finishing mill, while thin-gauge products may undergo up to a dozen passes (4 - 5 passes at BDM, 4 - 5 passes at IM, and 1 - 2 passes at FM), requiring several days.

At certain points in the rolling process, usually between passes at the breakdown mill, it is necessary to anneal the coil in one of two rough anneal (RA) furnaces. This step helps to reduce the stress generated by rolling, especially during passes where the reduction in thickness is 50% or higher. Rough annealing allows the coil to continue being rolled with less risk of quality problems such as breakage.

After a coil has been rolled to its final thickness, the next step is to trim it down to the width specified by the customer. This is done in the finishing area on one of three machines: the heavy gauge slitter (HGS), which is used for thick foils; the light gauge slitter (LGS), which is used for intermediate thicknesses; and the separator (SEP), which is used for thin-gauge products. The planning department is responsible for specifying the widths and weights to which each coil is trimmed. Planners try to optimize the slitting patterns to use as much of the coil as possible,

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minimizing scrap. The slitting step generally takes several hours. Coils which have been slit are referred to as ‘baby coils.’

Depending on the temper (hardness) required by the customer, baby coils may be taken directly to the packing area, or be subject to a final anneal (FA) step at one of six furnaces. Final annealing, with its associated cooling, adds about one day to the production time. At the packing area, finished baby coils are subject to quality checks by a team of inspectors. Once the quality is verified, operators pack the coils into the appropriate container - usually a wooden crate or plastic sleeve. The packaged coils are then sent to the finished goods warehouse, where they await pickup by the customer. While Alcoa Shanghai makes most of its products to order, it also maintains a finished goods inventory of the most popular specifications. Figure 2.7 shows the finished goods warehouse at Alcoa Shanghai.

![Figure 2.7: Alcoa Shanghai finished goods warehouse.](image)

Alcoa Shanghai’s process department maintains a spreadsheet that details the exact process for producing each type of product offered by the company. For example, for thin-gauge foil of a specific alloy, the process document specifies rolling parameters, annealing times, cooling times, and trim widths, among others. In practice, the production process often does not follow this document exactly, since it frequently must deal with complications such as capacity constraints.
and quality issues. For example, a temporary breakdown at the finishing mill may reduce its availability, prompting planners to shift some of its normal rolling passes to the intermediate mill. Additionally, poor quality may dictate rework on some coils, or may lead planners to redesignate coils (change the final specifications). Finally, process improvements are not always well documented, so it is not unusual to discover slight differences in the actual process between different shifts of operators.

The Alcoa Production System

The Alcoa Production System (APS) represents Alcoa’s adaptation of the Toyota Production System to aluminum manufacturing. A component of the Alcoa Business System (ABS), APS was devised to achieve consistency and high productivity across all of Alcoa’s manufacturing sites. Alcoa maintains a core group of APS experts at its Pittsburgh headquarters, and has been systematically implementing the system at its facilities in turn. APS is regarded internally as one of the company’s key competitive strengths.

At its most basic level, APS is a collection of three ‘overarching principles’ that guide the use of 20 interdependent sub-systems, as diagrammed in Figure 2.8.

![Figure 2.8: The Alcoa Production System (APS).](image)
Quickly summarized, the three overarching principles are:

1. **Make to use** – Make what the customer wants, when the customer wants it, and in the quantity the customer wants. This is in contrast to make-to-stock systems.

2. **Eliminate waste** – Make perfect product, waste-free, every time. Focus on the elimination of the seven kinds of waste.

3. **People linchpin the system** – People are the key to aligning the system to customer use rate, operating flawlessly within the system, and continually improving it.

The ideal condition is represented by full realization of these three principles. The 20 sub-systems are the means to achieving the ideal condition, though their usage should vary according to the demands of the particular facility.\(^9\)

With the help of an intern from MIT’s Leaders for Manufacturing program, Alcoa Shanghai began the implementation of APS in 1998. At the time of the author’s arrival, APS was effectively governing most of the plant’s floor operations. Implementation in non-floor operations, such as planning and procurement, faced more difficulties. Some of the key features of the Shanghai implementation are described in the following paragraphs.\(^10\)

APS imposes a pull system on the casting shop and the rolling area (BDM, IM, and FM) of Alcoa Shanghai’s facility. Production at each machine in these areas is governed by kanbans, small cards that carry specific instructions. Kanbans on a kanban board instruct operators on what to produce and when to produce it. Operators are also trained to transfer kanbans as necessary to ensure proper information flow across the line.

For example, a kanban at the IM board instructs the IM operator to perform a specific operation on a specific piece of starting material. To carry out this instruction, the operator removes the work-in-process (WIP) from the FM store, and sends a kanban back to the FM to instruct the

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\(^9\) The definitions associated with the Alcoa Production System are property of Alcoa. More detailed explanations of APS can be found in previous LFM theses, including Michael Kimber, *Definition and Implementation of a Visual Inventory Management System*, MIT, May 1999.

\(^10\) For a more detailed description, see Michael Kimber’s thesis, noted above.
operator there to replenish the WIP. After the proper operation has been completed, the IM operator then places the finished material in the IM store, where it awaits use by the FM operator. Meanwhile, the IM operator proceeds to the next kanban on the board. In this way, WIP is propagated downstream and information is propagated upstream simply and efficiently by kanban mechanics. As an added benefit, the kanban boards provide a visual representation of the current state of the facility. Figure 2.9 shows the kanban board that governs production at the finishing mill; the blue and white cards are the kanbans.

![Kanban Board at the Intermediate Mill](image)

**Figure 2.9: Kanban board at the intermediate mill.**

In order to facilitate the kanban pull system dictated by APS, WIP inventory is maintained in stores located between every pair of machines. (In this sense, the system is not truly ‘make to order,’ though it is still ‘make to use.’) These stores ensure that the downstream operator has starting material to pull from when a kanban calls for production of a certain product. If there is no material in the store for the operator to pull from, then the entire system will be delayed, causing waste. Thus, it is critical that the size of the stores be large enough to provide an adequate service level, but not so large that they cause unnecessarily high inventory. Indeed, a major task in the implementation of APS was the calculation of the optimal size of each WIP store. Figure 2.10 shows the store between the casting shop and the breakdown mill.
In the finishing and packing areas, APS calls for a push system to govern their production. The planning department relays customer order information to one of the three trimming machines (LGS, HGS, and SEP), instructing the operator there to produce the necessary baby coils. Once the slitting is completed, the baby coils are ‘pushed’ to the final anneal furnace operator (if necessary), and then to the packing area. There, the coils are packed according to customers’ instructions. Because trimming is usually the bottleneck step among these operations, there is minimal idle WIP in this part of the plant.

Alcoa Shanghai is proud of its APS implementation, as it has been successful in significantly reducing WIP inventories and cycle times. However, there is still a large untapped opportunity in extending APS beyond factory floor operations, to integrate production with other functions such as planning, quality, procurement, and sales. Moreover, APS calls for continuous improvement, and there is never any doubt among the people that improvement can always be made to the system. Even aside from improvement, a great amount of effort is required just to maintain the system, keeping it running smoothly and efficiently. Thus, Alcoa Shanghai’s APS implementation is seen as an ongoing process, with each step bringing the factory closer and closer to the ideal condition.
The Foil Business System

With the help of an American consultant, Alcoa Shanghai had installed the Foil Business System (FBS), a Microsoft Access database that records a wide range of production information. FBS includes data such as production times and quantities, machine operation parameters, and orders and shipments. User-friendly FBS terminals are installed in each production area and are also present in the offices of the Maintenance, Sales, Purchasing, Quality, and other departments. Operators are required to input information into FBS as they begin each unit of production. The system also records certain information automatically, such as production start and finish times. A small information systems staff maintains and customizes the Foil Business System according to the company’s changing needs.

The Foil Business System has provided the Alcoa Shanghai production organization with unprecedented access to real-time data. From FBS terminals, one can query the database for reports on almost every aspect of the factory, allowing continuous monitoring and optimization. Standard reports are generated on a regular basis and reported in production meetings, while a number of customized reports are used for more in-depth analyses. The reports are extremely useful for presenting a summary of the factory’s operational performance. FBS has been especially valuable to the Quality department, since the real-time data it provides is critical for effective quality improvement.
Chapter 3: Quality at Alcoa Shanghai

Having successfully implemented the Alcoa Production System across factory floor operations, management at Alcoa Shanghai shifted their focus in 1999 to quality improvement. Quality is viewed as the means to further capitalize on the success of APS. By achieving higher quality, the company will be able to reduce cost and delight customers at the same time. In the extremely price sensitive environment facing Alcoa Shanghai, high quality is seen as the only viable and sustainable competitive advantage.

3.1 The Importance of Quality

With limited resources, Alcoa Shanghai management had to choose carefully which of many improvement opportunities to pursue. APS, while it was regarded as highly successful, still had many gaps that could be filled. For example, there was not yet a strong integration with non-production operations such as purchasing and sales. There were also opportunities to improve the maintenance function, as machine downtimes often occurred unexpectedly. From this myriad of good opportunities, management decided that the company’s interests would best be served by focusing on quality improvement. This decision was justified on a number of bases:

3.1.1 Quality for quality’s sake

The first and most obvious reason for focusing on quality improvement is to enable the company to serve their customers better. Quality improvement, after all, should ultimately result in higher quality products. Assuming the cost of production does not increase, these higher quality products would then meet and surpass customers’ expectations.

Alcoa Shanghai’s customers were becoming increasingly demanding in terms of price, quality, and delivery. With excess supply of aluminum in the domestic market, these customers fully exercised their arsenal of Chinese business tactics. They negotiated for lower prices and faster delivery, and were quick to point out every small quality flaw. Some quality aspects which are important to the customer include thickness uniformity, consistency of material properties (hardness, tensile strength, etc.), surface finish, flatness, coil tightness (a coil wound too tight is
difficult to unwind), and porosity (presence of pinholes). Alcoa Shanghai’s sales and marketing department regularly survey their customers to get feedback on the company’s quality performance relative to competitors. Customer returns are also used as an additional metric of customer satisfaction.

3.1.2 Quality as a means of cost reduction

There is a school of thought that says high quality comes only at high cost. While this statement may be true in some situations, it is often not the case. This author believes that the cost of quality improvement depends on the starting point of the company in question. If the starting point is very low, where systems are operating haphazardly and people have no concern for quality at all, then quality improvement will have to come at some cost. This cost is necessary because the changes in systems and behaviors will be drastic. If the starting point is very high, where quality processes are already in place and people are well trained in the latest techniques, then quality improvement will also be somewhat costly. This is because any effort to further improve the quality will have only incremental results, so that a significant change in the quality level will require a significant effort, at significant cost.

In the middle of these two extremes, where the state of the company is such that quality is already on people’s minds but only the most basic systems and processes have been implemented, significant quality improvement is possible at low cost. Quality improvement in this situation can be achieved largely by modifying existing systems and processes to become more effective. Thus, only incremental costs will be incurred while significant improvements in quality are realized. (This is in contrast to the previous case in which significant costs are incurred in order to realize incremental quality improvement.) The benefits of performing quality improvement often include lower production cost, as scrap and rework are reduced. In many cases, these benefits outweigh the costs of actually performing the improvement activities, resulting in a negative effective cost of quality improvement. This concept is illustrated in Figure 3.1, in which the cost of quality improvement is shown to be negative in the middle of the continuum.

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11 Interview with Zhang Yulong, Quality Manager, Alcoa Shanghai Aluminum Products Co., June 1999.
At the start of the internship project, Alco Shanghai was viewed to be in the low to medium quality state at which improvement is beneficial in terms of both customer satisfaction and cost reduction. The potential for cost reduction stemmed primarily from the promise of increased product recovery - that is, getting more output for the same amount of input. Additionally, there was potential for reducing rework, which consumed extra resources and often led to second-grade products that had to be sold at substantial discount.

3.1.3 “Quality promotes logistics, logistics promotes quality.”

In their popular textbook entitled *Factory Physics*, Hopp and Spearman use this phrase to describe the necessary integration between quality and production systems. The expression implies that an improvement made to quality will also improve the logistics of the production system. Applied to Alco Shanghai, it means that the company’s implementation of APS will function more smoothly if the produced quality is high and consistent. When one considers the mechanism of APS, it is not difficult to see this relationship. As stated previously, APS is a pull system governed by kanbans. As such, there are at least two ways in which quality improvement can affect the logistics of APS:

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**Consistent quality increases the reliability of stores**

When a kanban instructs an operator at a particular machine to produce a certain specification, he or she will remove the required starting material from the store just upstream. This is the mechanism that enables APS to ‘make to use,’ and it relies on the presence of starting material in the store. Furthermore, the starting material that is available in the store must be of good quality; if not, the operator will spend time working on the material, end up with unusable product, and have to start over. Even worse, the operator may have to wait for the upstream machine to produce another unit of the starting material to replenish the store. Both these events add delays to the system, adding complexity to the logistics of production scheduling.

To help reduce such delays, the store sizes at Alcoa Shanghai are intentionally kept a little larger than required. This way, when an operator encounters a unit of starting material that is deemed to be unusable, there will be another backup unit available. The size of the store depends on both the quality of the upstream machine’s production and its consistency. If its quality is high and consistent, then a smaller store size will be sufficient to provide the necessary reliability. Therefore, any improvement activity that increases quality or makes it more consistent will allow a smaller store size, thus facilitating the logistics of APS.

**Reduced rework decreases replenishment time**

On a related note, the store size calculations in APS account for the production time required at each machine for each type of product. This production time dictates how quickly the machine is able to replenish the store just downstream of it. Therefore, the production time also affects the size of the store that is required. When the production time is short, the machine is able to replenish its store relatively quickly, and the store may be smaller. On the other hand, long production times will require larger store sizes to prevent WIP stockouts. Even with a short average production time, however, store sizes may need to be kept large if there is significant variation. This is necessary to provide a ‘buffer’ in the store that protects against stockouts during times when the machine’s production time is unusually long. Such variation is especially pronounced when there is rework.

At Alcoa Shanghai, rework is called for when an operator ends up with poor quality output but the inspector decides it is possible to salvage the output, usually as another product. The final
product is often also of low quality, but may be saleable. For example, poor quality 100-micron sheet may be further rolled down to second-grade 50-micron foil, which can be sold at a discount. Decisions such as this are made because selling at a discount is viewed as more economical than outright scrap. When rework is called for, the production time is greatly increased, since multiple operations must be performed instead of just one. This delay is a major source of variation in production times, and creates the need for excess WIP in the store. Thus, any reduction in rework will allow a smaller store size, again facilitating APS logistics.

Quality improvement enables APS improvement

The first stage of APS implementation focused on the pull system and the mechanics of kanban. To further improve the system, the second stage of implementation will have to focus on quality. Quality will enable Alcoa Shanghai to optimize store sizes, decrease lead times, balance production, and improve overall production scheduling and logistics. Figure 3.2 illustrates this evolution in the focus of APS implementation. Note that the next stage of implementation will concentrate on the extension of APS to non-production processes.

![Figure 3.2: The changing drivers of APS implementation.](image)

3.1.4 Quality as a focus for cultural change

A final reason for the emphasis on quality was to use it as a focal point for cultural change. It was the intention of Alcoa Shanghai’s management that quality improvement activities would help create a new culture that would pervade the entire organization and extend well beyond the

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13 There is some debate within Alcoa Shanghai on whether this philosophy is sound.
factory floor. Although the company had been a joint venture for some time, organization
dynamics were still largely reminiscent of the old Chinese state-owned enterprise, in which
managers often act as dictators and operators rarely express their ideas. Quality activities could
serve as a reason to solicit the active participation of more employees at all levels, encouraging
them to develop and use their problem-solving creativity.

On a lower level, it was also hoped that quality values would motivate employees to do a better
job, not just in production, but in all other processes as well. By direct participation in and
company-wide promotion of quality activities, employees would gain a mindset of waste
elimination and efficiency. They would learn to emphasize facts and focus on actionable
opportunities. Finally, they would learn methods of analysis and process improvement that can
be applied to a wide range of situations.

A framework for culture change

Peter Senge, in his book The Fifth Discipline, proposes three levels of explanation for any
complex situation, as shown in Figure 3.3.¹⁴

![Systemic Structure (generative)](image)

Patterns of Behavior (responsive)

Individual Events (reactive)

Figure 3.3: Peter Senge's three levels of explanation.

At the most basic level, events can be viewed and explained individually. For example, a reason
can be given for each of an employee’s individual actions. At this level, we find that employees’
actions are usually reactive – they detect a disturbance in their environment and try to resolve it.
When we look at many events and observe longer-term trends in employees’ actions, we begin to

¹⁴ Senge, Peter, The Fifth Discipline, page 52.
use behavioral explanations. At this level, we start to be able to predict how employees will respond to different situations, based on our understanding of their general behaviors. Finally, behaviors can often be explained in terms of the systems and processes that constitute the employees’ environment. At this highest level, we begin to understand how the systems we put in place shape employees’ behaviors and ultimately their individual actions. This systems level approach is the most powerful because it recognizes that the critical link between structure and behavior. Unfortunately, it is also the least common and most difficult approach to take.

The strongest levers of change reside at the systems level. If one is able to effectively change the systemic structure of an organization, then the behavior of people in that organization will change as well. Behavioral changes in turn cause people to react to situations differently, creating a whole new paradigm for doing things. The sustainability of this new paradigm depends on how deeply rooted the systemic change is. Thus, change implementation should be top-down, focusing mainly on systems. On the other hand, the design of change should be bottom-up: one should first consider the actions that are desired of people, the behaviors that lead to these actions, and finally the systems that encourage these behaviors. If these systems are designed carefully, then one will have control over all aspects of the organization’s work.

3.2 Alcoa Shanghai’s Initial Condition

The first step in any effort to improve a situation is to understand the starting point, the initial condition. This necessarily precedes all other tasks, even the design of the ending point, the target condition. By examining the initial condition, certain constraints may be uncovered that restrict the range of feasible target conditions. Furthermore, gaps and barriers to achieving the target condition will be revealed, guiding the development of the improvement process. This section describes some of the philosophy, processes, and artifacts that describe Alcoa Shanghai’s initial condition from the viewpoint of quality, as well as some of the gaps and barriers that were evident early on.

3.2.1 Existing quality philosophy

Quality was not entirely absent from the Alcoa Shanghai organization. The company had in place an existing Quality department, consisting of the quality manager, one quality engineer,
seven inspectors, and an administrative assistant. This staff was responsible for maintaining the quality processes at the factory and keeping records of quality metrics. In addition, the plant had recently achieved ISO 9000 certification, and the quality staff was also responsible for maintaining the documentation associated with that. Finally, the quality manager and engineer occasionally provided training to operators on various relevant topics.

While the quality department at Alcoa Shanghai was well established, the organization in fact had a relatively narrow understanding of quality. Essentially, they understood quality only as it applied to the company's interfaces with the external environment. Stated another way, quality was important to Alcoa Shanghai only because of its influence on the company's relationships with suppliers and customers. In dealing with suppliers, the primary concern was to ensure that the quality of incoming materials was up to a pre-specified standard. Similarly, in dealing with customers, the primary concern was to ensure that the quality of Alcoa Shanghai's products was up to the customers' standards. All of the quality processes in place were focused on achieving one or the other of these goals. There was very little concern or understanding of the effect quality had on internal production processes. For example, very few people understood quality as an enabler of APS.

The existing quality processes and artifacts at Alcoa Shanghai were consistent with this sentiment. A great deal of attention was paid to final inspection, where the inspectors verified each unit of outgoing product right before it was packed. The plant laboratory also paid significant attention to incoming materials, as they performed analyses to verify the chemical composition of raw aluminum ingots. On the other hand, very few processes were in place to monitor or control internal production processes. Operators were not trained to monitor their own produced quality, and even when they detected a problem, they were not trained to deal with it properly. At the start of this project, management had realized the benefits of having more internally focused quality processes and had begun to implement some ideas. Still, the company lacked a coherent system for managing quality in the production process.

3.2.2 Final inspection

The cornerstone of Alcoa Shanghai's existing quality management system was final inspection. The Quality department's seven inspectors spend most of their days in the packing area,
verifying finished products as they are about to be packed. The inspection is primarily visual, focusing mostly on surface defects such as lines, pinholes, discoloration, etc. Occasionally, the inspector will tear a few layers off the coil to test for tightness or stickiness. If a coil is deemed to be of insufficient quality for a particular customer’s requirements, the inspector may send it to be scrapped or designate it as second-grade product. Second-grade product is kept in the warehouse until the salespeople find a customer that is willing to purchase it, usually at a substantial discount. In fact, Alcoa Shanghai’s sales department keeps a list of customers who are specifically interested in these less expensive second-grade products.

3.2.3 The hospital rack

The APS implementation at Alcoa Shanghai provides for a hospital rack in the rolling area, on which operators may place coils that they believe have quality defects. For example, if an operator at one of the rolling mills notices an unusually large amount of oil stains on a coil, he or she may place that coil on the hospital rack rather than move it into the downstream store. The operator is required to write a brief description of the observed defect, but has no power to decide on the fate of the coil. The coil will wait at the hospital rack for an inspector to make the final judgment. (Inspectors generally visit the hospital rack at least once a day.) The inspector assesses the quality of the coil (again, through a primarily visual inspection) and decides on one of four possible actions:

- The coil may be passed without changes, in which case it is simply moved to the appropriate store.
- The coil may be passed as second-grade, in which case the operator will be instructed to produce another coil of the original specification. Meanwhile, the defective coil continues to wait on the hospital rack until a customer is identified that will accept second-grade product.
- The coil may be reworked, in which case the operator will be instructed to produce another coil of the original specification, and re-roll the defective coil into a thinner gauge. This is the nature of rework at Alcoa Shanghai, and the company actually maintains a rework schedule to handle such changes.
- Finally, the coil may be scrapped, in which case it is returned to the melting furnace and the operator produces a replacement.
Figure 3.4 shows the hospital rack. The fishbone-like post holds sheets of paper with operators’ descriptions of the quality problems they observed.

Figure 3.4: The hospital rack in the rolling area.

3.2.4 Incoming ingot inspection

Alcoa Shanghai maintains a modern laboratory in the plant, newly renovated since the establishment of the joint venture, with a six-member staff and capabilities for testing and analysis. One of the laboratory’s primary responsibilities is to verify the quality, in terms of chemical composition, of incoming aluminum ingot. Alcoa Shanghai purchases two types of ingot, pure aluminum and alloy, from two major suppliers. For pure aluminum, the company orders ingots of grade A00, which specifies 99.7% or greater purity, and trace amounts of impurities such as iron, silicon, magnesium, and copper. Alloy ingots are also expected to adhere to specifications that dictate the minimum and maximum amounts of aluminum and other metals. Figure 3.5 shows an area of the Alcoa Shanghai laboratory.
When a shipment of ingot is received, the laboratory staff takes a number of samples based on the size of the shipment and the supplier's quality history. For pure aluminum ingots, the sample is a block of aluminum that is polished on one face and analyzed by spectrometry. For alloy ingots, the sample consists of filings that are dissolved in base and analyzed by chemical titration. In either case, the analysis produces a listing of the concentrations of aluminum and other metals. Based on these results, the laboratory will judge each shipment of ingot to be of acceptable or unacceptable quality. The results are recorded on pre-formatted data sheets and secured in a binder in the laboratory.

When an ingot shipment is deemed to have unacceptable quality, Alcoa Shanghai's purchasing department will be notified and they will give feedback to the supplier. Usually, however, the shipment is not rejected. Instead, the casting shop will attempt to combine the poor quality ingots with high quality ingots in the same furnace melt, to produce an overall mixture that is acceptable.15 Fortunately, this type of fix has not been used very often, as suppliers have had excellent quality records.

15 Interview with Cao Xin, Casting Shop Manager, Alcoa Shanghai Aluminum Products Co., September 1999.
3.2.5 Other quality processes

The above three examples represent the most significant quality processes used at the plant, but Alcoa Shanghai also had a number of other processes in place. Of particular significance are the processes associated with the company’s ISO 9000 certification. These consist mainly of documentation required by ISO, such as Standard Operating Procedures and other safety documents. While ISO related processes require a great deal of work to maintain, they do not represent a significant quality control tool at the plant level because they do not involve much participation from the operators. The majority of ISO work is performed by the quality engineer, with support from the Process, Engineering, and APS departments.

Recognizing the need for more in-line quality control, management had recently introduced the use of visual quality control boards. These information centers are located at every mill, near the kanban board, and present a one-stop visual checklist for quality features. The information provided on these boards include recommended coolant temperatures, standard tolerances on thickness, and other tips for producing high quality. Also presented are physical samples of common surface defects, such as oil stains, lines, and wrinkles. These visual quality control boards are meant to give operators an easily accessible reference against which they can check their own work. It thus enables them to make better judgments on quality, allowing more efficient use of the hospital rack.

Finally, the Alcoa Production System has built into it certain processes that are consistent with and promote high quality. Alcoa Shanghai’s implementation of APS strongly emphasizes standardized work, a technique that allows for the consistent and repeatable operation of machines, even across different operators and different shifts. By doing this, standardized work helps to produce consistent and repeatable quality at each machine. This is especially important in the context of quality improvement, as it allows improvements made by one operator to be adopted by all operators. The use of a kanban-based pull system also favors high quality, as alluded to earlier by the phrase, “logistics promote quality.” By having limited store sizes, operators are under pressure to ensure that each coil they place in the downstream store is of sufficiently good quality. Complementary to this, the need to replenish stores quickly also encourages operators to check the quality of their starting material, in order to reduce the probability of rework or scrap later.
3.3 Quality Metrics

The Quality department maintains records of the plant’s quality performance on a monthly or more frequent basis. Some of the more important quality metrics are described in this section.

3.3.1 Product recovery

The single most important metric of quality performance is product recovery, a measure of the percentage yield of the production process. Mathematically, product recovery is calculated by the following equation:

\[
Product\ Recovery = \frac{Finished\ Goods - Customer\ Returns}{Starting\ Inv. + Production\ Starts - Ending\ Inv.}
\]

Equation 3.1

Product recovery is calculated plant-wide, as well as for each individual machine and each product type (defined by alloy and thickness). In general, the product recovery for thin-gauge products is about 10% lower than for other products because it is more difficult to produce, suffering from frequent breakages and surface defects such as pinholes. Therefore, a change in the plant-wide product recovery may indicate a change in true quality performance or simply a change in the product mix. Furthermore, there are consistent and explainable differences in the product recovery of different machines. For example, the finishing mill handles thin-gauge products almost exclusively, giving it lower product recovery than either the breakdown or intermediate mills.

While product recovery has some flaws as a quality metric, it is a useful summary of the plant’s operating performance. It is also popular with accountants because of its obvious relationship to the company’s financial performance.

3.3.2 Customer returns

The second most important quality metric at Alcoa Shanghai is customer returns, expressed as a percentage of shipped quantity. This is actually an indicator of customer satisfaction, but is obviously strongly correlated with product quality. Again, Alcoa Shanghai finds explainable differences in this metric for different product types.
The policy of Alcoa Shanghai is to allow customer returns for any reason. As a result, this metric is sometimes not an entirely accurate reflection of the company’s quality performance. Customers have been known to return product because they ordered too much in the first place and could not use it all. In at least one instance, a customer even returned to Alcoa Shanghai product purchased from another company! Like product recovery, customer returns is not a perfect indicator of quality, but it is a valuable metric nonetheless.

3.3.3 Other metrics

Product recovery and customer returns are the most widely used quality metrics at Alcoa Shanghai, but a number of others are also monitored. The laboratory, for example, maintains records of their ingot inspection results, as well as records of other tests it performs such as tensile strength. The Foil Business System can also be queried for certain quality indicators. While these provide useful insight into the performance of the company’s operations, they are not regularly reported metrics.

3.4 Quality Gaps and Opportunities

A study of the initial condition reveals some gaps and opportunities in the area of quality at Alcoa Shanghai. Some of the ones that the author focused on are mentioned here, but the reader should be able to identify a host of others.

3.4.1 Developing a modern philosophy of quality

In the earlier discussion on Alcoa Shanghai’s existing quality philosophy, it was suggested that very few people in the company had made the mental leap from quality for quality’s sake to quality as an enabler of improved logistics. The organization understood very well the role of quality in the company’s dealings with suppliers and customers. However, the effect of quality on internal processes was not as widely understood. Very few employees recognized quality improvement as the means to achieve increased production efficiency and reduced cost. Even fewer considered the relationship between quality and work satisfaction. Thus, an opportunity existed to teach a new philosophy of quality, one that drew clear links from quality to other functions, from APS to Human Resources.
3.4.2 Increased employee participation

In the initial condition, it was found that quality work was highly concentrated within the Quality department, with very little involvement of other employees. In particular, operators on the plant floor had surprisingly little responsibility to quality, given their closeness to the production process. When one speaks with these operators, it is clear that they have intimate knowledge of quality problems that occur in their respective areas. What they lack are the problem-solving skills to develop the right solution and the channel through which to express themselves. There was thus an opportunity to harness these employees’ knowledge by developing their skills and encouraging their participation in quality improvement activities.

3.4.3 Data collection and analysis

Alcoa Shanghai’s existing quality processes did not emphasize the use of quantitative data collection and analysis. Measurement data was rarely recorded outside of the laboratory, while quality metrics were based on production data from the Foil Business System. This was the case despite the fact that at many machines, measurement data is readily available. For example, each of the mills has active feedback systems that internally monitor a host of parameters, such as thickness, for controlling the drives. Some engineers had begun to record this data with a chart recorder, as shown in Figure 3.6. A relatively simple computer system can easily be set up to digitally download this type of data, which can then be used for more powerful analyses.

![Strip chart recorder connected to a mill drive.](image)

Figure 3.6: Strip chart recorder connected to a mill drive.
3.4.4 Proper record keeping

In areas where data was being generated, such as the laboratory with its ingot analysis, there was an opportunity to improve the record keeping techniques. In the initial condition, ingot analysis data was recorded on printed sheets of paper, then secured in a binder. As such, it is difficult to perform any kind of useful analysis, especially analysis that would require the use of a computer. Furthermore, it is difficult to share the data, since it all resides in a physical binder located in the laboratory. With a simple database on the local computer network, laboratory analysis results can be recorded digitally, facilitating analysis and sharing. Certain procedures can also be added to the database to perform the analysis automatically.

3.5 Barriers to Quality Improvement

With so many good opportunities for improvement, one must take care in choosing which areas to work on. The right set of initiatives must be carefully selected from all the possibilities, with consideration of their usefulness and the ability of the organization to adapt to new paradigms. Alcoa Shanghai is an organization that has faced and will continue to face many changes in both its internal and external environments. These changes are not always easy for the employees to cope with.

The barriers to change at Alcoa Shanghai can be categorized into time and people concerns. On the time side, one simply needs to be patient with these employees that are facing more change than they can handle, in all aspects of their lives. Adding to the difficulty is the fact that the Chinese Communist culture has traditionally resisted change, especially change influenced by the West. Ample time must be taken to convince the people of the virtues of new initiatives, in order to gain their true cooperation. Too many initiatives launched at the same time will create only confusion and loss of coherence in the people’s efforts.

On the people side, one must realize that the resources at Alcoa Shanghai are limited. Since the joint venture began, the plant’s headcount has steadily decreased while its output has steadily increased. Every employee already works 100% and more – operators come in for training several times each week outside of their normal forty hours. Any new quality improvement initiative will mean extra work for these people, at least initially before the timesaving results are
realized. Furthermore, from the viewpoint of a Western-trained engineer, the technical capabilities of the organization at Alcoa Shanghai are very limited. This must be considered before demanding that the organization make use of complex analytical methods. Proper training is extremely important.

A successful quality strategy for Alcoa Shanghai must take into account these barriers - they must either be overcome or else avoided. Because the conditions in this organization are unique, simply taking another company’s model and applying it here will lead to disastrous results. On the other hand, studying other models will reveal important insights that can help in designing the right strategy with the right set of initiatives. Therefore, the next chapter presents a brief overview of quality programs that are common in Japan and the West. Chapter 5 will begin discussion of the quality strategy that was developed specifically for Alcoa Shanghai.
Chapter 4: Overview of Common Quality Programs

Alcoa Shanghai needed a new strategy for quality, but it was not looking to invent anything new and revolutionary. On the contrary, management felt it would be wiser to borrow ideas from other companies that are more advanced in quality. Indeed, many companies, especially in Japan and the West, had long stressed quality as a priority in their manufacturing processes, and had come up with a number of successful quality programs. Before formulating Alcoa Shanghai’s own program, some of the more well-known quality programs were studied for their relevance to the company’s situation. A synopsis of these programs is presented here.

4.1 ISO 9000 Certification

ISO 9000 refers to a series of quality-related documents published by the International Organization for Standardization (ISO) since 1987. The 9000 series attempts to establish universal standards of quality by providing guidance on the selection of an appropriate quality management system for a manufacturer’s operations. The standards are intended to be advisory in nature, and compliance is voluntary. However, the ISO 9000 series has become so popular that in many industries, official certification is almost a requirement to serve the market.

Certification for ISO 9000 occurs through an auditing process. Prior to certification, manufacturing companies typically invest a large amount of time into carefully documenting all of their processes. This tedious process of documentation often uncovers many quality gaps in the organization, and some would argue that this is the real value to becoming ISO certified. Companies often learn a great deal about their own processes while creating the necessary documents. The seven steps leading to certification are as follows:

1. Evaluation of existing quality procedures against ISO 9000 standards.
2. Identification of corrective action needed to conform to ISO 9000 standards.
3. Preparation of a quality assurance program.
4. Definition, documentation and implementation of new procedures.
6. Pre-assessment meeting with registrar to analyze quality manual.
7. Actual assessment visit.
For official certification, as opposed to just stated compliance, the ISO 9000 assessment must be performed by an independent, ISO-approved auditor. The audit focuses on at least 20 elements of the company’s quality program, as listed in Table 4.1. Most of these elements are quite practical and not unique to ISO 9000. The auditor looks for evidence that the company under audit has thought of all these elements, and can demonstrate that a system has been built that incorporates all of them.

**TWENTY ELEMENTS OF AN ISO 9000 AUDIT**

1. Management responsibility
2. Quality system
3. Contract review
4. Design control
5. Document control
6. Purchasing
7. Purchaser-supplied product
8. Product identification and traceability
9. Process control
10. Inspection and testing
11. Inspection, measuring and test equipment
12. Inspection and test status
13. Control of nonconforming product
14. Corrective action
15. Handling, storage, packaging and delivery
16. Quality records
17. Internal quality audits
18. Training
19. Servicing
20. Statistical techniques

*Table 4.1: ISO 9000 audit elements.*

When a company passes the audit with satisfactory scores, it achieves ISO 9000 certification, and may advertise this fact in its marketing communications. Customers often look for the ‘ISO 9000 certified’ mark as a seal of quality. In many instances, the customer will choose to visit the supplier and perform their own audit, even if the supplier is officially certified. This helps to instill even more confidence in the supplier’s quality.
4.2 Total Quality Management (TQM)

Total Quality Management is a broad set of methods and practices that form a basis for systematic improvement and organizational learning. It originated in Japan and has been evolving for several decades. Today, TQM is one of the most popular quality programs with companies in almost all industries and regions of the world. Because TQM is so broad, only some of the features that are relevant to Alcoa Shanghai will be discussed here.

TQM tools can be categorized into four major areas of focus: continuous improvement, customer focus, total participation, and societal networking. Most tools, especially in the area of continuous improvement, stress the use of the scientific method: formulate a hypothesis, perform an experiment, check the results, and verify the hypothesis. In fact, this method is formalized in a seven step problem-solving process known as the WV model,\(^{16}\) illustrated in Figure 4.1.

![The WV Model](image)

**Figure 4.1: The WV model of problem solving.**

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The scientific method is also formalized in a famous model of continuous improvement known as the Plan, Do, Check, Act / Standardize, Do, Check, Act (PDCA/SDCA) cycles. This model distinguishes between daily work, which follows SDCA, and improvement work, which follows PDCA. In daily work, an employee knows the standard process (S), does work according to the standard (D), checks the results against the standard (C), and acts if there are any issues (A). If there are no issues or opportunities for improvement, then the SDCA cycle continues as usual. If an opportunity for improvement is identified, then the employee jumps over to the PDCA cycle. Here, the employee plans some kind of improvement (P), does the improvement (D), checks the results (C), and acts to standardize the improvement (A). If the results are not as desired, then the PDCA cycle continues until an effective improvement is created. Once this occurs, the improvement is integrated into the standard process, the employee jumps back to the SDCA cycle, and work continues as usual. The PDCA/SDCA cycles are illustrated in Figure 4.2.

![The Alternating PDCA/SDCA Cycles](image)

**Figure 4.2: The PDCA/SDCA cycles.**

A set of commonly used tools that enable the PDCA cycle are known as the seven Quality Control (QC) tools; these will be discussed in Chapter 6. Other tools include the KJ, or Language Processing (LP) method, which helps analyze language data, and Voice of the Customer (VOC), which helps uncover customer needs. These and other are covered in the text by Shiba, Graham, and Walden.

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17 Shiba et. al, p. 67.
4.3 Quality Control Circles (QCC)

Quality Control Circles is not really a quality program in itself; it is a common component of TQM. However, it deserves separate mention here because Alcoa Shanghai management was keenly interested in implementing this. Indeed, QCC eventually became a major part of the company’s new quality strategy.

Like many other quality programs, QCC originated in Japan and was highly successful there, prompting interest from Western companies. The circle is a small team of operators, usually from the same production area so they form a natural work group. All team members participate actively in the circle’s activities, which serve the dual objectives of quality control and quality improvement. While working toward these objectives, the group’s activities also develop the individual workers’ skills.

In Japan, two features of QCC are considered critical to the success of the teams’ projects. First, the projects utilize the proper process improvement methodologies. QCC members spend time to learn the skills they need to perform effective problem-solving, and follow a specific procedure. Second, QCC activities are voluntary. Workers form their teams on their own initiative, select their own problems to work on, and manage their own progress. Every step of the way, the team decides whether and how to continue.

Management’s role in QCC is to provide teams with the necessary support and resources, and give reward and recognition when due. This is an extremely critical role, and should not be taken lightly. Management involvement demonstrates to team members that their work is valuable and appreciated. Rewards and recognition provide motivation for the team to continue giving their best effort, and also for other workers to start up their own teams and projects. Management must also be ready to provide guidance when it senses that a team is at risk of going seriously astray.

While many Japanese companies have had considerable success with QCC, its implementation in Western companies has seen mixed results. In most Western companies, workers are less inclined to perform voluntary activities, and management has had difficulty providing the right kind of motivation. Many managers tried to maintain too much control of the teams’ activities,
such as dictating the problems they would work on and the schedule they would follow. As a result, these teams felt disempowered and lost interest in their work. Western managers have not been able to maintain a proper balance between monitoring the teams' activities and trusting the team to work on their own. In many cases, impatience is an interfering factor; managers often want to see the positive results of QCC without investing the up-front time to develop the necessary skills and culture.

Quality Control Circles as it was implemented by Alcoa Shanghai is discussed in Chapter 7.

4.4 Statistical Quality Control (SQC)

Like TQM, Statistical Quality Control is a broad collection of tools and techniques that are useful for quality control and quality improvement. The common feature of these tools is that they are rooted in a rigorous base of statistics. The most popular component of SQC is Statistical Process Control (SPC), but it also includes tools for process capability, design of experiments (DOE), and acceptance sampling. To keep things brief, only a basic description of SPC is given here. The reader may refer to any standard text on SQC for instruction on any of these tools.

Statistical Process Control is based on the philosophy of Dr. Walter Shewhart, who believed that variation has two types of sources: chance causes create natural variation that is inevitable, while assignable causes create special variation that can be reduced or eliminated. Natural variation is also known as 'background noise' and is inherent to the process, not a result of operator or machine failure. Special variation is usually the result of operator error or machine malfunction, and is usually large compared to the background noise. Because special variation is due to assignable causes, it can be reduced by addressing those causes. The objectives of SPC, then, are to detect when special variation occurs, identify the cause of it, remove the cause, and prevent it from recurring. By doing this over and over again, assignable causes will be systematically eliminated, leaving the process to run with only natural variation. When a process is in this state, it is said to be 'in control.'

The main tool of SPC is the control chart, whose purpose is to detect when special variation occurs. The control chart is a time-sequenced plot of a process parameter or a variable that is derived from one or more process parameters. The variable is plotted along with three lines: the
mean and the upper and lower control limits. The mean is simply the historical average value of the variable, while the control limits roughly indicate the amount of variation that is expected in that variable, if the process in control. Thus, when the variable goes beyond either of the control limits, it constitutes an alarm that some assignable cause has occurred and the process has gone out of control. Upper/lower control limits are typically defined by adding/subtracting three standard deviations to/from the mean. In practice, the calculations can be quite complex, since the standard deviation, and many times even the mean, may not be known exactly. Figure 4.3 shows an example of a control chart. This one so far has no alarms.

![Control Chart of Thickness](image)

**Figure 4.3: A typical control chart.**

Alcoa Shanghai had been interested in SQC, and SPC specifically, for some time but did not have the requisite technical background to implement it.
Chapter 5: Alcoa Shanghai’s Quality Strategy

With an understanding of Alcoa Shanghai’s environment and initial condition, and having reviewed several popular quality programs, the task at hand turned to designing the proper strategy that would lead the company toward reaching its quality improvement goals. The procedure for doing this involved the following steps: articulation of the company’s quality goals, developing a framework for thinking about quality, designing and communicating the quality strategy, and mapping the course of implementation. The outcome of each of these steps is summarized in this section.

5.1 Alcoa Shanghai’s Quality Goals

The goals of Alcoa Shanghai’s new quality strategy are basically to close the gaps and capitalize on the opportunities identified earlier. Since they have already been detailed in chapter 3, the goals will be listed here with only a brief explanation of each.

5.1.1 Create a new way of thinking about quality.

The culture at Alcoa Shanghai needs to be changed such that employees will have a more modern and thorough philosophy on quality and quality improvement. The quality philosophy should pervade and be understood by the entire organization, not limited only to the Quality department. All employees will share the company’s quality vision, and will speak of quality in a common language. Furthermore, each of Alcoa Shanghai’s 328 employees will play an active role in achieving the quality vision, and will fully comprehend the impact that his or her actions have. Some elements that should be part of this new understanding of quality include the following:

- Quality is a means for achieving customer satisfaction and delight.
- Quality is an enabler of better logistics in APS.
- Quality improvement leads to increased employee satisfaction.
- Quality improvement is a method of problem solving.
Establishment of a new philosophy is the most fundamental, and perhaps most challenging, part of Alcoa Shanghai’s new quality strategy. The extent to which all other goals can be achieved will depend critically on the extent to which a new quality culture can be created.

5.1.2 Increase employee participation in quality control and improvement.

In the initial condition, only the ten members of the Quality department were actively involved in quality control and improvement activities. While the word quality was heard frequently throughout the plant, most employees were unclear as to what role they played in that area. Yet, without their active involvement, sustainable quality improvement cannot really be achieved. Therefore, Alcoa Shanghai’s new quality strategy needs to define meaningful roles for each and every employee. Furthermore, each employee should be empowered to apply his or her creative ideas to quality improvement.

When focused on quality in production, the participation of operators is most critical. Quality control should be integrated into the mechanics of the Alcoa Production System, so that it becomes a natural part of their everyday work. Operators should be skilled in the use of proper tools to help them characterize and control the quality of their own work. They should also be able to identify opportunities for improvement in their own area, and use problem-solving methods to find creative and effective solutions. Finally, when these solutions have been proven to work, operators need to have the necessary communication channels to transfer their new skills to the rest of the organization. For non-production staff, their role is primarily to support the quality efforts of operators. This may involve providing training and technical support for quality control tools, or helping to devise, implement, and communicate quality improvement ideas.

5.1.3 Emphasize problem solving.

Implied above is the need to emphasize problem solving as the means of quality improvement. This is very tightly linked to participation – without the proper problem solving skills and techniques, operators will not be able to find effective solutions to the problems they identify, and will quickly lose the motivation to continue. By emphasizing structured problem solving, employees will be less likely to take a shotgun approach to quality improvement, and the
probability that their efforts turn out fruitless are minimized. The positive results they generate will motivate them to put in even more effort. All employees should be trained in a common method of problem solving, so that they all speak the same language, facilitating cooperation. This applies to operators as well as engineers, who play the support role in problem solving.

5.1.4 Emphasize data collection, recording, and analysis.

As in Total Quality Management, problem solving in Alcoa Shanghai’s new quality paradigm should be based on the scientific method. This necessarily means data will be required, so the company needs to develop competence in the collection, recording, and analysis of various forms of data. Analytical techniques may range from simple and qualitative to complex and highly quantitative. Employees will apply these techniques to real data, and use the results to gain insight into quality issues. The emphasis on data analysis will thus facilitate problem solving and help ensure that solutions are indeed effective and sustainable.

As explained in chapter 3, there are already several good opportunities at Alcoa Shanghai to improve data collection and recording without a great deal of added effort. Two examples of this are in the following areas:

1. *The laboratory*, where data on the chemical composition of aluminum ingots are collected and recorded on pieces of paper in a binder. This system makes it difficult to perform any kind of quantitative analysis on more than one set of data at a time. As a result, the laboratory uses its data only to judge single lots of ingots, and is unable to characterize historical trends in suppliers’ quality.

2. *The rolling mills*, where drives automatically take data for their own feedback control systems. These data, including thickness and flatness parameters, are invisible to the operator, except for a one-line printout that occurs every several minutes. A relatively simple computer system can be set up to download data from the mill drives, permitting quantitative analysis for quality control and improvement.

Engineers and operators at Alcoa Shanghai should be trained to identify opportunities such as these, and have a hunger for data that will drive them to utilize effective collection, recording, and analytical tools.
5.2 The Spheres of Quality™ Framework for Thinking About Quality

An early step in the creation of Alcoa Shanghai’s new quality strategy was the development of a framework to aid in thinking about the elements of the strategy. It was intended that the Quality department, as well as top management, would refer to this framework as they formulated the strategy to remind them of all the relevant issues. Such a framework was necessary because the company was trying to create significant cultural change. In these situations, there is always a natural tendency to revert to norms and traditions. A good framework helps reduce this tendency by focusing on the areas where change is required.

The framework, called the Spheres of Quality™, groups nine elements into three major categories – People, Process, and Metrics. The Spheres of Quality™ framework is illustrated in Figure 5.1, and a brief explanation follows below. Appendix 1 shows the slides used in a presentation to communicate the framework to Alcoa Shanghai.

![Figure 5.1: The Spheres of Quality™ framework.](image)

Quality is...

PEOPLE

Mindset

Standardized Work

Customer Focus

Incentives

PROCESS

Stability

Process Control

METRICS

Visual Management

Continuous Improvement
A complete quality strategy will include all the elements shown in the Spheres of Quality™. These are categorized into people, process, and metrics elements, though many of them actually span two or more categories and some of them are outside all three categories. Those that are between categories form the links that create a cohesive system out of all the elements, while those that are outside represent broad principles that govern how the system is sustained. All the elements collectively represent the culture of the organization. Thus, the Spheres of Quality™ framework recognizes that culture is not just people issues, but also includes the tools and devices found throughout the company.

In the people area, the strategy will establish a new mindset among employees that creates a desire to proactively participate in quality related activities. In the process area, the strategy will focus on achieving stability in production, in the sense that output quality will be predictable and controlled. With regard to metrics, the quality strategy will define a set of standards by which the company’s quality can be measured and communicated. These three elements - mindset, stability, and standards - are called first-tier elements in the Spheres of Quality™.

Second-tier elements in the Spheres of Quality™ are standardized work, incentives, and process control; each of these forms the link between two major categories. Standardized work recognizes the fact that most processes are operated by people. Popularized by its use in the Toyota Production System, standardized work is a tool that establishes best practices for each operation. The best practices are clearly documented and all operators are trained to follow them exactly. By creating stability and consistency in the operators’ actions, standardized work helps to ensure that the quality of process outputs is also stable and consistent.

The link between process and metrics is provided by process control tools. These tools characterize processes, allowing employees to assess their quality performance along a set of specified metrics. Process control tools are also used to improve and sustain quality, contributing to process stability. Finally, the use of proper incentives will motivate employees to reach and exceed the company’s stated quality standards, thus tying people with metrics. Incentives need not always be monetary, but they must be communicable and valuable to the employee. Used properly, these three second-tier elements reinforce each other and integrate the overall system.
At the center of the Spheres of Quality™, spanning all three major categories, is the single third-tier element of customer focus. As each of the other elements is addressed in formulating the quality strategy, it must be kept in mind that the ultimate purpose is to add value to the customer. Every person, process, and metric must have a customer identified, whether internal or external, and the relationship to the customer must be clearly defined and understood. Each employee must be able to articulate how his or her actions impact customer satisfaction.

Overseeing all the elements are continuous improvement and visual management, the two zero-tier elements of the Spheres of Quality. These fall outside any category because they are really principles that govern the management of the system. Continuous improvement requires no explanation here. Visual management refers to a system whereby the state of the factory can be assessed simply by looking at certain information displays. Kanban boards are an example of this, since they give visual information about the status of each machine’s production. For quality purposes, a visual management system would communicate the company’s quality performance and any issues it may be facing. A complete quality strategy must include provisions for both of these zero-tier elements.

For a review of all these elements, refer to Appendix 1.

5.3 Design of the Excellence through Quality Strategy

All the work done in assessing Alcoa Shanghai’s initial condition, identifying opportunities and barriers, reviewing common quality programs, and developing a framework culminated in the formulation of a quality strategy for Alcoa Shanghai. The strategy, called ‘Excellence through Quality,’ consists of a mix of components which management felt was appropriate to Alcoa Shanghai, given the company’s goals and capabilities. These components were borrowed from Total Quality, Statistical Quality Control, and other programs, but were customized to suit the organization. The strategy focuses mainly on production and includes roles for all operators, maintenance personnel, and engineers. Key themes in the strategy are more effective problem solving techniques and increased operator involvement in quality control. Figure 5.2 gives a graphical depiction of the Excellence through Quality strategy, and a brief discussion of the components follows. A Chinese version of this diagram is provided in Appendix 2.
The left side of the diagram shows the evolution of quality control at Alcoa Shanghai. At first, quality was controlled solely by final goods inspection at the packing area. With APS, some quality control responsibility was delegated to upstream processes. For example, rolling mill operators may use the hospital rack to hold what they perceive to be defective coils. In the future, Alcoa Shanghai hopes to have operators perform in-line quality inspection. In contrast to the current situation, operators would be able to make definitive judgments on the quality of coils they produce, rather than having to wait for an inspector to come to the hospital rack. When a quality problem is identified, the operator will make an immediate diagnosis and begin to fix the problem before more defective coils are produced. This would result in decreased waste, improved responsiveness, and higher quality production.

To have Alcoa Shanghai’s operators perform effective self-inspection is, of course, easier said than done. To enable them, they would have to receive the necessary training on quality
standards. In addition, there has to be in place problem solving methods to deal with the quality issues operators identify. The diagram shows training as an input to operator self inspection, while the output leads to a set of two major problem-solving programs. Operators are expected to participate in the Quality Control Circles (QCC) program, while engineers work on what management calls Core Technology. The concept of QCC is borrowed from the Japanese and has already been explained in Chapter 4. Core Technology refers to production parameters that have a significant effect on product quality. Each engineer is expected to focus on one or two areas, and explore ways to improve them. The QCC and Core Technology programs overlap, as operators and engineers will assist each other in identifying and addressing quality issues. Because this author’s work concerned mostly operators, the Core Technology program will not be discussed any further in this document.

The diagram shows an output arrow from the QCC and Core Technology box to another box that represents the problem solving technique Alcoa Shanghai wishes to standardize. Problem solving will be analytical, centered on root causes. Root cause analysis takes production data and observations such as rejections as input and leads to corrective and preventive actions. Not shown in the diagram are the analytical tools used in this process, such as the seven QC tools to be discussed in a future chapter.

When corrective and/or preventive actions are identified, they must then be incorporated into the operators’ standardized work procedures. This requires training operators in the new procedures as well as new, presumably higher, quality standards. Thus, the diagram shows an arrow from the problem solving box back to the training box, completing a loop. Operators continually move along this loop, discovering and solving new problems and increasing the standard of quality with every iteration.

The Excellence through Quality strategy is consistent with the goals of Alcoa Shanghai, and includes nearly all the elements in the Spheres of Quality framework. In fact, those elements that are not explicitly depicted are not neglected by the strategy, but are incorporated at a lower level. For example, incentives are to be built into the QCC program, while visual management will be an enabling feature of operator self inspection. Continuous improvement and customer focus are implied by the central loop. If implemented effectively, this strategy will continue to serve the
interests of Alcoa Shanghai even as the company’s internal and external environments evolve. Therefore, effort must now be directed to implementation.

5.4 Implementation Plan

Complete implementation of all the components of the Excellence through Quality strategy could not possibly be accomplished within a six-month timeframe. The technical capability of Alcoa Shanghai’s organization was not able immediately to support the kind of analysis desired. More importantly, employees would need time to adapt to the level of responsibility and participation called for by the strategy. Time must be allowed to gain their full buy-in and commitment to their respective roles.

Rather than implementing the entire strategy at once, an implementation plan was devised to introduce the various components in some sensible order. The plan is summarized as follows:

♦ **Training** – precedes every component. Training is the first step in the overall implementation, as every employee in the company needs to be familiar with the strategy and its benefits. Training is also ongoing throughout the implementation, to teach the skills necessary for each component.

♦ **Quality Control Circles (QCC)** – first program to be implemented. QCC will be implemented on a learning curve. Early on, there will be only a few QCC teams who will work very closely with the Quality department staff. These teams will use relatively simple analytical tools, and focus on problems that are deemed more tractable. As experience is gained, more QCC teams will be started up and they will be given more complex and quantitative tools.

♦ **Analytical Tools** – introduced as needs are identified. Analytical tools will be introduced to operators and engineers only when there is an opportunity to use them. Proper training will ensure that the tools are used effectively and will generate positive results. Applying the tools immediately after training helps to facilitate and sustain the learning. Simple tools will be introduced to the organization first, followed by more complex ones as employees gain experience.
The implementation plan was approved by Alcoa Shanghai’s top management and shared with the rest of the organization. In fact, some parts of the implementation had already begun even before the complete quality strategy and plan were drawn up. For example, training for QCC was already under way, since management had wanted to implement that program early on. The following three chapters give some details on the three parts of the implementation plan. It is important to note that the strategy implementation was only begun during the author’s tenure at Alcoa Shanghai; it is expected to be ongoing for some time to come. Thus, it was critical to ensure that the Quality department would be able to continue the implementation even after the author’s departure.
Chapter 6: Training the Organization

A major part of the quality strategy implementation was training. Alcoa Shanghai employees were already subject to a large amount of training, on topics such as safety and APS. Most of this training was conducted outside of normal work hours (usually before or after the operators’ shift), without extra compensation. As a result, it was not easy to generate enthusiasm for a new series of training sessions. On the other hand, training was absolutely essential to the implementation of the new quality strategy, since it represented such a significant shift in culture. The challenge, therefore, was to find a method of training that could effectively convey the quality vision and teach employees the skills they need to realize that vision.

This chapter describes some of the tasks associated with training for the new quality strategy. Appendices 3, 4, and 5 present the training materials that were developed as part of this work.

6.1 Training Strategy

Training is like a production process: its inputs are the training materials, its operators are trainers, and its outputs are the trainees’ new knowledge and skills. In alignment with this analogy, it was decided that quality training at Alcoa Shanghai should be guided by three APS-like principles:

6.1.1 Train to use.

Most professional educators agree that people’s retention of new skills is highest when they have an opportunity to apply the skill immediately after learning it. It follows from this that training at Alcoa Shanghai should be coordinated with the projects that trainees are about to undertake. For example, training on Quality Control (QC) tools should be delivered as operators are ready to begin their QCC projects. Likewise, training on Statistical Quality Control should begin when engineers have identified opportunities to use it.

6.1.2 Fit training to trainee.

In order to be most effective, it is necessary to design the training process and training materials with the trainee in mind. Customizing the training also helps to keep the attention of the
audience; all too often, their interest is lost as the trainer goes off on topics beyond their comprehension and concern. In the case of Alcoa Shanghai, this is especially important because employees already undergo numerous training session per week, many of which are not specifically catered to their interests. Furthermore, the technical level of operators and engineers must be taken into account when designing training on more technical topics such as SQC.

6.1.3 Train the trainers.

The implementation of Alcoa Shanghai’s quality strategy is a continuing effort, and it must be carried on by the company’s own people. Rather than simply delivering training to the people of Alcoa Shanghai, the approach taken was to develop trainers internally in the company. This gives assurance that the skills and competence reside within the organization. Furthermore, it permits the organization to redeliver the training when necessary without having to call in outside consultants. The author’s mission was thus to ‘train the trainers,’ then to coach them as they delivered the training to the rest of the organization.

These three principles are analogous to the overarching principles of the Alcoa Production System: make to use, eliminate waste, and people linchpin the system. Figure 6.1 illustrates the analogy.

![Diagram showing the analogy between Alcoa Production System and Training Strategy]

**Figure 6.1: Analogy between APS and training strategy.**
6.2 Training sessions

Training sessions for quality were conducted at Alcoa Shanghai for two basic purposes: awareness and skills development. Sessions in the first category were mostly informational, intended to communicate the company’s strategy and each employee’s role in it. These were the sessions that would motivate cultural change. Sessions in the second category were focused on specific skill sets and directed to specific groups of people. These were the sessions that would give employees the necessary tools to effect culture change.

Members of the Quality department conducted most of the training sessions. To be effective, they first studied the material themselves to the point where they felt comfortable teaching it to others. Typically, an ‘expert’ (usually the author) was present in the training room to help answer questions and clarify certain issues. In some cases, the author delivered the training with the assistance of a translator.

Some of the major training sessions, in the order of their occurrence at Alcoa Shanghai, were:

6.2.1 Promotion of quality goals, strategy, and vision.
Alcoa Shanghai’s quality goals, strategy, and vision were conveyed to the organization through formal and informal presentations. Formal presentations were given mostly to managers in order to gain their acceptance and support. These occurred during regular management meetings and were reviewed often. For the rest of the organization, the message was conveyed primarily through company publications, displays on the cafeteria bulletin board, and word of mouth on the factory floor. The quality strategy was also reviewed at the beginning of each of the other training sessions, with emphasis on the employees’ roles.

6.2.2 QCC and the seven QC tools.
At the start of the Quality Control Circles implementation, all operators, engineers, and maintenance personnel received training on the QCC network and the seven Quality Control (QC) tools. Training on QCC served a motivational purpose, stressing the potential impact that employee teams could make on the company’s quality performance. It also presented the structure of the QCC network, showing how teams would be organized and where they could
seek assistance and support. The latter training introduced employees to seven commonly used tools from Total Quality Management: check sheet, Pareto chart, fishbone diagram, run chart, histogram, scatter diagram, and control chart. These tools were reviewed when the QCC teams were ready to begin their projects.

6.2.3 Introduction to Statistical Quality Control.

Members of Alcoa Shanghai’s Process and Engineering departments were introduced to basic Statistical Quality Control (SQC) through a training session on this topic. The training focused on the general philosophy of SQC, then presented basic tools related to descriptive statistics, statistical inference, and control charts. The intention was to make the people aware of these tools and motivate them to find uses for these tools in their respective areas.

6.2.4 Acceptance Sampling.

Training on the topic of acceptance sampling was planned for the laboratory staff at Alcoa Shanghai. This staff was responsible for ensuring the quality of incoming materials such as aluminum ingots, and it was felt that the statistical methods of acceptance sampling could help them achieve greater performance. At the end of the author’s tenure with the company, training on this topic had not yet been delivered to the laboratory personnel; however, materials had been prepared and the Quality department members were ready to conduct the training.

6.3 Developing Training Materials

Training materials were prepared for each of the training sessions mentioned above. Developing content for the technical training was particularly challenging. While the subjects of statistics and quality control are familiar to most Western-trained engineers, they are relatively foreign to a Chinese organization such as Alcoa Shanghai. This fact must be taken into account when developing the training – simply borrowing materials from Western textbooks would have been ineffective. With this audience, it is necessary to start from a more basic level, explaining the logic and rationale every step of the way. Examples should be provided frequently to demonstrate the use of the tool being discussed. Furthermore, the attention of the audience can not be taken for granted; the material must also be presented in an interesting manner.
In developing the training materials, the author borrowed concepts from textbooks and other sources, and put them together in a way that suited the Alcoa Shanghai organization. The company’s very capable translators then translated the materials into Chinese. During the training sessions, hard copies of the training materials are handed out to trainees to serve as reference in the future. Training materials for the seven QC tools, statistical quality control, and acceptance sampling, in both English and Chinese, are presented in Appendices 3, 4, and 5, respectively.
Chapter 7: Quality Control Circles

Quality Control Circles (QCC) is a major component of Alcoa Shanghai’s new quality strategy. As described in Chapter 4, QCC is a forum through which operators apply their problem solving skills in to improve quality in their respective production areas. It is effective because it recognizes that operators are intimately familiar with their processes and often have unique insights into quality improvement opportunities. In the typical Japanese implementation, QCC teams are voluntary and largely autonomous. One operator is designated circle head and leads the group in problem solving activities. The key to success in this kind of structure is motivation, often involving incentives of some kind.

At Alcoa Shanghai, management felt there were huge benefits to be gained from implementing QCC. In addition to the quality improvements that would result from QCC projects, the program would also help to foster a culture of proactiveness and empowerment, as teams are permitted to choose their own area of focus and act autonomously. Operators would also develop leadership skills by serving as circle heads. The main challenge in implementing QCC was motivation – operators were expected to work on their QCC activities outside of normal work hours without formal compensation. However, management support for the program was strong, and generous rewards were promised for finished projects. Successful projects would also bring company-wide recognition to the team.

Alcoa Shanghai’s Quality department made the initial QCC announcement even before the quality strategy had been completely drawn up. The department manager, Mr. Zhang, had prepared slides to introduce the program, and had assigned all operators to QCC teams, with designated team leaders. The slides used by Mr. Zhang are included as Appendix 6; unfortunately, they are available only in Chinese.

The QCC program was announced in June 1999, and the first team commenced in early August. It was decided that the program would start with one ‘pilot team’ initially, with close guidance and support from Quality personnel and engineers. The lessons and feedback from this pilot team would then be incorporated into the program before other teams started up. As it turned out, the first project progressed so well that other teams started up before it was completed.
7.1 The Eight-Step Problem Solving Process

QCC projects at Alcoa Shanghai use an eight-step problem-solving process modified from the seven-step process of Total Quality Management. It is consistent with the well-known Plan, Do, Check, Act (PDCA) cycle, which in turn is based on the scientific method. The process is designed to produce solutions based on sound analysis and that experimentation. By following the eight steps as prescribed, teams would be guided to come up with their own solutions. The eight-step problem-solving process is shown in Figure 7.1.

<table>
<thead>
<tr>
<th>Plan</th>
<th>1. Choose Subject</th>
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<tbody>
<tr>
<td></td>
<td>2. Investigate Status</td>
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<td></td>
<td>3. Analyze Causes</td>
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<td>4. Develop Measures</td>
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<tr>
<td>Do</td>
<td>5. Implement Measures</td>
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<td>Check</td>
<td>6. Check Results</td>
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<tr>
<td>Act</td>
<td>7. Standardize Procedures</td>
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<td></td>
<td>8. Summarize &amp; Publicize Results</td>
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</tbody>
</table>

![The Eight-Step Problem-Solving Process](image)

Figure 7.1: The problem-solving process of QCC.

7.2 Structure of the QCC Network

Quality Control Circles do not involve only the operators. In fact, an entire network was defined in Alcoa Shanghai to support the QCC teams. The network includes roles for members of the Quality, APS, Engineering, and Process departments, among others. Employees were made aware of their roles, and their commitment was secured before launching the program. The QCC support network is illustrated in Figure 7.2; Appendix 7 presents the Chinese version. A brief explanation of the network follows the diagram.
Figure 7.2: Structure of QCC support network.

The QCC team is at the bottom right corner of the diagram, showing team members and circle heads consisting of operators and group leaders, respectively. Technical support is provided to the QCC team by members of various departments, including APS, Engineering, Process, and Manufacturing. These departments provide expertise in their respective areas, as necessary in problem solving efforts and implementation. The Quality department’s administrative assistant is responsible for making sure the QCC team has adequate communication links to the rest of the organization. This includes a means to request technical support and a forum for exchanging ideas and feedback. In addition, the quality assistant would help monitor the projects’ progress and promote successful results.

Overseeing the QCC teams are the roles of coordinator and advisor, played by the quality manager and quality engineer, respectively. The coordinator keeps in touch with all the teams and makes sure their projects are aligned with the company’s goals. The advisor is an expert on
the problem-solving process and provides assistance and support throughout the project. She interacts with the QCC teams on a fairly regular basis, and is responsible for managing their progress in the manner described in the next section. At the top of the QCC hierarchy is the Promotion Committee, made up of Alcoa Shanghai’s top management. This group provides motivation for the entire QCC program by regularly expressing their support. For example, the plant manager often attended team meetings to express his appreciation for their efforts.

The QCC network diagram also shows the structure of the supporting training programs. All departments received training on the company’s quality strategy and the role of QCC in realizing the vision. Technical training was given to those who would provide technical support, to prepare them for their role. Group leaders received some training on leadership skills, although most of it was delivered informally through coaching and feedback. Finally, team members were trained for awareness – of the QCC network structure, the problem-solving process, and the tools that were at their disposal.

7.3 QCC Project Management

As QCC advisor, the quality engineer, Mrs. Wong, was responsible for managing the progress of QCC teams. Even with the help of the author and Stephen Li, Alcoa Shanghai’s APS coordinator, detailed management of all the teams would require more time than she had. Thus, a system of hands-off project management was necessary.

The system that was devised consists of a series of three reports that the QCC teams submit at specific points in their project progress. The reports are synchronized with the eight-step problem-solving process: Report I was required after completion of step 1, Report II was required after completing step 4, and Report III was required after completing step 6. After step 8, when the project is fully completed, each team is expected to give a final presentation to all employees involved in the QCC program (actually, the presentation is step 8). With each report, the team gives a summary of the steps completed since the last report, a rough action plan and timeline for the next few steps, and a list of resources that would be required. Report I also asked the team to submit a logo, from which would be made stickers to apply to members’ hard hats. By giving this information, the QCC management team would be able to coordinate the
necessary technical support. They would also know the appropriate times to check back on the team’s progress. Teams were encouraged to follow their plans as closely as possible, but they were given full autonomy in determining their own timelines and meeting schedules. In this way, teams were almost entirely self-governed, unless they either fall significantly behind schedule or explicitly request assistance.

Figure 7.3 shows one of the project timelines that are to be submitted with the reports. Note that the detailed steps listed are only suggestions—teams need fill in dates only for those steps that are relevant to their project, and may add other steps not listed. Appendix 8 shows a complete set of QCC reports filled out and submitted by the first QCC team, who elected to call themselves IQ.

<table>
<thead>
<tr>
<th>The 8-Step QCC Process</th>
<th>Dates Completed</th>
<th>Project Dates</th>
<th>Person Responsible</th>
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</thead>
<tbody>
<tr>
<td>Step 1: Define a goal</td>
<td></td>
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<td>QCC Team Leader</td>
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<tr>
<td>QCC Report I</td>
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<tr>
<td>Step 2: Investigate data</td>
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<td>Plan for data collection</td>
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<td>Get required support</td>
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<td>Collect data</td>
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<td>Summarize data</td>
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<td>Step 3: Analyze data</td>
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<td>Brainstorm session</td>
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<td>Make conclusions</td>
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<td>Step 4: Develop solutions</td>
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<td>Propose solutions</td>
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<td>Decide on final solution</td>
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<tr>
<td>QCC Report II</td>
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<td>QCC Team Leader</td>
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<td>Step 5: Implement solutions</td>
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<tr>
<td>Plan for implementation</td>
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<tr>
<td>Get required support</td>
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<tr>
<td>Train</td>
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<td>Step 6: Test results</td>
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<td>Decide how to perform check</td>
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<tr>
<td>Collect data</td>
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<td>Make conclusions</td>
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<tr>
<td>Make recommendations</td>
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<tr>
<td>QCC Report III</td>
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<td></td>
<td>QCC Team Leader</td>
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<tr>
<td>Step 7: Maintain results</td>
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<td>Get required support</td>
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<td>Generate standard documents</td>
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<td>Finalize project</td>
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<tr>
<td>Step 8: Summarize and improve</td>
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<tr>
<td>Document project</td>
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<tr>
<td>Final presentation</td>
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<td>QCC Team</td>
</tr>
</tbody>
</table>

Figure 7.3: QCC project schedule template.
7.4 Project Results So Far

The first QCC team, initiated in August 1999, consisted of a group of eight operators from the rolling area, and was led by Huang Jun. The team named themselves ‘IQ’ and designed the logo shown in Figure 7.4. As their project, they chose to focus on thin-gauge flatness improvement at the finishing mill. Flatness is a quality feature that is especially important at the trimming area: poor flatness leads to excess waste as more material needs to be trimmed off the edges of the foil. There is no easy-to-perform measurement for flatness, but experienced trimming operators can easily observe it qualitatively.

Figure 7.4: IQ team logo.

The IQ team followed the eight-step problem-solving process and applied several of the QC tools, including the fishbone diagram for brainstorming possible root causes. From their analysis, they decided to change several parameters in the final process steps of thin-gauge foil production, and experimented with several coils before identifying the optimal settings for these parameters. Additional trials with these parameters resulted in consistently improved flatness, as verified by trimming operators. Thus the team had found a solution to their quality problem.

The IQ team’s completed reports are presented in Appendix 8, including the fishbone diagram they generated. At the end of their project, the team presented their results to the rest of the organization during a special meeting. The slides from this presentation (in Chinese only) are included as Appendix 9. Following the conclusion of this successful project, all members of the IQ team were rewarded with a generous monetary bonus. In addition, their work was publicized in company-wide communications.

Even before the IQ team had completely finished their project, other QCC teams began to start up in other areas of the plant. For example, in the trimming area, a team had decided to explore ways to reduce the amount of aluminum particles generated by slitting knives. Another team in the casting area was started to focus on improving thickness consistency in cast sheets. As of the end of the author’s tenure at Alcoa Shanghai, these teams had not completed their projects, but were progressing well.
Chapter 8: Basic Analytical Tools

The third component of Alcoa Shanghai’s quality strategy implementation is the introduction of basic analytical tools to the organization. This component is closely integrated with the other two components: the tools are taught to employees through training, and they are applied in QCC problem-solving activities. Aside from QCC, however, there were many other opportunities around the plant to use analytical tools. These tools include the seven QC tools already discussed, as well as other, more sophisticated ones. This chapter describes some of the basic analytical tools that were introduced to the organization, the method by which they were introduced, and the applications that were foreseen.

The introduction of analytical tools in fact proceeded quite slowly at Alcoa Shanghai. As mentioned in Chapter 6, one of the three principles of the training strategy is to train to use. Applied here, this principle dictates that tools should be introduced to the organization only when there has been identified an immediate application. In this way, employees have a chance to practice their new skills, and the skills will more likely be retained. Furthermore, Alcoa Shanghai wanted to ensure that these new skills remain resident within the company. Thus, each time a new tool was introduced, it was necessary to understand not just the mechanics of the tools, but also the fundamentals of how it works. This level of understanding takes extra time to develop, but helps to ensure that the newly developed skill becomes a sustained capability of the organization.

8.1 Data Collection and Analysis at Rolling Mills.

All three rolling mills at Alcoa Shanghai are run by drives that utilize active feedback control systems. These systems constantly monitor machine parameters and adjust them as necessary to provide stable output. For example, one important function of the feedback system is to control the thickness of the rolled output. The output thickness is directly affected by the gap between the upper and lower work rolls, which in turn is affected by the pressure applied to the rolls. To control thickness, the feedback system constantly monitors the roll gap, compares the gap to a
pre-specified standard, and adjusts the pressure accordingly to maintain a constant gap. Figure 8.1 shows a schematic of the mill rolling mechanism.

![Figure 8.1: Schematic of mill rolls.](image)

Thickness uniformity is an extremely important quality characteristic in Alcoa Shanghai’s production process. It is not only a desirable feature for the end customer, but is also critical to the company’s production efficiency. Inconsistent thickness, especially at more upstream processes, is a major root cause of coil breakages at downstream processes. For example, if the breakdown mill produces a coil with large thickness variation, then this coil is more likely to break while it is rolled at the finishing mill later. This is because the finishing mill is set at a certain tension to reduce the coil thickness to as low as six microns. If the thickness variation causes the thickness to go down to four microns at some point, then the coil will be unable to withstand the tension and it will break. Such a breakage causes waste in at least three ways:

1. A significant amount of material gets scrapped when the coil rolling is restarted.
2. The broken coil is now of an unusual size and may be difficult to use. A significant part of this coil may have to be scrapped later because it is not saleable.
3. Because of the scrap that occurs, all upstream processes that contributed to the production of this coil in some sense have gone to waste. They have lost productivity.
Engineers at Alcoa Shanghai recognized that there was an opportunity to download real-time thickness data from the mills' feedback control systems. Monitoring and analysis of this data would be useful for two purposes:

1. *Process control* – By monitoring the real-time thickness, engineers and operators would be able to detect when problems occur at the mill, and correct the problem before a large amount of poor quality material is produced. To do this, for example, operators may incorporate the thickness data into a simple control chart. When a problem is detected, analysis of the thickness data may help to identify the source of the problem and give clues as to how it can be corrected and eliminated. By detecting and correcting problems sooner, waste would be reduced.

2. *Process improvement* – Analyzing the thickness data will help engineers improve the process for better thickness uniformity. Even when the mills are operating normally (without any unusual problems), analysis of the data may help to identify sources of variation that may be eliminated or reduced. For example, the data may show a variation in thickness that is perfectly synchronized with another feature of the production process, thus giving a clue that the two are related. By controlling the other feature better, this particular thickness variation may be reduced. Appendix 10 illustrates one example of this type of analysis using Fourier transforms.

One engineer had in fact set up a simple system to record thickness data from the mills. As described in Chapter 2, this engineer connected a chart recorder to terminals at the mill drive that convey thickness data. This apparatus records the voltage across the terminals on a strip of paper, representing the thickness. The data is only qualitative, however, and is not well suited to any in-depth analysis. There was a need for a system that could record the thickness data quantitatively, and store that data in such a way that it could be accessed and analyzed later.

To fill this need, Alcoa Shanghai first considered building a computer system that would be a digital replacement for the chart recorder. This system would use hardware and software that can measure and record thickness data from the mill drives. The stored data can be monitored in real time, or it can be accessed at a later time for more in-depth analysis. A small team of engineers was formed to evaluate the feasibility of using LabVIEW software for this system. As
part of the evaluation, the team worked with a representative from LabVIEW to demonstrate the concept. During the demonstration, a computer running LabVIEW software was connected to the breakdown mill drive, and it recorded continuous thickness data as coils were rolled. The data was stored on the computer, then later accessed for quantitative analyses that previously were not possible with the chart recorder. One particularly insightful analysis is described in Appendix 10. While this demonstration clearly convinced Alcoa Shanghai’s engineers of the power of LabVIEW, the company eventually decided not to take this approach. It was felt that LabVIEW was too expensive, and too far beyond the technical capabilities of the company (so that consultants would be needed to implement the system, further increasing the cost). Such a system may be reconsidered at a later time.

In place of the LabVIEW system, Alcoa Shanghai had a team of engineering students from Shanghai Jiao Tong University (the best technical university in the area) build a simpler system. This system used a different approach to record thickness data, but did so at a much lower frequency of about once every minute. The scarcity of data points provided by this system limits the amount of analysis that can be performed for process improvement. However, it still allows monitoring the thickness for process control, and creates a historical record of thickness performance that is useful for future reference. The system is currently in place and running in the company.

8.2 Database for Ingot Analysis Results.

As mentioned in Chapter 3, Alcoa Shanghai’s laboratory staff is responsible for checking the quality, in terms of chemical composition, of incoming aluminum and alloy ingots. They do this by chemical analysis based on spectroscopy or titration. The results of the analysis have traditionally been recorded on paper forms, which are then put into a binder in the lab. This system works sufficiently well for judging ingot quality one batch at a time, and also provides a simple historical record. However, it does not facilitate a statistical analysis of suppliers’ past quality performance, which the laboratory staff was interested in having. They wished to be able to calculate statistical metrics related to variation and capability. In order to do this, it would be necessary to have the analysis results stored in an easily manipulatable digital format.
It was decided that a computer database would be created to allow the laboratory to store their analysis data. This database would be easy to use, and would generate reports of the statistical metrics that were desired. Furthermore, because the database would reside on Alcoa Shanghai’s computer network, everyone in the company would be able to access and analyze the data from any computer. In essence, this database would be similar to the Foil Business System, but be customized for the laboratory.

Such a database was created by the author using Microsoft Access. Called the Laboratory Data System, it allowed analysis data to be entered using convenient electronic forms that mimicked the paper forms. The system stored the data and allowed users to view historical data in a number of formats. It also allowed users to view automatically generated reports of relevant statistical metrics. Figure 8.2 shows a screen capture of the main window of the Laboratory Data System. Additional screen captures are shown in Appendix 11.

Figure 8.2: Main window of the Laboratory Data System.
8.3 Calculations for Statistical Process Control.

From training and other prior activities, the Quality department at Alcoa Shanghai had become interested in using statistical process control (SPC) at various areas in the plant. To do this, the engineers would need some tools for making basic calculations relevant to SPC. This section describes three instances where basic calculations were demonstrated using Excel spreadsheets. While these may seem straightforward to an engineer trained at MIT, they were in fact quite enlightening to the Alcoa Shanghai organization.

8.3.1 Control chart for thickness

With the thickness data that the plant had started to take, there was a clear opportunity to use simple control charts to monitor the process. These control charts would be set up to generate an alarm when the thickness exceeded an upper limit or fell below a lower limit. The alarm would indicate that a problem had occurred, and would call for the process to stop, allowing engineers to investigate and resolve the problem. The control chart is a very useful tool, especially because it is straightforward to use once it is set up correctly. This example demonstrated the setup of a control chart, including the calculation of control limits. Thickness data from the casting shop was used for this demonstration.

The thickness at the caster has a target value of six millimeters and is affected by process conditions such as roll gap and tension. The thickness of each cast coil is measured at several points, and the average of these measurements is recorded in the Foil Business System. Thus, FBS contains a historical record of thickness data from the caster.

For the thickness data, a relatively straightforward \( \bar{x} - R \) control chart with a sample size of five was recommended. This was considered appropriate because many machine parameters at the caster are set by operators according to their observations. For example, the operator sets the roll gap by taking several initial thickness measurements, then estimating the adjustment necessary to achieve the target value. In other words, the operators manually provide feedback control at the caster. Thus, there is reason to believe that variation from coil to coil may be partly due to differences in operator behavior. Taking a sample size of five helps to reduce this component of
variation. Note that because casting one coil takes about five hours, each operator produces at most two coils per shift.

For this particular setup, two control charts would be needed, and one point would be plotted on each chart for every five coils. The $\bar{x}$ chart tracks the average of the thicknesses of the last five coils, while the $R$ chart tracks the range (difference between maximum and minimum values) of the five coil thicknesses. On each chart, upper and lower control limits (abbreviated as UCL and LCL) are indicated; when a point falls outside of these limits, it generates an alarm. The control limits are calculated from historical data as follows:\(^\text{18}\)

For the $\bar{x}$ chart:

\[
\begin{align*}
UCL &= \bar{x} + A_2 \bar{R} \\
LCL &= \bar{x} - A_2 \bar{R}
\end{align*}
\]  
Equation 8.1

where $\bar{x}$ is the historical mean value of $\bar{x}$

$\bar{R}$ is the historical mean value of $R$

$A_2$ is a constant which equals 0.577 when the sample size is five

For the $R$ chart:

\[
\begin{align*}
UCL &= D_4 \bar{R} \\
LCL &= D_3 \bar{R}
\end{align*}
\]  
Equation 8.2

where $D_4$ is a constant which equals 2.115 when the sample size is five

$D_3$ is a constant which equals 0 when the sample size is five

Control chart parameters for the caster thickness data were calculated in this way using an Excel spreadsheet. The results are shown in Table 8.1.

\(^{18}\) Equations for control chart parameters can be found in any text on Statistical Process Control. For example, see Montgomery, D. C., Introduction to Statistical Quality Control, third edition, John Wiley & Sons, 1997.
8.3.2 Ingot supplier capability

The data kept by the laboratory on incoming ingot quality also presented an opportunity for implementing control charts. In addition, a statistical capability metric would be useful for judging suppliers on their quality performance. The control chart parameters and capability metric are in fact calculated automatically by the Laboratory Data System, but it is nonetheless important for the engineers to understand how they are calculated.

An Excel spreadsheet was used here to perform the relevant calculations based on six months of data. An excerpt of this spreadsheet is presented in Table 8.2, showing results for the primary supplier. In this case, the control chart suggested was a simple individuals chart, where each data point represented the result of a single analysis. Thus, the control limits are simply three standard deviations, or sigmas, away from the mean value. The capability is computed by comparing the upper control limit to the specified standard for A00-grade ingot, according to the following equation:

\[
\text{Capability} = \frac{\text{Mean} - \text{Standard}}{\text{Mean} - \text{LCL}} \tag{Equation 8.3}
\]

A confidence level is then computed from the capability – this represents the degree to which one may be sure, without testing, that any single batch of ingot is of acceptable quality. With Excel, the confidence level is calculated using the NORMSDIST function:

\[
\text{Confidence} = 2\times\text{NORMSDIST}(3\times\text{Capability}) - 1 \tag{Equation 8.4}
\]
These calculations are carried out for each chemical impurity that the A00 specification provides a standard for. The results show high capabilities and confidence levels for this supplier, indicating that this supplier has historically had very good quality performance.

More specifically, the spreadsheet shows that over the past six months, this ingot supplier has demonstrated a capability of about 1.0 in meeting the specified standard for aluminum content. The standard is for at least 99.70% of the ingot to consist of pure aluminum, leaving a maximum allowance of 0.30% for impurities. The supplier’s capability of 1.0 translates into a confidence level of about 99.7%. This means that for a shipment of ingot from this supplier, one may be 99.7% sure that the aluminum content will meet or exceed the standard, even without doing any inspection. Stated differently, for every 1000 tons of ingot supplied by this supplier, about 3 tons may be expected to fail the inspection. The capabilities and confidence levels for the other components are interpreted similarly.

Table 8.2: Statistical analysis of ingot quality.
8.3.3 Gage studies

The final class of analytical tools that was introduced to the Alcoa Shanghai organization was gage studies. This is a tool that helps to identify the sources of measured variability. It is based on the theory that any measurement variability partly reflects the true variability inherent in the product being tested, and partly reflects the error inherent in the measurement process. The measurement error may be further categorized into machine error and operator error. In quality control, the primary concern is to understand the variability inherent in the product itself. It is thus useful to be able to decompose measured variability into these various sources.

During the author’s tenure at Alcoa Shanghai, there was insufficient time to demonstrate gage calculations with actual data. However, training was given to the quality engineer on the method of these calculations, including relevant hypothetical examples. Because the training was not delivered to a large audience, it took the form of a technical paper, rather than a graphical presentation. The paper is included as Appendix 12.
Chapter 9: Lessons and Concluding Remarks

Although the implementation of the Excellence Through Quality strategy had only begun at Alcoa Shanghai, some positive results were already evident by the end of the internship project in December 1999. Employee involvement in quality activities was dramatically higher as more operators and engineers participated in Quality Control Circles. Product recovery had increased several percentage points since June, even as the plant shifted more of its production to thin-gauge foil. Most importantly, there was a general awareness of quality issues throughout the plant that had not existed before.

While the quality strategy described in this document may not represent any significant advancement in the field of modern quality management, the author believes there were several insights gained from the experience. Some of these are articulated below:

- Alcoa Shanghai’s quality strategy was successful because it was developed by the same people who would implement it and whose jobs would be affected by it. These were people who had worked at the plant for many years and were intimately familiar with the production process. Their input was sought after and respected during every step of the project. Because of this, the end result was a strategy that was fully supported by the organization. Implementation of the strategy was facilitated by this sense of shared vision.

- Developing a new quality strategy does not necessarily have to involve the invention of new quality management methods. Because quality revolutions have occurred in the West and Japan for some time now, there is a vast amount of quality knowledge and precedents that can be tapped. What is more important is to understand the conditions of the particular organization one is dealing with, and select the quality initiatives that are appropriate for the organization, given its unique goals and skills.

- People at all levels of the organization can be called upon to create effective change. While the technical level of the employees at Alcoa Shanghai are generally lower than that encountered in Western companies, it was not a barrier to implementing positive change. Technical skills are definitely helpful in many modern quality methods, but are not the most critical input. It is more important to have enthusiasm and a true thirst for improvement. At
Alcoa Shanghai, all members of the organization, from top management down to the factory floor operators, realized the need for change and subscribed to the new strategy. Their commitment will ultimately be responsible for the success of the strategy.

Perhaps the most significant lesson learned by the author occurred on a much more personal level. The experience at Alcoa Shanghai has taught the author a tremendous amount about living and working with the people of China. At first, the vast cultural differences caused a bit of shock and created some difficulties in working with the organization. However, in the end, the author has come to realize that people are basically the same at a fundamental level. Chinese employees are motivated to create excellence by the same things that motivate employees everywhere else – these include compensation, security, job satisfaction, respect, and the desire to have an impact. When these are provided, a strong momentum for change can be generated and sustained. Thus, manufacturing problems in China can be approached in the same way as problems in any other environment, as long as one retains an open mind of respect and cooperation, and genuinely devotes time to learn about the culture.
Appendix 1: Spheres of Quality Presentation

English Version

THE SPHERES OF QUALITY
FRAMEWORK

Quality is...
PEOPLE, PROCESS, & METRICS
CONTINUOUS IMPROVEMENT will raise our quality by focusing on all elements of our quality strategy. Both incremental and breakthrough improvements will be utilized. Activities will have the participation and support of all people in the company.

Quality is...
PEOPLE, PROCESS, & METRICS
VISUAL MANAGEMENT will provide everyone a clear assessment of the state of our quality. It will let problems surface quickly, and focus everyone’s attention to them. Visual management centers will also provide motivation to achieve our goals.
Quality is... **PEOPLE**

Our people need to have the right **MINDSET** for quality, including:
- the knowledge of quality standards
- an awareness of one's own actions
- the desire to do well
- the satisfaction from a job well done

---

Quality is... **PROCESS**

Our processes will have **STABILITY** to produce quality, including:
- the proper operation of equipment
- automation of routine steps
- control over process parameters
- an awareness of safety issues
- an understanding of the science

---

Quality is... **METRICS**

Our quality is measured against a set of **STANDARDS** that allow:
- an accurate assessment of our process
- benchmarking against the industry
- the unambiguous definition of goals
- a clear link between actions and impacts

---

Quality is... **PEOPLE**

To create a strong quality mindset in our people, we will provide:
- training to develop skills and attitudes
- support from all levels
- the empowerment to take action
- an efficient means of communication
- time for adjustment

---

Quality is... **PROCESS**

To achieve the necessary high level of stability, we will make use of:
- an efficient production system
- clear documentation of the process
- adequate maintenance resources
- support from process development
- support from engineering

---

Quality is... **METRICS**

To define our standards of quality, we should consider the following:
- the needs of our customers
- the capabilities of our own process
- the ease-of-use of the metric
- the completeness of the set
Quality is... **PEOPLE & PROCESS**

The link between our people and process is provided by Standardized Work (SW). This includes SW definition as well as:
- SOP documentation
- ISO-9000 documentation
- EHS documentation

**PEOPLE PROCESS METRICS**

Quality is... **PROCESS & METRICS**

The link between our process and metrics is provided by Statistical Quality Control (SQC). The elements of SQC include:
- DOE to optimize process parameters
- SPC to monitor the process stability
- Process Capability assessment

**PEOPLE PROCESS METRICS**

Quality is... **PEOPLE & METRICS**

The link between our people and metrics is provided by the use of Incentives to promote achievement. Incentives will include:
- monetary rewards
- peer recognition
- job satisfaction
- quality of life

**PEOPLE PROCESS METRICS**

Quality is... **PEOPLE, PROCESS, & METRICS**

The central element, CUSTOMER FOCUS, is the primary driver of our quality strategy. Every one of our processes will have a customer (internal or external) defined. In everything we do, we should be able to clearly state the impact of our actions on customer satisfaction.
品质是：

- 人（思想观念）
- 标准化工作
- 工艺
- 激励
- 客户至上
- 品质统计控制
- 衡量工具
- 不断改善
- 日视管理

Chinese Version (framework diagram only)
Appendix 2: Excellence Through Quality Strategy

English Version

Excellence through Quality

Previously: Finished products inspection in packing area.

Presently: Inspection pushed to earlier process stages: quality review at separator, heavy slitter, hospital rack.

Future: Operator self inspection +

Core Technology:
- Rolling Control
- Property
- Flatness
- Surface

Produce good products

Training on inspection standards at equipment

Root Cause Analysis

Corrective/Preventive Actions

Data, SQC

Internal Rejection

External Rejection
追求卓越品质 - 品质流程

以前：包装区成品检验

目前：检验往前推 → 分卷、厚切及部件的质量评审

内部剔除 → 客户剔除

分析原因 → 数据收集及处理（SQC）

纠正/预防措施

未来：操作工自检 → 进入制造

培训

机台检验的标准

生产出好产品

核心技术

- 机制技术
- 板形
- 内部机械性能
- 表面

操作工的QCC
Appendix 3: Seven QC Tools Training Materials

English Version

QCC Training: The Seven Quality Control Tools

Presented by: Shing Yin

QCC Training: 7 QC Tools

Introduction: The Seven Quality Control Tools

1. Check Sheet - to detect patterns in data
2. Pareto Chart - to display relative significance of problems
3. Cause & Effect (Fishbone) Diagram - to identify root causes
4. Run Chart - to display trends over time
5. Histogram - to display distribution of data by categories
6. Scatter Diagram - to display relationships between variables
7. Control Chart - to determine whether a process is in control

QCC Training: 7 QC Tools

Choose the right tool for your purpose!

QCC Training: 7 QC Tools

The Problem-Solving Method

<table>
<thead>
<tr>
<th>Tools</th>
<th>Plan</th>
<th>Do</th>
<th>Check</th>
<th>Act</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check Sheet, Pareto Chart</td>
<td>1. Choose Subject</td>
<td>5. Implement Measures</td>
<td>6. Check Results</td>
<td>7. Standardize</td>
</tr>
<tr>
<td>Check Sheet, Pareto Chart, Run Chart, Histogram</td>
<td>2. Investigate Status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cause &amp; Effect Diagram, Scatter Diagram</td>
<td>3. Analyze Cause</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creativity</td>
<td>4. Develop Measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pareto Chart, Histogram, Control Chart</td>
<td></td>
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</tbody>
</table>
The Check Sheet

- A logical starting point for most problem-solving cycles.
- Use to detect patterns in sample observations.
- Begins the process of translating opinions into facts.

General Format:

<table>
<thead>
<tr>
<th>Problem</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
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</tr>
</tbody>
</table>

Check Sheet Example:

Recording the occurrence of defects.

<table>
<thead>
<tr>
<th>Defect</th>
<th>JUNE</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrong Siz</td>
<td>111</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>111</td>
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<td>Wrong Tme</td>
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<td>111</td>
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<tr>
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<td>1</td>
<td>1</td>
<td>111</td>
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<td>22</td>
<td>18</td>
<td>22</td>
<td>18</td>
<td>103</td>
</tr>
</tbody>
</table>

Check Sheet Tips:

1. Make sure the recorded observations are representative.
2. Make sure the sampling process is efficient so people will do it.
3. Try to sample from a homogeneous population (same machine, same operator, etc.); or use a grouped sampling strategy.

Steps For Constructing A Check Sheet:

1. The team must agree on the event being observed.
2. Decide on a time period for data collection.
3. Design an appropriate form that is clear and easy-to-use.
4. Collect data consistently and honestly.

The Pareto Chart

- Helps to direct our attention and efforts.
- Use to display relative significance of problems or conditions.
- Based on data collected from check sheets or other methods.

General Format:

Steps For Constructing A Pareto Chart:

1. The team selects problems (categories) to be compared.
2. Decide on the comparison unit (frequency, cost, etc.) and time period to be studied.
3. Sort the categories from left to right in decreasing order.
4. For each category, draw a rectangle that represents its value in the comparison unit.
5. Optional: include a percentage scale on the right vertical axis.
**Pareto Chart Example:**
Showing the significance of different defects.

![Pareto Chart](image)

**Pareto Chart Tips:**
1. Be creative in uses:
   - Analyze problems with different comparison units.
     - Example: Look at both frequency and cost of defects.
   - Group problems into different categories.
     - Example: Look at defects by type, machine, and operator.
   - Measure the impact of improvement efforts.
     - Example: Create before and after Pareto Charts.
2. Use common sense - do not make decisions based on Pareto Charts alone.

**The Cause & Effect (Fishbone) Diagram**
- Helps to organize our brainstorming efforts.
- Identify, explore, and display possible root causes.
- A well-detailed diagram will look like fishbones.

**General Format:**

```
   CAUSES
   
   EFFECT
```

**Steps For Constructing A Cause & Effect Diagram:**
1. The team selects the problem to be analyzed.
2. Generate major possible causes: start with 4 M’s or 4 P’s.
   - 4 M’s: Manpower, Machinery, Methods, Material
   - 4 P’s: People, Plant, Policies, Procedures
3. For each cause, ask "Why does it happen?" and generate more detailed causes.
4. Interpret the diagram: look for causes that appear repeatedly, or seem the most tractable.

**Cause & Effect Diagram Example:**
Finding the root causes of low gas mileage.

![Cause & Effect Diagram](image)

**Cause & Effect Diagram Tips:**
1. Make sure everyone understands the problem statement.
2. Remember to look for causes, not symptoms.
3. Use any major categories that seem appropriate.
4. Let the diagram evolve continuously.
**The Run Chart**
- Helps verify our suspicions about problem causes.
- Visually shows trends over time.
- Simple to construct and use.

**General Format:**

```
<table>
<thead>
<tr>
<th>Time or Sequence</th>
<th>Measurement</th>
</tr>
</thead>
</table>
```

**Run Chart Example:**
Showing a decreasing trend after the fourth hour.

**Run Chart Tips:**
1. Record the data consistently.
2. Look for statistically significant trends and patterns:
   - Nine points in a row on the same side of the average.
   - Six points in a row steadily increasing or decreasing.
3. Be careful not to act on every variation; focus attention on truly vital changes in the process.

**Steps For Constructing A Run Chart:**
1. The team selects the measurement and time scale.
2. Plot observations on the chart as they are made.
3. Monitor the chart for suspicious trends and patterns.
4. Decide when an investigation should be carried out.

**The Histogram**
- Helps assess the amount of variation in a process.
- Displays the distribution of collected data.
- Reveals abnormal behaviors.

**General Format:**

```
<table>
<thead>
<tr>
<th>Frequency Count</th>
</tr>
</thead>
</table>
```

**Steps For Constructing A Histogram:**
1. The team prepares the data to be charted.
2. Decide on the number of bins to use.
   - A useful guide:
     | Data points | Bins |
     |-------------|------|
     | Under 50    | 5-7  |
     | 50 - 100    | 6-10 |
     | 100 - 250   | 7-12 |
     | Over 250    | 10-20|
3. Sort the data points into the bins.
4. Use bars to represent the number of data points in each bin.
**Histogram Example:**

Showing the distribution of waiting times at a machine.

![Histogram Example](image)

**Histogram Tips:**

1. The number of bins determines the detail displayed.
2. Look for unusual patterns:
   - Skewed (off-center peak) - may indicate an unbalanced process or sampling.
   - Bimodal (two peaks) - may indicate that the data is coming from multiple sources.
3. Don’t expect every process to yield a bell-shaped distribution.

**Scatter Diagram**

- Tests our theories about cause and effect relationships.
- Shows how one variable changes with another.
- Patterns suggest possible relationships.

**General Format:**

![Variable One](image) ![Variable Two](image)

**Steps For Constructing A Scatter Diagram:**

1. The team prepares paired samples of data to be plotted.
2. Designate each axis to represent one variable.
   - Usually: “cause” variable on the horizontal axis
   - “effect” variable on the vertical axis
3. Plot data on the chart. Use circles to represent repeated points.
4. Look for patterns that suggest relationships.

**Scatter Diagram Tips:**

1. Use as many data points as you can get.
2. Look for both direction and ‘tightness’ of the pattern:
   - Upward sloping - positive correlation.
   - Downward sloping - negative correlation.
   - Tightness - represents strength of the relationship.
3. Remember that patterns can not prove causal relationships; they only indicate that a correlation exists.
The Control Chart

- Determines whether a process is in statistical control.
- Helps to understand the source of variations.
- Helps to decide if a process needs to be fixed.

General Format:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Time of Sequence</th>
</tr>
</thead>
</table>

Steps For Constructing A Control Chart:

1. The team selects the process output to be monitored.
2. Appropriate control limits are calculated for the process:
   - Center Line (CL): average output value
   - Upper Control Limit (UCL): CL + 3σ (varies by application)
   - Lower Control Limit (LCL): CL - 3σ (varies by application)
3. Plot data points on the chart as they are collected.
4. Look for patterns that constitute 'out-of-control' alarms.

Control Chart Tips:

1. Distinguish between control limits and specification limits. A process that is in control does not necessarily meet customer needs.
2. Choose the correct type of control chart to use.
3. Calculate control limits carefully:
   - For statistical soundness, should be based on 25 or more data points.
4. Know the patterns that generate alarms.

Control Chart Example:

Showing consistent (in-control) thickness.
品管圈（QCC）培训：
品质管理的七个工具

编写：任承发

资料来源：《金盟管理》；《The Quality Jogger》；《QCC》

介绍：七个品管工具

1. 检查表 - 观察数据情况
2. 帕拉图 - 显示各类问题的重要性
3. 因果图 (鱼刺图) - 确定问题的根本原因
4. 趋势曲线图 - 显示一段时间内事件的发展趋势
5. 柱状图 - 显示不同类别数据的分布情况
6. 分布图 - 显示变量之间的关系
7. 控制曲线图 - 显示过程是否受控

根据需要，正确地选工具！

解决问题的步骤

<table>
<thead>
<tr>
<th>步骤</th>
<th>工具</th>
</tr>
</thead>
<tbody>
<tr>
<td>计划</td>
<td>1. 选择主题</td>
</tr>
<tr>
<td>2. 情况调查</td>
<td>控制表、帕拉图、趋势曲线图、柱状图</td>
</tr>
<tr>
<td>3. 分析原因</td>
<td>因果图、分布图</td>
</tr>
<tr>
<td>4. 研究对策</td>
<td>防范力</td>
</tr>
<tr>
<td>实施</td>
<td>5. 实施对策</td>
</tr>
<tr>
<td>检查</td>
<td>6. 检查结果</td>
</tr>
<tr>
<td>行动</td>
<td>7. 标准化</td>
</tr>
<tr>
<td>8. 资料保存</td>
<td></td>
</tr>
</tbody>
</table>

检查表

- 大多数解决问题程序的逻辑起点。
- 用于观察样本情况。
- 开始以观点转化为事实的过程。

一般格式：

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>总数</th>
</tr>
</thead>
<tbody>
<tr>
<td>变量</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>总数</td>
</tr>
<tr>
<td>总数</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

建立检查表的步骤：

1. 品管团队必须对所观察的事物达成共识。
2. 确定收集数据的时间段。
3. 设计适合的表格，须明了、便于使用。
4. 持续地、诚实地收集数据。
1. 确保所记录的项目有代表性。
2. 确保采取的措施，以便操作。
3. 尽量从同一来源采集（同样的机器、同样的操作员等）；或者使用分类取样的方法。

帕拉图的步骤：
1. 团队选择所要解决的问题。
2. 决定比较的单位（频次、成本等）和研究的时间段。
3. 将各类从左至右按序排列。
4. 为每一类别的数据画一个矩形，表示其中在比较单位中份的值。
5. 可选择使用：在右边竖轴上标出百分比。

帕拉图注意事项：
1. 创造性应用：
   - 使用不同比较单位分析问题。
     例：生产成本和频率。
   - 把问题划分为不同类别。
     例：根据缺陷类型（部件、操作人员）。
   - 考量改进工作的影响。
     例：建立于质量控制之后。
2. 用常识来判断 - 不要仅就帕拉图做决策。
### 因果 (鱼刺) 图
- 有助于将大家的脑力激荡结果组织起来。
- 变现，探究，呈现根本原因。
- 归纳详细的图解：鱼刺图。

一般格式：

![因果图示例](image)

### 建立因果图的步骤：
1. 团队选择需分析的问题。
2. 从4M或4P分析有可能的可能主要原因：
   - 4 M：人力，设备，方法，材料
   - 4 P：人，工厂，政策，程序
3. 针对每个原因，问一句“为什么会发生？”随后分析更具体的原因。
4. 解释图表：寻找反复出现的原因，或看起来最易解决的原因。

### 因果图注意事项：
1. 确保每个人都了解问题的状况。
2. 注意：寻找原因，而不是症状。
3. 适当地使用大的类别。
4. 让图表不断继续下去。

### 趋势曲线图
- 有助于验证对问题因素的怀疑。
- 视觉上显示出在时间段上的趋势。
- 指南和使用都容易。

一般格式：

![趋势曲线图](image)

### 建立趋势图的步骤：
1. 团队选择测量对象和时间段范围。
2. 在观测时，将结果画到图上。
3. 监视图表中可疑的趋势和图形。
4. 决定何时开展调查。
趋势图举例：
四个小时后呈现出下降趋势。

柱状图
1. 帮助评估某一过程中的变化量。
2. 显示所收集数据的分布情况。
3. 指示异常行为。

柱状图举例：
表示材料厚度的变化。

柱状图注意事项：
1. 确定范围和单位。
2. 寻找数据中的特殊特征。
   - 大小的异常值。
   - 数据分布的模式。
3. 提出可能的数据来源或因素。

趋势图注意事项：
1. 持续记录数据。
2. 寻找数据效果的趋势和范围：
   - 位于平均值同一侧的相似的点。
3. 注意不要针对每个变化采取行动。在过程中真正重要的变化上。
品管圈培训：7个品管工具

分布图

- 检验我们有关因果关系的理论。
- 表示一个变量是如何随另一个变量变化的。
- 图形表示了变量间可能存在关系。

一般性格式：

![分布图示例](image)

建立分布图的步骤：

1. 团队准备要绘制数据的成对样本。
2. 指定每个轴线所代表的变量。
   - “原因”变量在水平轴上。
   - “结果”变量在垂直轴上。
3. 将数据绘制在图表上，使用圆圈表示重复的点。
4. 寻求表示关系的图形。

分布图注意事项：

1. 可以获得多少数据点就使用多少数据点。
2. 寻求图形的方向和“致密度”：
   - 向上倾斜 - 正比关系
   - 向下倾斜 - 反比关系
   - 致密 - 表示关系的强度。
3. 注意：图形不能证明因果关系；
   - 它们只表示某种关系的存在。

控制曲线图

- 确定某个过程是否处于统计的控制中。
- 帮助理解变化的原因。
- 帮助决策某个过程是否需要予以调整。

一般性格式：

![控制曲线图示例](image)

建立控制图的步骤：

1. 团队选择要过程的监测对象。
2. 计算过程相应的控制限值：
   - 中心线 (CL)：平均值
   - 控制上限 (UCL)：CL + 3σ（因应用条件而定）
   - 控制下限 (LCL)：CL - 3σ（因应用条件而定）
3. 在收集数据点时将数据点绘制在图表上。
4. 寻求那些表示“失控”情况的图形。
控制图的例子：
表示一致的（处于控制的）厚度。

控制图注意事项：
1. 在控制极限和规格极限之间进行区别。
（处于控制中的某一过程不一定是客户的需求。）
2. 选择使用正确的控制图类型。
3. 仔细计算控制的极限：
  - 为了统计的准确性，应基于25个（或以上）数据点。
  - 计算公式是不一样的，视应用情况而定。
4. 须知道“失控”报警的图形。
Appendix 4: Introduction to SQC Training Materials

English Version

AGENDA
- Definitions of Quality
- The statistical understanding of Quality
- Statistical Quality Control
  - Basic statistics concepts
  - Statistical Process Control (SPC)

What is Quality?
• How can we define Quality?
• How can we evaluate Quality?

A traditional definition:
The Eight Dimensions of Quality (Garvin, 1987)
• Performance - will the product do the intended job?
• Reliability - how often does the product fail?
• Durability - how long does the product last?
• Serviceability - can the product be repaired easily?
• Aesthetics - does the product look good?
• Features - what does the product do?
• Perceived Quality - what is the reputation of the product?
• Conformance to Standards - is the product made as designed?
Another traditional definition:

**Quality** means fitness for use. This includes:

- **Quality of design**
  Is the product well-designed to perform its intended function?

- **Quality of conformance**
  Does the product conform to the specifications of its design?

A related definition:

**Quality Improvement** is the reduction of variability.

Why do we prefer these definitions?

- They are unambiguous.
- Variability can be directly measured.
- They can be applied universally.

Variability is inherently a statistical concept. Therefore,

- **Quality assessment should be based on statistics.**
- **Quality Improvement should utilize statistical methods.**

**Conclusion:**
We need to understand basic statistics and learn to apply statistical tools to quality improvement efforts.
The Statistical Understanding of Quality:

**Quality** assessment should be based on statistics.

**Example:**
- "Our thickness is mostly within specification."
- "Our thickness is within specification limits 97% of the time."
- "Our mean thickness is 6.4μm, with a standard deviation of 0.2μm; with spec limits of 6.4μm ± 0.5μm, our process capability is 0.67." (from statistical analysis)

Quality improvement should utilize statistical methods.

**Example:**
- "Let's try increasing the pressure a little and see what it does." (no evidence of statistical methods)
- "Thickness is inversely proportional to pressure. Set it at 200psi." (same, but insufficient, statistical method)
- "Our DOE results indicate that a pressure of 235psi is optimal." (best use of statistical methods)

This leads us to...

**Statistical Quality Control**

- The use of statistics and statistical tools in characterizing, monitoring, controlling, and improving quality.

**Review**

The modern definition of **Quality**:  
- Quality is inversely proportional to variability.  
- Quality Improvement is the reduction of variability.

The statistical understanding of **Quality**:  
- Quality assessment should be based on statistics.  
- Quality Improvement should utilize statistical methods.

**Descriptive Statistics**

Variation in manufacturing is inevitable; no two units of product are exactly identical, even if they are manufactured by the same process. How can we describe the variation?

- Graphical methods
- Numerical summaries
- Probability distributions

These tools are all part of descriptive statistics.
Descriptive Statistics: Probability Distributions

A probability distribution is a mathematical model of the variability in a process. There are two types of probability distributions:

- Continuous - used for variables whose values can be expressed on a continuous scale.
  Examples: Uniform, Normal, Exponential

- Discrete - used for variables that can only take on certain specific values, such as integers.
  Examples: Hypergeometric, Binomial, Poisson

The Binomial Distribution

- An important discrete distribution
- Describes processes with two mutually exclusive outcomes
- Mathematical form:
  \[ p(x) = \binom{n}{x} p^x (1-p)^{n-x} \]
  \[ p(x) = \frac{n^x}{x! (n-x)!} \]
- \( p(x) \) is the probability of having \( x \) successes in \( n \) trials
- \( p \) is the probability of an event occurring in any single trial
- Mean: \( \mu = np \)
- Variance: \( \sigma^2 = np(1-p) \)

The Normal Distribution

- An important continuous distribution
- Also called Gaussian or Bell-Curve
- Characterized by mean, \( \mu \) and variance, \( \sigma^2 \)
- Notation: \( x \sim N(\mu, \sigma^2) \)

But... Where do these parameters come from?

- How do we know what the mean (\( \mu \)) is?
- How do we know what the variance (\( \sigma^2 \)) is?
- How do we know what the probability (\( p \)) is?

Usually, we don't have perfect information about a process! In general, the parameters of a process are not known perfectly; furthermore, they are likely to change over time.
Statistical Inference:

The objective of statistical inference is to estimate our process parameters based on information from a (usually random) sample. Techniques include:

- Point and interval estimation
- Hypothesis testing
- Probability plotting

Confidence Intervals

- There are two main kinds of confidence intervals:
  - Two-sided: specifies both upper and lower limits
    Example: \( P(L \leq \mu \leq U) = 0.95 \)
  - One-sided: specifies only one limit (unbounded on other side)
    Example: \( P(\mu \leq U) = 0.975 \)

- Intervals may be defined for different confidence levels.
  Question: What is the interval for 100% confidence?

- Calculation of intervals depends on what information is known.

Errors in Hypothesis Testing

- Two types of errors can be made in hypothesis testing:
  - Type I: reject \( H_0 \) when \( H_0 \) is true
    Also called producer's risk - the risk that a good product will be rejected.
  - Type II: accept \( H_0 \) when \( H_0 \) is false
    Also called consumer's risk - the risk that a bad product will be accepted.

- We define the following probabilities:
  - \( \alpha = \) probability of type I error
  - \( \beta = \) probability of type II error
Statistical Inference: Probability Plotting

Parameter estimation and hypothesis testing techniques assume that our sample data fit a particular distribution. How do we know if it does?

A probability plot provides a simple graphical picture of how closely our data conform to a hypothesized distribution. It is one of several methods for testing 'goodness to fit.'

Statistical Process Control...

A collection of problem-solving tools that help improve process stability and capability by reducing variation. The major tools of SPC are also known as the Seven QC Tools:

- Check Sheet
- Pareto Chart
- Run Chart
- Cause & Effect Diagram
- Histogram
- Scatter Diagram
- Control Chart

The ultimate goal of SPC is to eliminate variability in our process.

Shewhart’s Theory of Variability

Some amount of variability will always exist in all processes. The sources of variability can be separated into two categories:

- Chance causes - due to small random events that are natural and unavoidable. This type of variability is inherent in the process and can be reduced only by changing the process. A process that operates with only chance causes is in control.
- Assignable causes - due to events that are not natural and can be avoided. Examples include machine malfunctions, operator errors, and defective raw materials. A process operating with assignable causes is out of control.

More on Variability...

- Usually, a process will operate in-control... with variation due to chance causes only.
- Occasionally, an assignable cause will occur, shifting the process to an out-of-control state. If the assignable cause is not fixed, the process will produce inconsistent output.

How can we detect when an assignable cause occurs?
The Objective of SPC

One of the major objectives of Statistical Process Control is to detect assignable causes as quickly as possible. When an assignable cause occurs, we want to investigate the process and take corrective action before many defective products are produced.

Remember: Assignable causes are preventable!

The control chart is the key tool for this purpose.

Why Control Charts?

- Control charts are a proven technique for improving productivity. A successful control chart program will reduce scrap and rework.
- Control charts are effective in defect prevention. Rather than relying on inspection, defects are prevented in the first place.
- Control charts prevent unnecessary process adjustment. By identifying the source of variation, we know when to adjust a process.
- Control charts provide diagnostic information. The pattern of points frequently contains information about the process.
- Control charts provide information about process capability. The stability of important process parameters is revealed.

Out-of-Control Alarms

When using control charts, we look for certain patterns that suggest an assignable cause has occurred; these patterns constitute "alarms." Some examples are:

- Any point that falls outside the control limits
- Nine consecutive points on the same side of the center line.
- Six consecutive points increasing or decreasing.
- Fourteen points in a row alternating up and down.

We will explain later why these patterns are alarms...

Key Elements of a Control Chart

- **Center Line (CL)** - represents the average value of the quality characteristic when the process is in-control.
- **Upper and Lower Control Limits (UCL, LCL)** - show the range within which nearly all sample points will fall when the process is in control.

If a point plots outside the control limits, we can conclude that an assignable cause has occurred and the process is out-of-control.

Control Limits

*How do we determine the control limits?*

Remember the probabilities \( \alpha \) and \( \beta \):

- \( \alpha \) = (reject good product) - producer's risk
- \( \beta \) = (accept bad product) - consumer's risk

\( \alpha \) is the probability of a point being outside the control limits even though the process is in-control (false alarm).

\( \beta \) is the probability of a point being within the control limits even though the process has gone out-of-control (missed alarm).
Controlling $\alpha$ and $\beta$

- A desired value for $\alpha$ can be achieved by choosing appropriate control limits. Typically, we use $\alpha = 0.27\%$.
- This means that if the process remains in-control, 99.73% of the points will fall within the control limits.

- A desired value for $\beta$ can be achieved by designing the proper sampling scheme. Typically, $\beta$ is decreased by increasing the sample size and/or frequency.

Three-Sigma Control Limits

Control limits that give $\alpha = 0.27\%$ are also called three-sigma ($3\sigma$) limits; recall that for a normal distribution, 99.73% of the area is within 3 standard deviations from the mean.

Typical control chart parameters are:

\[
\begin{align*}
UCL &= \mu + 3\sigma \\
CL &= \mu \\
LCL &= \mu - 3\sigma
\end{align*}
\]

(mean + 3 standard deviations)  
(mean)  
(mean - 3 standard deviations)

In practice, the calculation of control limits can be complex. (Why?)

Types of Control Charts

- Variables Control Chart - used when the quality characteristic can be measured and expressed as a number on a continuous scale.
  Example: thickness

- Attributes Control Chart - used when the quality characteristic can take on only certain specific values.
  Example: number of pinholes per unit area
什么是品质？
- 如何给品质下定义？
- 如何评估品质？

其它传统定义：
- 设计的品质
  产品的设计是否能够保证产品发挥预期的功能？
- 品质的一致性
  产品是否与设计一致？

传统的定义（加文，1987）
- 功能 - 产品是否达到预期目的？
- 可靠性 - 产品出现故障的频率是多少？
- 耐使用 - 产品可使用多长时间？
- 可修理性 - 产品是否易于修理？
- 外观 - 产品的外观如何？
- 特点 - 产品有什么特点？
- 声誉 - 产品的声誉如何？
- 标准的一致性 - 产品是否和设计的相同？
相关的定义：
品质改善就是减少可变性。

为什么我们要使用这些定义？
・这些定义容易理解，不会产生歧义。
・可以直接测量。
・这些定义应用面广。

品质与可变性成反比。
品质改善就是减少可变性。

如何将这些定义应用到以下方面：
・产品
・服务
・外部程序
・内部程序

“可变性”一词是统计学固有的概念。因为：
・品质评估需要建立在统计数字的基础上。
・品质改善应该使用统计学方法。

结论：
我们需要了解统计学的基本知识，学习将统计的工具应用于品质改善的活动中。

品质的统计含义：
品质评估必须建立在统计数字的基础上。

举例：
“我们的产品厚度绝大多数都在规定的范围之内。”
（举例说明）
“我们97%的产品厚度都在规定的范围之内。”
（举例说明）
“我们的平均厚度是6.4mm, 标准差是0.2mm，客户要求的
公差是6.5mm ± 0.5mm，工艺能力是0.67。”
（举例说明）

从统计角度理解品质：
品质改善应该使用统计学方法。
举例：
“让我们把压力增大一点，看看会怎么样。”
（举例说明）
“厚度与压力成反比，让我们设定到200psi。”
（举例说明）
“我们的DOE结果显示，最佳压力是235psi。”
（举例说明）
品质的现代定义：
- 品质与可变性成反比。
- 品质改善就是减少可变性。

从统计角度理解品质：
- 品质评估必须建立在统计数字的基础上。
- 应该应用统计方法改善品质。

描述统计法
在制造过程中，变化的情况是避免的。即使在一个工序中生产的两个产品，也不会是完全相同的。我们怎样才能描述变化的情况呢？

- 统计图
- 数字总结
- 概率分布

这些工具都是描述性统计法的一部分。

描述统计法：图表法
一些描述变化情况的图表法：
- 茎叶图
- 频率分布图（柱状图）
- 直方图

描述统计法：数字总结
为了总结变化情况，可计算下列数值：
- 平均数
- 中位数
- 标准
- 变差
- 变差数
- 五年均数

以上数值都很简单，应该理解透彻。他们提供了有关工序的重要信息。
描述统计法： 概率分布
概率分布是工序中变化情况的数学模型，包括以下两种类型：
• 连续的 - 用于数值可在连续的尺度轴上表示出来的变量。
  例如：均匀、正态、指数分布
• 不连续的 - 用于特定数值的变量，如整数。
  例如：二项、正态、泊松分布

正态分布
• 一种重要的连续分布
• 又称高斯分布或钟型分布
• 相关的数值有：平均数\( \mu \)，变化数和\( \sigma^2 \)
• 符号：\( X \sim N(\mu, \sigma^2) \)

二项分布
• 一种重要的不连续分布
• 描述同一工序中两种相互排斥的结果。
• 数学形式：
  \[ p(x) = \binom{n}{x} p^x (1-p)^{n-x} \]
  式中：
  \[ \binom{n}{x} = \frac{n!}{x!(n-x)!} \]
  \( p(x) \) 是n次中仅一次x的事件。
  \( p \) 是一次中事件的概率。
平均数：\( \mu = np \)
变化数：\( \sigma^2 = np(1-p) \)

但是... ... 这些参数从哪里来呢？
• 我们怎样知道平均数(\( \mu \)的值是多少？
• 我们怎样知道变化数(\( \sigma^2 \)的值是多少？
• 我们怎样知道概率(p)的值是多少？
通常，我们掌握的工序信息是不完整的。一般而言，工序的参数是不完善的，并且，参数很可能随时间而改变。

统计推论
统计推论的目的是根据从样本(一般是随机抽取的)收集来的信息估计我们的工序参数。它包括以下技术：
• 点与间隔的估计
• 假设测试
• 概率绘图

统计推论：点的估计
对随机抽样的n次观测，我们可以计算出：
• 样品平均数：\[ \bar{X} = \frac{\sum x}{n} \]
• 样品变化数：\[ S^2 = \frac{\sum (x_i - \bar{X})^2}{n-1} \]
这些可以作为实际的平均数和真实的变化数的点估计值：
\[ \mu = \bar{X} \quad \sigma^2 = S^2 \]
统计推论：假设测试

对于假设的估计和假设测试是基于样本数据为特定分布的假设的。

我们怎么知道它是特定的分布呢？

假设图提供了一个简单的图式，表示我们的数据和假设的分布情况的一致性。它是测试“相容一致”的几个方法之一。

信心间隔

信心间隔主要有两类：
- 偏差型：指定了上限和下限，例如：$P(L \leq \mu \leq U) = 0.95$
- 偏差型：只指定了一个界限（另外一边无界限），例如：$P(L < \mu < U) = 0.95$

信心可以确定不同的信心水平，
- 问：在95%的信区间，间隔是多少？
- 问：假设的计算基于已知的信息。

统计推论：假设条件

我们对于正态情况下的估计有多少信心？
- 如果我们对样品做了两次测量，会怎么样？
- 如果我们对样品做了1000次观测，会怎么样？

对于我们不知道的参数，最常用的是确定信心间隔。例如，我们可以计算：

$$P(L \leq \mu \leq U) = 0.95$$

“我们对于在L和U之间有95%的信区间。”
工序的统计控制（SPC）... ...

一系列解决问题的工具，通过减少偏差来提高工艺的稳定性和能力。主要的工具就是著名的七个管理工具:

7QC Tools

1. 管理层
2. 过程确认
3. 变化图
4. 控制图

SPC 的最终目标是消除我们工序的可变性。

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希瓦特的可变性理论

在所有的工序中，总是存在一定的可变性。可变性的根源可以分为两类:

- 潜在原因 - 少量的自然的，不可避免的随机事件。
  - 这类可变性是工序所固有的，只能通过改变工序来减少，具有可变原因存在的工序是受控的。
- 可确定原因 - 非自然的、可避免的事件。例如：机器故障，操作失误和有缺陷的原材料，有可确定的原因存在的工序是失控的。

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另外一种理解角度... ...

- 工序的平均数和标准差的变化反映可变原因的结果。

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可变性的其它情况... ...

- 通常，一个工序会受到一个存在可变原因引起的偏差。
- 有时候，会出现可确定原因，使得工序变得不受控。如果可确定原因没有解决，工序就不能生产出品质一致的产品。

我们怎样未发现确定原因？

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SPC 的目标

工序的统计控制的一个主要目标是尽快发现可确定原因。当确定原因出现时，我们要在大量有缺陷的产品产生之前，调查工序，采取解决措施。

记住：可确定原因是可以预防的！

控制曲线图是达到这个目的的关键工具。

控制曲线图

- 把样本值和样本数量或时间绘制在图中，用图的方式表示出质量特征。

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控制曲线图

- 把样本值和样本数量或时间绘制在图中，用图的方式表示出质量特征。

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- 128 -
为什么使用控制曲线图？
- 控制曲线图有利于实现生产率的技术。
- 成功的控制曲线图程序能减少浪费和停工。
- 控制曲线图能有效防止废品。
- 通过控制曲线图，可以发出警告信号，进行预测和预防。
- 控制曲线图能防止不必要的工艺调整。
- 控制曲线图有助于工艺控制。
- 控制曲线图提供有关工艺能力的信息。
- 可以显示工艺参数的稳定性。

失控报警
在使用控制曲线图时，我们要注意表示可确定原因已经达到预测的排列形式。这些排列形式就是“失控报警”。
例如：
- 有三个失控报警。
- 9个点连续出现在控制线的同一边。
- 6个点连续上升或下降。
- 14个点连续上下波动。
以后我们会解释为什么这些排列形式是失控。

控制 \( \alpha \) 和 \( \beta \)
- 理想的 \( \alpha \) 的值可以通过选择适当的控制线来获得。我们经常使用 0.27%。
- 理想的 \( \beta \) 的值可以通过选择适当的控制线来获得。通常，增加控制数或者频率，\( \beta \) 的值将会变小。

控制线的关键要素
- 中线 (CL) - 代表过程的控制; 品质特征的平均值。
- 上限和下限 (UCL, LCL) - 表示过程的控制范围。几乎所有样本点应该出现的范围。

如果一个点出现在控制界限之外，我们可以推断发生了可确定原因，过程处于失控状态。

三个 \( \sigma \) 的控制线
\( \alpha = 0.27\% \) 时的控制线又叫三个 \( \sigma \) (3\sigma) 界限。回忆正态分布图，99.73% 的部分在平均数的3个标准差的范围之内。

常用的控制曲线图的参数有:
- \( UCL = \mu + 3\sigma \) (平均数 + 3个标准差)
- \( CL = \mu \) (平均数)
- \( LCL = \mu - 3\sigma \) (平均数 - 3个标准差)

实际上，控制线的计算会很复杂——为什么？
再回到警报

问题：从统计观点来看，失控警报有哪些情况？

答案：任何看起来不太可能、通常在与α相类似概率的事件或排列形式。

因此，对于一个控制线为3σ的控制曲线图，任何特定的形式都有0.27%的可能性是警报。

又如电气技术的《品质保证控制手册》(1966) 提供了以表状及图状表示中条核机能的图表。

控制曲线图的类型

- 变量控制曲线图：用于品质特征可以测量并在连续的度量上以数字的形式表达出来的事件。
  例如：长度

- 特征控制曲线图：用于品质特征只能由特定数值表示的事件。
  例如：单位面积里针孔的数量
Schrodinger's Cats

A case study on acceptance sampling

by Shing Yin
Alcoa Shanghai Aluminum Products Co., Ltd.
October 20, 1999

The Acceptance Sampling Problem
Customer receives one lot of product from Supplier.

Question: Should Customer accept the lot, or return it to Supplier?

Generally, there are three approaches to this problem:
1. No inspection - accept the entire lot without inspecting.
2. 100% inspection - inspect every unit, reject the bad ones.
3. Acceptance sampling - inspect some units, then accept or reject entire lot.

First, An Introduction To Acceptance Sampling.
Acceptance Sampling Is...
... Inspection for the purpose of acceptance or rejection of a product, based on adherence to a standard.
... One of the oldest aspects of quality assurance.

Acceptance Sampling Is NOT...
... A substitute for statistical process control.
... A good long-term strategy.

Why Do Acceptance Sampling?
Some reasons may be:
- Testing methods are destructive.
- Cost of 100% inspection is extremely high.
- 100% inspection is technologically infeasible.
- Inspection error rate is high.
- Vendor has good quality history.
- Product has serious liability risks.
Errors In Acceptance Sampling

Since not all units are inspected, acceptance sampling has the potential for error. There are two types of errors:

- **Type I**: reject a good lot (supplier's risk). That is, Supplier gives Customer a lot of acceptable product, but Customer mistakenly rejects it. This is bad for the Supplier.

- **Type II**: accept a bad lot (customer's risk). That is, Supplier gives Customer a lot of unacceptable product, but Customer mistakenly accepts it. This is bad for the Customer.

Error Probabilities

The following are standard notations for the probability of making an error in acceptance sampling:

- $\alpha$ (alpha) = probability of making a Type I error.
- $\beta$ (beta) = probability of making a Type II error.

These probabilities depend on the specific situation:

- the acceptance sampling scheme being used.
- the quality of the lot being sampled.

More About Errors

Note that in any particular situation, only one type of error is possible (since there are always two choices, accept or reject, and only one can be an error). Thus, for any particular situation, we cannot define both $\alpha$ and $\beta$.

Furthermore, the situation must be clearly stated in order to calculate either $\alpha$ or $\beta$. That is, we must know the acceptance sampling scheme being used, as well as the level of quality of the lot being sampled.

But we don't know the quality of the lot...

Well, that's the point! If we already know the quality of the lot, then we would know for sure whether to accept or reject it, and there would be no probability for any type of error at all!

But, whether we know it or not, the lot does in fact have a definite level of quality, so there is in fact a right answer to the acceptance sampling problem (accept or reject).

But, since we don't know what the quality of the lot is, we can only define $\alpha$ and $\beta$ hypothetically. For example, we might say, "If the lot is of quality X, then our $\alpha$ is Y."

Get it?

And Now, The Cats...

Quantum mechanical physicists sometimes talk about Schrödinger's Cat. This poor kitty is put into a box with some poison, and the cover is closed. After one hour, is the cat alive or dead? Without opening the cover, I can't know the answer for sure... but that doesn't mean there is no answer! We all know that in fact, the cat must be either alive or dead.

Now let's say I have ten of these cats, all in separate boxes. Dr. Schrodinger wants to know if at least five cats are alive after one hour, but he will only allow me to open two boxes. By looking at the cats in these two boxes, I must guess if there are at least five cats still alive.

Aside: The Analogy

Dr. Schrodinger's question is analogous to the acceptance sampling problem. In this analogy, he is the customer, and his ten cats are the lot of products. I am his quality assurance engineer, and my task is to decide whether he should accept or reject the lot of cats. The decision depends on the answer to his question of whether there are at least five live cats. A 'yes' answer to Dr. Schrodinger's question constitutes acceptance, and a 'no' answer constitutes rejection. Furthermore, I will try to answer his question without looking at all the cats. That is, the fate of the entire lot will be decided by inspection of only a small sample.

These are precisely the conditions for acceptance sampling.
Schrodinger's Cats - a case study on acceptance sampling

My Strategy...

Being an intelligent physicist, I devise the following strategy for answering Dr. Schrodinger's question:

*Are there at least five live cats?*

- If I look at two cats, and they are both alive, then my answer will be 'yes.'
- If I look at two cats, and one of them are dead, then my answer will be 'yes.'
- If I look at two cats, and they are both dead, then my answer will be 'no.'

Decision Tree Diagram

I can express my strategy using a decision tree diagram:

```
2 cats inspected
  2 cats dead    yes
     2 cats dead no
```

I will choose the two cats randomly. My inspection of these two cats will consist of opening the box and looking at the cat to see if it is alive or dead. I will not touch the cats.

Hypothetical Situation 1...

Let's say that in fact, all ten of Schrodinger's cats are still alive, so regardless of which two cats I choose to look at, I will always see two live cats. Thus, my answer to Dr. Schrodinger will always be 'yes,' and it would indeed be the correct answer. There is zero probability that I will make the error of answering 'no,' so $\alpha$ in this case is zero.

Note that $\beta$ does not exist for this situation, since I can not make an error by answering 'yes.'

Hypothetical Situation 3...

Let's say that in fact, five of Schrodinger's ten cats have died already. In this case, the correct answer to his question should be 'yes,' since there are still five cats that are alive. However, when I randomly choose two cats to look at, there is a 22.2% chance that I will happen to choose two dead cats. If I do this, then I will answer 'no' and commit a Type I error. Therefore, my $\alpha$ in this situation is 22.2%.

In this situation, my strategy performs quite well, since I am still more likely to come up with the right answer than the wrong one.

Sidebar - How did I get 22.2%?

How many unique ways can I choose two cats out of ten?

Imagine I choose the cats one at a time. When I pick the first one, there are ten cats to choose from; when I pick the second one, there are nine to choose from. Thus, the total number of ways I can choose is $10 \times 9 = 90$. But not all 90 are unique, since if I choose cat A first and then cat B, that is the same as choosing cat B first and then cat A. Therefore, I must divide by 2 to arrive at 45 unique ways of choosing two cats from ten.

How many unique ways can I choose two dead cats?

The analysis is the same. In order to choose two dead cats, I must pick one of the five dead cats first, then pick one of the remaining four dead cats the second time, giving $5 \times 4 = 20$ ways to choose. But I must account for double counting again, so there are 10 unique ways of choosing two dead cats.

Thus, out of the 45 unique ways of choosing two cats, 10 of them will consist of two dead cats. Therefore, the probability of choosing two dead cats is $10/45$, or 22.2%.
We can also calculate the probability by enumerating all the possibilities. Let each cat have a letter: A B C D E F G H I J Let's assume A, B, C, D, and E are the five dead cats. All possible ways of choosing two cats are listed below:

<table>
<thead>
<tr>
<th>AB</th>
<th>AC</th>
<th>AD</th>
<th>AE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC</td>
<td>BD</td>
<td>BE</td>
<td>BF</td>
</tr>
<tr>
<td>CE</td>
<td>CF</td>
<td>CG</td>
<td>CH</td>
</tr>
<tr>
<td>DH</td>
<td>DJ</td>
<td>EL</td>
<td>EM</td>
</tr>
<tr>
<td>FL</td>
<td>FJ</td>
<td>GH</td>
<td>GI</td>
</tr>
<tr>
<td>HI</td>
<td>HJ</td>
<td>IJ</td>
<td></td>
</tr>
</tbody>
</table>

We see that there are 45 possibilities. The 10 in bold represent the possibilities of choosing two dead cats; that is, they contain only the letters A, B, C, D, and E. Therefore, the probability of choosing two dead cats is 10/45, or 22.2%.

And on and on...

If we do this for all possible situations, we can come up with the following table:

<table>
<thead>
<tr>
<th>Situation</th>
<th>p(yes)</th>
<th>alpha</th>
<th>beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>1 alive</td>
<td>20.0%</td>
<td>20.0%</td>
<td></td>
</tr>
<tr>
<td>2 alive</td>
<td>37.8%</td>
<td>37.8%</td>
<td></td>
</tr>
<tr>
<td>3 alive</td>
<td>53.3%</td>
<td>66.7%</td>
<td></td>
</tr>
<tr>
<td>4 alive</td>
<td>66.7%</td>
<td>66.7%</td>
<td></td>
</tr>
<tr>
<td>5 alive</td>
<td>77.8%</td>
<td>22.2%</td>
<td></td>
</tr>
<tr>
<td>6 alive</td>
<td>87.7%</td>
<td>13.3%</td>
<td></td>
</tr>
<tr>
<td>7 alive</td>
<td>93.3%</td>
<td>6.7%</td>
<td></td>
</tr>
<tr>
<td>8 alive</td>
<td>97.8%</td>
<td>2.2%</td>
<td></td>
</tr>
<tr>
<td>9 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>10 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td></td>
</tr>
</tbody>
</table>

The Operating Characteristic Chart

The operating characteristic (OC) chart for this problem shows the probability of giving a 'yes' answer in all possible situations:

*The dotted line shows the ideal case, where no errors are ever made.*

My New Strategy

To satisfy Dr. Schrodinger's new demand, I revise my strategy:
- If I look at two cats, and they are both alive, then my answer will be 'yes.'
- If I look at two cats, and one of them are dead, then my answer will be 'no.'
- If I look at two cats, and they are both dead, then my answer will be 'no.'

Basically, I am making it more difficult to answer 'yes.'
Schrodinger's Cats - a case study on acceptance sampling

Decision Tree Diagram

This is my new decision tree diagram:

2 cats inspected

My inspection procedure is still the same as it was before.

Revised OC Chart

The OC curve for both strategies is shown below:

Now Is This Good Enough?

Dr. Schrodinger reviews my new results and sees that I have indeed lowered the \( \alpha \) values. However, he also notices that my \( \beta \) values have increased, so he is still dissatisfied.

Can't we have low values for both \( \alpha \) and \( \beta \)? Isn't there something else we can do?

Schrodinger's Cats - a case study on acceptance sampling

Results Of New Strategy...

Going through the same analysis, I come up with the following results:

<table>
<thead>
<tr>
<th>Situation</th>
<th>p(yes)</th>
<th>alpha</th>
<th>beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>2 alive</td>
<td>2.2%</td>
<td>2.2%</td>
<td>2.2%</td>
</tr>
<tr>
<td>3 alive</td>
<td>6.7%</td>
<td>6.7%</td>
<td>6.7%</td>
</tr>
<tr>
<td>4 alive</td>
<td>13.3%</td>
<td>13.3%</td>
<td>13.3%</td>
</tr>
<tr>
<td>5 alive</td>
<td>22.2%</td>
<td>77.8%</td>
<td></td>
</tr>
<tr>
<td>6 alive</td>
<td>33.3%</td>
<td>66.7%</td>
<td></td>
</tr>
<tr>
<td>7 alive</td>
<td>46.7%</td>
<td>53.3%</td>
<td></td>
</tr>
<tr>
<td>8 alive</td>
<td>62.2%</td>
<td>37.8%</td>
<td></td>
</tr>
<tr>
<td>9 alive</td>
<td>80.0%</td>
<td>20.0%</td>
<td></td>
</tr>
<tr>
<td>10 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td></td>
</tr>
</tbody>
</table>

Schrodinger's Cats - a case study on acceptance sampling

Inspect Five Cats

5 cats inspected

Result:

<table>
<thead>
<tr>
<th>Situation</th>
<th>p(yes)</th>
<th>alpha</th>
<th>beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>2 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>3 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>4 alive</td>
<td>8%</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>5 alive</td>
<td>26.2%</td>
<td>26.2%</td>
<td>26.2%</td>
</tr>
<tr>
<td>6 alive</td>
<td>50.0%</td>
<td>50.0%</td>
<td></td>
</tr>
<tr>
<td>7 alive</td>
<td>72.2%</td>
<td>27.8%</td>
<td></td>
</tr>
<tr>
<td>8 alive</td>
<td>91.7%</td>
<td>8.3%</td>
<td></td>
</tr>
<tr>
<td>9 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td></td>
</tr>
<tr>
<td>10 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td></td>
</tr>
</tbody>
</table>

Inspection procedure is still the same as it was before.

Good News, Bad News

The good news: Yes, there are other things we can do to get lower values for both \( \alpha \) and \( \beta \).

The bad news: We will need to inspect more cats.

Before he agrees, Dr. Schrodinger wants to hear some proposals.
Schrodinger's Cats - a case study on acceptance sampling

Inspect Ten Cats

10 cats inspected

Result:

<table>
<thead>
<tr>
<th>Situation</th>
<th>p(x=1)</th>
<th>alpha</th>
<th>beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>2 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>3 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>4 alive</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>5 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>6 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>7 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>8 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>9 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>10 alive</td>
<td>100.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

The ideal case - never make an error!

More Proposals

Looking at the chart, Dr. Schrodinger says the OC curve for 'Inspect 5 cats' looks satisfactory. But can't we inspect fewer than 5 cats and get the same result?

I devise the following strategy to meet this new challenge:

The Double Sampling Plan

My new strategy is called a 'double sampling plan' since it requires up to two samples to make a decision. All my previous strategies were 'single sampling plans' since they require only one sample to make a decision.

This particular double sampling plan turns out to have the same OC curve as the single plan that inspects five cats. However, on average, the double plan will require slightly less inspection, since there will be many cases in which I can make a decision after looking only at the first sample of four cats. Thus, the average number of cats inspected will be between four and five.

The ideal case - never make an error!

One More Question...

Dr. Schrodinger is pleased with the analysis and all the proposals. But he has one more question: what if I make a mistake with my inspection? How does that affect the results of my sampling plan?

Answer: In general, the possibility of inspection error will increase both \( \alpha \) and \( \beta \). It will also make it impossible for either of them to be zero in any situation. For example, even if all ten of Schrodinger's cats were alive, I may look at two of them and mistake them for being dead (maybe they're just sleeping). Then I would have committed a Type I error, due entirely to poor inspection. The probability of this happening is directly related to the reliability of my inspection.
Summary - What have we learned from Schrodinger's Cats?

An acceptance sampling scheme has three major components:

- **Sampling rules** - how many units will I inspect, and how will I choose these units from the lot?
- **Inspection rules** - how will I inspect the units in my sample?
- **Decision rules** - how will I make a decision on the lot, based on the results of my inspection?

The effectiveness of an acceptance sampling scheme depends on all three of these components.

Summary - continued

The effectiveness of an acceptance sampling scheme is measured by the probabilities of committing Type I and Type II errors. An operating characteristic (OC) curve is a good way to illustrate the performance of a sampling scheme. The curve shows the probability of accepting a lot given a certain level of quality in the lot.

Different sampling plans can lead to the same OC curve. In general, double and multiple sampling plans can give the same performance with fewer samples on average. However, they are more complicated to design and carry out.
施罗丁格的猫
—关于进货抽查检验的个案研究

任承发

美邦（上海）贸易有限公司
1999年10月20日

进货抽查检验的问题
客户从供应商那里收到一批产品。问题：客户应该接受还是退货？

通常，有三种解决方案：
1. 免检 — 不通过检验就接受整批产品。
2. 100% 检验 — 检验每个产品，把不好的退货。
3. 进货抽查检验 — 检验部分产品，然后接受或退回整批产品。

进货抽查检验不是……

为什么要做进货抽查检验？

有这样一些原因：
- 检验方法是破坏性的。
- 100% 检验的开支极高。
- 100% 检验没有技术可行性。
- 检验误差率很高。
- 供应商过去的品质情况良好。
- 产品很有可能具有危险性。

进货抽查中的错误

由于不是检验所有的产品，进货抽查有可能产生错误。错误的类型有以下两种：
- 第一类：退回好的产品（供应商的风险），即：供应商提供合格的产品，但客户错误地退回了货，这对供应商不利。
- 第二类：接受了坏的产品（客户的风险），即：供应商提供不合格的产品，但客户错误地接受了，这对客户不利。

错误的概率

下面是进货抽查中发生错误的概率的标准符号：
- \( \alpha \)（阿尔法）= 发生第一类错误的概率
- \( \beta \)（贝塔）= 发生第二类错误的概率

这些概率取决于以下具体情况：
- 所使用的检验方案。
- 抽样的那批产品的质量。
关于错误的说明

请注意，在同一种情况下，只会发生一种错误（因为只有两种选择：接受或退货，非此即彼）。因此，在同一种情况下，我们不能同时有α和β。

另外，为了计算α和β，需要清楚地说明情况，即，我们必须知道进货抽样方案，以及所抽样的那批产品的质量。

但是，我们不知道这批产品的质量......

啊，这就是问题！如果我们已经知道这批产品的质量，我们就能确定应该接受或退货，也根本不可能犯任何一种错误！

但是，无论我们是否知道，这批产品的质量实际是确定的，因而实际上对于进货检验的问题（应该接受还是退货）也有正确的答案的。

然而，因为我们不知道这批产品的质量，我们只能假定性地确定α和β。例如，我们可能会说：“如果这批产品的质量是X，那么α是Y。”

理解了吗？

现在，让我们再来看那些猫......

据物理学家们有时谈到施罗丁格的猫。这个可怜的小家伙被关在放了毒药的箱子里。一小时以后，这只猫活着还是死了？在未打开箱子的情况下，我不知道确切的答案......但这不等于说没有答案！实际上，我们都知道，这只猫不是活就是死了。

现在，让我们假设有十只猫，分别关在各自的箱子里。施罗丁格博士想知道：一小时后是否至少有五只猫还活着。不过，他只允许我打开两只箱子作检查。根据这两只箱子里的猫的情况，我必须推测是否至少有五只猫还活着。

*施罗丁格博士：著名的奥地利物理学家。他同时研究了物理和化学，受到多种物理和化学学派的影响。

小插曲：猫的问题和进货检验的关系

施罗丁格博士的问题和进货检验的问题很相似，我们可以这样来看：他是客户：那十只猫是收到的一批产品。我是他的品质工程师，任务是决定是否接受这些猫。决定的标准就是他的问题：是否至少有五只猫还活着。如果答案是“是”，则接受；如果答案是“否”，则退货。并且，我得在不检查所有的猫的条件下，给出答案。也就是说，在批产品的命运决定于少部分样品的检验。

这个问题和进货检验的情况完全一致。

我的策略......

作为一名聪明的物理学家，我想出下面的策略来回答施罗丁格博士的问题。

是否至少有五只猫还活着？

- 如果我检查两只猫，它们都活着，那么我给出的答案是：
  “是”。
- 如果我检查两只猫，它们当中只有一只死了，那么我给出的答案是：
  “是”。
- 如果我检查两只猫，它们都死了，那么我给出的答案是：
  “非”。
决定路线图

我可以用一个决定路线图来表达我的策略：

我将随机抽取两只猫。我的检查过程是：打开箱子：观察箱子里的猫，看看活与死、死还是死了。我不会接触猫。
假设1...

假设：实际上，根据研究结果，我们可以得出，实际情况是“是”，即此对问题的回答总是“是”，而且也是正确的。我的回答不可能是“否”，即即时的β 为零。

要说明的是：由于我的回答是“是”，而且是正确的，所以，此时β 不存在。

假设2...

假设：实际上，根据研究结果，我们可以得出，实际情况是“是”，即此对问题的回答总是“是”，而且也是正确的。我的回答不可能是“否”，即即时的β 为零。

要说明的是：由于我的回答是“是”，而且是正确的，所以，此时α 不存在。

假设3...

假设：实际上，根据研究结果，我们可以得出，实际情况是“是”，即此对问题的回答总是“是”，而且也是正确的。我的回答不可能是“否”，即即时的β 为零。

在这种情况，我的策略很成功，因为我给出答案的正确率比较高。

小插曲 - 我是如何得到22.2%的？

从十只猫里选两只猫，有多少种不同的方法？

我们可以列出所有可能的结果，然后计算出选择两只猫的不同方法。

我们可以看到有15种可能性。用黑体标出的是10种选出两只猫的可能性。即只含有A、B、C、D和E的情况。因此，选中两只猫的机率是10/45，或者22.2%。

小插曲 - 续

我们也可以列出所有可能的结果，然后计算出选择两只猫的不同方法。
以次类推... ...

如果我们对每种可能情况都做这样的分析，我们可以得出下面的表格：

<table>
<thead>
<tr>
<th>活动的数量</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>1</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>2</td>
<td>37.8%</td>
<td>37.8%</td>
</tr>
<tr>
<td>3</td>
<td>53.3%</td>
<td>53.3%</td>
</tr>
<tr>
<td>4</td>
<td>66.7%</td>
<td>66.7%</td>
</tr>
<tr>
<td>5</td>
<td>77.8%</td>
<td>22.2%</td>
</tr>
<tr>
<td>6</td>
<td>88.7%</td>
<td>11.3%</td>
</tr>
<tr>
<td>7</td>
<td>93.3%</td>
<td>6.7%</td>
</tr>
<tr>
<td>8</td>
<td>97.8%</td>
<td>2.2%</td>
</tr>
<tr>
<td>9</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>10</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

运行特性图

这个问题的运行特性曲线图表示了在所有情况下给出回答“是”的机率：

![运行特性图](image)

线代表理想值，下表显示的状态。

我的新策略

为了满足罗丁格博士的新要求，我改变了我的策略：

- 如果我检查两只猫，它们都活着，我的答案是“是”。
- 如果我检查两只猫，其中一只死了，我的答案是“否”。
- 如果我检查两只猫，它们都死了，我的答案是“否”。

基本的思路是增加回答“是”的难度。

决定路线图

这是我的新的决定路线图：

![路线图](image)

我的检查程序仍然与以前相同。

新策略的结果...

通过同样的分析，我得出下列结果：

<table>
<thead>
<tr>
<th>活动的数量</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>2</td>
<td>22.2%</td>
<td>77.8%</td>
</tr>
<tr>
<td>3</td>
<td>40.7%</td>
<td>59.3%</td>
</tr>
<tr>
<td>4</td>
<td>62.2%</td>
<td>37.8%</td>
</tr>
<tr>
<td>5</td>
<td>80.0%</td>
<td>20.0%</td>
</tr>
<tr>
<td>6</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
新的OC图

下面是两种策略的OC曲线:

运行特性图

现在是否足够好了呢？

施罗丁格博士看了我的结果，了解到我的结果中β的值还是太高了，他不满意。

我们是否可以将α和β的值都降低？我们还能做些什么？

好消息和坏消息

好消息：我们可以做一些事情降低α和β的值。

坏消息：我们得检查更多的猫。

施罗丁格博士在同意之前，还想再听一听建议。

检验五只猫

结果：

<table>
<thead>
<tr>
<th>检验的数据</th>
<th>α值</th>
<th>β值</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>2</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>3</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>4</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>5</td>
<td>50.0%</td>
<td>50.0%</td>
</tr>
<tr>
<td>6</td>
<td>73.8%</td>
<td>26.2%</td>
</tr>
<tr>
<td>7</td>
<td>91.7%</td>
<td>8.3%</td>
</tr>
<tr>
<td>8</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>9</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>10</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

检验十只猫

结果：

<table>
<thead>
<tr>
<th>检验的数据</th>
<th>α值</th>
<th>β值</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>1</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>2</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>3</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>4</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>5</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>6</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>7</td>
<td>100.0%</td>
<td>0.0%</td>
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<tr>
<td>8</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>9</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>10</td>
<td>100.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

所有的结果

我们发现检验的猫越多，我们的结果越好。下图是所有策略的OC曲线。

理想状况——永远不可能！
更多的建议

看了曲线图，施罗丁格博士说，“检验3只猫”的曲线看起来还可以，不过，我是否能检验5只猫的结果，而得到同样的结果呢？

我修改了方案如下，以便满足新的要求：

1. 检验2只猫
2. 检验4只猫
3. 检验6只猫

两次抽样计划

我的新策略被称为“两次抽样计划”，因为它要求我们更准确地决定。在第一阶段，我使用新的策略，即“一次抽样计划”，因为只要求做一次抽样，就作出决定。

在某些情况下，两次抽样计划和检验5只猫的抽样计划的OC曲线图是相同的。在这种总的情况下，两次抽样计划中的样品数量总是相同的。尽管如此，两次抽样计划可能在检验第一阶段的四只猫之后，就作出决定。因而，平均检验的猫的数量是在四到五之间。

其它抽样计划

- 多次抽样计划 - 与两次抽样计划相类似，只是步骤要多一些。在最后一步之前，我们可以作出接受/退货或再抽样的决定。
- 连续抽样计划 - 与多次抽样计划相类似，只是抽样的数量是固定的。每一抽样，我们检验一个样品，然后作出接受/退货或再抽样的决定。

以上的抽样计划都可以进行设计，从而得到与我们的一次抽样计划相同的OC曲线。但是，它们比较复杂，一般不常用。

还有一个问题......

施罗丁格博士对于这些分析和建议很高兴。不过，他还有一个问题：如果我的检验出了差错怎么办？它对我的抽样计划有什么影响？

答：总的来说，可能出现的检验误差会增大α和β的值，而且，也会使得这两个数值在任何情况下都会很小。例如，即使施罗丁格先生的报告是正确的，我可能检验了两只猫，并且认为它们相同。如果在检验第一阶段的两只猫之后，就作出决定，那么，我就因为犯了第一类错误，犯了第二类错误。这种情况的发生与我的检验可靠性直接相关。

总结 - 从施罗丁格的猫的问题中，我们学到了什么？

一个进货抽样计划包含三个主要内容：
- 抽样规则 - 我需要检查多少样品，怎样从一批货中抽样？
- 检验规则 - 怎样检验我的抽样？
- 作决定的规则 - 我如何根据检验的结果对一批货作出决定？

进货抽样的效果取决于以上三个内容。

总结（续）

进货抽样的效果取决于第一类和第二类错误的发生机率。运行特征（OC）曲线图是描述抽样计划效果的较好方法。它根据一批货中部分产品的质量，描述了接受这批货的机率。

不同的抽样计划可以得出不同的OC曲线。一般地，两次和多次抽样计划可使用平均较少的样品数，而达到同样的效果。不过，它们的设计和实施都比较复杂。
Appendix 6: QCC Announcement Slides (Chinese only)

The following slides were prepared by Zhang Yulong, Quality Manager, Alcoa Shanghai.

QCC培训
(Quality Control Circle)
一九九九年六月
培训内容

1. 推行QCC的意义
2. 活动方法
3. 统计品管的7种工具
4. 对QCC成员的要求
5. 怎样当好组长

1. 推行QCC的意义
1. 是实现“全员参与、改善工艺、质量和服务”的重要途径。
   - QCC是员工全员参与质量管理的一种形式。

2. 开展QCC活动是提高企业素质的重要环节
   - 目标管理技术
   - 人性管理技术

- 145 -
3. 开展QCC活动是提高产品质量，降低生产成本的良好形式
   - 鼓励生产合格的产品，确保客户满意
   - 减少废品，降低生产成本，增强企业的竞争能力

   人的大部分时间是在工作场所度过，我们希望在一个尊重人性、工作有意义的环境中工作，这就是品管圈希望达成的理想。

2. QCC活动方法
   1. QCC活动的4个阶段
      - 计划 Plan 简称：P
      - 实施 Do 简称：D
      - 检查 Check 简称：C
      - 行动 Action 简称：A

     循环图

   2. QCC活动的9个步骤
      1) 选择课题
         - 品质
         - 显示
         - 废品
         - 生产
         - 交货
         - 客户
         - 管理
         - 效率
         - 价值

      2) 调查现状
         - 顾客调查
         - 内部调查
         - 市场调查
         - 竞争对手调查
         - 生产现场调查
         - 检查表
         - 调查
         - 调查

      3) 分析问题原因
         - 个案
         - 现场
         - 现场
         - 现场
         - 现场

   4) 制定对策
      排除“不良源”
         - 问题
         - 操作
         - 操作
         - 操作
         - 操作
         - 操作
         - 操作
         - 操作
         - 操作
         - 操作
         - 操作

   5) 实施对策
      - 排除“不良源”
        - 操作
        - 操作
        - 操作
        - 操作
        - 操作
        - 操作
        - 操作
        - 操作
        - 操作
        - 操作

   6) 检查实施结果
      - 检查
      - 检查
      - 检查
      - 检查
      - 检查
      - 检查
      - 检查
      - 检查
      - 检查
      - 检查

   7) 标准化
      - 将正确的对策，措施文件化
      - 标准化
      - 规范化

      - 以改善技术、产品为基准
      - 改善
      - 改善
      - 改善
      - 改善
      - 改善
四．对QCC成员的要求
1. 有一颗赤诚的心
2. 冷静地思考更好的办法，避免偏激和抱怨
3. 了解内部/外部顾客的需求
4. 熟悉本岗位的技术标准与工艺、操作规程
5. 掌握品管分析统计工具
6. 严肃认真地参与QCC活动
7. 营造开朗而热烈的工作气氛
8. 提高目标意识，弘扬团队合作的绩效

五．怎样当好组长
1. 以身作则——带头
   有宽阔的胸襟
   有幽默的谈吐
   有智慧的头脑
   有敏锐的洞察力
   有正确的领导艺术
   有科学的管理方法
2. 善于总结经验教训和推广经验
Appendix 7: QCC Support Structure

English Version
品质圈支撑结构：

品质圈工作委员会

总经理

副总经理

厂长

所有部门

培训部

品质经理

品质工程师

品管助理

APS、工程部、工艺部、制造部

沟通

技术

技术

支持

圈长

成员

品管圈 (CCC)
### QCC (QUALITY CONTROL CIRCLES)

<table>
<thead>
<tr>
<th>TEAM NAME: IA</th>
</tr>
</thead>
</table>

#### Listing of Team Members

<table>
<thead>
<tr>
<th>姓名</th>
<th>黄俊</th>
<th>胡凯民</th>
<th>陈令琪</th>
<th>陆文明</th>
<th>隋家群</th>
<th>陆守权</th>
</tr>
</thead>
<tbody>
<tr>
<td>(QCC Team Leader)</td>
<td>顾群利</td>
<td>陆伟东</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Project Title

改善双零产品专区

#### Description of Project

在乳剂15A和双张叠乱时,由于无控制方式改为自动方式再加上CPC相对小一点,通过

#### Resources Required for Next Steps

1. 新生产按扭,指定调试卷
2. 带同工艺,搜集改善前后之老机和15A数据
Steps 2: Investigate Status

Date to be completed: 8/27
Person responsible: 谢发民

Actions:
- 双层产品的表面受高压成卷的问题，以至每个月
  - 变型的半成品不对，需退和改制的产品达３
  - 不合格品率超３倍

Steps 3: Analyze Cause

Date to be completed: 8/28
Person responsible: 黄浩

Actions:
- 双层成品在双层叠卷时，精轧机操作人员手
  - 票模式的后果

Steps 4: Develop Measures

Date to be completed: 8/28
Person responsible: 黄浩

Actions:
- 排除试验卷，按常规工艺各载 33 小
  - 精轧机开料和卷取，在轧制过程中都用票模式
  - 增加了 LOAD 和油温相应变动一下

Other Comments

Next meeting date: [Blank]
项目名称 改善双零产品不齐度

步骤2: 调查现状的结果和结论
Results and Conclusions of Step 2: Investigate Status
双零产品每月因标准不齐度退货比例，如果改进一些话，完全有可能更好一点。

步骤3: 分析原因的结果和结论
Results and Conclusions of Step 3: Analyze Cause
造成标准差的原因很多，但检验机的最后一道工序参数上的不合理和操作方式的差别，如改进一些工艺参数，完全有可能把双零产品的平齐度得到提高。

步骤4: 制定对策的结果和结论
Results of Step 4: Develop Measures
改用自动喷油的方式，适当降低喷油量，对标准不齐度适当收油，再对一些工艺参数调整一下。

QCC Report II page 1.
Resources Required for Next Steps

**Step 5: Implement Measures**

**Rough Plans**

**Step 6: Check Results**

**Actions:**

- Use 55° to 56° steel 15 minutes, then neutralize, and use neutralization control method.
- Oil temperature is 48°C, and lubricant injection is manual.

**Actions:**

- Sheet thickness has increased, and there is a deviation from the expected goal.
- Steel 15 minutes, then 19 minutes, neutralization temperature is slightly higher, and the second and third runs were performed. The results showed that the low temperature changed to a larger extent.

**Other Comments**

- Next meeting date:

QCC Report II page 2.
Fishbone diagram included with QCC Report II.
步骤5: 实施对策的结果和结论
Results and Conclusions of Step 5: Implement Measures
1. 池温的降低对板型平直作用明显。
2. 开料14#对板型的平直控制比15#和16#要明显好，比15#的断带次数要少一些。
3. 自动液油方式也很关键的一步。
4. 5变反馈打开，检查板型好的控制，使它增加了。
5. 梯型自动控制，因精神板型/倾斜控制调卡号
步骤6: 检查结果的结果和结论很小，作用不明显，有时因梯型显示的差差。
Results and Conclusions of Step 6: Check Results 有误动作，反而起到相反作用
1. 从不合格品的品率表中，看进，所有品率表都没有，说明合格率
2. 从现场钢卷机看到的情况是，板型不板，这些合格的
操作人员得到一致认可。
3. 这说明我们改善的方向，方法都是对的。

QCC Report III page 1.
What are the team's recommendations?

初步计划 Rough Plans

步骤7: 标准化 Step 7: Standardize

Date to be completed: [ ]
Person responsible: [ ]

Actions:
1. Process review these reports and observe actual procedure.
2. Process will make any additional suggestions & approve final procedure.
3. Rewrite SOP to include these changes.
4. Train all operators.

步骤8: 总结和公布 Step 8: Summarize and Publicize Results

Date to be completed: [ ]
Person responsible: [ ]

Actions:
Organize meeting w/ Mr. Zhang; Huang Jun will make brief presentation on his QCC story.

Other Comments

Presentation date: [ ]

QCC Report III page 2.
### The 8-Step QCC Process

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Dates Completed</th>
<th>Plan Dates</th>
<th>Person Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1: Choose Topic</td>
<td>First QCC meeting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2: Investigate Status</td>
<td>Plan for data collection</td>
<td></td>
<td></td>
<td>QCC Team Leader</td>
</tr>
<tr>
<td></td>
<td>Get required support</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collect data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Summarize data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3: Analyze Cause</td>
<td>Brainstorm session</td>
<td></td>
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<tr>
<td></td>
<td>Make conclusions</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Step 4: Develop Measures</td>
<td>Propose solutions</td>
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<td>QCC Team Leader</td>
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<tr>
<td></td>
<td>Decide on best solution</td>
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</tr>
<tr>
<td>Step 5: Implement Measures</td>
<td>Plan for implementation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Get required support</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Implement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 6: Check Results</td>
<td>Decide how to perform check</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Collect data</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Make conclusions</td>
<td></td>
<td></td>
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<td>Make recommendations</td>
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<td>Step 7: Standardize</td>
<td>Get required support</td>
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<td>QCC Team Leader</td>
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<tr>
<td></td>
<td>Generate standard documents</td>
<td></td>
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<td></td>
<td>Train relevant parties</td>
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</tr>
<tr>
<td>Step 8: Summarize and Publicize</td>
<td>Document project</td>
<td></td>
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<tr>
<td></td>
<td>Create presentation</td>
<td></td>
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<tr>
<td></td>
<td>Final Presentation</td>
<td></td>
<td></td>
<td>QCC Team</td>
</tr>
</tbody>
</table>

Next Meeting Date: __________

QCC Project Plan and Schedule (revised and submitted with each report).
IQ QCC 活动

成员名单：
黄俊 - 圈长
胡意民  金守权
陆维琪  顾群利
卢士明  陆伟东
徐家群

项目名称：改善双零产品的平整度

开始日期：1999/8/12

步骤2：调查现状
每月因板型不好剔退的产品占很大比例。

步骤3：分析原因
我们使用鱼刺图进行分析，发现造成板型差的原因很多，但精轧机最后一个道次不合理的工艺参数和
操作方式是比较重要的。

步骤4：制定对策
改用自动喷油的方式，适当降低油温，再对一些工艺参数作调整。
步骤5：对策的实施

在生产部和工艺部的大力支持下（特别感谢爱民先生），IQ品管圈首先做了4个实验卷。后来又继续实验了更多的铝卷。等一下将介绍实验的具体技术数据。
Appendix 10: Fourier Analysis of Thickness Data

All mill drives at Alcoa Shanghai utilize feedback control systems to maintain consistent spacing between the work rolls, which dictates the rolled thickness. The feedback system relies on a constant monitoring of the thickness. Thus there is an opportunity to collect this data using a computer system connected to the mill drive.

As part of an evaluation of LabVIEW software for data collection and analysis, thickness data was collected from the breakdown mill drive. The data was analyzed using Fourier transform techniques. The analysis is presented here as one example of the power of data analysis.

The data collection setup consisted of LabVIEW software and an analog-to-digital conversion (ADC) board installed on an IBM Thinkpad notebook computer, connected to a pair of terminals on the mill drive. These terminals relay thickness data to the drive computer. Thus, the voltage across the terminals is directly proportional to the measured thickness. The ADC reads this voltage and LabVIEW stores the readings into a data file.

The plotted thickness data is shown at the top of Figure A10.1. This data was taken over a period of about 80 seconds, while the breakdown mill was in the middle of running a second pass on a typical coil. The plot clearly shows a large-amplitude, long-period, regular variation, completing about six cycles during the 80 seconds. The plot also shows much smaller, higher-frequency variation in the thickness. Much of this is probably noise; however, it is useful to see if there is any regularity to this smaller variation.

Fourier transforms are a useful tool for doing this. A Fourier transform is capable of separating noise from truly regular variation. The periods of regular variation show up as peaks in a plot of the transformed data. Numerous software packages are capable of performing Fourier transforms; Mathcad was used in this case. In Mathcad’s output, the peaks in the Fourier

---

transform show up at values that indicate the number of cycles completed by, or frequency of, that variation. For example, a peak at a value of 10 indicates that there is a regular variation in the data that completed 10 cycles over the timescale of the data.

The Fourier transform of the thickness data is shown at the bottom of Figure A10.1. The large peak at the left, at a value of about 6, represents the large variation that is easily visible in the raw data. This is not a surprise, but the transform also shows a double peak at around 11-13, and another significant peak at around 23. These indicate that there are other regular variations in the raw data, which are not easily discernible without the Fourier transform.

![Data from Breakdown Mill](image)

**Figure A10.1: Analysis of thickness data from the breakdown mill.**

Now that the regular variations are identified, the challenge turns to finding their sources. One hypothesis was that the variations in thickness originated at the casting shop. Unlike the mills, Alcoa Shanghai’s casters did not employ active feedback control systems, mostly because they run at much slower speeds. Thus, there was reason to believe that they may produce thickness variations in the cast sheets. To test this hypothesis, the following analysis was performed.
First, here is some data relevant to the analysis. For a second pass (such as the one from which the thickness data was taken), the breakdown mill rolls run at about 150 rpm, and it takes about 12 minutes to complete one coil. The caster, on the other hand, runs at about 0.345 rpm when casting a coil, and each coil takes about 5 hours to complete. Thus, compared to the breakdown mill, the caster takes about 25 times longer to process the same amount of material.

The thickness data presented in Figure 1 was taken over a period of about 80 seconds; this represents about 200 revolutions of the breakdown mill rolls. This is equivalent to about 2000 seconds on the caster, or 33.3 minutes, which represents 11.5 revolutions of the caster rolls.

If the caster roll were off-center, it would cause a thickness variation that is synchronized with the roll’s revolutions. That is, every time the roll made a complete revolution, the thickness would also complete one full cycle of variation. Therefore, an off-center caster roll would result in thickness variation that would produce a Fourier transform peak at about 11.5; this indeed shows up in the data analysis. The fact that a double peak is observed can be explained by the fact that the caster has two rolls: a top roll and a bottom roll. If each roll were off-center, and their diameters varied slightly, then they would produce the double peak we observe.

If the caster roll were not perfectly round (that is, it is somewhat oval), then it would cause the thickness to vary twice as fast as the caster’s revolution. This is because every time the oval caster roll made one revolution, the gap would go from narrow to wide to narrow to wide again. This would show up in the Fourier transform as a peak at 23, twice of 11.5; this is indeed observed in the actual data.

The conclusion from this analysis is that there is some evidence suggesting that the caster at Alcoa Shanghai may need some re-alignment. The thickness data seem to show effects of both off-center and oval rolls.

In fact, however, the most troublesome feature in the thickness data remains unexplained. The peak at 6.5 is clearly the largest and most obvious variation, but it does not seem to have been caused by irregularities in the caster rolls. To find the true cause of this variation, the engineers at Alcoa Shanghai should continue to formulate hypotheses and test them through analyses such as that described here.
Appendix 11: Screen Captures of Laboratory Data System

Laboratory Data System - Main Window.

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### ALUMINUM INGOT TEST RECORDS

**Shipment Number/Receive Date**
- 990002 11/26/99
- 990001 11/24/99

**Sample Number:**

**Sample Date:**

**Test Operator:**

**TEST RESULTS**
- Al: [ ] 0
- Si: [ ] 0
- Fe: [ ] 0
- Cu: [ ] 0
- Mg: [ ] 0
- Ga: [ ] 0
- Na: [ ] 0
- Ca: [ ] 0
- Li: [ ] 0
- Others(max): [ ] 0

**Accept?**

[ ] Accept

[ ] Delete This Record

Record: 103 of 103
**ALCOA (SHANGHAI) ALUMINUM PRODUCTS CO., LTD.**

*The Laboratory Data System*

**Statistical Summary of Test Results**

<table>
<thead>
<tr>
<th>Element</th>
<th>Average</th>
<th>Std. Deviation</th>
<th>UCL</th>
<th>LCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>99.75686</td>
<td>0.01596</td>
<td>99.80474</td>
<td>99.70889</td>
</tr>
<tr>
<td>Si</td>
<td>0.03841</td>
<td>0.00384</td>
<td>0.04994</td>
<td>0.02688</td>
</tr>
<tr>
<td>Fe</td>
<td>0.14770</td>
<td>0.02554</td>
<td>0.22432</td>
<td>0.07107</td>
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<tr>
<td>Cu</td>
<td>0.00158</td>
<td>0.00297</td>
<td>0.01050</td>
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</tr>
<tr>
<td>Mg</td>
<td>0.00092</td>
<td>0.00080</td>
<td>0.00330</td>
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</tr>
<tr>
<td>Ga</td>
<td>0.01334</td>
<td>0.00223</td>
<td>0.02002</td>
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<td>0.00017</td>
<td>0.00041</td>
<td>0.00139</td>
<td>0.00000</td>
</tr>
<tr>
<td>Ca</td>
<td>0.00011</td>
<td>0.00099</td>
<td>0.00308</td>
<td>0.00000</td>
</tr>
<tr>
<td>Li</td>
<td>0.00010</td>
<td>0.00002</td>
<td>0.00015</td>
<td>0.00004</td>
</tr>
<tr>
<td>Others</td>
<td>0.02000</td>
<td>0.00000</td>
<td>0.02001</td>
<td>0.01999</td>
</tr>
</tbody>
</table>

*Process Capability (Al Content):* 1.188

Laboratory Data System – Automated Statistics Report.
Appendix 12: Technical Paper on Gage Studies

GAGE STUDIES – a tool for assessing measurement capability

An important aspect of SPC implementation efforts is ensuring adequate gage (measurement) and inspection system capability. In any measurement, the total observed variability is due to variability in the product itself and variability in the measurement method.

\[ \sigma^2_{\text{total}} = \sigma^2_{\text{product}} + \sigma^2_{\text{gage}} \]

Furthermore, the measurement error is related to the repeatability and reproducibility of the measurement system. Repeatability refers to the precision of the measurement instrument itself, while reproducibility is the variability due to different operators performing the measurement (each operator may perform the measurement in a slightly different way).

\[ \sigma^2_{\text{gage}} = \sigma^2_{\text{repeatability}} + \sigma^2_{\text{reproducibility}} \]

To demonstrate how to do gage studies, let’s use some cases based on the testing of silicon (Si) content in aluminum-silicon (Al-Si) ingots.

BACKGROUND

The test for Si content is used to determine the amount of silicon in an aluminum-silicon ingot. To perform the test, holes are drilled into the ingots to produce powder. The powder is collected, dissolved in a base, and titrated using an appropriate acid solution. Usually, we expect the Si content to be uniform within an ingot, so it does not matter where the holes are drilled. We also expect all ingots from the same melt to have the same chemical composition.
CASE 1

Suppose we have only one operator that performs the Si content test, so there is no reproducibility component to the gage variability (it is entirely due to repeatability). In addition to the gage variability, we also want to know how much the Si content varies between ingots from the same melt (that is, we want to measure product variability).

Procedure:

1. Take ten ingots from the same melt, and from each ingot produce enough powder for two test samples.

2. Measure the Si content in each of the twenty samples in the usual way.

3. Record the mean (average of the two samples) and the range (difference between the two samples) of Si content for each ingot.

4. From the data, compute the overall mean, the overall standard deviation, and the mean range.

5. The overall standard deviation reflects the total variability, $\sigma_{\text{total}}$.

6. The standard deviation of gage error is equal to the mean range divided by 1.128 (the value of $d_2$ for a sample size of 2).

   $$\sigma_{\text{gage}} = \frac{\bar{R}}{d_2} = \frac{\bar{R}}{1.128}$$

7. The variability of Si content inherent in the ingots is given by:

   $$\sigma_{\text{product}} = \sqrt{\sigma_{\text{total}}^2 - \sigma_{\text{gage}}^2}$$
Example:

**Si Content in Al-Si Ingots**

<table>
<thead>
<tr>
<th>Ingot</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Mean</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>20</td>
<td>20.5</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>19</td>
<td>18</td>
<td>18.5</td>
<td>1</td>
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<td>3</td>
<td>18</td>
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</tr>
<tr>
<td>5</td>
<td>19</td>
<td>20</td>
<td>19.5</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>18</td>
<td>19</td>
<td>18.5</td>
<td>1</td>
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<td>1</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>19</td>
<td>17</td>
<td>18</td>
<td>2</td>
</tr>
</tbody>
</table>

Mean: 19.55

Overall Deviation: 1.15

**Results:**

\[
\sigma_{total} = 1.15 \\
\sigma_{gage} = \frac{0.90}{1.128} = 0.80 \\
\sigma_{product} = \sqrt{1.15^2 - 0.80^2} = 0.82
\]
Interpretation:

1. We can take powder from a single ingot and take one measurement on it. Then:

2. We can be 65% confident (one-sigma) that the true Si content in that ingot is within ±0.80 of our measurement, and 95% confident (two-sigma) that the true Si content is within ±1.60 of our measurement.

3. We can be 65% confident (one-sigma) that the average Si content over all the ingots in the melt is within ±1.15 of our measurement, and 95% confident (two-sigma) that the average Si content is within ±2.30 of our measurement.

4. We can take powder from a single ingot and make several measurements on it. Then, we can be 65% confident that the average Si content over all the ingots in the melt is within 0.82 of the average of our measurements, and 95% confident that the average Si content is within 1.64 of the average of our measurements.

5. We can take powder from several ingots, mix them together, and take one measurement on the mixture. Then, we can be 65% confident that the average Si content over all the ingots in the melt is within ±0.80 of our measurement, and 95% confident that the average Si content is within ±1.60 of our measurement.

6. We can take powder from several ingots, mix them together, and take several measurements on the mixture. Then, we can be fairly confident that the average Si content over all the ingots in the melt is close to the average of our measurements. The exact confidence level would depend on how many ingots and how many measurements we use.

Thus, by knowing the components of our variability, we can design an optimal sampling and testing scheme.
CASE 2

Suppose we have three operators who perform the Si content test, so we are interested in decomposing the gage variability into repeatability and reproducibility.

Procedure:

1. Take ten ingots from the same melt, and from each ingot produce enough powder for six test samples.

2. Have each operator perform the Si content measurement on two samples from each ingot.

3. Compute the overall mean, overall standard deviation, and mean range separately for each operator’s results.

4. Compute the average of the three mean ranges (the mean-mean range). The repeatability is obtained dividing the mean-mean range by 1.128 ($d_2$ for sample size of 2).

$$\sigma_{\text{repeatability}} = \frac{\overline{R}}{d_2} = \frac{\overline{R}}{1.128}$$

5. Compute the range of the overall means (the largest mean minus the smallest mean). The reproducibility is this value divided by 1.693 ($d_2$ for sample size of 3).

$$R_x = x_{\max} - \overline{x}_{\min}$$

$$\sigma_{\text{reproducibility}} = \frac{R_x}{d_2} = \frac{R_x}{1.693}$$

6. The total gage variability (measurement error) is given by:

$$\sigma_{\text{gage}} = \sqrt{\sigma_{\text{repeatability}}^2 + \sigma_{\text{reproducibility}}^2}$$
Example:

<table>
<thead>
<tr>
<th>Ingot</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Mean</th>
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Results:

\[
\text{MeanRange} = \overline{R} = 1.10
\]

\[
\sigma_{\text{repeatability}} = \frac{1.10}{1.128} = 0.975
\]

\[
R_\text{ave} = 19.55 - 19.2 = 0.35
\]

\[
\sigma_{\text{reproducibility}} = \frac{0.35}{1.693} = 0.207
\]

\[
\sigma_{\text{gage}} = \sqrt{0.975^2 + 0.207^2} = 0.997
\]
Interpretation:

1. In general, the total gage variability computed this way will be larger than the gage variability computed in Case 1, since we are now including the variability due to different operators.

2. From these results, we conclude that repeatability error comprises the major component of gage variability. In contrast, the reproducibility is not as significant a problem. If we feel the gage variability is too large, we should focus on improving the repeatability. That is, we should consider how to improve the precision of the measurement instrumentation and/or technique. On the other hand, we would not get as much benefit from rigorously standardizing the test operation or designating a single test operator.

APPENDIX
Values of $d_2$ for different sample sizes:

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Bibliography


