Budapest University of Technology and Economics

Faculty of Economic and Social Sciences

Department of Management and Business Economics

Árva, G. - Surman, V.

Quality Management

Course material

Budapest, 2019

PADA | PALLAS ATHÉNÉ DOMUS ANIMAE ALAPÍTVÁNY

The production of this publication is funded by the Pallas Athene Domus Animae Foundation.
A kiadvány a Pallas Athéné Domus Animae Alapítvány támogatásával valósult meg.

Table of contents

1. QUALITY MANAGEMENT – NOWADAYS

Handling quality-related issues is as old as humanity. That is, the recognition of the need for quality and its importance is not the novelty of the last few decades. The first stages of quality management as a discipline can only be traced back to the era of scientific management at the turn of the century. The development of quality management is linked to the spread of industrial production and production processes. The concept of quality, the methods and techniques of quality management have undergone significant changes, especially in recent decades. Traditionally, the term quality refers to durable and well-designed products that comply with standards and regulations. Nowadays, it is widely acknowledged that the quality of product manufacturing and service delivery is essential if companies seek to achieve customer satisfaction, consumer protection and high profits

The milestones of the 100-year-long history of quality management have made companies face new challenges time-to-time. By the end of the 20th century, economic development reached a level where quality management would not only be addressed by various business organizations and institutions, but the knowledge needed to manage quality is in focus at higher education institutions (Bedzsula, Topár, 2014). The purpose of this material is to give a comprehensive picture of quality management systems by presenting the most widely used methods and techniques.

1.1. Why do we have to pay attention to quality?

The customer encounters numerous products (services) on the market, sets specific demands and requirements in connection with them and decides to purchase the product (service) if it meets these needs. These expectations are not only technical, safety and economical, but also quality related. On the one hand, the latter refers to the specific characteristics of the product (service); on the other hand, the customer has expectations towards the company, too. As a result of the increased competition, companies are forced to provide their customers with the highest quality product (service). Thus, quality is increasingly a prerequisite for the marketability of products (services) and a barrier to entry into a particular market at several industries.

Besides that, the customer has not only requirements related to the product (service), but it is also significant whether he trusts the product manufacturer (service provider) company. If organizations seek to gain the trust of their customers, it is necessary to put quality at the heart of the entire business management and leadership and to apply quality management methods. Competition is becoming more and more intense with different organizations trying to convince customers that quality is the driving force behind all activities. There are several ways to get this conviction: there are those who obtain third-party certificates demonstrating the fulfilment of specific standard requirements (such as ISO 9001). Furthermore, the need for internal renewal is increasingly emphasized. Thus, the range of organizations that demonstrate Total Quality Management (TQM) principles by seeking and winning recognized quality prizes based on self-evaluation (such as National Quality Award, regional quality awards) is expanding. One of the tools for arising and maintaining customer confidence is the introduction and certification of formalized quality management systems, while the other is the application of total quality management.

In recent decades, domestic enterprises and institutions have undergone significant changes. The need to remain on the market and to maintain and improve competitiveness has also forced the domestic organizations to focus on customer requirements. As a consequence, issues related to the design and effective operation of the quality management system have been brought to the forefront of the organizations (Topár, 2012).

1.2. How could total quality be defined?

Quality is one of the most frequently mentioned concepts not only in the business world but also in our everyday lives. We use it for both products and services, and it is a kind of general standard in our consciousness. There is no universally applicable scale system or measurement method, yet everyone qualifies and evaluates everything according to what he or she considers relevant.

To understand what the total quality is, we must first clarify the meaning of quality. One of the approaches is that success and the possibilities to improve performance are primarily determined not only by the products but also by the operation. The critical point is that quality depends mainly on the viewer. People deal with quality every day, even if they do not realize it. After all, we meet quality when we buy vegetables, go to a restaurant, make a monthly purchase, buy a car, a house, a TV or even a laptop. Perceived quality is an extremely critical factor in distinguishing products and services on the market. People are choosing products and services by a series of criteria, and this determines the perceived level of quality. The next example clearly shows the customer-oriented quality approach. The majority of people makes decisions based on the following criteria:

- service,
- time of the service,
- food preparation,
- environment and atmosphere,
- price,
- variety of choices.

Quality can be examined from two perspectives: product or process quality. Product quality is the goodness of the output of a finished product or an activity. However, today's quality management systems deal directly with product quality rarely. Product quality approaches have been used mostly at the early developmental stages of quality inspection and quality control. As a result of a change in attitude in the 1970s, the emphasis moved from product quality to process quality. Process quality is about the whole process of production, how the process of e.g. machine assembly can be characterized, how monitorable and manageable the connected tasks are, and how organizations manage the situation. It is important to emphasize that product quality and process quality are interrelated concepts, as product quality is achieved through process quality (Kövesi, Topár, 2006).

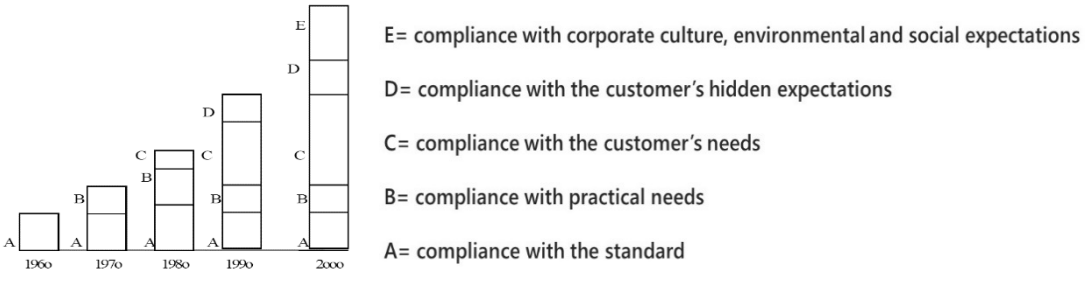


Figure 1.1.: The development of the concept of quality

Another approach to a quality definition is that quality means meeting different expectations and needs. The connection between these expectations and their development over time are illustrated in Figure 1.1.:

- Performance that meets or exceeds standards.

- Performance that meets customer expectations.
- Continuously meet customer requirements and expectations.
- Satisfy customers today, and become even better tomorrow.

There exist several interpretations and hundreds of definitions of the concept of quality itself. In the early stages, the quality was seen as a feature of usability and was identified as compliance with specifications.

In his Book (Out of Crisis), W. E. Deming, a pioneer of quality, points out that quality must always be defined from the perspective of stakeholders. Customers are a part of quality, as well as the employees, and the company as a whole. Moreover, all of them see quality a little differently, although these approaches overlap each other.

Although Deming's profound book is a bit outdated, his quality-related thoughts are still valid and transparent. He emphasized that quality is made up of many different criteria that are always changing. Also, people find each of the criteria differently important and valuable. That is why it is vital to measure and examine the expectations of customers periodically.

As a result of a paradigm shift in market demand, the concept of quality has changed: meeting customers' unspoken, spoken and latent needs (within the applicable legal and regulatory framework). This definition implies that the product provides what the customer needs. Of course, beyond the expectations of customers, there are market and social factors that may affect these customer needs, but the priority of customer needs is not disputed.

The following modern definition (World Quality Day, 2010) examines this sophisticated approach from the organization’s point of view: quality is innovation and care. There must be better (more effective) solutions within the organization in terms of:

- the products, services,
- the management and processes,
- the reduction of scraps and wastes,
- the improvement of leadership, and
- the increase of market share

to improve profitability and increase market competitiveness.

The organization must care about:

- society, environment, sustainability,
- customers, partners, people,
- health, safety, protection, and
- business continuity,

for an effective risk reduction. According to the previous quality definition, both activities must be carried out to increase the satisfaction of stakeholders (customers, partners).

These advanced concepts have been established by companies seeking long-term success in the overall operation and these ideas are considered to be a core business strategy (Tenner, DeToro, 2004). Quality is, therefore, a dynamic concept that can be interpreted at all levels from product to organi-

zation. However, quality is only a tool for achieving the goal, which is to ensure the long-term competitiveness of the organization and to provide an outstanding product/service to the customer (Kövesi, Topár, 2006).

Let us examine each part of the approach separately: The dynamic state indicates that quality can change and continuously changes with respect to time and according to circumstances. For example, consumption is a trivial criterion when buying cars, but at a time when fuel is relatively inexpensive, horsepower or acceleration time may be more attractive to customers. Products, services, people, processes and environmental elements are all essential. Quality is not only given by the product, but by people, processes of the operation, and the environment. In the short term, two competitors focusing on continuous development may provide a very similar product of the same quality. However, the company that is looking at quality will gain in the long run, and most often in the short run as well. The reason for this is that the quality of the product usually reflects the quality of the whole organization. The outstanding value suggests that quality is a critical element of creating real value.

1.3. What does quality management mean?

Quality management includes the activities that the organization makes to ensure that its product (service) meets customer needs. Numerous activities are needed to ensure that customer needs are fulfilled.

The purpose of establishing, operating and improving quality management systems is, on the one hand, to increase sales, on the other hand, to increase efficiency and effectiveness. A well-functioning quality management system strengthens the market position of the organization, contributes to increasing customer satisfaction and customer loyalty, and enables potential new customers' numbers to grow, resulting rises of the demand and so increases sales. At the same time, a well-functioning quality management system contributes to increasing efficiency and effectiveness by delivering cost savings and productivity gained through the application of "economic quality" and "right the first time and every time".

1.4. Quality management evolution stages

In the following, we review the developmental stages of quality management systems and the characteristics of these stages. Please note, that these systems, and the methods strictly related, have been developed in the manufacturing sectors, and service providers have later adapted the advantageous philosophies and methods. However, problems could occur if the adaptation does not consider the unique features that characterize the particular sector since the characteristics of each sector justify the use of different methods. In the following, the quality management systems are reviewed, based on the "traditional" production sectors (Figure 1.2.).

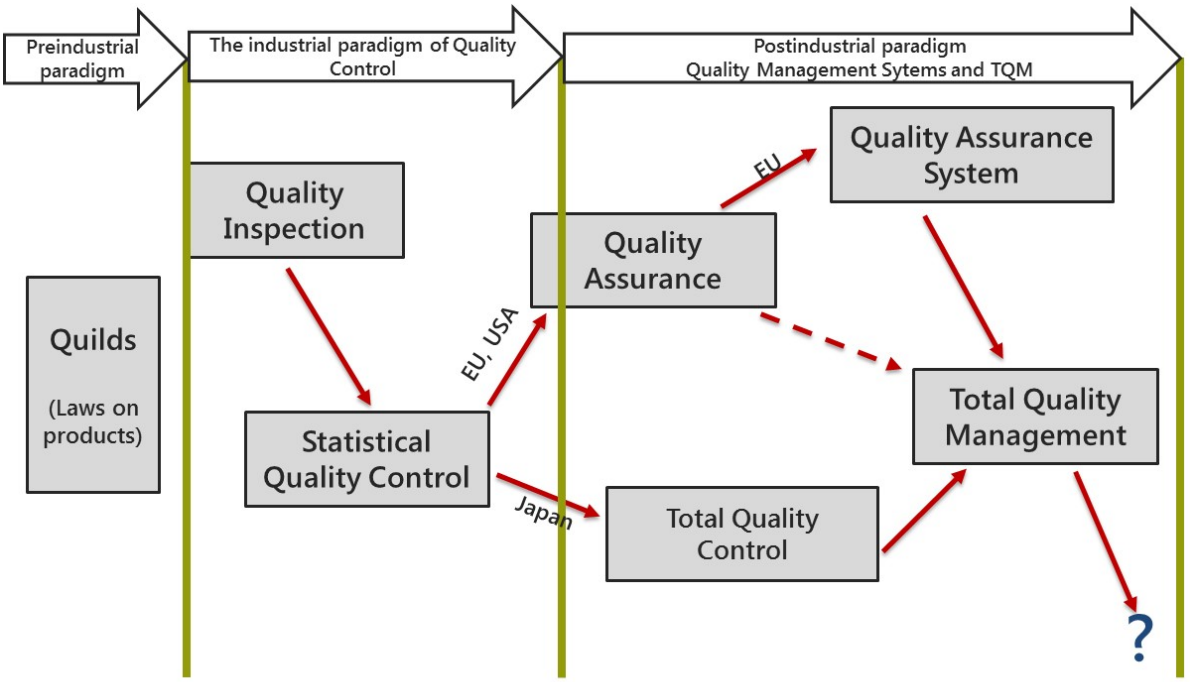


Figure 1.2.: The development of quality management

1.4.1. Quality inspection (between the 1910s and 1950s)

The beginnings of quality management are linked to the era of 'Taylor's scientific management'. Traditionally, the quality of a product was assured by quality inspection activities. The main principle of the quality inspection was to consistently judge whether the produced items meet the pre-set quality requirements (usually defined in standards, space different specifications). In industrial production processes, the task of inspecting the final product was commissioned by independent, qualified inspectors. Thus, quality inspection has become an independent profession, which became the indispensable part of the manufacturing processes by checking and certifying the final products. Various measurements and tests have been used to assess the suitability of product characteristics and to compare these characteristics to predefined requirements (Kövesi, Topár, 2006).

- Primary purpose: to identify the defects.
- The emphasis of activity: providing homogeneous products.
- Used methods: standardization and measurement.
- The quality inspection department is responsible for quality.
- The task of quality inspectors: checking, sorting, making calculations and qualification.

Therefore, quality inspection is nothing more than measuring the characteristics of a product and comparing the results with the requirements to determine whether we have achieved compliance with the pre-stated quality characteristics.

The major disadvantage is that the applied methods are primarily concerned with defining the defects at the end of the process, so there is no possibility of feedback during the process. The costs of rejected products are high, companies do not initiate significant repairs, improvements, and do not deal with the products after they have been sold or delivered. A further disadvantage is that top managers are entirely disconnected from the quality function, so they get little information. Therefore, they do not have the necessary knowledge if intervention is needed.

1.4.2. Quality control (between the 1930s and 1980s)

While applying the mathematical statistics methods, it is not required any more to subject each piece to the necessary examinations and final checks. Based on an appropriate sample, we can deduce the features of the population (the total quantity) by applying probability theory. The theoretical development of quality inspection systems is linked to the statistician, Walter A. Shewhart. The basis of the theory and practice of control charts, a quality management method, is also related to his work. He achieved significant results in developing sample-based quality control procedures.

The traditional approach has tried to ensure that customers get the right quality with post-production quality inspection. However, the ever-increasing demand for quality has led to the development of new methods. The science of technology, work organization and quality inspection have evolved, and this development has led to the second phase of quality management, the era of quality control. It has become clear that quality cannot be 'checked' but should be 'incorporated' into the product. Elements based on this conclusion have gradually appeared in production (Kövesi, Topár, 2006).

The spread of mass production thus had a positive effect on quality inspection based on the principles of mathematical statistics. The great novelty of the quality control era was that during the manufacturing process quality measurements were already carried out, and the processes were designed to meet the requirements of the product. In the case of quality control with statistical sampling, the processes are not only inspected but controlled, and the corrective actions get a role as well.

- Primary purpose: inspection and control.
- Aim: providing a homogeneous product with fewer inspection.
- Methods: statistical tools and techniques.
- Production and other technical departments are responsible for quality.
- Quality professionals are responsible for troubleshooting and applying statistical methods.

In this era, statistical methods were applied to technical processes. Examining the sample taken from the population representing all of the manufactured items made it possible to obtain sufficient information using appropriate mathematical-statistical methods and draw conclusions about the characteristics of the population. The term quality means in this era the appropriate application of statistical methods in production process analysis.

1.4.3. Quality assurance and quality management systems (from the 1970s to nowadays)

With quality assurance activities being transformed into an internal subsystem of the organization, the development of quality management has entered the era of quality management systems. A novelty in comparison with the previous stages is that not only the production departments and processes but all the departments of the company cooperate to control and direct the organizational processes. Thus, the QM system is developed with the purpose of continually ensuring the coordination of the tasks of various departments directly or indirectly involved into the satisfaction of consumers' expectations. There are many ways to set up quality management systems, but most often, it is done based on the ISO 9000 series. These standards guide the development of QM systems. ISO 9000 and other similar systems of standards help to make uncoordinated system components work according to a unified logic, eliminating the fluctuation in quality. (Kövesi, Topár, 2006).

- Primary purpose: coordination of activities.

- Aim: make the quality management system focus on the broader production chain and failure prevention.
- Applied methods are quality projects and systems.
- Quality professionals are responsible for quality planning, quality program management and continuous quality assessment.
- All departments involved in satisfying customers' needs are responsible for quality.

In this era, quality has extended to almost the entire organizational structure of the business, not only a particular organizational department is responsible for the quality, but it is the result of all departments' cooperation. They discovered that it is more economical to scan the entire organization than the individual products. In the 1970s, quality began to become the synonym of customer satisfaction.

In this era, quality management is a combination of coordinated activities designed to help in managing quality issues in an organization. Directing and managing an organization in terms of quality mean defining quality policy, quality goals, quality plan, resource allocation, quality inspection, assurance, and continuous improvement. It is essential to organize and implement quality inspection activities for all products, processes and services (whether inside or outside the company), and to confront results with targets in specified intervals.

Quality assurance goes beyond quality control since just monitoring and measuring the defects are not sufficient enough. Companies have to make their system more efficient and 'forward-looking' by incorporating elements into their quality assurance system which transform quality assurance system methods and rules into planned, regular activities.

The quality assurance systems built in this way transform the perception of quality, the emphasis is on quality issues. In the quality assurance system, the concept of quality is not directly related to the product, but to the processes that create the products or services. The concept is that a product will be of quality consistently meeting the needs of the customers if a well-functioning company with well-organized processes creates it.

1.4.4. ISO 900 family of standards

The ISO 9000 family of standards has been developed to help organizations of different types or sizes to implement and operate an effective quality management system. The application of the standard system requires knowledge of the requirements of four world-class standards.

- The **ISO 9000:2015** standard describes the basics of quality management systems developed according to the ISO 9000 family of standards and defines the terminology used.
- The **ISO 9001:2015** standard defines the general requirements for a quality management system that an organization creates to demonstrate its ability to deliver products that meet the requirements with the purpose of increasing customer satisfaction.
- **ISO 9004:2018** guides how to improve the applied methods of the organization and to increase customer's and other stakeholders' satisfaction.
- **ISO 19011:2018** provides the basis for auditing quality management and environmental management systems.

These standards form a coherent set of quality management system standards that facilitates applying organizations' mutual understanding and acceptance of systems in different business or partner relationships. The developed quality assurance systems comply with the ISO 9001 standard. The "level"

of the standards applied in the given organization cannot be interpreted, just that the regulation of the system matches the “quality maturity level” of the organization.

If a company fulfils the requirements of the ISO 9001, accredited organizations could certificate it. The certification is valid for three years. The operation of the company is checked every year or every six months during these three years. Certifications can be renewed.

Principles of quality assurance

The focus of the ISO 9000 family of standards is shifting from structure to process, and the newest version (2015) has not eight, but seven main principles – the fourth and fifth principles of the pervious release were combined. The TQM elements were strengthened in the principles. These principles are:

1. Customer-Oriented Organization: Since the organization depends on its customers, it needs to be aware of the customers' current and future needs and expectations.
2. Leadership: Leaders must align the goals of the organization into a single entity. Leaders should develop an internal workplace environment where employees can fully align with common goals and objectives.
3. Employee Involvement: Employees are an essential part of the organization's operation at all levels of the organization to achieve its goals.
4. Process-based approach: The desired outcomes can be achieved more effectively if resources and activities are treated as processes.
5. System Approach and Management: The efficiency and effectiveness of the organization are improved by identifying, understanding and managing interacting processes.
6. Continuous Improvement: Continuous improvement is the primary goal of the organization.
7. Factual Decision Making: A sound decision is based on the analysis of data and information.
8. Mutually Beneficial Supplier Relationships: The organization and its suppliers are interdependent, and both parties prefer mutually beneficial cooperation.

ISO 9001:2015

In 2015, the newest version of ISO 9001 was released, based on the experience of the previous applications. In this standard, the International Organization for Standardization (ISO) has set a goal to create a unified structure that significantly supports further harmonization with other corporate management systems.

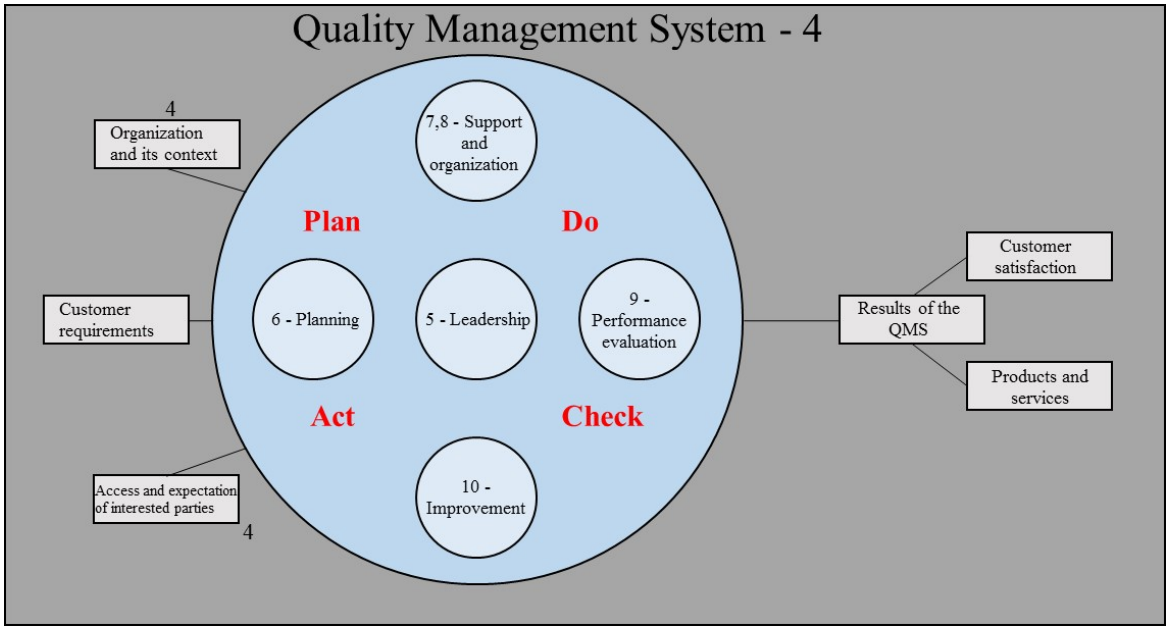


Figure 1.3.: Representation of the structure of ISO 9001:2015 in the PDCA cycle (based on ISO, 2016)

Requirements

- The environment of the organization: understanding the business environment, the needs and expectations of the stakeholders, the scope of the quality management system.
- Leadership: reviewing leadership skills and commitment, defining quality policies and organizational roles, responsibilities and competences.
- Planning: activities related to risks and opportunities and designing quality goals and planning their achievement.
- Support: assuring resources, preparedness, awareness, appropriate communication, documented information.
- Operation: planning the operation and the supervision of the organization.
- Performance evaluation: determining the operation measurement, analysis and evaluation of the collected data, developing internal audit and management review practices.
- Improvement: developing continuous improvement practices, defining non-compliance management and corrective actions. (ISO, 2016)

The following areas have been given greater dominance in the general requirements of ISO 9001:2015:

- Strengthening the elements of process management at every point in the operation of the entire system, including the analysis of the processes, process innovation, strengthening the role of the process owner.
- Integration of risk-based approach appears in the interpretation and implementation of system requirements. (organizational - strategic - compliance - operational risk)
- The elements of life-cycle management appear in the design, development and production process.
- Managing the financial resources and controlling information of organizations.

1.4.5. Total Quality Management (from the 1980s to nowadays)

Based on the previous concerns, the quality was defined in the early 1980s as competitiveness, meaning a higher level of quality at lower costs. The first goal was to develop organizational processes more efficiently. This approach has led to the development of Total Quality Management philosophy.

TQM is a management philosophy and corporate practice that utilizes the human and material resources available in the most effective way to achieve the organizational goals. As mentioned above, TQM builds from top to down, from the level of management and covers the entire organization, and it includes not only processes but also direction and resources. Emphasis is placed on customer satisfaction and continuous improvement of organizational operation. The way to achieve quality is to ensure a steady competitive situation. Everyone is responsible for quality.

- Primary purpose: strategic influence.
- The way to achieve quality is to ensure a permanent competitive position.
- The emphasis of the activity is on the market and customer needs.
- The management and all employees are responsible for quality.
- The role and task of quality professionals are planning, education, training, setting up quality programs, and the organization of goals.

TQM is neither a final destination nor the last station. Development at this stage will not stop, and further, more advanced trends will emerge and gain ground, since the fierce competition forces companies to improve their existing methods.

1.4.6. Total quality control

Figure 1.2. shows the stages of the development of quality management, considering the different characteristics of each country and continent. This model distinguishes six stages. Quality control has progressed in two directions: Japanese Total Quality Control (TQC) and European QA (Quality Assurance). In the following, we review the basics of the quality management approach and system developed in Japan. In many cases, we can consider the principles and methods of TQC as a starting point. It should not be forgotten, however, that Japan's social and corporate culture is fundamentally different from that of the US and European countries (Kövesi, Topár, 2006).

After World War II, the United States launched a support program similar to the European Marshall Aid in Japan. Under the program, American specialists travelled to Japan, and they taught the latest production management and quality techniques to Japanese professionals. At the same time, thousands of Japanese engineers and other corporate executives went to the United States and participated in factory visits and courses. Targeted courses, mass courses differentiated by age, department and profession have been launched and as a result, these ‘decades of the Japanese Miracle’, a national quality program, has been successfully extended to the whole society and many generations.

The first interpretation of competitiveness resulted in mass production with low wages and high labour intensity focusing on low costs. That is, the first Japanese export products were cheap and of poor quality. Of course, this did not lead to a breakthrough in exports, so they were forced to move on. The next recognition was that, by offering cheaper products than the competitors, it is no longer possible to gain a competitive advantage, instead, they have to meet the needs and expectations of the customers at a higher level than the others.

One of the features of the Japanese school is the bottom-up spread of the quality philosophy , i.e. the involvement of workers through quality circles. A quality circle is an association of employees at a particular workplace to improve quality, primarily by meeting outside of working hours. Individuality is not at all typical of the Japanese, they share their results without personal benefits, cooperate, so it is successful to rely on quality circles. In a Japanese organization, quality is based on all fully empowered employees. Other essential features include mass application and dissemination of elementary quality techniques and making continuous improvement a philosophy and everyday practice. Simple statistical and problem-solving methods have been massively used in quality circles by applying them in the implementation of quality goals.

The Japanese TQC model is rooted in social traditions. In the Total Quality Control, the idea collection (brainstorming), development, production and sales are implemented in their own system. The other element of the Japanese model is totality. TQC was the first conscious quality system the scope of which was beyond statistical quality control. It has integrated market research, manufacturing technology development, manufacturing conditions into a single unit, creating a market-to-market quality control system.

1.4.7. Comparison of quality schools

Thus, three quality schools can be distinguished: Japanese, American and European. Although these schools contain many common features, remarkable differences can be mentioned based on aspects such as how the quality approach spreads within the organization; or what unique specialities it has. Table 1.1. summarizes the main characteristics of each quality school.

Therefore, it can be concluded that the significant developmental stages emerged in the most developed industrial areas of the world. The characteristics of a quality school or the reasons for the start of a development phase are not always due to the stimulating effects of international competition, but rather stem from the economic, political and cultural context of the three regions. The culture of the given region is the basis for the application of the quality philosophies and the schools and methods developed from them. While in America, there is an active management layer surrounded by a success-oriented community, Japan is characterized by a culture-rooted public spirit, whereas Europe by expertise, training and formalized rules.

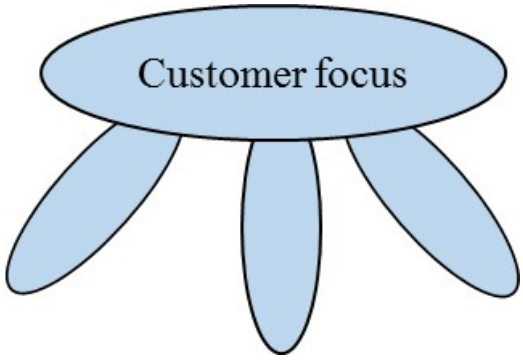
Table 1.1.: Quality schools (Szabó, 2002, 12)

Features	Japanese	American	European
Spread	Multitudinous, bottom-up	Top-down, snowball principle	Production and technology management
Carrier layer	Quality circles	Top management	Middle management
Specialties	Totality, basic, simple tools and techniques	Management environment, different focus	Standardization, regulation
Key elements	Quality circles	Management climate	Documented monitoring, shadowing
Hungarian gap	Motivational	Management	Quality culture and IT

2. THE TOTAL QUALITY APPROACH IN QUALITY MANAGEMENT

Organizations can stay alive and grow in a globally competitive market only if they deliver outstanding value to their customers. The achievement of organizational excellence is the ability of the company to deliver outstanding value continuously in the long term. The outstanding value has three principal elements: outstanding quality, outstanding cost and outstanding service. However, total quality means much more. Total quality is a broad approach that includes three major elements of outstanding value. Continuous improvement of products, services, and processes, as well as reducing costs form altogether the total quality. Only the organizations that effectively adapt the total quality approach to their operation can achieve organizational excellence.

There are many different definitions of total quality. One possible approach is the tripod chair principle (Figure 2.1.), where the seat of the chair is customer focus. The customer is in the driver's seat as an arbitrator for what quality is. Each foot is a comprehensive element of total quality philosophy (measurements/actions, people, processes). The measurements/actions foot points out that quality should always be measured. The people foot highlights that quality can only be produced by people who are genuinely empowered and dedicated and perform in their job correctly. Ultimately, the process foot pinpoints the need to continuously and endlessly develop processes.



Measurements/actions	People	Processes
• Statistical process control • Benchmarking • Quality tools	• Built-in quality • Quality is expected, not looked for • Empowered employees	• Continuous improvement • Good is not good enough

Figure 2.1.: Tripod chair of total quality (based on Goetsch, Davis, 2016)

The way of achievement is distinguishing the total quality approach from the traditional ones. The distinguishing features, which support the strategy of the organization are the followings: strategic approach, customer focus (internal and external), quality commitment, decision making and problem solving in a scientific approach, long-term commitment, teamwork, continuous process improvement, bottom-up education and training, freedom through control, commitment to purpose, involvement and empowerment of workers. Competitiveness introduces, reinforces the need for total quality.

Here are some of the significant differences between traditional and total quality approaches:

- **Productivity vs quality.** The traditional approach says that productivity and quality are not available at the same time. While according to the total quality approach, long-term productivity is the result of quality development and improvement.

- **Determining quality.** According to the traditional approach, quality is the compliance with the customer requirements, according to the new perception, it is reaching the satisfaction of customers' and exceeding their expectations.
- **Measuring quality.** According to the traditional approach, measurements deal with determining the level of acceptance of non-conformance and the percentage of error, while the total quality approach focuses on achieving the highest level of customer satisfaction.
- **Achieving quality.** We move from quality inspection to designing products and processes and achieving goals through effective control methods.
- **Attitudes to faults.** According to the traditional attitude, faults are calculated (parts per hundred). According to the total quality approach, effective control techniques are introduced to prevent faults, and the measurement unit is parts-per-million (ppm).
- **Quality as a function.** The total quality approach is that quality is no longer a stand-alone function, but the responsibility of the whole organization and everyone involved.
- **Responsibility for quality.** According to the new vision, in 85%, poor quality is the management's fault.
- **Supplier relations.** Based on the old approach, it is short-term and cost-based, and with the new approach it is moving towards long-term and quality-oriented relationships.

2.1. Key elements of total quality

Strategy-based

Organizations working to achieve total quality have a comprehensive strategy that includes the following elements: vision, mission, overall goals and related activities. The strategic plan developed through a total quality approach aims at providing the organizations with a sustainable competitive advantage as world leader quality and continual improvement.

Customer focus (internal and external)

External customers determine the quality of the product/service, while the internal customers help to define and maintain the quality of the stakeholders, processes and environment.

Commitment to quality

After defining quality, the organization must work to become committed to achieve and exceed the defined quality level. So, every stakeholder at all levels should be asked over and over again: how could we do better? Since something good enough is no longer good enough.

A scientific approach to decision making and problem-solving

Many people think that empowering employees or total quality are just another name for soft management or resource management. Although it is true that social skills, competence and empowerment are dominant in this approach, but they are only one part of the equation. A scientific approach to work design, decision making and problem-solving are essential as well.

Teamwork

Most of the significant competitive advantages are in individual departments. The internal competition requires much energy, which could be spent on developing quality and external competitiveness.

Continuous improvement of processes

Develop the entire system in order to improve the quality of products and services continuously.

Bottom-up education and training

Education is essential in a total quality approach, as this is the best way to develop employees, and it can help hard workers to learn how to work smart.

Freedom through regulation

The ultimate goal is to involve more people into decision making by providing them insight or participation into decision-making procedures. As a result, employees feel that decisions are made closer to them which enhances their loyalty. Critics of the total quality approach often argue that empowerment is a loss of management control.

Commitment to Goals

It is imperative that in organizations that want to adapt to this vision, all employees should be involved in the implementation and should feel the aims and goals as theirs.

Employee involvement and empowerment

Employee involvement is twofold. First of all, it increases the chances of making the right decision, better plan, more efficient development and implementation by getting to know and comparing the approaches of the stakeholders. Secondly, people who will have to implement and put into practice the decision will feel it as theirs. Empowerment does not only mean involving the employees but a way of conduct that considers employees' opinions. Perhaps this is the most ambiguous part of this approach.

Top performance

When the concept of total quality is properly implemented, each level of the organization provides the highest possible performance. That is, every employee and process work excellently. Moreover, top performance is the base of competition in the international environment.

2.2. TQM philosophy

Over the past decades, it has become clear that quality depends not only on how the workers do their work, and not just how the staff deals with the customer. Quality depends highly on the leaders of the organization who are responsible for success. Top-level managers distribute resources, decide which markets the company wants to penetrate, and choose and put into practice the management processes that will allow the company to fulfil its mission.

As defined in ISO 8402:1994 (Pfeifer, 2002)

[TQM is]'a management approach of an organisation centred on quality, based on the participation of all its members and aiming at long term success through customer satisfaction and benefits to all members of the organisation and society.'

TQM is a management philosophy that focuses on customer orientation, employee engagement, empowerment, and continuous improvement.

Combining the different teachings of the quality gurus with practical experience, a simple but effective model for the application of TQM has been developed. This model (Figure 2.2) is based on three fundamental principles and six additional elements of TQM (Tenner, DeToro, 2004).

- Principles: focusing on both external and internal customers; focusing on improving processes to deliver reliable and acceptable products/services; and focusing on how to utilize the talent of those who work with us.
- Supporting elements: leadership, education and training, supporting structures, communication, reward and recognition, measurement.

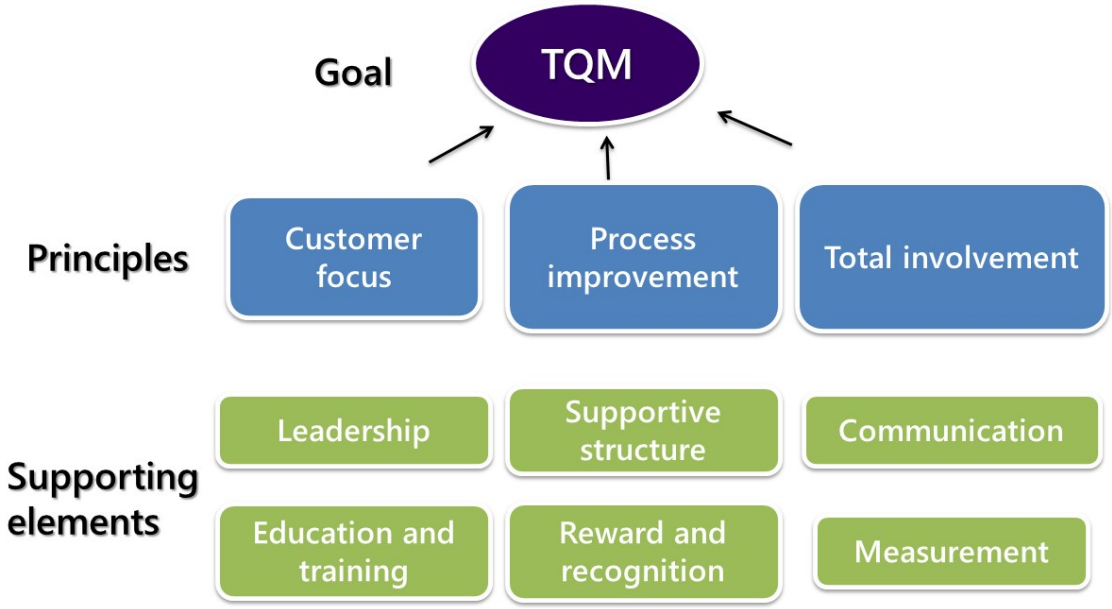


Figure 2.2: Main principles and supporting elements of TQM (Tenner, DeToro, 2004)

2.2.1. Basic principles

1. Customer focus. Providing quality service is based on the concept that the needs and expectations of customers have to be fulfilled each and every time so that the organization as a whole can fulfil its goal. This concept requires a thorough mapping and analysis of customer needs. When we get a clear picture of these needs, we need to provide a way to fully satisfy them. Implementing customer focus begins with identifying the customer, that is, determining who our customers are. We all assume that we can do this easily, but over time, we realize that in certain situations, it is not so easy to answer this question accurately. The customer is the person to whom the organization passes its product. In this approach, the concept of customer is extended to the so-called internal customers as well. By the internal customer, we mean employees who utilize the results of our work in their own work processes. If we already know who our customers are, we can begin to explore their needs. Customers usually perceive the quality of a product or service by comparing that product or service with the vague expectation they connected to it before it was purchased. Successful organizations can simultaneously define in advance unspoken, basic expectations, stated specifications and demands expressed by the customer, as well as latent (hidden) needs not previously recognized even by the customer, but later appreciated. After getting to know the customer's needs, the customer-centred operation will be completed within the organization if the recognized customer needs are the basis for process development. With the rapid adaptation to customer needs, the organization can create a satisfied and loyal customer base.

2. Continuous process improvement. According to the concept of continuous improvement, the operation is the result of a series of closely related steps and activities; at the end of the process, an output (product or service) is generated. All steps in the process should be monitored and improved to reduce deviations and improve the reliability of the process. The first goal of continuous improvement is to create reliable processes in the sense that we get the desired output (result/product/service) in each time without any difference. If we minimize the variation, but the result is still unacceptable, the second step in the process improvement is redesigning the process. Process redesign aims at creating an output that can meet the needs of customers better. The approach is illustrated in this sentence: 'If we keep doing what we're doing, we're going to keep getting what we're getting.' (Tenner, DeToro, 2004, 133).

3. Total commitment. This approach begins with the active direction of the top management of the organization (institution) and includes actions that utilize the knowledge of all the employees to gain market benefits. However, this situation only occurs if all employees know the mission, the vision, the values, the business policy, the objectives, and the methodology of the organization, understand the role of their workgroup within the organization and can align themselves with them. In addition to this, it is also necessary for employees to be able to perform better based on their abilities and knowledge and to develop mutual trust between employees and managers. Along with these conditions, we have more empowered employees. Such employees have a wide-ranging authorization to improve products, create new and flexible work structures, improve processes, and meet customers' needs. These efforts also involve suppliers who, after a given period, become partners by working with a wide range of empowered employees to benefit the entire organization.

2.2.2. Supporting elements

Leadership. Organizational (institutional) managers should work as an example by applying TQM tools and language, requiring the use of specific data, and rewarding those who successfully apply TQM concepts. When we introduce the TQM as a fundamental leadership and management process, the role of organizational leaders as spokespersons, teachers and real leaders should be emphasized. Leaders need to understand that TQM is a process that consists of such principles and supporting elements that they must manage in order to achieve continuous improvement of quality.

Education and training. Education and training for all employees provide the information they need about the organization's mission, vision, direction, and strategy. Also, this training provides the specific skills the employees need to improve quality, improve efficiency and performance and solve problems.

Supporting structures. Various experts can support the implementation of the TQM process. Such a circle of supporters or experts can help managers to understand the essence of TQM and they may also help to build a network of quality professionals in other parts of the organization.

Communication. The success of TQM depends to a large extent on communication among all members of the organization, suppliers and customers. Leaders need to develop open communication channels, where employees can send and receive information about the TQM process, thereby building a commitment to change. Communication is excellent if it is clear, understandable and honest in its content.

Reward and recognition. Teams and individuals who successfully implement quality management tools and develop processes should be recognized, preferably rewarded. Recognizing successful quality practioners provides role models for others in the organization.

Measurement. The use of the data is particularly crucial for the introduction and application of the TQM process. Data and information should replace subjective opinions, and everyone should understand: it is not important what we think, but what we know.

3. TOTAL COMMITMENT

Total commitment is one of the principal elements of TQM. Through this, the idea of winning loyal customers is reflected in the organization with the purpose of winning employees, loyal suppliers and partners. Total commitment brings together and summarizes the effort of all groups: managers, workers and suppliers.

3.1. Roles of leadership

When the TQM is introduced, a team of senior executives needs to carry out several necessary activities. These top-level managers bear the ultimate responsibility for the success of the organization and have the power to steer, set up business policies, distribute funds, and choose the markets in which the firm will participate. These individuals are responsible to customers, employees, and ultimately, the owners of the company for sustainable success.

TQM requires specific skills related to both leadership and management.The difference between the two roles is characterized by Bennis and Biederman (2009) concisely:

"Leaders are people who do the right thing; managers are people who do things right."

Table 3.1. shows the difference between the role of managers and leaders. In the implementation stage of TQM, the management roles helping to deliver results comes to the forefront as well as that of the leaders working on the system repair. As TQM is being developed, the traditional roles of planning, organizing, directing, harmonizing, and controlling are becoming less and less relevant and important. Instead, we will find leaders who have visions, align, empower, train and care about their employees. (Tenner, DeToro, 2004)

Table 3.1.: Roles of managers and leaders

The roles of leaders and managers	
Managers	**Leaders**
Planning	Vision
Organizing	Alignment
Directing	Empowerment
Harmonizing	Education, training
Controlling	Care
REACHING THE RESULTS	**IMPROVING THE SYSTEM**

The difference between the two roles can also be formulated as: '*The leader has followers, while the manager has subordinates*'.

The continuous improvement of all products, services and processes is accelerated if everyone every day questions the status quo. Leaders can create conditions for this challenge by developing the answer to the following six basic questions:

1. Why does the organization exist, what is our goal? (mission)
2. What will we do in the future? What do we want to become? (vision)

3. What do we believe in, and what do we expect to be respected by everyone? (values)
4. What policies can we provide to our employees on how to deliver products and services to our customers? (business policy)
5. What are the long-term and short-term results that will enable us to fulfil our mission and implement our vision? (goals and objectives)
6. How will we progress towards our vision and fulfil our goals and objectives? (methodology)

The answers to the first three questions are the cornerstones of the leadership role. The mission defines why the organization exists. The vision clarifies what the organization wants to do, and fundamental values explain how we want to act. The answers to the remaining three questions provide details and build on these pillars.

These questions seem to be simple, but they are incredibly complex and difficult to answer when the products and services of an organization are overcome by new technologies, competent and aggressive rivals, or other changes. However, if any of these questions are left unanswered, it will be hard to understand customer requirements, to effectively distribute resources, and ultimately, to capitalize on the talent of employees. (Kövesi, Topár, 2006)

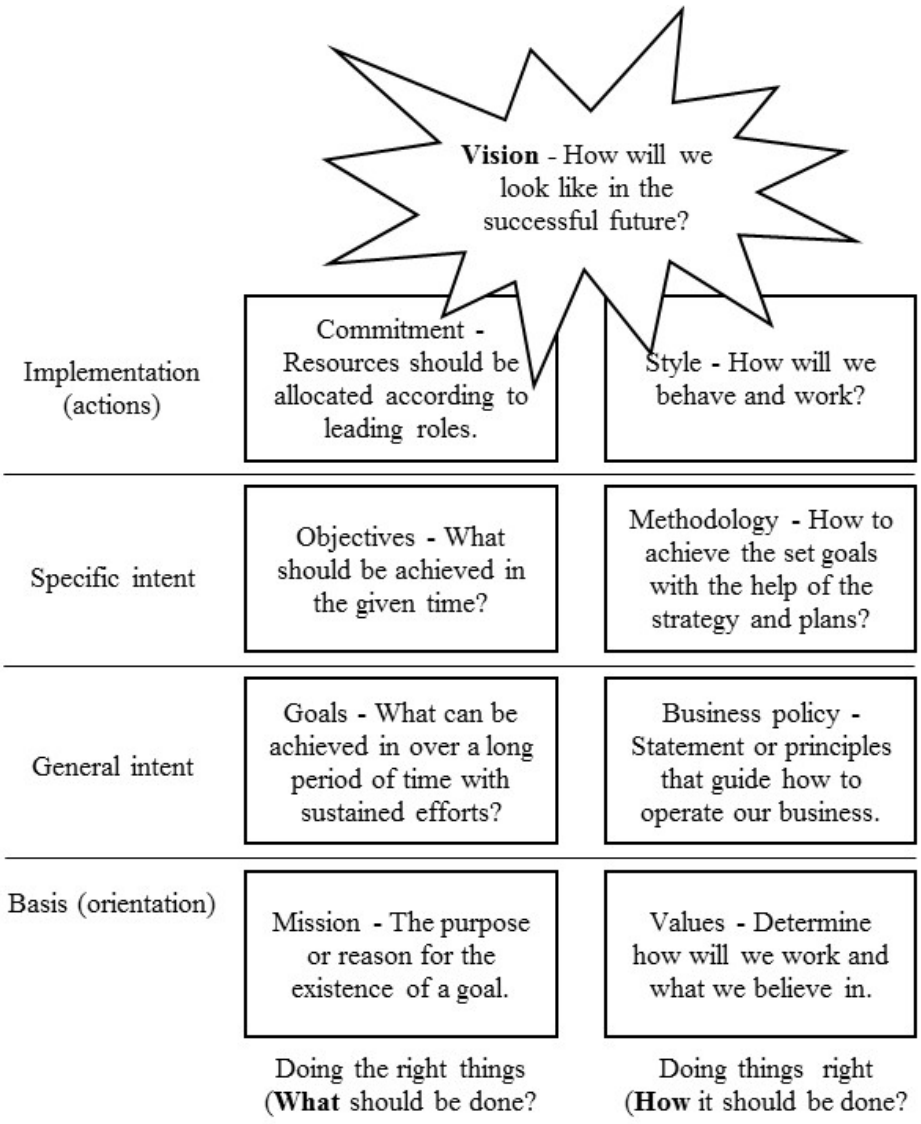


Figure 3.1.: The tasks of leaders

3.2. Other elements of leadership

The last two elements of the leader's role are related to the actions of the management's daily work. Commitment reveals what the leaders do and how the funds are distributed. Workstyle shows how they do their job.

3.2.1. Commitment

Since many different examples illustrate the importance of leadership in TQM-environment, senior managers should demonstrate their commitment each and every time. Demonstration of commitment can take many different forms, and outsiders can recognize it from the words and actions of the leaders.

The first opportunity to demonstrate commitment is the redistribution of resources, and when it comes to cover the costs of ancillary staff who will implement the extensive training program needed for the introduction of TQM. Will the funds be available? Can some funds be channelled here from traditional training programs?

It is equally essential that senior managers demonstrate their commitment by participating in the same training program in which everyone else does. Will top-level managers use the tools, jargon and other processes necessary for continuous improvement? Alternatively, only their subordinates will be instructed to use it?

Are senior managers willing to set up the necessary structures to support TQM, such as councils and steering committees? Are they willing to contribute to these structures themselves? Are they willing to take on this responsibility?

Are senior managers able to demonstrate their long-term commitment to continuous improvement, even when the cost of improvement seems to be too high? Commitment is more than new types of procedures, business policies, instructions, letters and speeches. Employees expect the top management's commitment, and they monitor the manager's behaviour and style for signs and evidence.

It is expected that managers will be asked questions and tested by employees about what they believe how committed they are.

3.2.2. Workstyle

'What we do is not the only important thing; how we do it, is just as important. Let us lead by example; be a good role model.'

The leader who applies TQM should consider the following guidelines:

1. Leaders base their decisions on data. Opinions are interesting, but the decision must be based on what we know and not what we think.
2. Leaders are resources, coaches and helpers to their direct co-workers.
3. Leaders are actively involved in the process. Acquire new information with their employees. Thus, an experienced, knowledgeable leader can help others in their efforts to improve continually.
4. Leaders raise commitment. They make sure that everyone understands the mission, vision, values, and goals of the organization. Also, managers ensure that everybody knows his or her role and strive to contribute to the collective effort. (Topár, 2005)

5. Leaders raise confidence. They encourage everybody to do his or her best and they also support personal development.
6. Leaders can say thanks. Also, they do it in a material and non-material form.

3.3. Empowered employees

What does empowerment mean?

Adequate steps needed to be taken in the next three dimensions to achieve a great deal of authority, and to empower the employees.

Alignment is the first dimension of empowerment. All employees should know the mission, vision, values, business policy, objectives and methodology of the organization. Also, the broad management of the organization as a whole should be sharpened. The message should be disseminated to each level of the organization in order to help defining the role of the workgroups and individuals.

Employees in perfect alignment are not only aware of their role but are also committed to it. Their leaders inspire them to work for the mutual benefit of the organization and themselves. This devotion is a commitment, and it cannot be sold or bought. We have to earn it. The traditional hierarchical organization did not demand commitment; for its authoritarian style, obedience was enough.

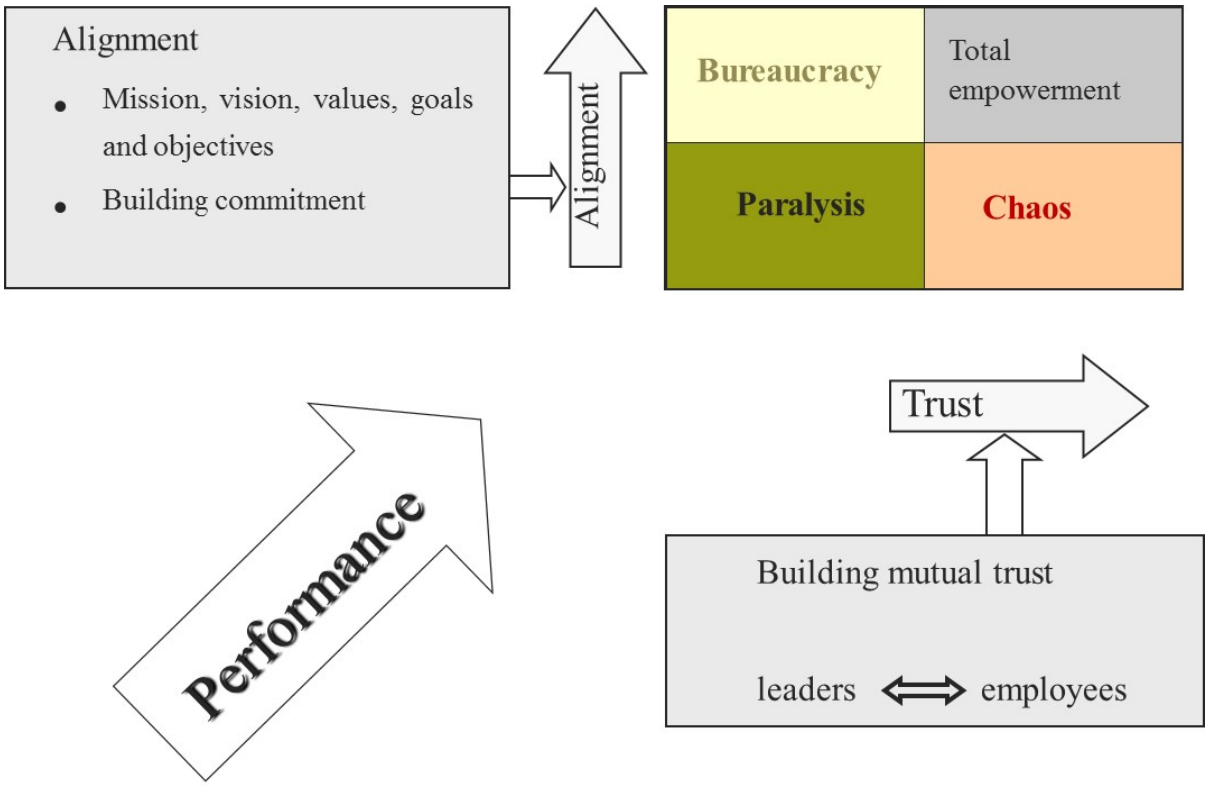


Figure 3.2: The requirements of commitment

The small gap between obedience and commitment have to be explained. The primary difference between obedience and commitment is that people who are committed to managing an organization want to do it honestly. While for the engagement with great powers, there must be commitment, in the short term, leaders may need to be content with obedience. Commitment cannot be forced on anyone; the effort to do so will, at best, only result in obedience. Nothing else can be done just to create an environment that is favourable for the growth of commitment.

The second dimension is performance. Employees must have the skills, abilities and knowledge necessary to carry out their work. Also, they must have the resources from the organization: materials, methods and machines. In our experience, many organizations outperform this dimension. Through the selection criteria, the newly contracted employees can be ‘over-qualified’, and investments in facilities, equipment and training have far outstripped the growth in the other two dimensions - trust and alignment.

Mutual trust is the third dimension of empowerment. Once we have developed the alignment and the performance, we are in a position to unleash the power, creativity and ingenuity of our workforce. However, this will not happen unless we can provide the aforementioned third dimension. Employees need to have trust in management and feel that management trusts them.

Therefore, we can see that total empowerment is due to the productive work of the leader.

By answering the following questions, we can show how our management system symbolizes the level of trust towards our employees that we represent. Does business policy restrict employees' access to money or physical goods? Is the information flow denied in any ways? If total empowerment is based on alignment, performance, and trust, then it is illogical to expect employees to feel this high power without feeling the trust towards them. It is very straightforward: treat people in the same respectful way that we would expect to be treated.

With this, we do not want to suggest that a company manager should remove all of its security systems. These may be very necessary, as the given manager cannot trust every employee. Lack of trust can be the result of the selection process, but it may also be the result of outdated practices. (Tenner, DeToro, 2004)

4. CUSTOMER FOCUS

The most fundamental principle of TQM philosophy is customer focus, and its successful application is an indispensable element of the long-term survival of an organization. With its application, we want to meet the expectations of our customers as much as possible. The real purpose should be that while buying the products and services placed on the market by the organization, the customers feel and recognize the added value. Meeting expectations can only be achieved if we know who our customers are, what their expectations are, and what level of performance our competitors and we deliver. By applying the principle of customer focus, we try to find answers to these three questions by utilizing practical and efficient organizational methods.

4.1. Identifying the customer

When identifying the customer, we look for the answer to a simple question: who is our customer. However, in practice, it is not always easy to give an accurate answer. If we sell our products and services in the organizational market, it is relatively easy to identify the specific group of people with whom we negotiate while making the deal. By getting meaningful feedback on the fulfilled orders, we can continuously develop quality.

In some cases, the buyer and the user of the product are different. Nevertheless, accurate knowledge of their needs is essential. Our task is complicated if we want to identify our customers in the consumer market for amass-product. However, every effort should be made to find out who our customers are (which market segment) and what their needs are. In quality matters, this group is called external customers, and they are individuals and organizations outside the organization to whom we sell our products and services. The precise identification and careful examination of this group significantly contribute to the success of the organizations.

In the TQM philosophy, the principle of customer focus is extended to internal customers as well. Employees must also identify the customers within the organization and must pay particular attention to their expectations and feedback. During the implementation of organizational processes, the internal customers of the given participant or organizational unit will be those who take over the (semi-finished) products within the organization or use the services provided. These transfers and interactions should be managed and investigated in a similar way to external customers. First, identify the person, the organizational unit to whom we deliver the product of our work, and request information about the needs, expectations, and requirements that we should meet. The importance of this concept should be evident for everybody in the organization. For example, the internal customer of someone working alongside a conveyor belt is a colleague whose work follows his. Inappropriate work is likely to result in immediate and direct feedback, and could even spoil or make it impossible to continue the production. This approach emphasizes that no organization can successfully meet the needs of its external customers if products or services taken over by employees are inadequate. Mathematically it is easy to prove that fully satisfying the external customers' needs is impossible if the process participants cannot pass 100% perfect products to each other. For example, at a five-persons process (conveyor belt), if all meet the needs of internal customers to 90%, then the product delivered to the external customers will be below 60%. (90% x 90% x 90% x 90% x 90% = 59%).

From a quality point of view - considering the former two interpretations - the customer is the one to whom we pass on the results of our work.

4.2. What do our customers want?

Once we have determined who our customers of what we produce are, we can examine what they expect, that is, what they need from us, from the 'supplier'. Quality is determined by the customers and it is meant to satisfy their needs and expectations each and every time. Sometimes, surprisingly, customers themselves do not know their own needs exactly and expect the supplier to assist in clarifying their needs. Identifying needs provides an opportunity to build a partnership that can bring many benefits to both parties and long-term cooperation.

The TQM philosophy expects its followers to be able to diagnose and fully satisfy the full range of customer expectations, regardless of the features of a particular customer. We should ask the following questions regarding the expectations of the identified customers (market segment):

- What characteristics do customers want?
- What level of performance is needed to meet their expectations for each feature?
- What is the relative importance of the different characteristics?
- How satisfied are customers with the current level of performance in terms of features?

Customers expect to get value in the product or service they purchase or use. It is often stated that the customer is always right because the quality of the product or service is determined based on their expectations. However, in practice, the customer is not always right, and often, they are those who cause the problem. So, it may be a better motto that although customers are not always right, they must always be well treated and their opinions have to be understood and respected.

Many models have to be delivered to clarify how the customers define quality or what matters to them (like product/service quality, employees of the organization, organizational image, price). Some of the most basic models are introduced below.

4.2.1. Faster, cheaper, better

In this approach, value is defined as gaining things from the given organization that are faster, better, or cheaper than they are elsewhere. Figure 4.1. shows these customer expectations as three dimensions. These features are the determinants of market competition, and in everyday life, the contracts of organizations typically deal with them.

- Time can be interpreted in two ways: we want to get as many from the product or service and as quickly as possible.
- In terms of price, we are trying to find a solution as cheap as possible.
- On the quality issue, we see 'better' as something satisfying our expectations. The clarification of the latter is the most difficult based on what has already been presented. In general, this is usually divided into two areas. On the one hand, the quality of the product, which refers to the physical characteristics. On the other hand, the quality of the service, which includes the features that the customer sees and experiences. The interpretation of quality is supported by separate models in these two specific areas.

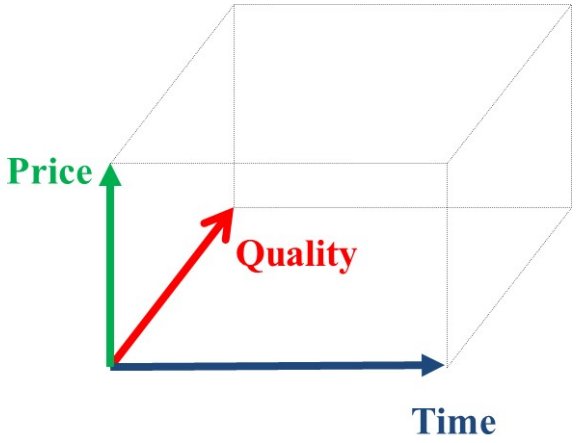


Figure 4.1.: Faster, cheaper, better

4.2.2. Eight dimensions of product quality

David Garvin (1988) defined eight dimensions that help to understand the quality characteristics of products. It is worth noting that some of the dimensions mutually reinforce each other, while others are the other way around. By being able to understand what trade-offs our customers want among these dimensions, we can gain a significant competitive advantage. Garvin's eight dimensions of product quality are:

1. Performance: the primary function of the product.
2. Special features: secondary, additional features that extend the core functionality.
3. Reliability: the probability that a product will not fail within a specified period under specified circumstances.
4. Conformance: the degree to which the planned and operating characteristics of a product conform to the accepted standard.
5. Durability: the length of time while the product can be used before it deteriorates to such an extent it has become so unusable that the replacement with a new product is more desirable than repair.
6. Serviceability: the possibility, speed and ease of repair. The courtesy and competence experienced during the repair process are connected to this as well.
7. Aesthetics: the aesthetic factor is mostly the result of personal judgment and reflection of individual opinion. This is a highly subjective dimension (how the product looks, how the product sounds, its touch, taste or smell).
8. Perceived quality: the brand, the reputation and the associated reputation can be decisive. Consumers do not always have exhaustive information about the characteristics of a product or service. In such cases, only indirect measurement methods or perceived quality detection are the starting points for comparing individual brands.

4.2.3. Ten determinants for service quality

Based on empirical research, Berry et al. (1985) formulated ten determinants of service quality. The categories are as follows:

1. Reliability: a constant level of performance that provides customer trust; providing the right service for the first time; adherence to promises; accuracy.
2. Responsiveness: the willingness or readiness of the employee to provide the service.
3. Competence: having the skills and knowledge to deliver the service.
4. Access: approachability and ease of access; waiting time; operating time.
5. Courtesy: the polite and respectful attitude, the attentiveness and friendliness of the staff towards the customer.
6. Communication: informing customers on an ongoing basis with the appropriate language; monitoring the customer's word and signs.
7. Credibility: trustworthiness, honesty; reputation.
8. Security: freedom from hazards, risks and doubts (physical security; financial security; discretion).
9. Understanding the customer: striving to understand the wants, unspoken and spoken needs of the customer.
10. Tangibles: the physical appearance of the service; the external image of the service premises; the appearance of staff members; state of used tools and equipment.

Many of the ten determinants of service quality that Berry et al. (1985) have expressed (proposed) were considered less usable in practice, resulting in a shortened list of five broader elements:

- reliability (ability to perform the service accurately),
- assurance (knowledge, ability, credibility, courtesy of employees),
- tangibles (physical appearance),
- empathy (care, attention to the individual), and
- responsiveness (willingness to help, to provide the service).

4.2.4. The collection of quality features

With the models just presented, each organization can build a comprehensive system of quality features for their products and services. As shown in Table 4.1., Garvin’s dimensions and Berry’s determinants can be connected to the single list: faster, better, cheaper.

Table 4.1.: The collection of quality features (Tenner, DeToro, 2004)

	Deliverable things	Interrelationship
Faster	Accessibility	Responsiveness
	Comfort	Accessibility
Better	Performance	Reliability
	Extra features	Safety
	Reliability	Competence
	According to standards	Credibility
	Serviceability	Empathy
	Aesthetic appearance	Communication
	Perceived quality	Style
Cheaper	Price	

The elements of quality can be divided into two components: deliverable things and interrelationships. On the one hand, we consider the qualities that we provide to our customers as deliverable things. On the other hand, interrelationships are the characteristics of behaviours and styles that affect customers while being part of the process. By defining the deliverable things and interrelationships with the involvement of customers, this framework can be useful for identifying the possibilities for improvement in the long run.

4.2.5. Unspoken, spoken and latent needs

In order to better meet customer expectations, it is necessary to measure quality, but first of all, the characteristics that are important to them need to be defined. Features expected by customers form a hierarchy of three levels: basic expectations, specifications/needs, and delight, as shown in Fig. 4.2. These three levels are often called unspoken (implicit), spoken (explicit) and latent needs. Classification in this way helps to understand and define the level of performance required to meet customer expectations.

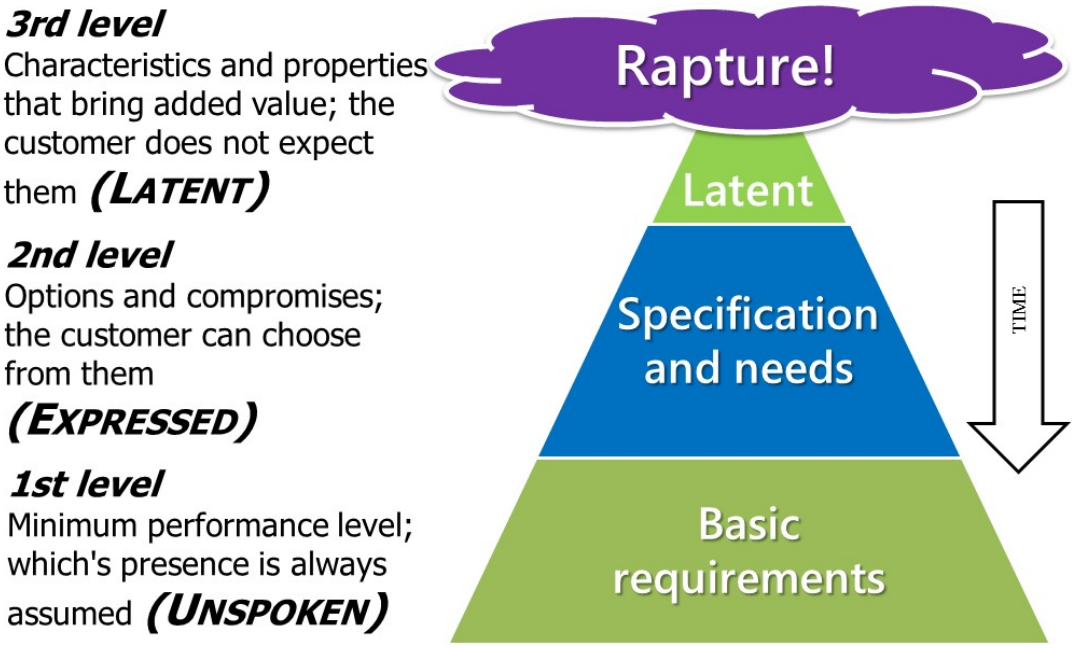


Figure 4.2.: Unspoken, expressed and latent needs (Tenner, DeToro, 2004)

The lowest level, the unspoken needs of the model are the basic requirements that indicate the minimum performance level. We always assume that they are present, and if they are missing, customers will always be dissatisfied. The mid-level, spoken needs are represented by specifications and needs that are visible and optional to the customers. Regarding the spoken needs, customers openly negotiate and compromise on terms. The highest level of performance is represented by the extras of added value that the customer was unaware of, but welcomes with great pleasure. At the level of latent needs, the needs are real but not visible and not evident to the customer. However, excellent performance at this level does not merely mean that we deliver more than previously agreed.

If we can recognize the characteristics associated with the performance levels, we will see which features need to be discussed in details. Applying this model helps to predict how the customer satisfaction levels respond to changes in typical attributes, and what expectation trends can be expected in the future, and so on. In conversations with customers, we need to focus on the features of level two, as customers are sure that the basic expectations (level 1) are fully met. It cannot be expected from the customers to evaluate 3rd level special features without experiencing them, either.

A characteristic of the model – regrettably from the supplier side - is that it is neither permanent nor temporal. At the very same moment, very similar customer segments in different parts of the world evaluate the same features differently, thus setting up a different hierarchy. On the other hand, in a given location, in a given customer segment, it can be observed that over time, the characteristics of the top-level are rolling down to lower levels. To put it bluntly: what caused delight as a latent need yesterday can be pronounced as a spoken need today. Just as features form the second level of expectations nowadays can be expected to be implicit needs later on.

There also exist a 'hidden' level of performance that will only be visible when disappointed customers return to their 'supplier'. It can be proved that a positive response to the complaints can directly make an advantage. If we can deal with complaints quickly and efficiently, we make our customer loyal instead of disappointing him.

4.3. Methods for customer satisfaction analysis

The ultimate purpose of defining products, identifying customers and their needs is to fulfil the customer's needs and expectations and thereby increase customer satisfaction. As we have already pinpointed, the needs and expectations of the customers are steadily increasing. While we meet their current needs, they are getting more favourable opportunities from the competitors. Companies that focus too heavily on the inside and do not monitor market changes will lose their customers over time and thus their market share. The employees need to focus not only on meeting the needs of their direct internal customer but also on the ultimate external customer who will eventually become a customer of the product. He is the one who ultimately pays the bill to fund the organization's efforts. All individuals need to know how the products and services are judged on the market and that external customers pay for the job. This idea is indispensable for creating customer focus. The essence of achieving quality is identifying customer needs and satisfying them.

Two groups of information flow from customers to suppliers in the organization:

- requirements: the product and service characteristics expected by the customer before the item has been delivered;
- feedback: feedback about what the customer liked and disliked in the product (satisfaction or dissatisfaction).

Figure 4.3.: Undertanding the customers

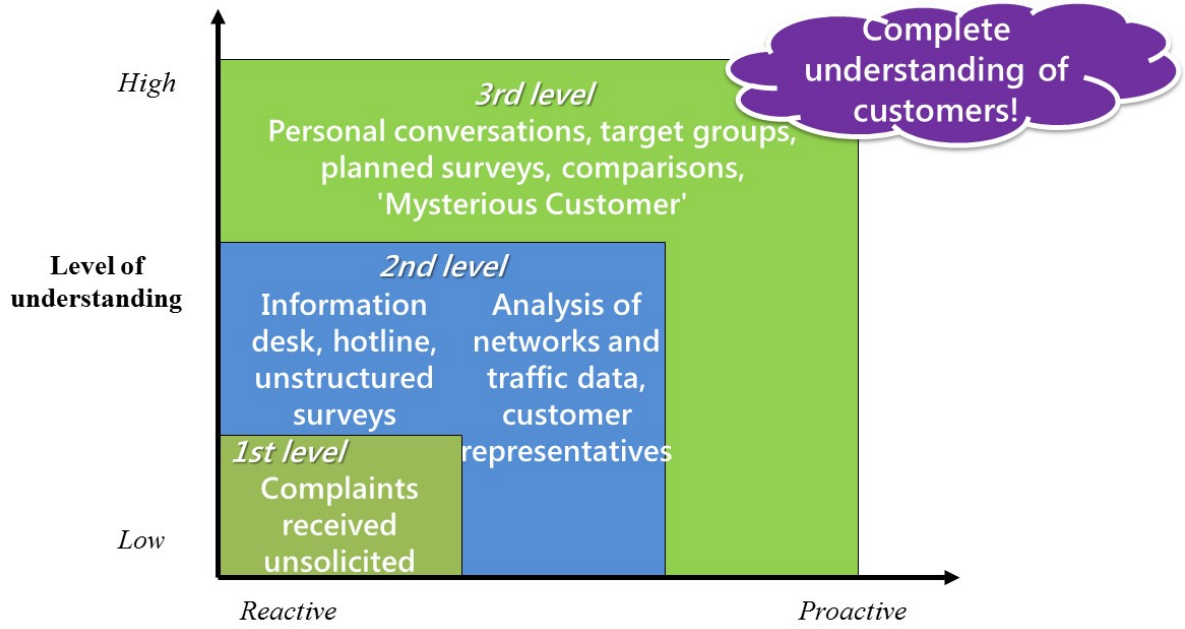


Figure 4.3 shows a two-dimensional framework for grouping mechanisms for understanding customers, in which the horizontal axis represents the approach initiated by the supplier moving from reactive to proactive, while the other axis indicates the level of understanding likely to be achieved by each mechanism. The extent of the individual levels is not distinct, but three different levels can be distinguished. The boundaries of the methods are not as sharp as we have shown in the figure.

Level 1 refers to a *reactive attitude* that provides only a minimal understanding of customer expectations. Reactive attitude is primarily about collecting complaints. In this case, many factors make it challenging to get to know the expectations and satisfaction level of customers:

- The information stems from a biased, non-typical customer group which is angry enough to complain and they do it often already in the form of a solution.

- Not everyone of the angry customers voluntarily provides information to the organization, even if they do, not totally.
- Organizations at this level are usually not ready for real collection and meaningful analysis of such data. not prepared enough for the collection and analysis of this kind of data.
- Employees of the organization who receive the information in this way are mostly concerned with trying to solve customer problems or defending themselves against accusations.

These obstructive factors can be minimized, thus maximizing the value of level 1 mechanisms is possible. Customers mostly do not complain because they do not have information on:

- how to address their complaint, or
- whom they should address it to, or
- because they feel that the complaint is not worth the effort.

They can be helped on the one hand, by clarifying the possible ways of complaining, on the other hand, by trying to make an advantage out of trouble as responding quickly and effectively to problems. It is worth to supporting and rewarding the employees who receive the complaints.

We can reach a higher level of understanding at level 2 if we listen to customers through active approaches. We are actively communicating with customers but paying attention to customer expectations is only a secondary goal. The fundamental goal is to answer customer questions or to sell more/new products. Active approach is effective, but it is still not a complete solution, since the following mechanisms are designed to meet their own goals: information desks or hot lines analysing traffic data, customer representative feedbacks and unstructured surveys.

To fully understand the expectations, there is a need for methods that have been developed to collect this information. Level 3 approaches include personal conversations, focus groups, and designed surveys. A particular method is mystery shopping, which allows the company to get to know its customers' point of view.,In addition to that, mystery shopping enables companies to gain objective data on the service.. Discussions and surveys with previous customers can often provide concrete, objective information about the shortcoming of our products and services.

4.3.1. Customer window model

The customer window model is a method that can be used to examine customers' needs, expectations and perceptions, and to interpret the results. First, we clarify and divide the customer base into segments. Later, using questionnaires, we determine the relative satisfaction with product or service characteristics, (received or not) and their importance (desirable or not). Finally, the results are organized into four quadrants (Figure 4.4). one can determine whether a particular quality characteristic is desirable or not and whether the consumer received it or not. Finally, the results are organized into four quadrants (Figure 4.4).

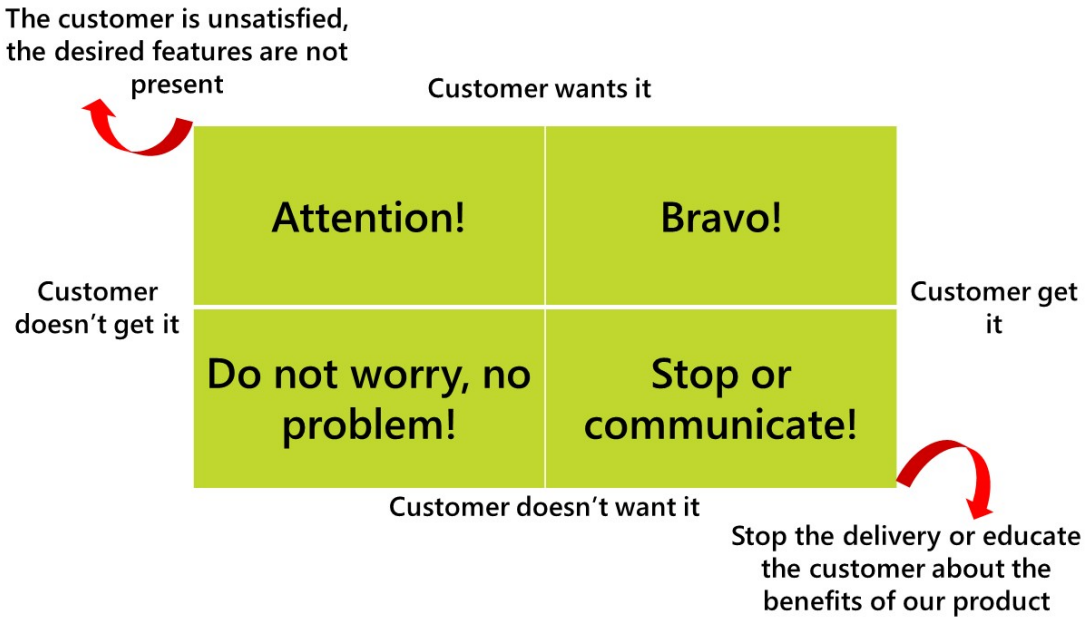


Figure 4.4.: Customer window quadrants (Tenner, DeToro, 2004)

Four areas are shown in the figure:

1. Keep up the good work – Bravo! – the most desirable: elements of existing competitive advantage
2. Concentrate here – Attention! – to be developed: a source of problems,
3. Low priority – Do not worry, no problem! – low priority: developments are less effective
4. Possible overkill – Stop or communicate! – unnecessary use of resources: performance can be reduced, or customer expectations increased.

The method is also called the importance-performance analysis (IPA).

4.3.2. Quality Function Deployment

Quality Function Deployment (QFD) is a Japanese quality management method that uses a well-structured matrix technique to match the customer's needs to technical features. Further, the method component features define process characteristics and manufacturing tool settings. After all, understanding customers includes identifying customers and their needs and how the organization can meet their needs. Defining QFD method and process is the primary and most important goal of the organization before production begins. Total customer satisfaction and the minimum amount of design changes can be ensured only by this method.Once a product has been defined, QFD allows us to focus on customer needs during design processes. (Kiran, 2017)

Yoji Akao and Shigeru Mizuno developed QFD in Japan at the end of the 1960s. In 1997, an international symposium aimed at creating a unified body to help coordinate many local QFD organizations, efforts and events. The method had spread to the industry after the ICQFD (International Council for Quality Function Deployment) was founded. Each ISQFD symposium award the International QFD Akao Award. (Kiran, 2017)

QFD is a well-structured design method with which the product characteristics and critical values of the production process are adapted to customer needs. Customer expectations can be translated into technical language, the manufacturer's language, in every stage of product development and production.That is,, the QFD summarizes and connects the Voice of the Customer (VOC) and the Voice of

the Organization (VOO) values, and as such, 'both sides of the coin' are incorporated in this technique. At the same time, it is also a documentation tool that allows us to get an overview of the design steps afterwards.

The advantage of using QFD over other methods is communication and teamwork among design, procurement and manufacturing professionals. QFD reduces the likelihood of misinterpretation of emerging needs and expectations. As a result, we get the importance order of the product and process parameters to reduce the time needed for development.

A unique feature of the method is that the special tables used for the different mappings are called houses according to their specific shape and layout.

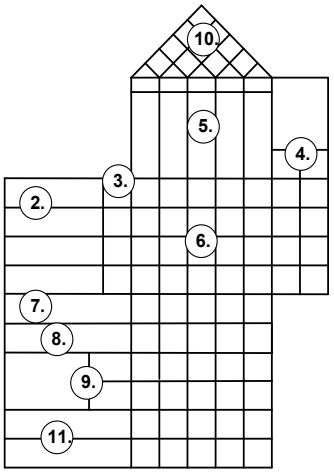


Figure 4.5.: The structure of the quality house

Figure 4.6. shows that there are four QFD houses in total in the QFD process. The first house (Figure 4.5.), which is commonly referred to as a quality house based on the customer needs, contains a list of technical characteristics that affect the mentioned needs and the determination of their value. These characteristics are the starting point of the second house, which is responsible for defining the detailed characteristics of the components. The next house is drawn with involving the management. In this phase, based on the subtasks, the technological characteristics of the components that require inspection and control are developed. The third house is the transition between planning and implementation and is used to determine the technological (production) characteristics. In the fourth house, control points and methods can be developed based on technological features.

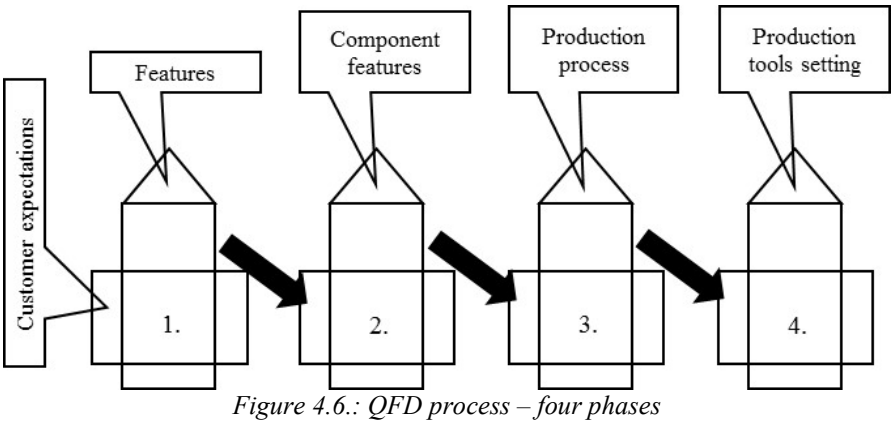


Figure 4.6.: QFD process – four phases

Figure 4.6. shows that the QFD can determine the target values of the entire design and production process, derived from primary customer requirements.

Steps in the quality house method (steps shown in Figure 4.5):

1. Determine the purpose of using the selected tool. It can be used to develop a new product, to improve an existing product, or even to introduce a new technology or service.
2. Customer/User Needs Assessment (VOC). At this step, the rules for representative sampling have to be considered based on which the appropriate group of users of individuals can be chosen. Several methods can be used to assess the needs, e.g. questionnaire, interview, brainstorming technique. It is vital to use the customer's own words when collecting the requirements and not to reformulate them using technical language. At the same time, however, it is advisable to investigate whether the regulatory or other requirements do not conflict with the requirements.
3. Not every need is equally important. To illustrate this, we assign a weight number of 1-5 in a separate column. For example, peer-to-peer comparison or user ratings can applied to determine the weights.
4. User opinion, evaluation, competition analysis. Transparency is enhanced by a chart attached to the side of the House, one of the axes of which is the customer needs, and the other axis contains the individual grades. This opinion can serve as a basis for the company's strategic plan for the service in question.
5. The next step is to answer the “how” question (VOO). In this case, the technical characteristics that affect the satisfaction of the individual customer’s needs are determined in the language of the designers and engineers. These technical parameters describe the product with measurable characteristics so that the result can be measured and compared to the goals.
6. Completing the connection matrix. This step is the essence of QFD application. Confront customers' needs with the appropriate technical solutions. In this step, we assign one or more technical features to each user requirement, i.e. we replace the user's wishes with the appropriate technical parameters or solutions. The matrix form is best used to represent this connection system. We have a look at each need - technical parameter pair. Of course, only those pairs are identified, for which the relationship can be interpreted. Leave the remaining squares blank. In the interpretable grid points, we can also indicate the strength of the relationship, as the impact can be different. These links should be numbered or signalled. For example, in the case of numbering, at the points of intersectionthe following points can be given to characterize the influence:

   1 - a strong negative relationship (the increase of one characteristic causes the decrease of the other);

   2 - negative relationship;

   3 - no connection;

   4 - positive relationship;

   5 - a strong positive relationship (the increase of one characteristic causes the increase of the other characteristic).

It is important to note that if there is an urgent need for a technical feature, it is worth paying attention to it. However, if the column remains empty, only the designers consider it essential. In this latter case, it is worth examining whether it is worth to deal with the given technical parameter.

7. Examining organizational feasibility. An important aspect of comparing individual technical solutions is how difficult it is to implement it. Here, it is worth considering all the effects at the organizational level.
8. Defining target values. For each technical parameter, we must strive to give a specific value as an objective to be achieved.
9. Technical analysis. The experts of the organization examine their own and the competing products and classify them according to the technical parameters, usually on a scale of 1-5.
10. Filling the roof matrix. The effect of the technical features cannot be separated from each other. With the help of the roof matrix, we examine, among other things, whether there is a connection between the important and the less important technical characteristics. The same method can be used to mark these relationships as in the connection matrix. A scale from 1 to 5, in which the numbers have the same meaning as described above.
11. Determination of important values. In this step, the most significant advantage of QFD is shown. It can formulate and quantify the resulting impact of information, data, and customer preferences that are systematically collected from different areas in the priority numbers. The results of the calculations are displayed at the bottom of the House (Quality Proposal). There are several methods to determine the importance of technical characteristics. For example, we can use a connection that considers the direction of correlation:

$$F_j = \sum_{i=1}^{n} S_i \left(k_{ij} - 3\right)\left(5 - V_i\right)$$

where F_i – the importance of the user's need; S_i – the weight of the user's need; k_{ij} – the element of the relationship matrix; V_i – the perception of internal customers; i – the rows of the relationship matrix; j – the columns of the relationship matrix.

So, the importance value can be calculated based on the elements of the relationship matrix and the order of the customer requirements. It is worth examining the formula. It can be seen that if the user considers the current situation to be suitable for a particular need (5), the second member of the formula on the right side will be 0, reducing the final result, the importance value. If there are more of such requirements for a technical parameter, it means that it is not worth dealing with the development. However, the question arises what happens if we do not consider the current assessment of customers. Then the second member falls out. The order of importance numbers does not change; only lower values are obtained.

The completion of the additional QFD 'houses' is done along with similar logic, but with different content.

5. PROCESS MANAGEMENT

5.1. Process approach

One of the main principles of TQM's philosophy and all of the dominant quality management trends of today is the process approach. As organizational size increases, functional organizational units come to the forefront, and employees live their daily lives within their organizational units. Their job is not to meet the needs of their internal customers, but to meet their superiors' expectations. However, the success of an organization is determined by those activities that serve the needs of external customers, in addition to that focusing on the internal customers is an inevitable element of success as well. The application of the process approach, regardless of organizational size, focuses on these activities and make them the key which will serve the development of the operations. Thus, applying the process approach requires dealing with the processes without regard to the boundaries of organizational units (Figure 5.1)

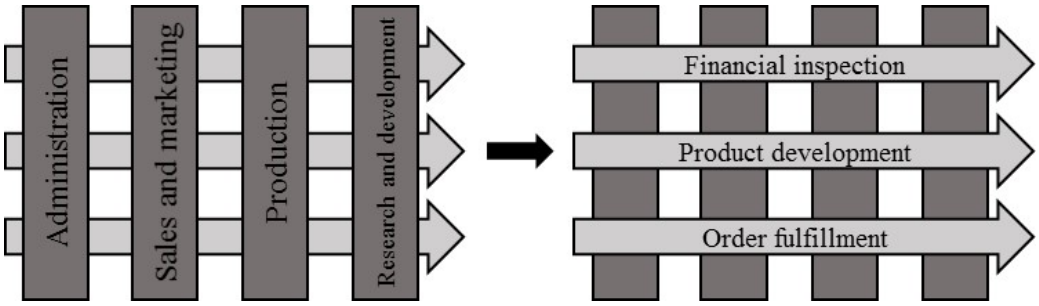


Figure 5.1.: Process approach among organizational departments

Based on several different process definitions a general definition can be created: a chain of activities in a specific order that transforms

- inputs into outputs
- for a partner or another process
- with the help of individuals, processes, and tools (resources). (Tenner, DeToro, 2004)

Many models support the understanding of organizational processes. The macro-level approach focusing on roles and interactions is shown in Figure 5.2.

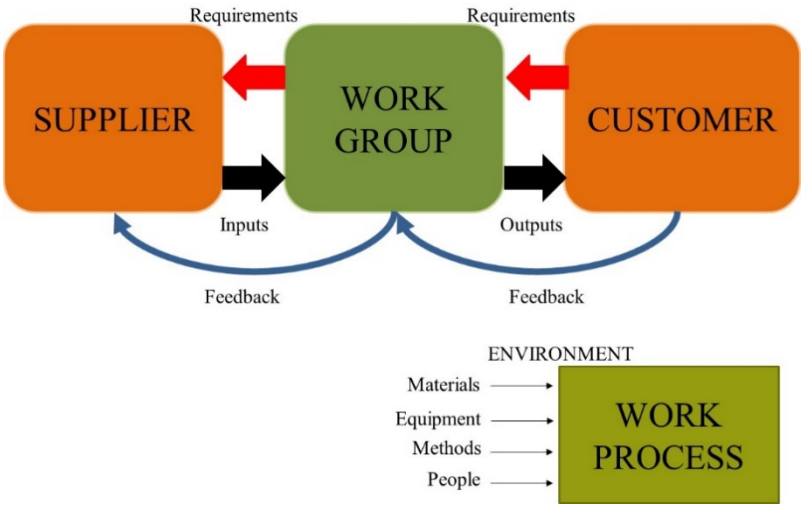


Figure 5.2.: Participants of the process and their connections (Tenner, DeToro, 2004)

Four groups of people are involved in the operation and improvement of processes (Tenner, DeToro, 2004):

- Customers: the person (or people) for whom the product is being made (or for whom the service is being provided). Customers are the people who use the product or service directly or insert it as input into their workflow (internal customers).
- Workgroup: the person (or people) who is working in the process to produce or deliver the desired product.
- Suppliers: the person (or people) who provides input to the workflow. The workers in the process are considered as the customers of the supplier.
- Owner: the person (or people) who is responsible for the operation and improvement of the process.

As described above, customers determine the product required from the process, through two broad categories of information that flow from customers to the work group. The first category includes needs: a description of what customers want, expect and need. The needs determine what the process should create. Feedback is the second fundamental element of communication: explaining how well (or how badly) the product was delivered compared to the customer's expectations. This feedback is vital to improve the process since the main aim of process improvement is to minimize the 'gap' between the characteristics delivered to the customer and their expectations. On the supplier's side, the product flows, and the information flow reflects the customer's side.

The process approach is illustrated by the following micro-level focused model (Figure 5.3.), which helps to understand the two underlying critical issues.

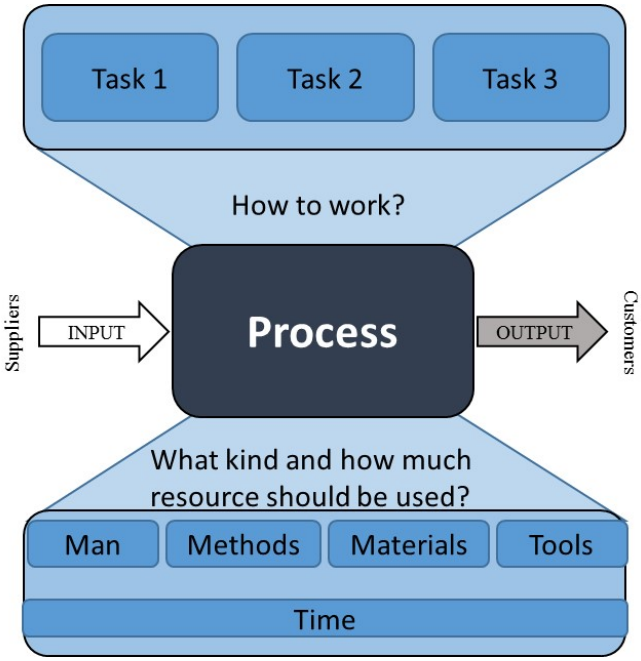


Figure 5.3.: Two key questions are needed to be answered to achieve process-centred thinking

By identifying the process, we look for the answer to the following two questions:

1. How should we work, i.e. what activities do we have to implement?
2. What kind and how much resources should we use to carry out our activities?

It is also worth highlighting the following features of any process:

- goal-oriented, that is, the implementation of the list of activities has a clearly defined purpose;

- creates value for the customer, that is, it seeks to satisfy the needs and expectations of external or internal (the next performers of the process) customers;
- a characteristic of it is the transformational nature meaning the inputs will be the further shaped outputs by the implementation of the activities.

Recognizing the importance of processes has brought the process management area to life. The process management approach considers the organization as a system and network of processes, which includes the coordinated efforts of repair and improvement. Many organizational processes need to cooperate with HR, IT, controlling and other areas, which makes process management a complex activity. In connection with other functions, the structure supporting the organizational strategy and its implementation should be considered.

The activities related to the processes:

- identification: for understanding the organizational operation,
- control: for achieving the stated and expected performance,
- analysing results and improvement: by optimizing existing processes or creating new ones.

On the one hand, identified and controlled processes can ensure that the organization operates in a clear and standard way. On the other hand, it provides the opportunity to carry out measurements and thus make well-founded developments possible.

The most important, necessary activities for managing any organizational process are summarized in Gabriel Pall's Quality Process Management book (Pall, 1987, in Tenner, DeToro, 2004):

- Identification of the owner: identifying the person or group responsible for the design, operation and repair of the process.
- Planning: developing a structured and disciplined approach that helps to understand, define and document all the process components and their interactions with each other.
- Check: ensuring the efficient operation of processes so that all of the products are produced predictably, and they meet our expectations.
- Measurement: determining of performance characteristics that meet customer needs and setting criteria for the acquisition, accuracy, and frequency of measurement and control data.
- Improvement: increasing process efficiency by permanently implementing the identified improvements.
- Optimization: increasing efficiency and productivity by permanently integrating the identified improvements.

5.2. Process identification and classification

Identifying and grouping organizational processes are the first steps in process management. It is advisable to prepare the process inventory or process map, which contains a detailed list of the processes of the organization, so its compilation is indispensable for system-level investigations. It is advisable to identify the external customers, suppliers (and associated products, services, resources, raw materials) of the organization during the collection of the processes, and then assign them to more detailed processes. A process owner is responsible for operating the entire list of activities and is authorized to correct or improve the process, even by crossing the functional boundaries of the organization.

The collected processes can be grouped according to different aspects. Generally, the following more or less overlapping major groups are identified, based on the characteristics of the process and its role in the organization:

- main processes;
- supporting processes;
- supplementary (additional) processes;
- management processes;
- key (critical to success) processes.

The *main processes* are the processes related to the primary aim of the organization, the satisfaction of external customer/partner needs. They significantly contribute to achieving the goals of the organization. One may recognize them as the processes at the beginning and end of which external customers are and as such, these processes have a direct impact on external customers satisfaction. *Supporting processes* accompany the main processes, provide data and information, and support the implementation of core activities. *Supplementary processes* are only loosely linked to the core activity of the organization, but it is not possible to perform the necessary activities effectively without them. Processes related to organization management, strategy identification and implementation are called *management processes*.

Key processes differ significantly from the previous groups. These are processes that fundamentally affect the success of the organization. Not only the main processes can be key processes, Indeed, key processes may stem from any groups mentioned above. In order to find the key processes of an organization, it is necessary to identify those processes that have the most significant impact on customers. The following questions should be considered (Tenner, DeToro, 2004):

- Which products and services are the most important for customers?
- Which processes produce these products and services?
- What are the key factors that stimulate action within the organization and which processes are the ones that turn customer inputs into products?
- Which processes are most in focus?
- Which processes have the most significant impact on the levels of performance required by customers?
- According to the data and common sense, which processes provide the highest level of improvement opportunities?

The answers to the above-written questions will, of course, be dissimilar for different types of organizations, and may vary from time to time. Depending on the current situation and strategic goals of the organization, the focus can also shift from the main processes to supporting processes. Identifying key processes is also crucial because the organization needs to focus on the improvement of these processes, and it should provide the resources available for improvement accordingly. However, as these processes often cross functional boundaries, they are often paid less attention than needed.

Several methods can be used to record organizational processes. They can be described in plain text, in tabular form, with a graphical solution (flowchart), or by using process models supported by methodology- and databanks. Whatever method we choose, the types of information to be recorded should be identified by the definition of organizational processes (and models), and by the personal needs.

5.3. Process improvement

Organizational departments, employees, traditionally focus their attention on functional goals, to perform, maintain and control the operations and activities under their supervision. Process owners need to focus on the entire, comprehensive system that delivers products and services to customers and improve the performance of this system.

TQM philosophy improves quality on the one hand, by prevention, and on the other hand, by a systematic development of key processes. These corrections, improvements are never about firefighting, i.e. they are not primarily focused on short-term problem-solving.

Business managers are often accused of being short-sighted and mostly focused only on the short term. One of the manifestations of this phenomenon is the significant attention on short-term fixing of problems and immediate results. One of the keys of breaking out of this circle and establishing a longer-term perspective is to strengthen the underlying business processes rather than dealing with each specific product, order, and difference. Process improvement represents the second fundamental principle of TQM, focusing on the systematic and continuous improvement of processes.

5.3.1. The six steps process improvement model

The six-steps process improvement model (Tenner, DeToro, 2004) is a commonly used method, the elements of which can be found in other methods as well. This model illustrates at best the steps we need to take to improve processes systematically. The model is well suited for both the production and non-production sectors. The six steps of the model are shown in Figure 5.4.

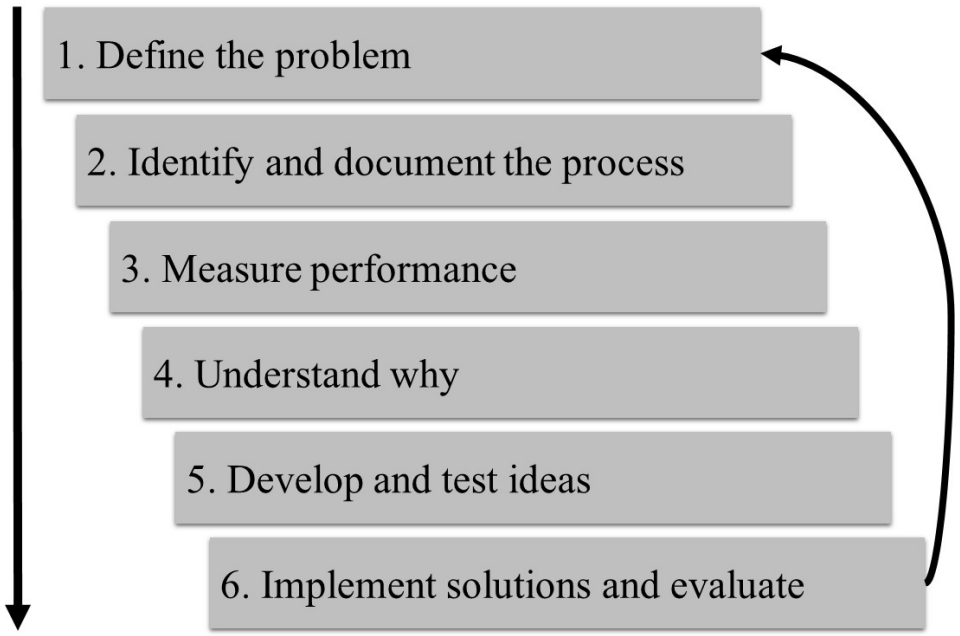


Figure 5.4.: Six steps process improvement model (Tenner, DeToro, 2004)

As a starting point, we identify the products, customers, and workflows that produce these products. The method then proceeds with a thorough examination of customer needs and defines the difference, the gap between the performance of the associated workflow and the mentioned customer expectations. Then the exploration and analysis of these processes should be carried out in order to understand the hidden causes of these gaps. It also encourages the development of new products and processes

and requires that these new ideas be tested with data. Then, appropriate changes are applied in practice, their effects are evaluated, and the entire cycle is repeated to ensure continuous improvement. Table 5.3. describes a checklist for performing these process improvement tasks.

Table 5.3.: Typical actions and features of six steps process improvement model (Tenner, DeToro, 2004)

1.	**Define the problem**
	- Identify the final product - Identify the customers - Define the needs - Identify the processes - Identify the owner of the process
2.	**Identify and document the process**
	- Flowchart - Model - Identify the participants
3.	**Measure performance**
	- Customer satisfaction - Customer needs - Delivered final product - Process parameters - Cost of quality
4.	**Understand why**
	- Distinguish the main areas - Analyze the root causes - Understand the differences - Common reasons - Specific reasons - Performance
5.	**Develop and test ideas**
	- Develop new ideas - Experiment - Examine ideas to address the root causes
6.	**Implement solutions and evaluate**
	- Plan the proposals, ideas - Implement system changes - Document changes in the system - Evaluate system performance - Evaluate the six steps - Reward participants - Let's start again from step 1

5.3.2. PDCA cycle

The six-step map guides us to the application of a basic improvement strategy, known as four different names: P - D - C - A, plan - do - check - act, Shewhart cycle or Deming cycle (Garvin, 1988). The ‘plan’ section is guided by the first four steps along the road map, which help to clarify the problems and formulate hypotheses for their causes. Step 5 covers the ‘do’ and ‘check’ sections by testing the previously formulated hypotheses. Step 6 closes the cycle (‘act’) by applying process improvements in practice and systemizing them. (Figure 5.5.)

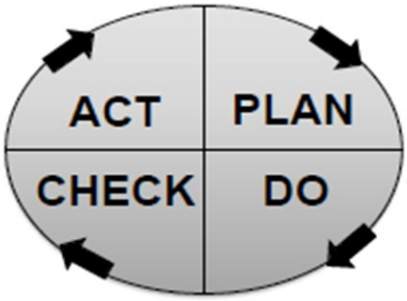


Figure 5.5.: PDCA cycle

Apart from PDCA, there are a high number of alternative methods, and many organizations have started to use the six-step model modified according to their own needs.. Some have modified the terms to include their jargon. Some have reduced the number of steps by combining a few elements, while others have increased the number of steps by separating them. A popular alternative, for example, is the PDSA cycle, where the third step is Study, which means studying the results and drawing conclusions.

5.3.3. DMAIC cycle

The structured and well-developed solution of the problems, the improvement of processes in Six Sigma programs, are implemented with the help of the DMAIC methodology, which focuses on the Plan phase of the PDCA cycle. Like the PDCA, the DMAIC word is the abbreviation of the initials of each step:

- Define: defining process improvement goals in line with corporate strategy and customer expectations. In this step, we will look for failure (problem) opportunities, prioritize topics for improvement, select the scope of the project, and compile the team working on it.
- Measure: mapping of the functional characteristics of the given process, selection of indicators, planning of data collection, and carrying out of measurements.
- Analyze: analysis of data, creation of process maps, determination of causes, determination of improvement possibilities.
- Improve: developing, designing and implementing creative solutions to avoid problems in the future.
- Control: checking the implemented improvements, examining whether the changes result in better outcomes and whether the typical process parameters are permanently improving.

5.4. Quality management methods and tools

In our world, recently showing ever more rapid development and becoming more complex, the process of problem analysis and finding the possible alternatives are not easy tasks. In many cases, there is no time to find the right solution because in many cases there are too many variables. Often, we do not know all the environmental conditions, and a single person is no longer able to see and know all the areas affected by a problem. Taking these characteristics into account, teamwork and the application of different management methods are typical ways of organizational operation today.

In the quality management literature and practice, nowadays 50-100 different methods and techniques are proposed. This number is difficult to determine because some of the newer methods appear as the mutations of a previously known. It is challenging to decide on these mutation methods whether they can be considered as a stand-aloneapproach,, so we can only give a rough number.

Some of the methods and techniques, like the fishbone diagram, have been explicitly developed in quality management practices. However, the majority of the methods comes from other management areas or other fields of science (e.g. flowcharts, histograms, brainstorming).

Because of the relatively high number of methods, researchers formed five groups of quality management methods.

1. Idea collecting and problem-solving methods

The application of quality management methods generally is executed in the form of teamwork. During this teamwork, it is essential to summarize the ideas and opinions of each participant, as getting to know them can lead to better, more innovative solutions. That is why it is essential to know the methods available. In this group, we consider the brainstorming as the most valuable primary method, but we should also mention affinity diagram, NCM and Delphi methods. These techniques should not be considered as the centrepiece of quality management, but rather as tools that provide the team with a starting point for the application of multiple methods.

2. Methods for describing processes and collecting and analysing data related to processes

In practice, related to quality assurance systems (e.g. ISO 9000, IATF 16949) or quality management models (TQM, Six Sigma) it is expected to be able to describe activities, document and monitor processes. This group includes methods that help to understand the process-based organizational operation and to measure related goals and outcomes. The most important of these methods is the flowchart, but here are some other methods, such as process description, competency matrices, checklists, question lists, and data collection sheets.

3. Failure Analysis Methods

Although state-of-the-art quality management models emphasize the prevention of failures, in practice, even the most carefully designed processes are affected by errors sometimes. Analysing the problems that have already occurred or are likely to occur offers the possibility to modify the process so that one can avoid the emergence of the problem. As such, failure analysis methods can be considered as some of the most effective QM tools and they are also widely applied to risk assessment. Among these methods, the most important, most commonly used methods are the ABC-Pareto method, the cause-and-effect analysis, and the FMEA method, 5M-9M, 5W + 1H, tree diagram, cause-and-effect matrix.

4. Methods for process control and assessment of process performance

At first glance, quality management may be found as a field using only soft techniques with not so many numbers. However, this is not the case at all. Many quality management tools use measurements, counting, mathematical-statistical methods to analyse and evaluate each production or service process. These methods are primarily related to quality control and statistical process control. Here are methods such as control charts, process, machine, and measuring equipment capability methods.

5. Other methods and techniques

In addition to the methods mentioned above, further quality management methods are known, but we do not wish to group them separately according to their field of application, just pointing out some, e.g. QFD, 5S method, 8D report or Kano model.

The wide range of methods used in quality management can often be grouped or categorized according to other characteristics. One such commonly used approach is to form three groups according to the strengths of the methods:

- Hard methods: they are generally based on strong mathematical concepts; their application area is restricted. Hard methods can have more application conditions; they give the same reliability with fewer data.
- Quasi-objective methods: they usually work with scoring, ranking, their field of application is unique, and they have specific application conditions.
- Heuristic, soft methods: usually do not require, or only a small mathematical basis and their field of application is extensive. Soft methods rarely have application conditions; they provide the same reliability with significantly more data.

In this paper, we discuss only a few quality management methods and tools in detail.

5.4.1. Flowchart

A flowchart is an excellent tool for visualizing and understanding the process steps and their logical, chronological order. It is like a map that gives the same picture of the process itself as a geographic map navigates its user. It makes clear the connection among process steps facilitating the implementation of fault-free operation and the identification of improvement and repair possibilities. It gives an overview of the events and activities the process includes, presents their order and connection. The flowchart serves as a starting point for documenting and describing processes, allowing a more thorough examination, analysis and the assignment of necessary improvements. In the flowchart, each step is represented by various symbols, and the direction of the process, step by step, is represented by arrows that link the individual symbols. There are several variations of flowcharts, and various symbols can also be applied.

Generally, we distinguish four types of flowcharts:

- process flowcharts,
- competence flowchart,
- operation process chart,
- flow diagram.

The flowchart effectively helps the members and organizational units involved in the process to get a consistent view of the process and its operation. They can also be used to reveal whether the chain of process steps is adequately formed. Moreover, it shows the complexity of the process, explores disfunctioning areas, unnecessary steps or connections, and the places where simplification is possible. In the process of creating a flowchart, hidden redundancies, delays, dead ends, and indirect paths can be explored.

It is important to note that flowcharts provide the benefits mentioned above only if they accurately reflect the current process flow. Meaning, that flowcharts are accurate if the participants do want to explore what is happening in the process, and the team is aware of the actual operation.

In the following, the most common symbols are presented. Although we can use different symbols, it is vital to give the description all symbols used, and always use them as described.

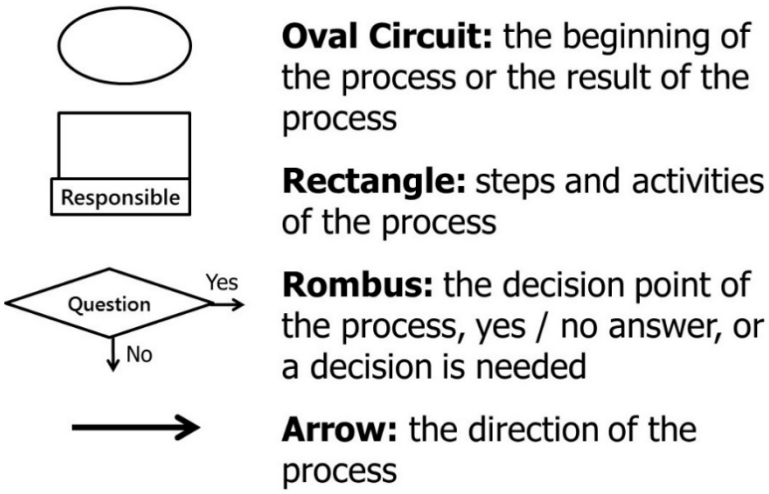


Figure 5.6.: Flowchart symbols

There are two types of flowcharts based on the level of detail in the investigation. They can be used effectively in different practical situations.

- High-level flowcharts or macro flowcharts: they contain just as much information as is needed for a general understanding of the process and they include no decision points. Here, a rectangle denotes a sub-process, which can be expanded to denote a plurality of activities and decision points. Typically, in such a macro flowchart, an activity is not connected to one responsible person; for example, it represents the collection of all processes related to a department or a division. (Figure 5.7.)

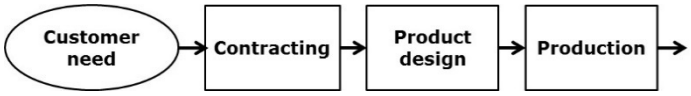


Figure 5.7.: Macro flowchart

- Detailed flowcharts contain every activity and decision points. We can draw different flowcharts depending on the level of detail. The degree of detail is the team's decision. (Figure 5.8.)

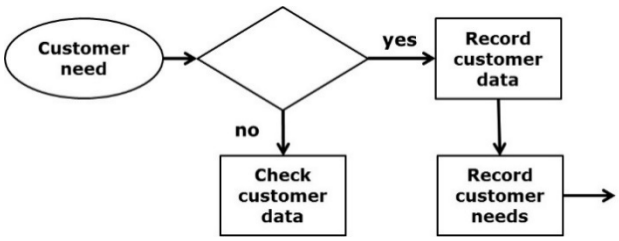


Figure 5.8.: Micro, detailed flowchart

The general process of creating a flowchart:

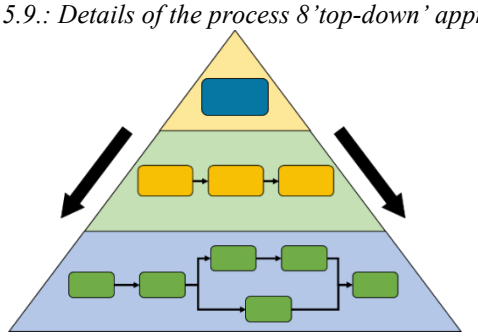
1. Identify the process, define its boundaries, define the start and endpoints.
2. Select the type of flowchart, the level of detail, and the symbols to be used.
3. Identify the steps and activities of the process and determine the order of the steps, activities and connections.
4. Prepare the flowchart with the help of appropriate symbols.
5. Examine the completeness of the chart (Are the symbols correct? Are all connections closed? Is there a connection point for each extension point?).

6. Evaluate the flowchart. (Involve the participants in the implementation. Is the process as it should be? Are there complicated, unnecessary parts? Does the current process differ from the ideal flow of the process? If yes, to what extent?)

When preparing the flowchart, it is recommended to consider the following:

- First of all, it is worth generating the picture roughly, and then gradually detailing it. This mapping approach is called top-down. Determining the appropriate level of detail is crucial. (Figure 5.9.)
- Each step needs to be examined in detail; accuracy and honesty are essential.
- Identify delays, loops, expectations, and value-creating steps.
- Check the completed flowchart with the help of the members of the organization involved in the process so that everyone can comment on it.

Figure 5.9.: Details of the process 8'top-down' approach)



5.4.2. Pareto analysis (ABC-diagram)

The most well-known, most commonly used method of failure analysis is the Pareto procedure, named after Vilfredo Pareto, an Italian economist. His idea was that a small portion of items has the most significant impact, while the larger part of the items has only a small impact. This insight comes from the observation that, in his era, the vast majority of Italy's land holdings were owned by a minor group: 80 % of the wealth belonged to 20% of the owners. This observation is the origin of the 80/20 principle.

By applying it, the 'significant few', can be well separated from the 'trivial many'. Pareto analysis is a method of categorizing the causes. By further categorizing the critical causes and linking Pareto analysis to other methods, we can make new categorization until we reach the 'vital few' group (Brocka, Brocka, 1992).

This observation has been extended to other areas of management. Today, the Pareto principle is the basis for several analytical methods used effectively in many areas of enterprise management and decision-making. For example, the approach can be used to identify the principal causes of problems, to analyse the causes of faults in quality management, and to determine the relative importance of each item in inventory management. In practice, the primary task of failure analysis is to identify the 'significant few' among all possible types of errors, error groups, errors places, error causes, factors, which can be significantly reduced by eliminating these failures. Joseph Juran, a famous quality guru, translated the Pareto principle into the area of failure analysis. He argues that in a system influenced by many factors, 80 percent of the actual errors is the result of 20 percent of the possible failure types. These will be the ones on which we should concentrate our limited resources, and later the more in-depth analyses and the concrete improvement and development actions.

In most cases, failure types can be divided into three particular groups: A, B, and C. In quality management, 'A' or critical failures are the 'vital few' type of error that result in a significant proportion of the presence of failures. Conversely, category 'C' is made up of failures that hardly play a role in the examined problem, and their impact is not significant. The 'B' type failures are not worth considering in the short term, but after the elimination of the 'A' type errors, these can be critical errors over time.

The Pareto or ABC diagram (in Figure 5.10.) is a unique bar chart, used for Pareto analysis. The horizontal axis (X) represents the possible types of failures and groups of failures arranged in decreasing importance. The vertical axis (Y) denotes the relative weight, frequency, and importance of each error type as the height of the columns. The quantity displayed on the Y-axis is most often the frequency or relative frequency (failure rate) of each type of error. The frequency of failures can be quantified (in the case of a properly designed failure analysis system). It may also be appropriate to select the quantities that represent the loss caused by the particular type of failure. An analysis of the costs of failures would be fundamentally better from an economic point of view, but in several practical application it is hardly possible to accurately determine the costs of errors. As a compromise between frequency and failure cost, in practice, there are Pareto analyses that evaluate each type of failure according to some weighted frequency. Determining the weights can be – at least in some cases – subjective, and therefore, the most frequent representation is based on frequency (Dale et al., 2007).

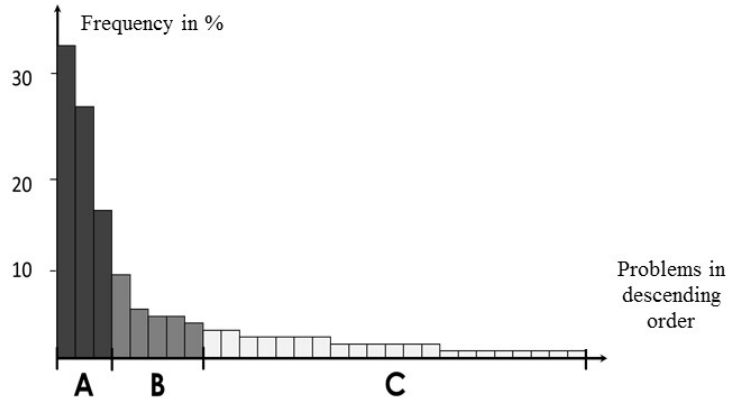


Figure 5.10.: Typical ABC (Pareto) diagram

The first step of Pareto analysis is to determine the problem to be analysed and the information to be collected as accurately as possible, based on which we need to identify the possible and relevant failure types related to the problem. It is also necessary to decide on which unit of measurement the severity is measured. It is advisable to choose the most measurable (objective) index that expresses the severity of the faults. In order to complete the data collection, the period to be examined is to be determined as well, and a data collection sheet suitable for the investigation needs to be created. It is worth to record the planned data collection process in advance. Efforts should be made to gather as much data as possible.

While creating an ABC diagram, the data grouped into the failure types must first be summarized, and their relative frequency must be determined. In the bar chart, the severity of the causes is displayed in descending order. (Except for the "Other" category that is always the last column.) The process of creating the chart is often supplemented by drawing the cumulative curve - the values of the cumulative relative frequencies. The slope of this and the intersection of the horizontal line with the cumulative curve at the 80% value indicate the most pressing problems. (Besides, it should be

noted that in practice, even the 1/3 - 2/3 ratio pair can be considered as a good result. For example, the most important types of errors are about one-third of all types of errors and generally cause about two-thirds of the undesirable effect.After determining the sever causes of the problem, it is possible to present the priorities of the causes with other analyses.

Figure 5.11. shows the problems and complaints of students regarding the comprehensibility of university lectures organized into a Pareto diagram. Students could vote for typical, predefined problems (P), and finally, based on the relative frequency of the given votes, the ABC diagram was created. It has become visible which areas should be given more attention to according to the students' opinions.

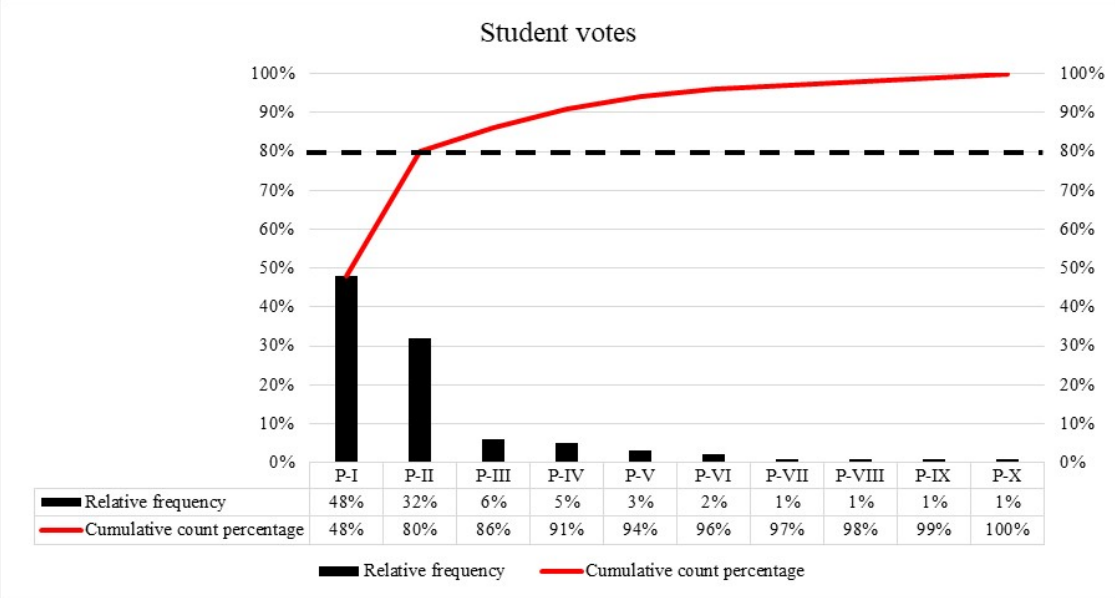


Figure 5.11.: ABC-diagram with cumulative count percentige

The advantage of using Pareto analysis is that it illustrates the relative importance of problems and their causes in a simple, quick-to-analyse (-interpret) way. It helps to identify critical issues, select specific causes, and draw attention to problems that could be eliminated or their impact reduced. Carrying out the analysis protects against fake solutions like focusing or spending resources on less important causes (Summers, 2010).

By comparing the analysis before and after the implementation of the improvement activities, the effectiveness of the improvement can be measured, and it can be examined whether the key issues have been solved. The reason of this is that it indicates visibly the benefits gained from improvement and thereby further encourages developments. Pareto analysis can be performed from different perspectives in order to approach and understand the problems in several aspects.

Pareto analysis requires the availability of a sufficiently extensive, regularly and consciously collected data and information background, from a relatively long period.

Occasionally, the Pareto Chart does not clearly show the priority of the causes (a flat Pareto Chart), which may have several typical causes. One possible reason is that there is not enough data which can be handled by extending the observation period. It is sometimes worth checking whether data collection has been done correctly, i.e. whether the data stems from different machines, products or operators, which quite often accounts for confusing results. Secondly, it is worth checking whether an appropriate period has been investigated. An example of the movement of failure groups over time is given in Figure 5.12. where the causes of a product-related failure were examined in different quarters.

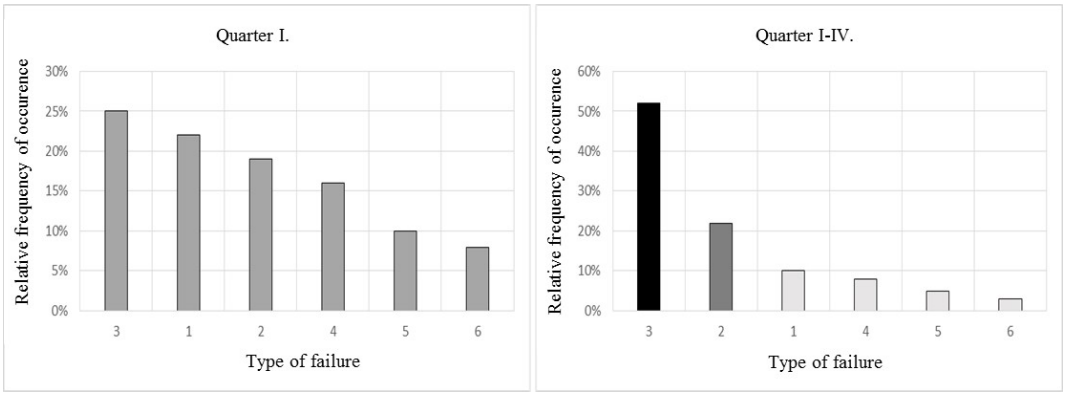


Figure 5.12.: Investigation of the same product's production in different time intervals

The ineffective image of the ABC chart may also be due to inadequate identification of the failure groups. In this case, re-grouping of the failure sources and the repetitive data processing may be necessary. Occasionally, it can be a problem that one measures the severity of failures in an inappropriate dimension: instead of frequency, the distribution of the costs of failures can be completely different (George et al., 2005). An example is shown in Figure 5.13. where a packing company investigated the complaints received from customers based on their frequency and then on the caused damage.

As a result of successful improvement actions, a flat figure is expected, as the aim of the measures was to solve the original problem.

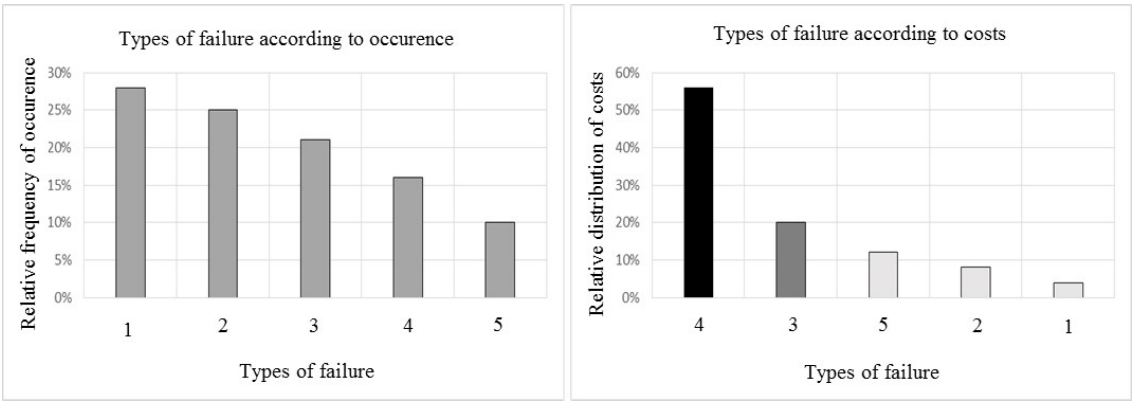


Figure 5.13.: The same problem is examined in different dimensions

5.4.3. Cause-and-effect analysis

One of the most commonly used cause-and-effect analyses is the technique called cause-and-effect, Ishikawa or Fishbone diagram. It is a fundamental principle that an error could occur unless all its causes are known and eliminated. The method arranges the causes that influence the given problem in a clear, coherent, logically arranged, fishbone-shaped diagram (Figure 5.14.). Besides the fact that the causes are linked directly to the undesirable effect, this diagram can also present causes that are causing (indirect) causes. Moreover, this technique also reveals their relationship with each other and with the problem. When applying, it is advisable to try to dig up the root of the causes to find the real root causes, and to draw an as broad and in-depth context as possible.

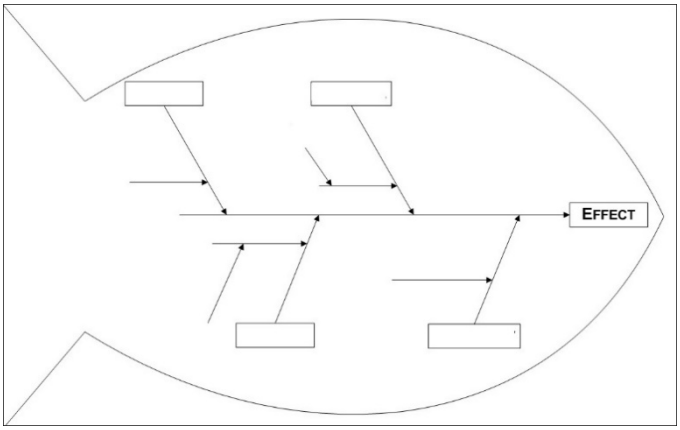


Figure 5.14.: Fishbone diagram

In order to solve an emerging problem, we need to collect the causes, that is, we need to identify the factors that trigger the cause. In order to get the right actions to eliminate the problem, we need to plan them based on an analysis of the causes. It is advisable to apply a technique that is also visualized to identify cause-and-effect relationships. Visualization helps to illustrate the causes in a hierarchical system with the problem to be solved and their relationship with each other, thus reflecting the underlying chain of causes related to the problem.

Accordingly, the causes have two major categories: some of the causes can be interpreted as primary or direct causes, whereas others are indirect causes. The hierarchical, multi-level arrangement of the causes can help the analyst to get to the root of the problem.

The first step in creating a cause-and-effect diagram is to define the problem to be investigated precisely. If possible, it is advisable to identify the effect quantitatively so that the results can be measured objectively at the end of the problem-solving process. It is also recommended to express the phenomena and events, identified as the causes, quantitatively so that objective evaluation could take place. The problem that appears as the effect should be written in the 'head of the fish ' (into a rectangle) and then the backbone of the chart is drawn.

Generally, the diagram should be drawn in group work. The result of a successful brainstorming is a large number of ideas, that appear in a confused, disintegrated, disagreeable manner at first. The chart can also be used to arrange the causes gained during a brainstorming session, in order to graphically represent the relationship among the obtained ideas. The collected causes should be assigned to the appropriate categories, and the 'bones' should be developed. These can be rearranged, according to cause-and-effect, hierarchical conditions (Summers, 2010).

In identifying the direct and the indirect causes, attention should be paid on not to ignore any of the critical elements that may be a cause of the investigated problem. That is why we often create the cause-and-effect diagram using pre-formulated classifications. These general classifications are known as the 4M or 9M method, and they are nothing more than the general pre-requisites of properly functioning processes. That is, according to the 4M method, the following groups of causes should be taken into account when searching for potential causes:

- machine;
- material;
- method;
- man.

The 4M could be extended to 9M:

- measurement;
- maintenance;
- money;
- milieu;
- motivation.

According to another classification, the logical order of the process steps and their essential phases are considered to be the main groups of factors and causes.

The essence of the method is its completeness, i.e. it assesses and maps the influencing factors as comprehensively as possible. To this end, the author(s) should ask the question 'Why does this cause happen?' over and over again. The 5 Whys technique helps to reach this goal. When drawing the fishbone diagram, the cause-and-effect relationships revealed in the first and second steps are usually symptoms and not the real root-causes. Consistent application of the 5Why approach, i.e. at least five times asking the question (Why?) helps the team to reveal the underlying but sometimes invisible root causes (George et al., 2005) (Figure 5.15.)

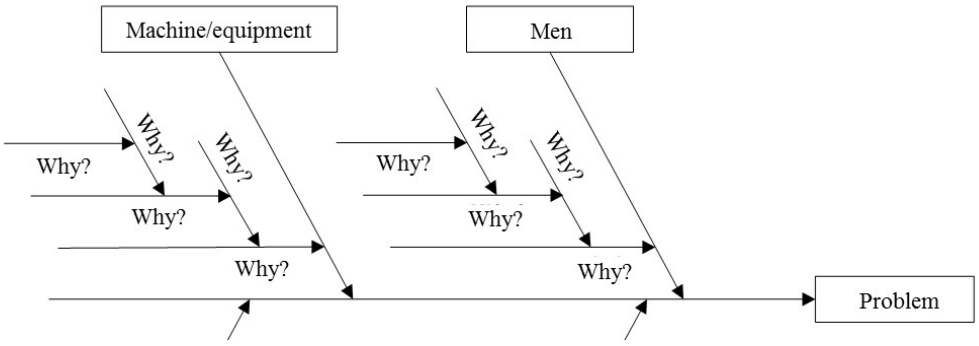


Figure 5.15.: Fishbone diagram with the 5Why?

When evaluating the completed figure, it is also worth having a look at the factors that have the most significant impact on the problem. The easiest way to do this is to find the causes that apprear in several categories. With the involvement of team members, the roots can be evaluated, based on their frequency or severity, by using a pre-recorded voting method (Brocka, Brocka, 1992, Bedzsula et al., 2014).

The compilation of a 'good' fishbone diagram requires a long time, a significant amount of resources, a significant data and information background, patient and persistent work, and assumes team members who are experts in the problem or who are strongly related to it. Successful completion results in a complete cause-and-effect system. Its effectiveness and results are, therefore, only apparent in the long run.

The considerable time and energy required by the method and the persistent, patient work required as well may, in some cases, cause a negative attitude from the workers and organizational resistance to using the fishbone diagram. However, this resistance can be overcome with the appropriate managerial attitude and communication. The motivation of the employees can be increased, and the benefits of the method and the positive effects on the production process can already be seen in the short term.

The Ishikawa diagram supports individual and group learning and improvement. On the one hand, participation in creating the cause-and-effect diagram and discussing ideas with others members of

the group, help the participants to focus on new things and relationships. This method makes it possible to understand the complex cause-and-effect relationship system behind the problem. On the other hand, the completed diagram can also be used to analyse the current situation; the stakeholders can understand the relationship among their work, their working environment and the problem.

Another advantage of using the diagram is that it helps the group involved in preparing the diagram to focus on the problem and treat the real causes instead of treating the symptoms.

5.4.4. Failure Mode and Effect Analysis (FMEA)

The Failure Mode and Effect Analysis (FMEA) is a popular method of quality management. It aims at identifying hidden, low-probability failures that could have a significant impact on products or processes when they occur. Initially, it was used in the case of projects and investments that had a unique, small series of final products. Typically, such as missile technology and astronautics, where it was not possible to build a large number of prototypes because deadlines would not have allowed trial runs for years.

In most cases, the method is used for failure analysis, failure mapping, risk analysis, mostly in the automotive industry. The automotive quality management standards and requirement systems demand manufacturers to use the FMEA. This method may have become known worldwide as a result of the US automotive manufacturers' QS-9000 requirements. FMEA is gaining increasing popularity method in other fields also and a solution to assess the risks of various possible errors.

Other possible application fields:

- new product development;
- product or technology change;
- considering safety requirements;
- improvement of processes and services;
- risk management.

The FMEA method is implemented in such a way that a properly arranged professional team first collects possible failures and their causes and effects. Each possible failure is assessed on a 10-point rating scale according to the following three factors:

- Severity: the seriousness of the given factor, cause and effect of the failure during the use by the customer.
- Ease of detection: how easy it is to recognize the given influencing factor, failure cause. Note, that the higher the probability of detecting the failure, the less the number assigned to the problem is. That is, if the problem is easy-to-detect, D will low, whereas a problem which is hard to uncover, results in higher D numbers.
- Occurrence: how often the given failure, factor occurs.

Then they assess the potential failures and influencing factors based on *risk priority numbers* (RPN), which is the multiplication of the previously mentioned three factors:

$$RPN_{ijk} = O_{ijk} \cdot S_{ijk} \cdot D_{ijk}$$

where ’k’ danger of ’i’ element’s ’j’ failure is examined based on the values of O-occurrence, S-severity, D-detection.

Considering the weights, we need to develop concrete quality improvement actions for the critical causes (RPN greater than 125, based on the used scales). The proposed action will become a task with specific responsibility and deadline, with the approval of the manager with the appropriate authority. After the quality improvement action is taken, it is advisable to determine the weightings for the improved situation on a repeated FMEA. This repetition will allow us to evaluate the effectiveness of quality improvement activities.

Two main types of FMEA can be distinguished depending on the studied area.

- We use design (concept) FMEA to detect and eliminate construction and design failures;

- Process FMEA is employed to analyse a production or service process.

In practice, the FMEA evaluation form (Figure 5.16) can be used advantageously. In the columns of 'severity of failure', 'occurrence of the failure' and 'ease of detection of the failure', the scale score according to the given aspect is written, in the RPN (Risk Priority Number) column the multiplication of them should be written. The remaining columns should be filled with textual data.

Process step / Input	Possible failure type	Possible failure consequences	S	Possible cause of failure	O	Current control	D	RPN	Proposed action
Which process step / input should be analyzed?	*How the failure can occur at the analyzed process step / input?*	*What kind of effect has the failure on the result?*		*What can be the reason of the occurence?*		*What is the current preventive action?*			*What is the proposed action to reduce the occurence of the cause and to improve the recognition?*

Figure 5.16.: Possible heading of process FMEA

As the first step in the FMEA analysis, the elements of the examined product or service are identified, and then the possible failure modes associated with each element are collected. This is followed by the analyses: failure effects and their severity, causes and their frequency, and current control actions and the determination of their ability to detect failures are investigated. After defining risk priority numbers according to the formula, failures should be ranked, and in the case of the most critical causes, improvement actions should be developed.

In light of the identified relationships, there are three ways to reduce the risks:

- preventing the occurrence: reduce the probability of occurrence of a failure (O ↓);
- reducing effect: reduce the effect of a failure (S ↓);
- improving recognisability: improve the possibility of recognizing a failure (D ↑, the value on the scale is reduced).

Practical solutions for risk reduction in practice: security and warning systems; process/construction redesign; executing tests and simulations.

The implementation of improvement actions should also be specified, and the person responsible for implementing it and the deadline should be defined as well. After the introduction of the actions, the analysis should be re-done, conclusions have to be drawn on the effectiveness of the actions, and new ones should be developed if necessary.

6. BASICS OF STATISTICAL PROCESS CONTROL

Achieving customers' satisfaction is the ultimate goal of any quality management activity. Both the ISO 9001 set of standards and the TQM are aiming at fully satisfying the customers of the organization. Complete satisfaction of customers and their loyalty, of course, require that the product sold to the customers should be defect-free. Defect-free production, however, cannot be achieved without continuously monitoring and assessing the manufacturing processes.

According to Montgomery (2009), it is impossible to inspect or to test quality into a product. Instead, the product must be built right the first time. Defect-free production requires stable manufacturing processes that are operated so that they are able to at least meet but at best exceed customers' expectations. Statistical Process Control (SPC) is an essential part of any quality management system due to the fact that a properly designed on-line statistical process control is a primary tool for achieving stable processes that are also able to meet the customers' expectations in the long run. The underlying idea of SPC is to exactly measure how much variation a process experiences. Due to environmental factors, no process is able to operate without any variation, meaning that the consecutive products of the manufacturing process are not exactly the same. Though, they resemble each other, some of the quality characteristics of these products will show a slight difference. However, based on some statistical principles, one may define the amount of difference (or more precisely: variability) which can be considered as 'normal'. If one gets to know precisely the 'normal' variability of the process, this knowledge will offer two possibilities to keep the process 'under control'. First, one will be able to detect if something goes wrong with the process. Secondly, he or she will be able to determine how well the process is performing relative to the products' specifications that represent the acceptable level of process performance from the customers' point of view. The former goal is about 'keeping the process in control, that is, under surveillance', while the latter one is about operating the process so that it can meet the customers' requirements.

In the following sections, two powerful statistical tools are introduced that can help to achieve the two goals mentioned above (Oakland, Oakland, 2018):

- control charts are employed to detect the occurrence of problems within the manufacturing process, that is, the control chart signals when intervention into the process and corrective actions are necessary, whereas
- process capability assessment helps to predict how well the process will hold to the tolerances; that is, how well the process is performing from the customers' point of view.

6.1. The mathematical background of statistical process control

Let us assume, that the 'goodness' of a product can be characterized by some measurable characteristics, like the filling volume of the coke doses, the length or width of an item or the bursting strength, etc. By the law of large numbers and as a result of the so-called central limit theorem, most of these quality characteristics can be considered as a random variable which is approximately normally distributed (Iman, Conover, 1989). The normal or Gauss distribution is given by two parameters. The expected value (or mean) of the Gauss distribution is denoted by μ and this parameter locates the centre of the distribution, while the standard deviation, denoted by σ describes, how widely the distribution is 'spread around the mean' and parameter σ is responsible for the shape of the curve as well: the higher the value of σ is, the more 'spread out' the distribution around the mean is. Each normal distribution has a bell-shaped probability density function (PDF). A PDF is always adjusted

in height so that the total area under the PDF (and above the x-axis) equals to 1. As such, probabilities can be represented by the area under the PDF function. That is, to find the probability of a random variable X being between x_1 and x_2, the area under the PDF between x_1 and x_2 should be calculated. This process requires some calculation effort, thought, for particular x_1 and x_2 pairs, the area under the PDF is given in Table 6.1. (Amsden et al., 1989; Proschan, Shaw, 2016):

Table 6.1.: Percentage of the PDF between particular lower and upper boundaries

Lower boundary	**Upper boundary**	**Percentage between the lower and upper boundary**
$\mu - \sigma$	$\mu + \sigma$	68.26
$\mu - 2\sigma$	$\mu + 2\sigma$	95.44
$\boldsymbol{\mu - 3\sigma}$	$\boldsymbol{\mu + 3\sigma}$	**99.73**
$\mu - 4\sigma$	$\mu + 4\sigma$	99.9937
$\mu - 5\sigma$	$\mu + 5\sigma$	99.999943
$\mu - 6\sigma$	$\mu + 6\sigma$	99.9999998

That is, regardless of the actual values of parameter μ and σ, 99.73% of the density function falls between the $\mu - 3\sigma$ and the $\mu + 3\sigma$ 'boundaries'. In other words, 99.73% of the possible values of the examined process will fall between the $\mu - 3\sigma$ and the $\mu + 3\sigma$ 'boundaries'. This variation is usually called the 'natural variation' of the process, while the boundaries at $\mu - 3\sigma$ and the $\mu + 3\sigma$ are considered as the natural tolerance limits of the process. Examining this 'natural variation' inherent in the process lays the foundation of the basic statistical control techniques. Figure 6.1. shows some examples of the PDF of the normal probability distribution along with depicting the role of its parameters and the 'natural variation'.

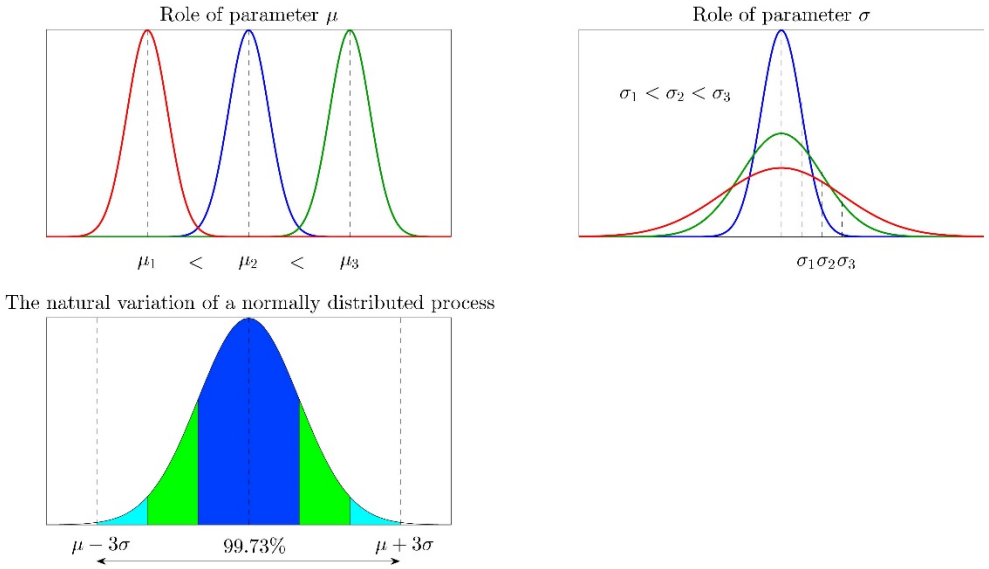


Figure 6.1.: Examples of the PDF of the normal distribution, the role of its parameters and the natural variation of a normally distributed process

6.2. Common and special causes of variability

Owing to the operational circumstances (that is, resulting from factors that continuously surround and affect the process, like changes in the humidity, the temperature and so on), in any productions process, a certain amount of inherent or natural variability will always exist. This natural variability or 'background noise' is the cumulative effect of many, small, from each other usually independent factors that are essentially unavoidable. As these factors continuously surround the process, one may say, they form an inherent part of the process, without regard how well designed, carefully operated and maintained the studied process is. This natural variability is referred to as the 'common or chance causes of variability'. A process which is operated with only these common causes of variation present is said to be in statistical control. As long as only these common causes are present in a process, the process could be left alone, since its performance is thought to be stable over time (Montgomery, 2009; Oakland, Oakland, 2018).

On the contrary, there are other types of factors that are not part of the common causes and as such, they should be eliminated from the process. Usually, the occurrence of this, so-called special causes results in an unacceptable level of performance, which accounts for a variability which is larger than the natural variability. This variability is usually the result of operator errors, defective raw materials or improperly adjusted or controlled machines. We refer to these sources of variability that are not part of the common causes as special causes (Shewart originally referred to them as assignable causes). Special causes are only occasionally present in the process. Henceforth, processes that are operating under the influence of special causes are called out-of-control processes. Getting rid of the special causes, thus, is an essential goal if one seeks to improve the process and to achieve a stable process performance (Montgomery, 2009; Oakland, Oakland, 2018).

The following figure (Figure 6.2.) represents some out-of-control (with the parameters continuously changing as time goes on) and some in-control (with the parameters being stable over time) processes.

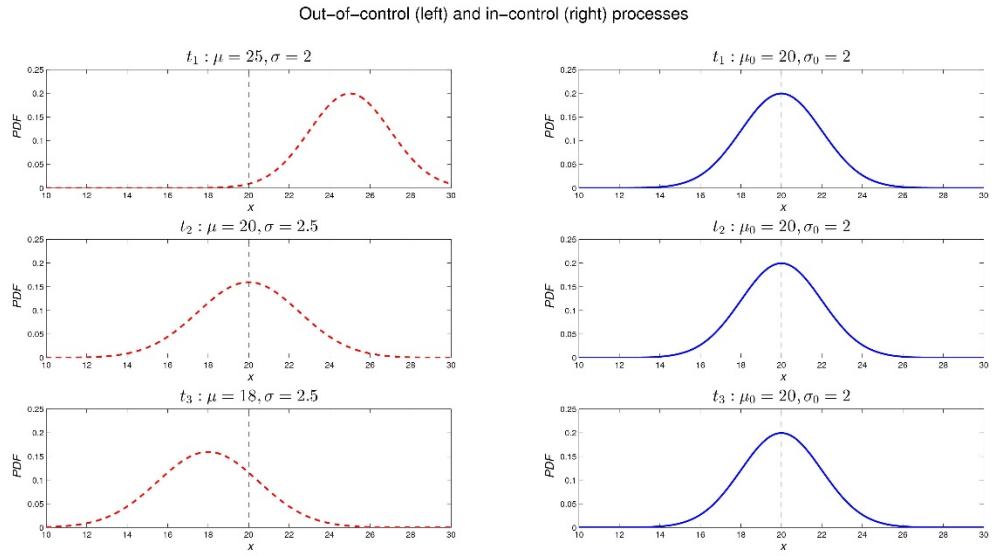


Figure 6.2.: Examples of in-control (right-hand side) and out-of-control (left-hand side) processes.

The right-hand side of Figure 6.2. represents a process considered to be in-control. Let us assume that the process mean and its standard deviation are characterized at three consecutive periods. At time t_1 the expected value is $\mu_0 = 20$, while the standard deviation is $\sigma_0 = 2$. Since the parameters of an in-control process are stable over time, at time t_2 and later at time t_3 as well $\mu = \mu_0 = 20$ and $\sigma = \sigma_0 = 2$. That is, as long as the process is in control, there is no change in the value of parameters μ and σ. The process represented by the red curves on the left side of Figure 6.2., however, has gone out-of-control. At time t_1, $\mu = 25$ (recall, that the in-control values are $\mu_0 = 20$ and $\sigma_0 = 2$, respectively), that is, there is a shift in the mean of the distribution. At time t_2, another special cause occurred shifting the process' standard deviation to $\sigma = 2.5$, which is higher than the standard deviation of the in-control state ($\sigma_0 = 2$) . At time t_3, both the mean ($\mu = 18$) and the standard deviation ($\sigma = 2.5$) take out-of-control values.

Processes are often able to operate in the in-control state for relatively long periods. However, no process is truly stable forever. That is, eventually special causes occur, seemingly at random, resulting in a shift either in the expected value or the standard deviation of the process. Shifts in the process parameters customarily lead to a higher proportion of nonconforming units. One of the major objectives of SPC is to detect the occurrence of special causes as early as possible it is so that investigation and corrective action could be undertaken before many nonconforming units would be produced. The control chart is widely used for this purpose. Note, however, that statistical techniques only detect the occurrence of special causes, but they do not tell us what this special cause actually is (Wheeeler, Chambers 2010).

6.3. Control charts

The majority of the quality characteristics can be expressed in terms of a numerical measurement and it could be proved that most of these quality characteristics can be described by the normal distribution. Examples include the volume, the weight, the height, the pH or the resistance. A quality characteristic which can be measured on some continuous scale of measurement is called a variable.

Applying a control-chart for real-time process surveillance consists of the following steps:

- Based on past data, the so-called control limits are determined.
- The sampling frequency and the sample size are chosen.
- In each period, a sample is taken and the sample characteristics are plotted on the control chart.
- The control limits are chosen so that if the process is in-control (that is, assuming that only common causes of variability are present and as such, the process parameters are stable over time), nearly all of the points representing the quality characteristics of the sample should fall between the both control limits. As long as the sample characteristics are plotted within the both control limits, no action is necessary because the process is thought to be in control. If one point is plotted beyond the control limits, it is interpreted as a piece of evidence that the process has gone out of control and investigation and correction actions are necessary (Erdei, 2018).

The previous ideas are displayed in Figure 6.3.:

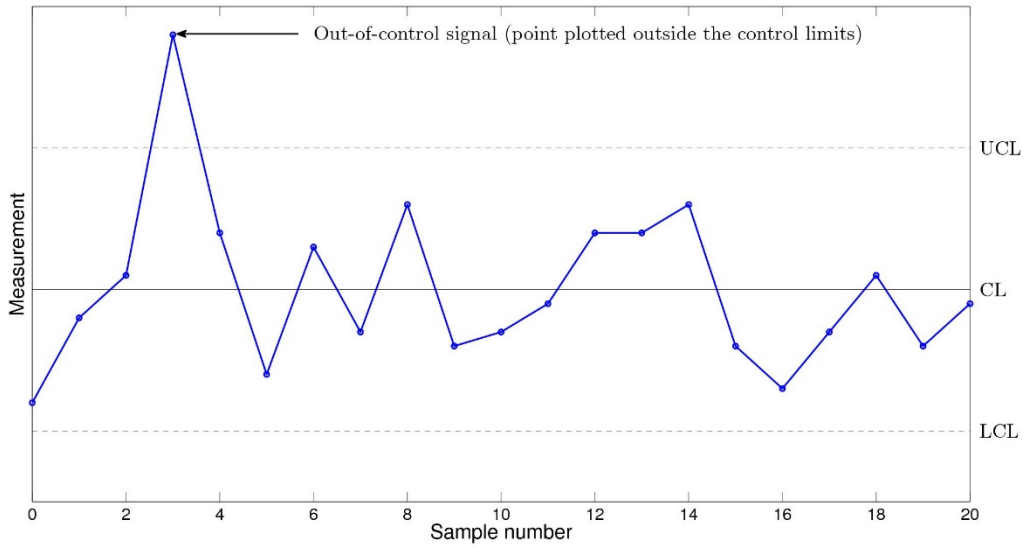


Figure 6.3.: General idea of control chart application. The process is assumed to be in-control if the points are plotted within the control limits, whereas a point outside the control limits is interpreted as an evidence that the process has gone out of control.

The x-axis in Figure 6.3. represents the sample number or the time when a sample is taken, while the y-axis denotes the observed value of the quality characteristic. Figure 6.3. also contains the two control limits and the centre line. It can be seen in Figure 6.3. that the measured quality characteristic in the case of sample number 3 falls above the upper control limit, which indicates that a special cause occurred when sample nr. 3 was taken. That is, after noticing the out-of-control signal, investigation and corrective action should be executed to find and then to eliminate the special cause resulting in the out-of-control state when sample nr. 3 was taken. Since the other 19 points are plotted within the control limits, in these cases the process is assumed to be in control and no further action is necessary. That is, the point violating the control limit when sample nr. 3 was taken is an indication that a special cause is present in the process when this sample was taken. On the other hand, the slight variation of the remaining 19 points is due to the common causes, that are always assumed to be present in the process, the presence of which, however, does not mean any trouble and as a result, the process can be left alone (Montgomery, 2009).

6.3.1. Establishing the $\bar{X}$ and R-charts

When dealing with a quality characteristic, it is usually needed to monitor both the expected value and the variability of the quality characteristic of interest. In practice, however, μ and σ are usually unknown and as a result, they should be estimated from preliminary samples which are taken when the process is thought to be in control. The expected value of the quality characteristic is usually monitored by the $\bar{X}$-chart, while the standard deviation can be controlled either by the R-chart or the s-chart (Montgomery, 2009). The R-chart utilizes the range of the samples, the s-chart the sample standard deviation for monitoring the standard deviation of the manufacturing process.

Let us assume that altogether m samples have been taken from the process and each of the samples contains n inspected items. Current industrial practice tends to favour smaller (with the sample size n being 4, 5 or 6 items), more recent samples. Montgomerry (2009) recommends collecting at least

20 or 25 samples to determine the control limits. Let $X_{i,1}, X_{i,2}, \dots, X_{i,n}$ denote the first, the second, and the last measurement on the quality characteristic when the i-th sample was taken, respectively.

Usually, the R-chart or the s-chart is set up first. The reason for this is the fact that the control limits on the $\bar{X}$-chart depend on the standard deviation of the process which requires that the standard deviation should be in control, otherwise the control limits on the $\bar{X}$-chart will not have much meaning. In the followings, the construction of the R-chart will be discussed (Wheeeler, Chambers 2010; Oakland, Oakland, 2018).

In order to find the control limits on the R-chart, the range of each of the collected samples should be computed. The range of a sample is simply the difference between the largest ($X_{i,max}$) and smallest observation ($X_{i,min}$) within the given sample (Donelly, 2012), that is:

$$R_i = X_{i,max} - X_{i,min} \tag{1.}$$

where R_i denotes the range of the i-th sample. Let $R_1, R_2, \dots R_m$ denote the range of the collected m samples. The average range (the mean of the ranges), denoted by $\bar{R}$ is:

$$\bar{R} = \frac{R_1 + R_2 + \cdots + R_m}{m} \tag{2.}$$

Based on this, the centre line and the corresponding control limits can be determined as:

$$\mathrm{UCL}_R = D_4 \cdot \bar{R} \tag{3.}$$

$$CL_R = \bar{R} \tag{4.}$$

$$\mathrm{LCL}_R = D_3 \cdot \bar{R} \tag{5.}$$

The values of constants D_3 and D_4 are listed in the Appendix. Note, that the values of constants D_3 and D_4 depend on the sample size! It is worth mentioning as well, that the lower control limit on the R-chart is always zero if the sample size does not exceed six units.

After computing the control limits for the R-chart, the ranges of the collected samples should be plotted on the chart. If all the sample ranges fall between the control limits, the standard deviation (σ) is thought to be in control. On the other hand, if at least one sample's range violates the control limits, this will be interpreted as a piece of evidence that the standard deviation of the manufacturing process has gone out of control when the sample the range of which violates the control limits was taken.

If the R-chart indicates the standard deviation of the process to be in control, one could set up the $\bar{X}$-chart, which is employed to monitor the expected value of the production process. Let again $X_{i,1}, X_{i,2}, \dots, X_{i,n}$ denote the first, the second, and the last observed value of the investigated quality characteristic within a given, i-th sample. The average of the i-th sample, denoted by $\bar{X}_i$ is the sum of the observed data within this sample divided by the sample size n, that is:

$$\bar{X}_i = \frac{\sum_{j=1}^{n} X_{i,j}}{n} = \frac{X_{i,1} + X_{i,2} + \cdots + X_{i,n}}{n} \tag{6.}$$

The mean of the other samples can be computed in the same way. Let $\overline{X_1}, \overline{X_2}, \dots, \overline{X_m}$ be the average of the first, the second, and the last, m-th sample, respectively. Based on them, the grand average (the average of the subgroups' averages) can be computed as follows:

$$\bar{\bar{X}} = \frac{\sum_{i=1}^{m} \bar{X}_i}{m} = \frac{\overline{X_1} + \overline{X_2} + \cdots + \overline{X_m}}{m} \tag{7.}$$

The grand average in (7.) will be used as a centre line on the $\bar{X}$-chart, while the corresponding control limits are given as:

$$\mathrm{UCL}_{\bar{X}} = \bar{\bar{X}} + A_2 \cdot \bar{R} \tag{8.}$$

$$CL_{\bar{X}} = \bar{\bar{X}} \tag{9.}$$

$$\mathrm{LCL}_{\bar{X}} = \bar{\bar{X}} - A_2 \cdot \bar{R} \tag{10.}$$

where the values for the constant A_2 are listed for various sample sizes in the Appendix (Montgomery, 2009).

If the control limits for the $\bar{X}$-chart are set up, the corresponding samples' averages should be plotted on the chart. As it can be seen from equations (8.)-(10.), the control limits on the $\bar{X}$-chart are symmetric to its centre line, which is not true in the case of the R-chart. After plotting the samples' averages on the $\bar{X}$-chart, one should check whether there are points violating the control limits. If neither of the samples' mean falls above the upper control limit or below the lower control limit, the expected value of the production process is thought to be in control. On the contrary, a sample mean plotted outside the control limits indicates that the expected value of the production process had gone out of control when this particular sample was taken.

It is worth pointing out that a process which is in control means only that the process parameters are stable over time. An in-control process, however, does not necessarily mean that the process is able to fulfil the customers' requirements. If the process is found to be in control, further investigation, the so-called process capability assessment is needed to determine whether the process is able to meet the customers' expectations. The stability of process parameters, however, is an important precondition of any 'well-working' processes.

6.3.2. Phase I. and phase II. application of control charts

Montgomery (2009) argues that two different phases of control chart application can be distinguished, the so-called phase I. and phase II. application. The former one is a retrospective analysis with the goal of bringing the process into the state of statistical control, while the latter one is an on-line process surveillance.

First, in phase I., a set of process data is collected and analysed all at once in a retrospective analysis. Usually, at least 20 or 25 samples are taken (Kemény (1999) suggests investigating at least 100, but at best 200 items), based on which the trial control limits could be determined. That is, the control limits are set up based on the data of the m samples and the same data is plotted on the chart. The main goal of phase I. application is to determine whether the process was in control when the preliminary samples were taken. Usually, the process is thought to be out-of-control initially, and as such, the main purpose of control charts in the phase I. application is to help engineers or operating personnel to bring the process into the state of statistical control by eliminating the inherent special causes. The phase I. application of control charts is usually an iterative process: the points outside the control limits should be carefully investigated, looking for potential special causes. If operating personnel succeeds in eliminating the special causes being responsible for out-of-control signals, the corresponding points on the chart are excluded and a new set of control limits are calculated based on the remaining points. Some points which were in control in the previous investigation, however, might

be out-of-control after recalculating the control limits because of the fact that the new control limits are generally tighter than the old ones. This cycle is needed to be executed as long as all of the points are plotted within the control limits telling operating personnel that all of the special causes were eliminated from the manufacturing process. The second phase begins after all of the special causes are eliminated during the phase I. application, that is, if one has a 'clean' set of process data. In phase II., the previously established control limits are employed for on-line process surveillance, that is, the charts are applied for continuously monitoring the process performance. During the phase II. application, in consecutive periods of time, a sample is taken, and the calculated sample characteristics (the range and the mean of the sample) are compared to the control limits. As long as the sample's range or its mean does not violate the control limits, no further action is necessary since the process is still in-control. Should a sample's range or mean fall beyond the control limits, intervention is needed and operating personnel should begin with investigating the process with the purpose of identifying and then eliminating the special cause which is responsible for the out-of-control warning. It is worth emphasizing that the control chart indicates only that a special cause is present in the process, but it does not tell us, what this special cause is.

Montgomery (2009) recommends that the phase II. application of charts should be accompanied by a so-called Out-of-control Action Plan (OCAP). The OCAP is a flowchart or text-based document that directs operating personnel what to do if a special cause occurs. Moreover, the OCAP is a living document in the sense that it will be continuously reviewed and updated as more knowledge on the process is obtained.

6.4. Estimating the process parameters

As already discussed, the $\bar{X}$ and the R-charts are widely used to monitor the expected value and the standard deviation of the manufacturing process. These charts can also be utilized to estimate the process parameters. That is, the expected value and the standard deviation of a normally distributed process can be estimated based on the $\bar{X}$ and the R-charts, which are applied to control these process parameters (Montgomery, 2009). Note, that the charts utilize the sample range and the sample average (two indices computed based on the characteristics of the investigated items), whereas the expected value and the standard deviation refer to the whole population, that is, to the characteristics of all of the produced units.

The grand average $\bar{\bar{X}}$, which is used as a centre line on the $\bar{\bar{X}}$-chart, can be used to estimate the expected value (μ) of the process, that is:

$$\mu \cong \bar{\bar{X}} \tag{11.}$$

Based on the relative range of the normal distribution, the standard deviation (σ) of the process can be estimated as:

$$\sigma \cong \frac{\bar{R}}{d_2} \tag{12.}$$

where the values of constant d_2 are listed in the Appendix for various sample sizes. It is worth mentioning that using the range method for estimating the standard deviation is recommended only in the case of smaller samples. Note, that these estimates are only point estimates of the population's parameters and as such, they are subjected to statistical fluctuation, that is, to sampling error. In other words, if one obtains some other samples, calculates its grand average and the mean of the ranges, he

or she might arrive at different estimates of the process parameters. Since the aforementioned estimates are unbiased, though, the estimated values will vary around the real population value. (Iman, Conover, 1989).

6.5. Benefits of control charts

Based on the previous considerations, at least five benefits account for the popularity of control charts, namely (Montgomery, 2009; Erdei, 2018):

- Control charts are a proven technique for improving productivity due to reducing scrap and rework.
- Control charts are effective in preventing defects.
- Control charts prevent unnecessary process adjustments by exactly signalling when intervention is needed.
- The pattern of points (e.g. cyclic behaviour or trend in the dataset) provides diagnostic information to an experienced engineer.
- Based on control charts, the process capability can be determined. Process capability (to be introduced later on) is about measuring the variability relative to the product's specifications and then about determining whether the process is able to meet the customers' expectations.

6.5.1. Performance of control charts

Despite their advantages, due to sampling error, the application of control charts sometimes leads to misleading conclusions about process stability. The sampling error itself refers to the natural variability inherent among samples from a population and it is always present when only samples are investigated instead of the whole population. That is, if one does not check all of the items from a given population (in our case, if not all of the manufactured products areinvestigated), but obtains a sample instead (only some of the manufactured items are checked), the sample characteristics, like its mean or sample standard deviation, may differ from the corresponding characteristics of the whole population. As a result, one may arrive at false conclusions about the population, provided that the difference between the sample's and the population's quality characteristics is large enough.

The two, different types of errors that can occur when utilizing control charts for process performance monitoring are the so-called type I. and type II. errors (Montgomery, 2009; Erdei, 2018):

- The type I. error, or α risk is the probability of concluding the process based on the sample to be out-of-control, when in reality it is in-control. The type I. error leads to unnecessary process adjustment or operating personnel searches for special causes that do not exist. The probability of the type I. error can be chosen when one sets up the control charts. The previously introduced, so called three-sigma control limits yield to $\alpha = 0.0027$ type I. error.
- The type II. error or β risk is the probability of not detecting a process shift, that is, considering the process to be in-control (based on the sample), when in reality, it has been gone out-of-control. The probability of the type II. error depends on the magnitude of the shift which occurred in the process mean or standard deviation, that is, it cannot be chosen directly. Smaller process shifts usually result in a relatively high probability of type II. error. The exact probability of the type II. error can be obtained from the Operating Characteristic Curves (OC Curves) of the charts. For further reading, Montgomery's (2009) book is an excellent source.

The type I. and type II. errors are inversely proportional, that is, if one decreases the probability of the type I. error (which can be freely chosen), the probability of the type II. error will increase and on the other way around. Decreasing the probability of both the type I. and type II. error can be achieved by increasing the sample size, since an increase in the sample size usually decreases the sampling error. It is worth emphasizing, that the type I. and type II. errors have the same meaning as have the type I. and type II. errors in the case of hypothesis testing (Donnelly, 2014). This is because of the fact that the control chart corresponds to a special hypothesis test carried out in consecutive periods; in the case of the R-charts, the null hypothesis refers to the standard deviation of the manufacturing process ($H_0: \sigma = \sigma_0; H_1: \sigma \neq \sigma_0$), while in the case of the $\bar{X}$-chart, the null hypothesis is about the population's expected value ($H_0: \mu = \mu_0; H_1: \mu \neq \mu_0$). Interpreting the control charts as a hypothesis test allows us to accept the null hypothesis as long as the points are plotted within the control limits. On the contrary, a point violating the control limits suggests that the null hypothesis should be rejected indicating that the expected value or the standard deviation is no longer equal to the in-control value.

6.6. Process capability assessment

After having achieved a stable process performance, one may be interested in whether the remaining natural variation as a result of the common causes is small enough to meet customers' requirements. Analysing the variability of the process relative to the requirements or specifications is called process capability assessment and it is widely used through the product life-cycle to support managerial decisions. The ultimate goal of process capability assessment is to reduce the variability of manufacturing processes. Besides that, carrying out a process capability study helps to predict the fraction of nonconforming units or to confirm the vendor's ability to meet the established standards. It should be emphasized here that process capability assessment can be carried out only after the process has been brought into the state of statistical control. Unless the process is in-control, the parameters are unstable and their future values are uncertain (Montgomery, 2009).

For any production process, the customer, the product designer or the engineers set up so-called specification limits. Usually, there is a lower specification limit (LSL) and an upper specification limit (USL). The process output is considered as acceptable as long as the actual value of the quality characteristic is greater than the LSL but less than the USL. That is, if X denotes a critical-to-quality characteristic, for example the diameter of a bearing, the product conforms to the expectations if $LSL \leq X \leq USL$, while if $X < LSL$ or $USL < X$, the product's quality characteristic falls outside the specifications and as such, the product is not acceptable.

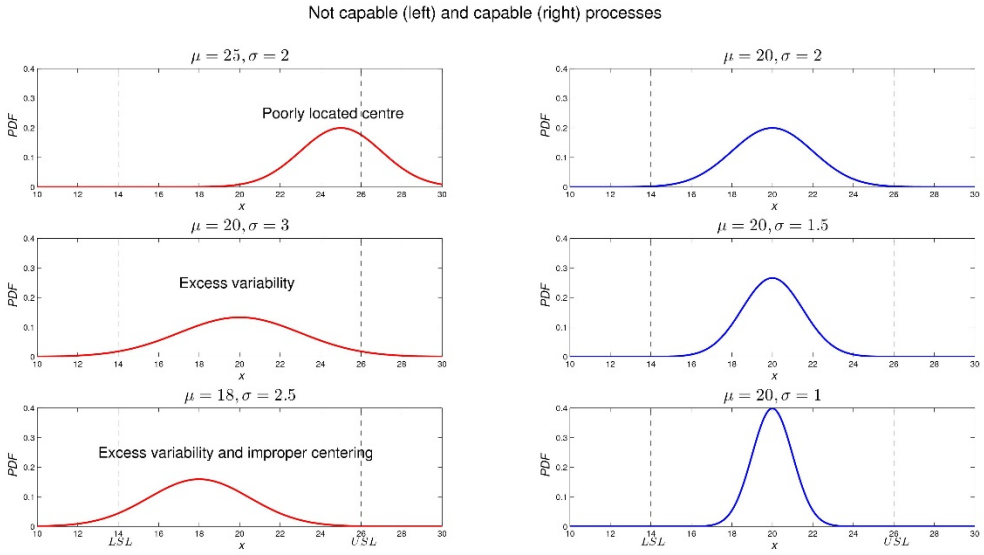


Figure 6.4.: Processes that are capable of meeting the customers' requirements (right-side) and that are not capable to meet the customers' expectations (left-side)

Figure 6.4. depicts the visual interpretation of process capability. It has been already proved that the area under the PDF is 1. The left-hand side of Figure 6.4. shows three processes having a poor capability due to the fact that a significant part of the PDF is located outside the specification limits, which corresponds to the process fallout. The higher proportion of nonconforming units can be resulted from poorly located centre of the distribution or from excess variability. These considerations suggest as well that improving the capability can be achieved either by centring the process or by reducing its variability. On the contrary, the processes depicted on the right-hand-side of Figure 6.4. are operated so that almost the entire part of the PDF falls within the specification limits. Since the process yield (that is, the fraction of conforming units) is proportional to the area under the PDF falling between the two specification limits, in the case of these processes, only a few defective units are expected to be produced.

Henceforth, the process which is considered to be capable is operated so that at least the three-sigma variation around its expected value, that is, the natural variation of the process is less than the width of the specification interval. As such, at least the 99.73% of the PDF is located between the specification limits.

6.6.1. Process capability indices

The process capability is often characterised by a simple, quantitative index, called process capability ratio (PCR), which is defined as the width of the specification band (that is, the distance between the upper and the lower specification limit) relative to the six-sigma standard deviation of the process.

$$C_p = \frac{USL - LSL}{6\sigma} \qquad (13.)$$

Since the natural tolerance limits of a normally distributed process located at $\mu - 3\sigma$ and at $\mu + 3\sigma$ contain 99.73% and the 6σ 'spread' of the possible values of the process, if the natural tolerance limits are exactly equal to the specification limits, the process capability ratio will be equal to unity, which corresponds to 99.73% process yield and as a consequence, to 0.27% process fallout as displayed in Figure 6.5. (Oakland, Oakland, 2018).

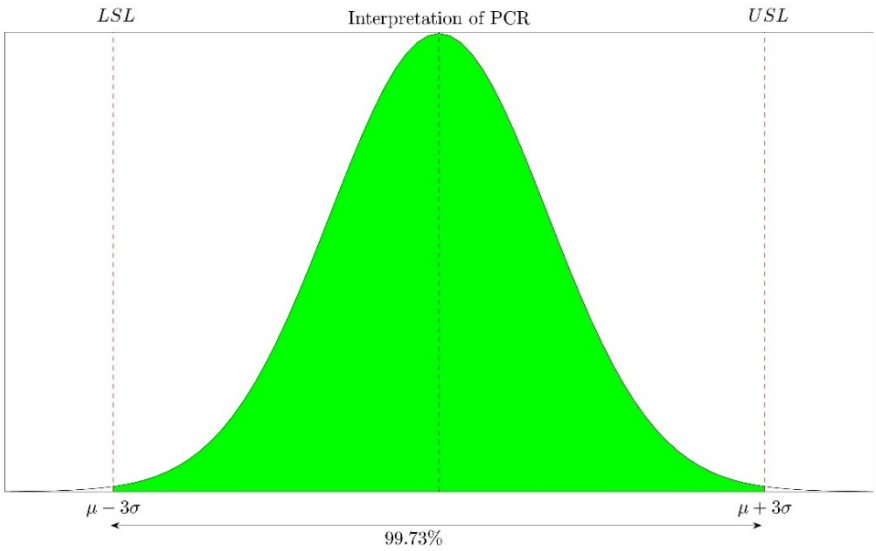


Figure 6.5.: Interpretation of process capability ratio

As the standard deviation (σ) of the process decreases, the process capability ratio will increase (since the width of the specification band is assumed to be constant). A C_p of 1.0 or greater means that the machine or process is capable of producing parts with a natural variation less than the tolerance and therefore, it is able to fulfil the requirements stated externally (Amsden et al., 1989). That is, the standard deviation of the process and the process capability ratio C_p are inversely proportional: a decrease in the standard deviation increases the value of the C_p index. As a result, as the standard deviation decreases, the ability of the process to meet the expectations improves. The sigma level (SL) will indicate the 'spread' around the mean which falls within the specification limits:

$$\mathrm{SL} = 3 \cdot \mathrm{C_p} \qquad (14.)$$

That is, the higher the sigma level, the higher the spread around the mean that the specification band covers and as a result, the smaller the expected number of nonconforming units is. The following figure (Figure 6.6.) depicts how the standard deviation of the process affects the process capability ratio and thereby the ability of the process to produce items which can meet the specifications.

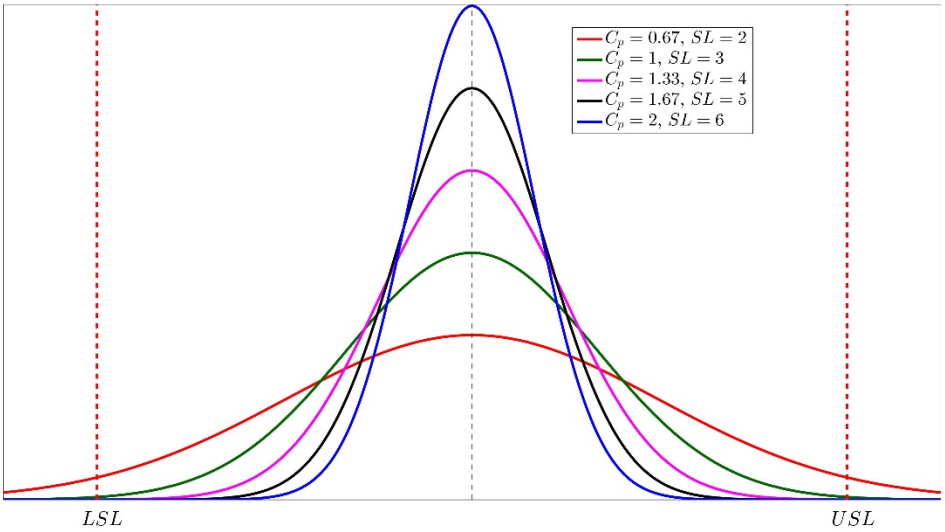


Figure 6.6.: Some typical values of the process capability ratio C_p

Table 6.2. contains some typical values of the process capability ratio C_p and the corresponding number of the defective items in parts-per-million (ppm). The latter denotes how many items are expected to be defective out of one million produced units. Similarly to the standard deviation of the process, the ppm is also inversely proportional to the value of the C_p ratio; the higher the value of C_p is, the less nonconforming units are expected to be produced.

It is worth emphasizing that the process capability indices are quite sensitive to the theoretical distribution of the dataset (Montgomery, 2009). Even a small deviation from the normal distribution can lead to a disproportionally higher percentage of nonconforming units than those listed in Table 6.2.

Table 6.2.: Some typical values of the process capability ratio C_p, and the corresponding sigma-level and ppm values

C_p	Sigma level	ppm
1.00	3	2700
1.33	4	63.5
1.67	5	0.57
2	6	0.002

The process capability ratio in equation (13.) has a useful practical interpretation. Namely its reciprocal is the percentage of the specification or tolerance band used up by the natural variation process. That is,

$$\mathrm{P} = \frac{1}{C_p} \cdot [100\%] \qquad (15.)$$

Equation (15.) indicates that the natural variation of a process with $C_p = 1$ uses up 100%, while that of with $C_p = 2$ only 50% of the specification zone.

When computing the process capability ratio C_p, we assumed that the process has both lower and upper specifications. In some cases, however, only a lower (e.g. in the case of bursting strength) or an upper specification (concentration of some unwanted material) is given. In these cases, the corresponding process capability ratios are defined as follows:

$$C_{p,l} = \frac{\mu - \mathrm{LSL}}{3\sigma} \tag{16.}$$

$$C_{p,u} = \frac{\mathrm{USL} - \mu}{3\sigma} \tag{17.}$$

where the process capability ratio $C_{p,l}$ is used if only a lower specification is given, and similarly, if only an upper specification exists on the quality characteristic, the capability ratio $C_{p,u}$ is applied to characterize the process performance.

The process capability ratio C_p in (13.) is easy to calculate and interpret, but it does not take into account where the process mean is located within the specification band. That is, the C_p ratio is not affected by shifts in the expected value of the process, though, based on Figure 6.7., one may conclude that the poorly located centre of the distribution distorts the process capability. This unfavourable property of the C_p ratio is due to the fact that C_p simply measures the width of the specification band relative to the natural variability of the process, but neither the spread of the specification band nor the natural variability of the process itself depend on where the process mean is located relative to the specifications. Figure 6.7. depicts this situation.

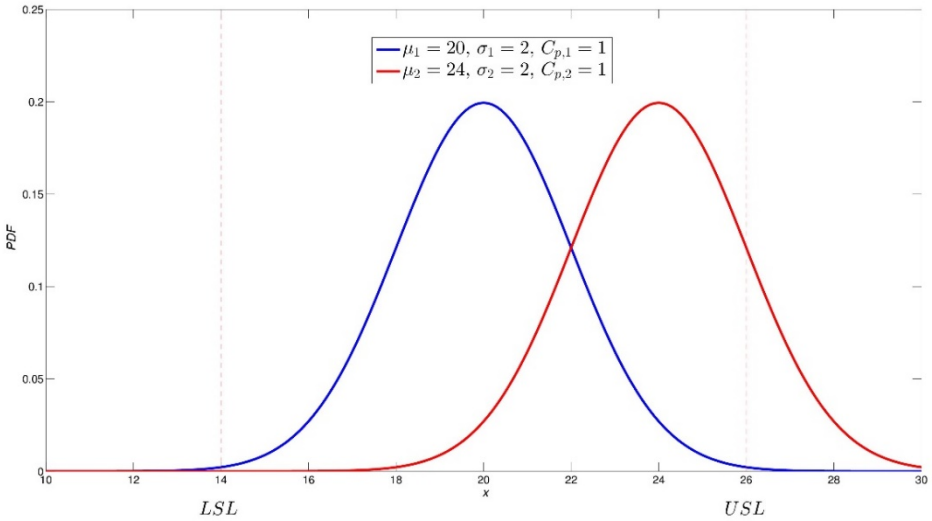


Figure 6.7.: Change in the process performance as a result of the sift in the mean

The blue curve in Figure 6.7. represents a process with $\mu_1 = 20$ and $\sigma_1 = 2$. The corresponding $LSL = 14$, while the $USL = 26$. As a result, the capability ratio of this process is:

$$\mathrm{C_{p,1}} = \frac{USL - LSL}{6\sigma_1} = \frac{26 - 14}{6 \cdot 2} = 1. \tag{18.}$$

The red curve represents a process with $\mu_2 = 24$ and $\sigma_2 = 2$ with the same specification limits. Obviously, the process represented by the red curve has a far worse capability due to the shift in its mean. The process capability ratio, however is:

$$\mathrm{C_{p,2}} = \frac{USL - LSL}{6\sigma_2} = \frac{26 - 14}{6 \cdot 2} = 1. \tag{19.}$$

This is due to the fact that this process has the same standard deviation and the same specification limits as has the process represented by the blue curve and the current value of the capability ratio C_p depends only on these two values.

The performance of off-centred processes is usually given by the so-called $C_{p,k}$ ratio that takes the process centering into account as well by examining the distance between the process centre and both of the specification limits. The $C_{p,k}$ ratio is given by:

$$C_{p,k} = \min\left\{\frac{\mu - LSL}{3\sigma}; \frac{USL - \mu}{3\sigma}\right\} = min\{C_{p,l}; C_{p,u}\}. \tag{20.}$$

The interpretation of the process capability ratio $C_{p,k}$ is displayed in Figure 6.8.

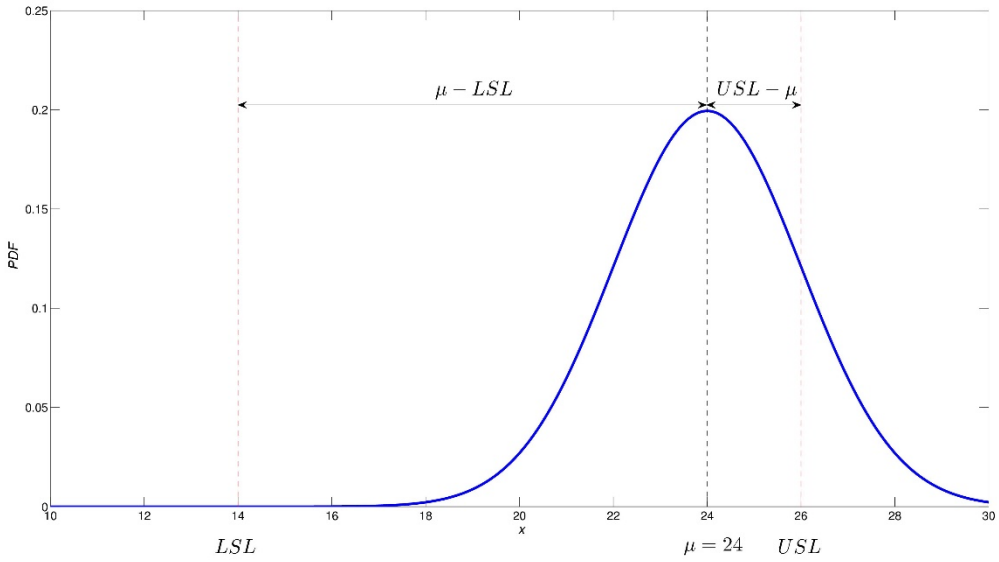


Figure 6.8.: Interpretation of the process capability ratio $C_{p,k}$ in the case of out-of-control processes

Generally, if $C_p = C_{p,k}$, then the process is centred at the midpoint of the specification interval. If the mean is located not exactly at the midpoint of the specification band, the distance between the process mean and one of the specification limits will decrease leading to a $C_{p,k} < C_p$. If $C_{p,k} = 0$, then the process centre coincides with either specification limit, while if $C_{p,k} < 0$, then the process mean has already shifted beyond the specifications. The magnitude of the difference between the C_p and $C_{p,k}$ is a direct measure of how off-centre a process is operating (Erdei, 2018). These off-centred situations are shown in Figure 6.9.

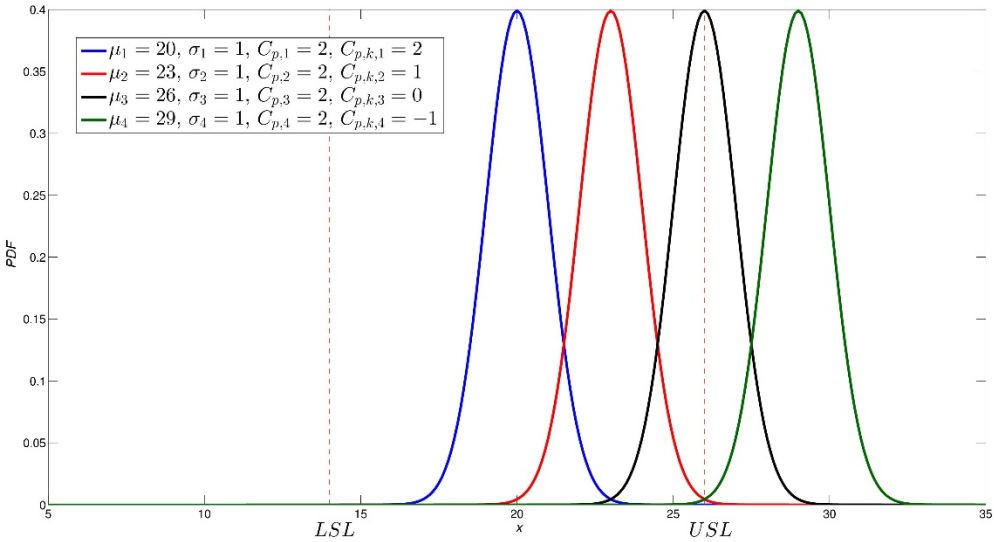


Figure 6.9.: Result of the shift in the process mean in the value of the process capability ratio $C_{p,k}$

Despite the lack of the ability to take into account where the process mean is located relative to the specifications, the process capability ratio C_p has a useful practical implementation. Namely, C_p measures the potential capability of the process, that is, the best possible capability of the process, which can be achieved by centering the process. Since it is recommended to carry out a process capability assessment only for manufacturing processes that are in-control, the standard deviation cannot be reduced easily, since the standard deviation of an in-control process is thought to be the result of the common causes that are an inherent part of the process even in cases of in-control processes. Centring the process, on the other hand, usually can be achieved by adjustments on the machine. That is, $C_{p,k}$ measures the current capability or performance of the process, while the potential or ideal performance of the process is given by the process capability ratio C_p (Montgomery, 2009; Wheeler, Chambers, 2010).

6.7. A demonstrative example[1]

Parts manufactured by an injection moulding process are subjected to a compressive strength test. Twenty samples of five parts each are collected, and the compressive strengths (in psi) are shown in Table 6.3.

Table 6.3.: Measurement of the samples

Sample no.	Compressive strength (psi)					Sample mean	Sample range
	X_1	X_2	X_3	X_4	X_5		
1	83	81.2	78.7	75.7	77	79.12	7.3
2	88.6	78.3	78.8	71	84.2	80.18	17.6
3	85.7	75.8	84.3	75.2	81	80.4	10.5
4	80.8	74.4	82.5	74.1	75.7	77.5	8.4
5	83.4	78.4	82.6	78.2	78.9	80.3	5.2
6	75.3	79.9	87.3	89.7	81.8	82.8	14.4
7	74.5	78	80.8	73.4	79.7	77.28	7.4
8	79.2	84.4	81.5	86	74.5	81.12	11.5
9	80.5	86.2	76.2	74.1	80.2		
10	75.7	75.2	71.1	82.1	74.3	75.68	11
11	80	81.5	78.4	73.8	78.1	78.36	7.7
12	80.6	81.8	79.3	73.8	81.7	79.44	8
13	82.7	81.3	79.1	82	79.5	80.92	3.6
14	79.2	74.9	78.6	77.7	75.3	77.14	4.3
15	85.5	82.1	82.8	73.4	71.7	79.1	13.8
16	78.8	79.6	80.2	79.1	80.8		
17	82.1	78.2	75.5	78.2	82.1	79.22	6.6
18	84.5	76.9	83.5	81.2	79.2	81.06	7.6
19	79	77.8	81.2	84.8	81.6	80.88	7
20	84.5	73.1	78.6	78.7	80.6	79.1	11.4

a) The injection moulding process is to be monitored by X bar and R charts. Establish the control limits and determine whether the process is in-control!

b) Estimate the process' actual and potential capability if the specifications for the compressive strengths are $80 \pm 8\ psi$!

c) Evaluate the process performance!

d) Evaluate the process performance!

[1] The dataset stems from Montgomery, 2009.

Solution:

a) The injection moulding process is to be monitored by X bar and R charts. Establish the control limits and determine whether the process is in-control!

1) First, the range and mean of sample 9 are to be calculated:

The following table contains the five measured data belonging to sample 9:

Sample no.	Compressive strength (psi)				
	X_1	X_2	X_3	X_4	X_5
9	80.5	86.2	76.2	74.1	80.2

The range of the sample is the difference between the highest and smallest observed value when this particular sample was taken:

$$R_9 = X_{9,max} - X_{9,min} = 86.2 - 74.1 = 12.1$$

The sample average is the sum of the measured data (when this sample was taken) divided by the sample size, which is in this case five items:

$$\overline{X_9} = \frac{\sum_{i=1}^{n} X_{9,1}}{n} = \frac{X_{9,1} + X_{9,2} + X_{9,3} + X_{9,4} + X_{9,5}}{5} = \frac{80.5 + 86.2 + 76.2 + 74.1 + 80.2}{5} = 79.44$$

2) Then, the range and mean of sample 16 is identified in the same way as in the case of sample 9:

Sample no.	Compressive strength (psi)				
	X_1	X_2	X_3	X_4	X_5
16	78.8	79.6	80.2	79.1	80.8

Range of sample 16: $R_{16} = X_{16,max} - X_{16,min} = 80.8 - 78.8 = 2$

Mean of sample 16:

$$\overline{X_{16}} = \frac{\sum_{i=1}^{n} X_{16,1}}{n} = \frac{X_{16,1}+X_{16,2}+X_{16,3}+X_{16,4}+X_{16,5}}{5} = \frac{78.8+79.6+80.2+79.1+80.8}{5} = 79.7$$

The mean and the range of all of the samples are listed in the following Table:

Sample no.	Sample mean	Sample range
1	79.12	7.3
2	80.18	17.6
3	80.4	10.5
4	77.5	8.4
5	80.3	5.2
6	82.8	14.4
7	77.28	7.4
8	81.12	11.5
9	79.44	12.1
10	75.68	11
11	78.36	7.7
12	79.44	8
13	80.92	3.6
14	77.14	4.3
15	79.1	13.8
16	79.7	2
17	79.22	6.6
18	81.06	7.6
19	80.88	7
20	79.1	11.4

3) Then, the average range is calculated:

The average range is the mean of the ranges, that is, the sum of the sample's ranges divided by the number of the collected samples.

$$\bar{R} = \frac{\sum_{i=1}^{m} R_i}{m} = \frac{R_1+R_2+\cdots+R_{20}}{20} = \frac{7.3+17.6+10.5+\cdots+11.4}{20} = 8.87$$

This average range will be used as the centre line on the R chart.

4) Grand average (average of the subgroups' average):

$$\bar{\bar{X}} = \frac{\sum_{i=1}^{m} \bar{X}_i}{m} = \frac{\overline{X_1}+\overline{X_2}+\cdots+\overline{X_{20}}}{20} = \frac{79.12+80.18+\cdots+79.1}{20} = 79.437$$

The grand average will be used as the centre line on the X bar chart.

5) Control limits for the R chart:

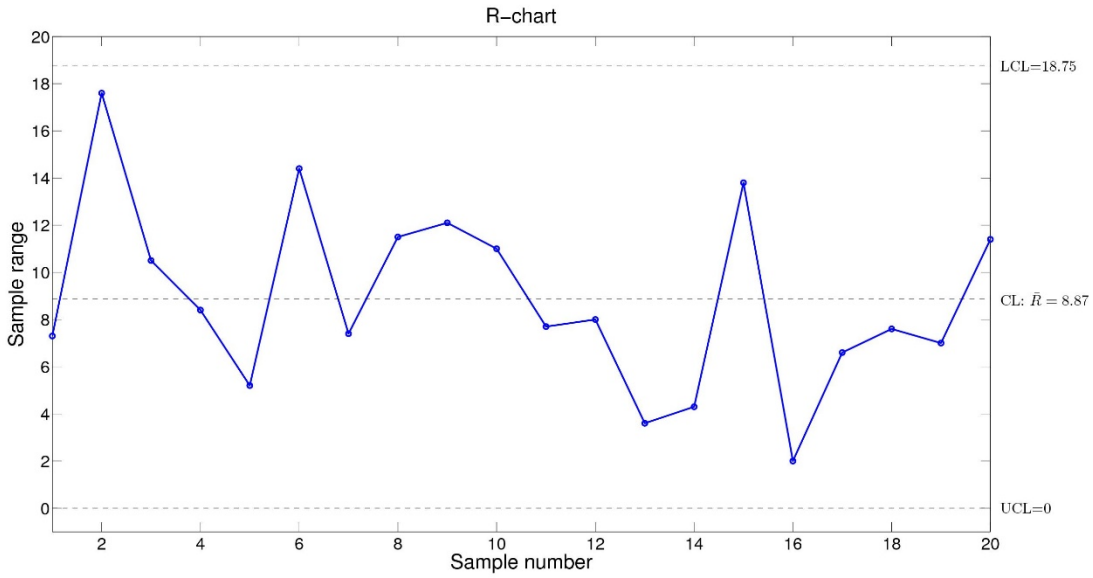
The average range $\bar{R}$ was calculated in step 3, while the values of constant D_3 and D_4 can be found in the table in the Appendix. Note that these constants depend on the sample size (how many items are checked each and every time when a sample is taken; that is, items-per sample) but do not depend on how many samples are investigated.

In this case, the sample size $n = 5$, so that the constants for this sample sizes are utilized (see Table A1 in Appendix to find the aforementioned constants).

$$UCL_R = D_4\bar{R} = 2.114 * 8.87 = 18.75118$$

$$LCL_R = D_3\bar{R} = 0 * 8.87 = 0 \text{ (Note that } LCL_R = 0, \text{ if } n \leq 6)$$

6) Plot the dataset (the ranges of the samples) on the chart. The R-chart contains the range of the samples. Each point represents a sample's range. Since neither of the points falls outside the control limit so that the process standard deviation is assumed to be in control. The X bar chart can be established only if the R charts indicates the process variability to be in control.



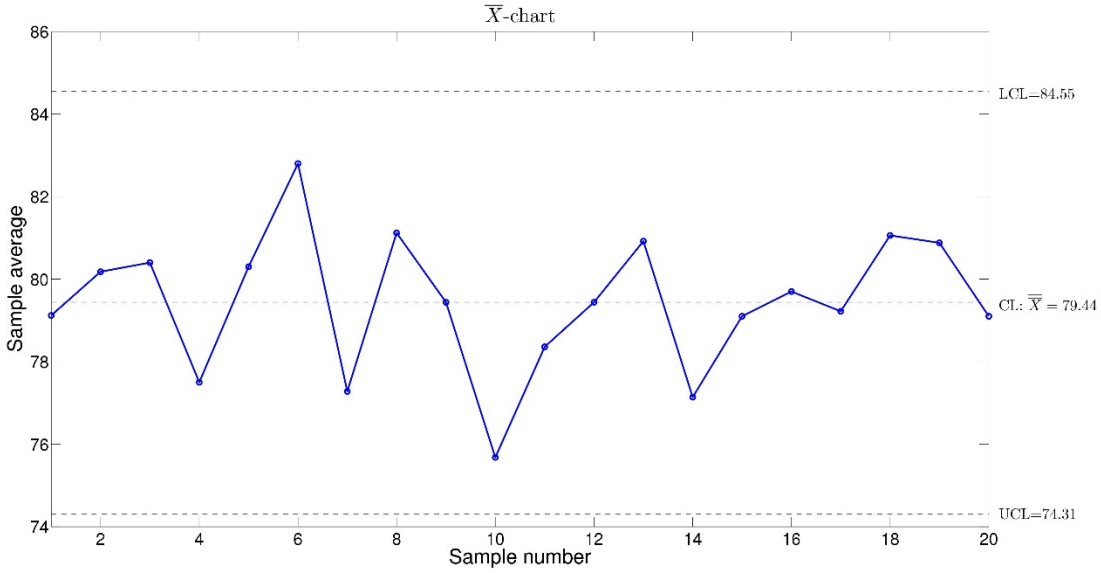
7) Control limits for the X bar chart:

The grand average has been already computed in step 4, and the constant A_2 is to be found for the sample size of 5. The values of constant A_2 are listed in the Appendix in Table A1.

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R} = 79{,}437 + 0.577 * 8.87 = 84.55499$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2\bar{R} = 79{,}437 - 0.577 * 8.87 = 74.31901$$

8) Plot the samples' averages on the chart. All of the points are plotted within the control limits, so that the process expected value is in-control.



b) Estimate the process' actual and potential capability if the specifications for the compressive strengths are $80 \pm 8\ psi$!

9) Estimate the process parameters:

In order to be able to characterize the process' performance, its parameters needed to be estimated. The expected value of the manufacturing process is estimated by the grand average as:

$\mu \cong \bar{\bar{X}}$ so that $\mu \cong 79.437$

The standard deviation of the manufacturing process is estimated based on the grand average and the constant d_2 (for sample size $n = 5$).

$$\sigma \cong \frac{\bar{R}}{d_2}\ \sigma \cong \frac{8.87}{2.326} \cong 3.813$$

10) Actual process capability:

It is known that $LSL = 72\ psi$ and $USL = 88\ psi$. The C_{pk} index characterizes the actual capability of the manufacturing process. Note, that LSL and USL are given externally, while the process parameters μ and σ are estimated from the data collected.

$$C_{pk} = min(C_{pl}; C_{pu}) = min\left(\frac{\mu - LSL}{3\sigma}; \frac{USL - \mu}{3\sigma}\right) = min\left(\frac{79.437 - 72}{3*3.813}; \frac{88 - 79.437}{3*3.813}\right) =$$

$$min(0.65; 0.749) = 0.65$$

11) Potential process capability (can be achieved by centring the process).

The C_p ratio indicates the potential performance of the process:

$$C_p = \left(\frac{USL - LSL}{6\sigma}\right) = \left(\frac{88 - 72}{6*3.813}\right) = 0.699$$

c) Evaluate the process performance!

12) There is a slight shift in the mean (since $C_{pk} < C_p$); both the potential and the actual capability indicate a poor process performance (because of $C_p < 1.33$; that is, C_p is less than the minimum requirement of 1.33); that is, the variability must be reduced.

d) Estimate the process fallout, if the process is operated at its potential capability!

Recall Table 6.2. or Table A2 in the appendix, which contain the actual value of the process capability ratio C_p and the corresponding ppm values. Since C_p and the process fallout are inversely proportional and $C_p < 1$, the $ppm > 2700$. That is, the process produces more than 2700 defective items out of one million manufactured items.

Cp	Sigma level (SL=3Cp)	ppm (process fall-out)
1	3	2700
1.33	4	63.5
1.67	5	0.57
2	6	0.002

Appendix

Table A1: Constants to compute the control limits

n	A_2	A_3	$\tilde{A}_2$	B_3	B_4	d_2	D_3	D_4	E_2
2	1.880	2.659	1.880	-	3.267	1.128	-	3.267	2.659
3	1.023	1.954	1.187	-	2.568	1.693	-	2.574	1.772
4	0.729	1.628	0.796	-	2.266	2.059	-	2.282	1.457
5	0.577	1.427	0.691	-	2.089	2.326	-	2.114	1.290
6	0.483	1.287	0.548	0.030	1.970	2.534	-	2.004	1.184
7	0.419	1.182	0.508	0.118	1.882	2.704	0.076	1.924	1.109
8	0.373	1.099	0.433	0.185	1.815	2.847	0.136	1.864	1.054
9	0.337	1.032	0.412	0.239	1.761	2.970	0.184	1.816	1.010
10	0.308	0.975	0.362	0.284	1.716	3.078	0.223	1.777	0.975
11	0.285	0.927		0.321	1.679	3.173	0.256	1.744	0.946
12	0.266	0.886		0.354	1.646	3.258	0.283	1.717	0.921
13	0.249	0.850		0.382	1.618	3.336	0.307	1.693	0.899
14	0.235	0.817		0.406	1.594	3.407	0.328	1.672	0.881
15	0.223	0.789		0.428	1.572	3.472	0.347	1.653	0.864
16	0.212	0.763		0.448	1.552	3.532	0.363	1.637	0.849
17	0.203	0.739		0.466	1.534	3.588	0.378	1.622	0.836
18	0.194	0.718		0.482	1.518	3.640	0.391	1.608	0.824
19	0.187	0.698		0.497	1.503	3.689	0.403	1.597	0.813
20	0.180	0.680		0.510	1.490	3.735	0.415	1.585	0.803
21	0.173	0.663		0.523	1.477	3.778	0.425	1.575	0.794
22	0.167	0.647		0.534	1.466	3.819	0.434	1.566	0.786
23	0.162	0.633		0.545	1.455	3.858	0.443	1.557	0.778
24	0.157	0.619		0.555	1.445	3.895	0.451	1.548	0.770
25	0.153	0.606		0.565	1.435	3.931	0.459	1.541	0.763

Table A2. Process capability indices and the corresponding number of expected defective items

Cp	Sigma level (SL=3Cp)	ppm (process fallout)
1	3	2700
1.33	4	63.5
1.67	5	0.57
2	6	0.002

7. REFERENCES

Amsden, R.T., Butler, H.E., Amsden D.M. (1989): SPC Simplified, Quality Resources, White Plains.

Bedzsula B., Topár J. (2014): Minőségmenedzsment szemlélet és eszközök szerepe a felsőoktatás fejlesztésében. Magyar Minőség, 23(3), 34-47.

Bedzsula B., Topár J., Tóth Zs.E. (2014): Minőségmenedzsment, MSc oktatási segédlet, BME ÜTI, Budapest.

Berry, L., Parasuraman, A., Zeithaml, V.A. (1985): A Conceptual Model of Service Quality and Its Implications for Future Research. Journal of Marketing, 49(4), 41-50.

Brocka, B., Brocka, M.S. (1992): Quality Management. New York: Business One Irwin.

Dale, B.G., Wiele, T., Iwaarden, J., (2007): Managing Quality (5th ed.)., Singapore: Blackwell Publishing.

Donnelly, R.A. (2014): Business Statistics, 2nd Edition, Pearson, London.

Erdei, J. (2018): Minőségmenedzsment, oktatási segédanyag, Budapesti Műszaki és Gazdaságtudományi Egyetem, Menedzsment és Vállalkozásgazdaságtan Tanszék.

Garvin, D.A. (1988): Managing Quality, The Strategic and Competitive Edge. New York: The Free Press.

George M.L., Rowlands D., Price M., Maxey J. (2005): The Lean Six Sigma Pocket Toolbook. New York: McGraw-Hill.

Goetsch, D.L., Davis, S.B. (2016): Quality Management for Organizational Excellence – Introduction to Total Quality, Pearson.

Iman, R.L., Conover, W.J. (1989): Modern Business Statistics, 2nd Edition, John Wiley & Sons, Hoboken.

ISO (2016): Selection and use of the ISO 9000 family of standards, http://www.iso.org/iso/selection_and_use_of_iso_9000_family_of_standards_2016_en.pdf, 2016.08.10.

Kemény S. (1999): Statisztikai minőség- (megfelelőség-) szabályozás, Műszaki Könyvkiadó, Magyar Minőség Társaság, Budapest.

Kiran, D.R., (2017): Total Quality Management: Key Concepts and Case Studies, Elsevier.

Kövesi J., Topár J. (szerk.) (2006): A minőségmenedzsment alapjai. Budapest: Typotex Kiadó.

Montgomery, D.C. (2009): Introduction to Statistical Process Control, 6th Edition, John Wiley & Sons, Hoboken.

Oakland, J., Oakland, R. (2018): Statistical Process Control, 7rd Edition, Routledge, Abingdon.

Pall, A.G. (1987): Quality Process Management, Prentice-Hall

Pfeifer, T. (2002): Quality Management: Strategies, Methods, Technique, Hanser Fachbuchverlag.

Proschman, M. A., Shaw, P. A. (2016): Essentials of Probability Theory for Statisticians, CRC Press, Boca Raton.

Summers, D.C.S. (2010): Quality. Boston: Prentice Hall.

Szabó G. Cs, (2002): Minőségmenedzsment módszerek, oktatási segédanyag, BME GTK MBA képzés, Budapest.

Tenner, A.R., DeToro, I.J. (2004): Teljes körű minőségmenedzsment TQM, Műszaki Könyvkiadó, Budapest.

Topár, J. (2012): Minőségmenedzsment trendek a termelő- és szolgáltató szektorokban. In: Topár J., szerk. 2012. A műszaki menedzsment aktuális kérdései. Budapest, Műszaki Kiadó, 87-104.

Topár, J. (2005): A humánerő, mint a minőség kulcsa: minőségszemlélet humánerőforrás alapon - a humánerő szerepének összehasonlítása az egészségügyben alkalmazott minőségmodellekben. V. Debreceni Egészségügyi Minőségügyi Napok (DEMIN V.)

Warren G. Bennis, Patricia Ward Biederman (2009). “The Essential Bennis”, p.198, John Wiley & Sons.

Wheeler, D.J., Chambers, D.S. (2010): Understanding Statistical Process Control, 3rd Edition, SPC Press, Knoxville.

World Quality Day (2010):

https://www.indiansinkuwait.com/ShowArticle.aspx?ID=8136&SECTION=0, 2019.08.10.