Total Quality Management
TQM

What is quality ?
Why is quality important ?
How can quality be improved ?
How is a process controlled ?
How can products be controlled ?

Contents

S. Shiba, A. Graham, D. Walden, *A new American TQM*, Productivity Press, Portland, Or, 1993.
Ph. Smans, G. Ver Elst, *Qualité Assurée*, VIF Editions, 1994.

Definition of Quality

Defining quality is far from easy. Just try to find why you find that a product is not of quality. Is a Mercedes a high quality car ? Is a Lada ? Is a course of quality ?

What is Quality ?

- grade of service / product
- reliability
- safety
- consistency
- consumer's perception

The notion of quality often subsumes a comparison between products. Product A is better than B and therefore has a higher quality. However, the word "better" is vague and different definitions can be used.

Quality:

- means "degree of excellence"
- implies "comparison"
- is not absolute

Evolution of Quality Concepts

Here we detail how the definition of quality did evolve over time.

1) Fitness to standard

Here is a first definition.
It just says that a product is of quality if it is what it is supposed to be.

definition: conformance to the specifications

The quality is thus checked by comparison between the output and the specifications.

methods:
- Standardization;
- Statistical quality control;
- Inspection.

Standardization is the set of actions taken for the product and the process to be clearly identified. A set of written procedures for example. The classical test for checking whether standardization has taken place is: "If the people go, do the procedures stay ?"
Inspection is a simple mean by which the items are sorted. Good items are kept and bad ones are dropped. We can decide to check all the products (total inspection) or only some of them (statistical control). Inspection plans are discussed later in this chapter.

drawbacks:
- Inspectors are "the enemy";
- Inspections do not add any value;
- Conformance to specifications does not mean conformance to needs

Based on this last drawback, the following definition was introduced.

2) Fitness of use

Here, a product is of quality if it performs as expected not as specified. The difference is between the intended use of a product (its specification) and its real use.

definition: conformance to the expected use

A screwdriver is specified for a given size. We generally want to use the same screwdriver for any kind of screws. And maybe for opening a can of paint. Note that the fitness of use is difficult to reach since this use may vary over customers and time.

methods: market research / contact

Here we enter the world of marketing. The only way is to ask the consumer.

drawbacks:
- Inspectors are "the enemy";
- Inspections do not add any value

"Fitness of use" supposes that definition of the specifications are "consumer based". Fitness of use requires thus fitness to (the new) specifications and therefore also requires inspections.
Higher quality implies better inspection and therefore higher costs.
Too large inspection costs could also be dangerous.
The answer is then the following. Instead of "inspecting" the quality of the product, the focus came on "building" the quality in the product.

Evolution of Quality Concepts (Cntd)

3) Fitness of cost

This means high quality in the eye of the users but now at low or reasonable cost.

definition: conformance to the expected use and to the expected price.

To reach this goal you need to reduce the variability of the processes so that no products have to be discarded (and therefore none need to be checked). The only way of reaching this goal is to control the processes and not the products.

methods:
- Statistical quality control (SQC)
- Stochastic process control (SPC);
- Providing feedback at each step;
- Promote participation of the workers in the design and improvement;
(7 QC steps and 7 QC tools)

SPC is a technique aiming at controlling the process by which products are made. The aim is to detect any disfunctioning of the process. Techniques are described in more details later in the chapter.

Each worker should provide some feedback on the work of his/her predecessor. The goal is first to detect any mistake as quickly as possible and second to allow some learning to take place.

drawbacks: - everybody can copy

Examples are given by the four Asian tigers: Korea, Hong Kong, Taiwan, Singapore.

4) Fitness to latent requirement

This means high quality in the eye of the users and low cost.

definition: conformance to the unexpected needs

Examples of products which fitted to latent requirements are the Polaroid camera and the walkman. The idea is to give the company a monopoly for a while.

Example: the watch

The "fitness to standards" is reached when all parts are ok; the "fitness to use" means that the watch gives the correct time; the "fitness of cost" means the watch works and its price is ok. Finally, the swatch is an example of the fitness to latent requirement.

Summary: specifications need to be derived from what customers think;

Do not imagine what they want, ask them and select their needs as your objectives.

quality mechanisms are needed to assure the products meet the specifications;

You then need to be sure your product meet the objectives (their needs).

these mechanisms should not increase the cost of the product - on the contrary.

The quality mechanisms need to be built-in (in the processes or in the people).

A four-level Model

In the paper *The process of total quality management* [in *Managing Quality*, London:Philip Allan, 1990] Dales, Lascelles and Plunkett outline another four-level model of the evolution of quality management. In addition to the framework it proposes, clear definitions of quality terms are also provided.

Level 1. Inspection

measure the characteristics of a product and compare them with its specifications;

The goal here is the fitness of standards. This is the passive "inspecting" attitude.

Level 2. Quality Control

inspection performed by the workers themselves with a feedback loop to the production line;

Here we avoid the "inspector" effect and allow some learning to take place.

Level 3. Quality Assurance

set of (implemented) predefined and systematic activities necessary to give confidence in the process quality;

One step further. Quality procedures are designed and planned as a whole to ensure that no bad products be delivered. We do not just rely on everybody's work and control. This introduces the notion of a coherent set of quality procedures/tests.
The given confidence (in the definition of QA) is important both for the producer and for the customer.

Level 4. Total Quality Management

management centered on quality and based on the participation of everybody which aims at the customer satisfaction and at the improvement of the company's personnel, of the company and of the society.

The ultimate step. A quality assurance plan is operational but the management, the workers and the customers continuously interact to review / improve this plan.

Evolution of Thinking: TQM

The highest quality level is made of four main elements:

1) Focus on the customers
   (fitness to use or to latent requirements)
2) Continuous improvement
   (fitness to standard and of cost)
3) Total participation
4) Societal Networking

Let us review these 4 elements successively.

1. Focus on the customers

Here are two examples of explicit guidelines used to focus on the customers.
The first example is that of HP. They recommend each worker / employee / department to raise the following questions:

1. Who are my customers ?
2. What are their needs ?
3. What is my product or service ?
4. What are my customers' measures or expectations?
5. What is my process for meeting their needs ?
6. Does my product or service meet these needs ?
7. What actions are needed to improve my process ?

The second example is from Motorola.

1. Identify the work you do.
2. Identify whom you do it for.
3. What do you need to do your work? from whom?
4. Map the process.
5. Mistake-proof the process and eliminate delays
6. Establish quality and cycle time (flow time) measurements and improve goals.

2) Continuous improvement

To improve a product/process is not obvious. A methodology is necessary. Here is the one called "the seven quality control (7QC) steps" that is made, oh wonder, of 7 steps.

1. Select a theme

First, we should determine the problem on which we will concentrate. Examples are: "decrease the number of late deliveries"; "decrease the misforecast"; "decrease orders lost". Formulating the theme as a weakness helps to state the theme as a problem not as a solution. Let us consider here, as a guiding example, the theme: "decrease the number of students not attending the POM course".

2. Collect and analyze data

Use: Check sheets, Histogram, Pareto diagram

After the theme has been stated, one should not hurry for solutions. The first thing to do is to consider the reality again by collecting data related to the selected theme.
Check sheets, histograms, Pareto diagrams and scatter diagrams are all QC tools which help collecting and analyzing the data.
For our goal, the data are all the students: those of the POM course, those of another course given by the same professor, those of courses on the same subject, those of courses given at the same time, etc. All these students should be polled.
A Pareto analysis of the data could reveal the main weakness. Assume that the reason found is: the students do not understand anything (this is just an example).

3. Analyze causes

Use: Cause-and-effect diagram

The goal here is to go back to the root cause of the problem. A classical tool for finding the root cause is the cause-and-effect diagram which addresses all types of problem/error sources: man, process, material and environment. Here are examples of causes of each type: a bad professor (the man), the way the course is given (the process), inadequate student backgrounds (material) or noisy classrooms (environment).
Whatever technique you used to determine the root cause, the systematic nature of the technique is essential.
Still as an example, assume that the root cause of the disinterest of the students for the POM course is that it requires to much mathematics they do not master (inadequate raw material or inadequate process).

4. Plan and implement solution

The next step is to find a remedy to the root cause.
For our example, one could imagine some training for the mathematics needed for the course. This solution could be tested on a small sample. Other remedies could be tried.

5. Evaluate effects

Again, before implementing the solution on a large scale, one should check the effect of this remedy in the real life. Only when it shows to be effective, it can be standardized.

6. Standardize the solution

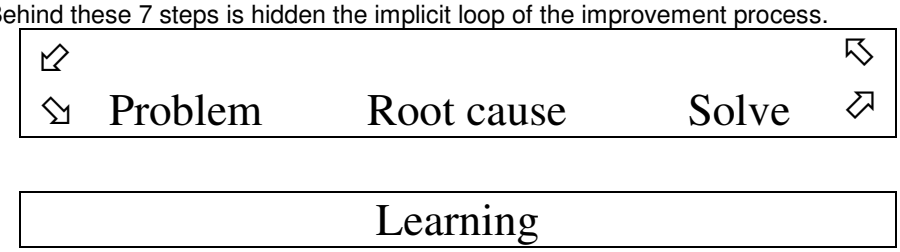
At this point, the improvement is implemented on a regular basis.

7. Reflect on process and the next problem

Here some reflections about the improvement process are necessary. Maybe, some systematic checks should be incorporated. Maybe, a better data collection system should be used (next time). Maybe ...

Iteration: Plan/Standardize- Do - Check - Act (P/S DCA)

Behind these 7 steps is hidden the implicit loop of the improvement process.



Note that this kind of loop is what everybody facing a problem does. Two aspects need to be stressed: the systematic analysis and the systematic check with the reality.

Example: Observing the bricklayer

F.W. Taylor already used this kind of approach to improve production processes.

☹ scientific management

☺ simplify, combine, eliminate (motion economy)

A corollary of the continuous improvement approach is the need for measures and indicators. These are necessary at all levels. First, to be aware of problems; second to be able to determine the root causes; and finally to check that a real solution was found.

Need for measures / indicators

These measures should fulfill the following conditions.

- reflect the organization's goal
- must be controllable
- must allow feedback (at all levels)

They must translate the objectives in indicators and everybody must agree with (and, first, be aware of) these indicators.

- **Dangers**

  Measures are not perfect

  Measures are not taken serious

Using a unique indicator (or too few) will open the door for any misuse. As an exercise, propose an indicator for measuring the quality of a course and then imagine what should be done to increase the value of this indicator without really improving the course.

- **General Features**

  Measures must be taken;

  Cooperative measure, not anti worker measures;

  Several measures are necessary;

  Do not forget the meaning of the indicator.

3) Total participation

If we want the continuous improvement to take place, we should let the workers do it.

Continuous improvement is a worker's task

The workers are usually more competent than the managers to improve the system.

What workers want:

Here is a list of the most desired features.

• Goals which are clear, challenging and reachable
• Means to reach the goal
• Responsibility for the outcome
• Information about the corporate goals
• Participation in decisions
• Salary
• Job security
• Interesting work
• Self-development

And most of these features must be granted if you want a continuous improvement system.

4) Societal Networking

The TQM mentality also assumes that your company positively interacts with the "society" in which it operates.

- National promotional organization
- training
- knowledge dissemination
- societal promotional activities
- national standard certification
- development of new methods

ISO-9000

ISO stands for International Standard Organization.

Approach:

In order to manufacture products of high quality at the right cost, the manufacturing processes (and not the products, or at a smaller extent) must be controlled. This gives birth to a set of specifications, procedures and tests for checking the manufacturing processes (QA plan). This QA plan should normally guarantee that quality products are manufactured. The next step is to apply the same specification process to the quality assurance system itself in order to be sure that the QA plan is regularly and adequately reviewed. In other words, a quality assurance plan should be designed for the whole company. This is the ISO-9000 norm.

1. Develop an internal quality assurance plan

2. Certify it by an official organization

Objectives

quality: reduce non-quality costs
improve fitness to standard/use/cost
dynamism: review the objectives/methods
marketing: give confidence to the customers

Principles of ISO-9000

The principles on which the norms are based are the following:

- Say what you do

This means: write down clearly how things must be done. Get a written reference of the procedures.

- Do what you said

This means: be sure everybody follows the procedure you wrote.

- Record it, check it and correct it if needed

This means:
- write down what you obtained by following the procedure;
- check the results and record these checks;
- take actions if something goes wrong (according to well defined procedures that will be followed and checked again).

= framework for implementing a quality system

These principles are somehow very vague. This is intentional. It just makes you responsible of deciding what quality is. Once you decided what quality is, the ISO9000 norm imposes you to describe clearly by which procedures you will assess this quality and how you will guarantee these procedures are really implemented.

≠ a set of specified actions

It does never tell you which precise actions you should take, which precise procedure you should implement. This remains under your responsibility.

ISO-9000: Structure

5 norms :

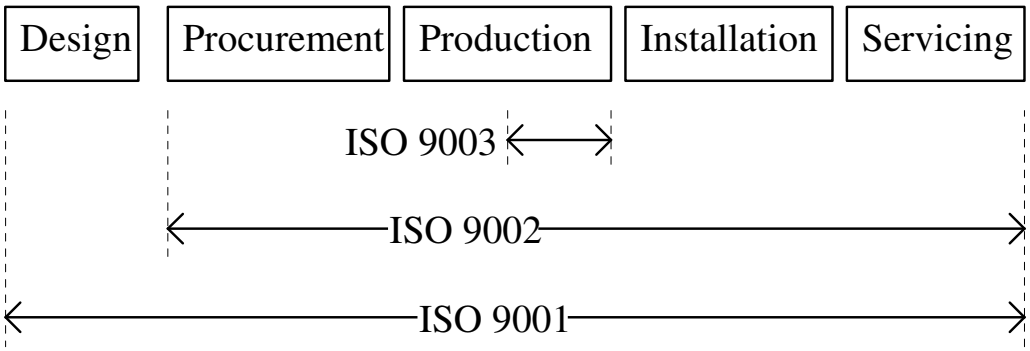
The ISO 9000 norm series consists of 5 different norms numbered 9000, ..., 9004.

Guidelines for use : 9000 and 9004

The ISO 9000 norm is more a user guide which explains the difference between the norms and which gives advises on how to implement them. The ISO 9004 gives additional hints on the implementation of a quality system.

Quality Systems : 9001, 9002 and 9003

The three other norms are well-defined standards. They specify the framework for the implementation of the quality systems. They differ by the breadth of the activities which are performed in you company.



9003 Model for Quality Assurance in Final Inspection Test

This is the basic certification which first aimed at guaranteeing that the final products meet the final specifications. This should be the norm aimed at by companies only involved in the manufacturing of well-defined standard products.

9002: Model for Quality Assurance in Production, Installation and Servicing

This is the norm aimed by companies with pre or post manufacturing functions.

9001: Model for Quality Assurance in Design, Production, Installation and Servicing

It is the broadest norm. It does not mean it is more difficult but that the norm applies to a company with the broadest spectrum of functions. As shown by the above drawing, it should be aimed at by companies with a real design function.

Elements of the ISO 9000 Quality System

The ISO-9000 norm is made of 20 different elements referring to different operations and therefore to different parts of the company's organization. A useful exercise consists in drawing a mapping between the company's functions and the elements of the norm.

1. Management Responsibility

In order to have a coherent approach to quality, the initiative and the control should come from the top management. It insures you will get the product the marketing claims is selling.
Practically, the management is required
to define a policy and objectives (i.e. a strategy in terms of defect, delay, service ...);
to define an organization (who's doing what and who's reporting to whom and when);
and to review the system (that is, to define review meetings and procedures for checking whether the organization and the objectives remain adequate).

2. Quality System

The first component of the quality system is the set of procedures which will be used to guarantee the quality in accordance with the policy and the objectives defined above. These procedures, the way they are organized and the way they work together must be described formally (Say what you do). Most of the procedures will be described in the following sections.

3. Contract Review

Quality here means that when a contract is signed, it will be fulfilled as contracted. This means that only clear contracts will be accepted; that any difference between the offer and the contract will be checked; that any modification of the contract will be taken into account adequately and that, above all, we have the means for fulfilling the contract. Again clear procedures are needed here.
Examples: ordering a PC with an English version of Windows
(get an English PC with English plugs !!!)
modify the order to get a qwerty keyboard
(the preloaded software still assumed an azerty keyboard)

4. Design Control

This part is proper to the ISO 9001 norm (not in ISO 9002).
To control the design you must first define the successive phases of the conception (the route), their organization and their interfaces. You must then describe the acceptance/selection procedures used in each phase (this allows the design to be proved).
A special effort must be devoted to the input and to the output of the design. Show how the input (of the design) is checked as being: legal - coherent - complete - in agreement with the contract) and show how the output of the design is checked as being legal, coherent and in agreement with the requirements.
These procedures must namely specify:

- how you check that output is correct (have the procedures been followed?);
- how you check that output is conformable to requirements;
- how you manage subsequent changes in the design.

Note on the level of details needed: compare the level of job descriptions in:
a pizza hut : every job is clearly described; and in
a restaurant: the *Maitre d'hôtel* knows what he has to do.

5. Document Control

This ensures that documents are available and accessed by who needs them.
It also ensures that the right version has been obtained and is in use.
This is in favor of using rather procedural form to distribute documents.
example: school (communication of important and unimportant information)
For very important changes, one may ask to return or destroy the old versions.

6. Purchasing

The question here is how you guarantee that the products you buy are of quality. In order to solve it you need:

1. to define which guarantee your subcontractors must present and
2. to check these guarantees and to record your measures.

In order to guarantee the products you get are those you wanted, you need:

1. to define clearly the purchase data and
2. to make a control or to get the assurance one is done.

7. Customer-Supplied Material

How do you handle the products which are supplied by the customers?
(example: containers, material to be sent).
Detail the procedure you use to inform the customer of any loss or damage.

8. Product Identification and Traceability

If necessary, define clear procedure for identifying a product from the moment it has been received up to the moment it has been installed again.
The two basic operations are:

- identify (give a unique number, maybe a lot number) and
- trace (where it has been, with which components it has been manufactured, ...)

examples: bar code systems; carriers must be able to trace all the products (DHL)

9. Process Control

Here you need to plan all the processes (production, installation, services) which have an impact on quality. This means:

- to write the procedures;
- to define what are the adequate tools and environment;
- to define the norms and check whether some equipments should not be certified
- to define how the process must be controlled and on which basis;
- to define the maintenance.

example of structure for a process:

- what is the process for?
- who should perform it?
- which machine and which environment can be used?
- what other documents are relevant for this process/equipment?
- which input with which acceptance criteria (refer to 10)?
- how the process works?
- what must be controlled / what is OK / what is NOK (refer to 10)?
- what should be done if NOK (refer to 13 and 14) ?

example: making coffee

10. Inspection and Testing

You need to verify that the product you are producing satisfies the requirements.
Describe which parameters will be measured, where and how.
If needed, describe also the machines required for these measurements and describe the actions to be taken if something is NOK.
You can distinguish between the checks at the input, during processing and at the end.
If some necessary checks are skipped, then the product must be traceable and marked explicitly as such in order to find it back later if needed.
If you use sampling plans or acceptance intervals, refer to 20.
example: taste coffee

11. Inspection, Measuring, and Test Equipment

You must ensure that the adequate testing equipment is used and that they are adequately calibrated. You therefore need

- to list the needed testing/measuring equipment and for each,
- to determine the required accuracy and
- to determine the operating conditions (warehousing, calibration, ...).

12. Inspection and Test Status

You must ensure that the controlled items are properly marked (identified) and recorded.
Define how to recognize not tested products, tested products ok, tested products nok.
Define which charts must be used for processes and how to record them.

13. Control of Non conforming Product

You need to ensure that the adequate actions are taken for non conforming products in order to avoid using or delivering them. Tell also how they will handled afterwards.

14. Corrective Action

The treatment of non conformance must follow the following general scheme:
1. describe clearly the problems (which test did fail, which criteria was used ...);
2. define immediate short-term responses (13) and avoid new NOK ;
3. identify the basic reason for the non conformance;
4. define long-term corrective actions;
5. define the follow-up of these actions.

15. Handling, Storage, Packaging and Delivery

We must ensure that the product remains ok from the final test up to its delivery.
The following operations are relevant:

- handling (how to manipulate it);
- packaging (including identifying and labeling);
- storing (conditions on the storage area);
- preserving (not getting stolen or taken inadvertently);
- delivery (use the right carrier mode and conditions).

16. Quality Records

All the actions related to quality must be recorded and stored. The objectives are:

- to prove you are behaving well (for certification audit);
- to provide you with the material needed for conducting quality improvement actions.

You should thus:

- define how you will store these documents
- define how you will organize these documents
- define how you will make their access possible and efficient

Here is (non-exhaustive) list of documents you should somehow keep.

- top management quality reviews
- quality book
- test reports
- contracts
- numbering of parts
- subcontractors evaluation
- personnel formation
- internal audit reports
- corrective action request and reports
- customer complaints

17. Internal Quality Audits

The need for internal audits must be clear to everybody. If you want a system to work well you should check it from time to time. These audits must be performed by internal people who have been trained and who are not in direct contact with the audited services. They must check whether :

- - the asks are performed as documented and well;
- - the proper documents and material are used;
- - the procedures are adequate (to review the efficiency of the quality system)

You may refer to ISO 10011 for how to conduct audits.

18. Training

The training of all your people is a requirement if you want your organization to improve. With respect to ISO-9001, you must

- be sure the worker can use the new machine that has been bought and
- be sure the worker can follow the procedures which have been defined.

Practically, the training requires a complete planning.
(get what the people want, get what they need and plan the training's)

19. Servicing

Examples of services are : a help line, a full service one year guarantee, the formation of the customer for using the product.
The notion of quality for a service is not different than that of a product. You must:

- select the quality of the service (the performance);
- discuss what is really needed to reach these performances;
- define the requirements, the formation, ... for achieving the performances.

20. Statistical Techniques

With reference to the points 9 or 10, you defined earlier how the processes (9) and how the products (10) would be tested. These tests could be based on sampling plans or statistical process control (SPC). In both cases, you must motivate the technique you use and describe how you parametrize the method. Refer to the part of the course on statistical techniques.

Getting the ISO 900x Certification

Obtaining the certification is not an easy task.
From the point of view of the approaches, the ideal situation is when the quality procedures which already exist are sufficient for obtaining the certification. In other words, the best attitude is: "introduce the concept of total quality management in your company" and you will get the ISO-9000 certification almost as a by-product. The certification should thus not be a goal *per se*. However, in the practice, the marketing advantage is often the main drive behind the certification.
From a practical point of view, some administrative steps are needed. The fulfillment of these steps is best managed as a project.

"Obtaining the certification" is a project

Depending on the size of your group, you will do the job alone or you will build a whole team with a project leader.

- define a team / a project leader

Since it is a project you need to detail the different tasks and estimate their length.

- define a plan

Among all these tasks, the most crucial one are those corresponding to the checks.
Reviewing the current state and performing internal audits are therefore essential.

- team setup
- team formation
- personal (in)formation
- selection / formation of internal auditors
- evaluation of the current state

Here starts the continuous improvement loop.

⇒ one more application of the PDCA .

⇒ information / formation / implication of all

- definition of needs
- description of the needed procedures
- implementation
- internal audit (as early as possible)
- corrective actions

When all the needs have been fulfilled, do not consider the work as being finished. Everybody should have learned the "continuous improvement" principle.

- final quality manual (as late as possible)
- certification audit
- manage the post-certification

Post-Certification

Once the certification has been obtained, three directions should be pursued. You should systematically re-assess your efforts; try to evolve from this certification towards a real TQM spirit and also reconsider the complete process by which you deliver products or services. These three directions are discussed below.

1. Re-allocate the efforts / Continuous improvement loop

The first step is to consider whether the efforts spent in order to guarantee the quality are well balanced. This can be done by applying the 7QC steps. The regular re-evaluation of the quality and non-quality costs is crucial here.

$\Rightarrow$ Evaluate the cost of quality

There is an obvious distinction between the money spent in order to avoid quality problems, in order to detect quality problems and in order to solve quality problems.

prevention:		education, cause removal, preventive maintenance
appraisal:		test, measurement, inspection, problem analysis
failure	internal:	scarp, rework, disorganization
	external:	warranty, liabilities, reputation

2. Enlarge the scope : ISO9000 $\rightarrow$ TQM

The European foundation for quality management (EFQM) has been founded by a group of 14 European companies. Its aim is the promotion of TQM in Europe

EFQM model

The EFQM proposes a model for auditing the quality of your company as a whole. The points 1 to 3 are called the factors; the points 4 and 5 the results.

1. Leadership

How the managers insulffate, promote, award the values of TQM in their departments and in the company.

2.a Human Resource Mngt

You want everybody to give his/her best for the continuous improvement action. What do you do for that (organization, formation, promotion, encouragement's, communication) ?

2.b Strategy

How important is the role of quality in the determination of the strategic decisions?

2.c Resources

Do we really use our financial, information, physical and technological resources in the best way?

3. Processes

How do we document, check and improve our processes ?

4.a Personnel satisfaction

How the personnel values his company ? Do we give them the right freedom, responsibility, formation and means for its most adequate development ?

4.b Customer satisfaction

How customers value the company and its products?

4.c Integration in the society

How is my company perceived in the society?

5. Operational results

What are my results compared to what was expected?
Each of these aspects has a proper weight so that a global value for your company can be derived. A similar system exists in the USA where the best company is awarded (the Baldrige Award).

3. Process Re-engineering

Here is the definition of process re-engineering proposed by their initiators:

The fundamental redesign of business processes

$\Rightarrow$ to improve: cost, quality, service, speed

The focus is on the processes. Re-engineering is a three step procedure.

1. analyze the existing processes

The goal is to understand the processes in great details in order to be able to determine what is necessary in terms of product features. The analysis does not focus on how things are made but on what is done.

2. find which product features are required

On the basis of what is required, in terms of features, a new design of the process can take place.

3. propose a new process from scratch

This design should be performed from scratch to avoid being biased by the current state. Of course, the new design should be more efficient than the previous one.

Pair: TQM - PR

TQM is a method which aims at improving all the steps of a process. It can be seen as a "policy of small steps". When you are convinced that all the optimized steps cannot return more, the time is come to put the whole process into questions.
Also, the TQM approach will clearly tell you what is needed, which feature are necessary and which process are not performing as well as you would like. In other words, the TQM will tell you where PR could be necessary and will provide you with the required data.
Similarly, TQM will give you methods and techniques to be sure that the new process design works as expected.

For more information, please refer to the following book:
Hammer M. and Champy J., *Reegineering the corporation*, Nicholas Brealey Publishing, London, 1993.

Statistical Aspect of Quality Control

TQM (but also normal quality assurance) requires mechanisms to check the products and the processes. In the remainder of this section, we will focus on two such mechanisms: the acceptance sampling and the control charts.

The aim of acceptance sampling is to decide whether a product lot is good or not. This is thus an inspection technique. However, the goal is to be able to decide (accept) about a whole lot of product by inspecting a small sample only (sampling).

! Products Extract a sample from a lot
Observe the sample
Estimate the quality of the complete lot

Based on the observation performed on a sample, we derive conclusions for the complete lot. In general, only two decisions are possible: accept the lot or reject it.

Acceptance sampling

You could observe 0-1 variables such (the product works or does not work, the product is broken or not, the product weights more than 900 gr. or not) or continuous variables (how much does the product weight, measure, ...). This is called sampling on attribute in the first case and on variable, in the second.

- Attributes (0-1)
- Variables (continuous)

Control charts aim at measuring the quality of the process (and not of the products).

! Process Extract a production sample
Observe the sample
Estimate the quality of the production process

Here the goal is to check whether the process still performs well. We want to detect variation in the process as soon as possible. We want for example to know whether some adjustments are needed, whether some piece of equipment must be replaced, etc.

Control charts

Again, the variables that are measured can be 0-1 (attribute) or more general (variables).

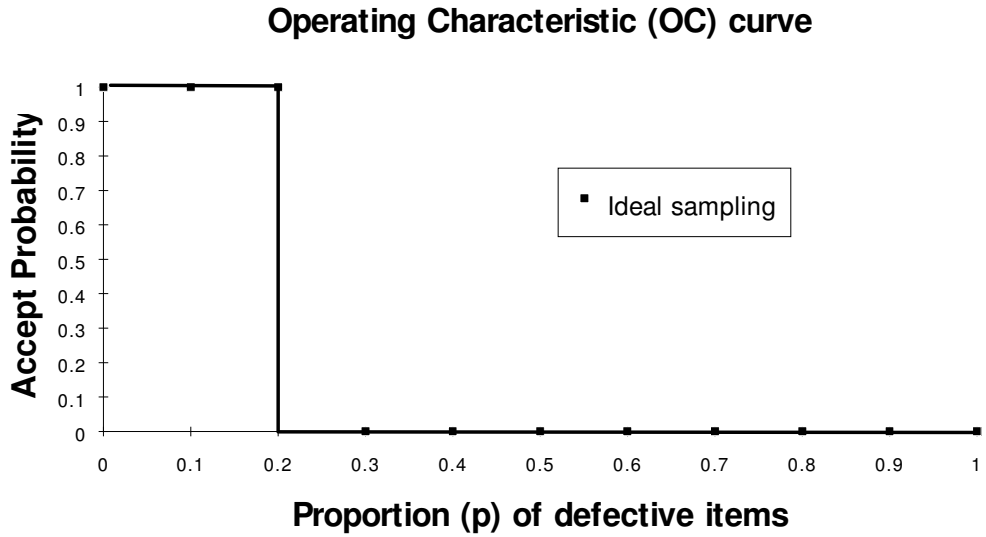
- Attributes
- Variables

Sampling Plan for Attributes

Remember that an attribute is a 0/1 variable such "the product is defect free or not". Let us assume we produced a large lot of products. We know we cannot guarantee that all the products are defect free. Producing a defective product can always happen. However, we would like to define a limit. And ideally this limit should be clear.

Ideal discrimination:

If the percentage of defective items (p) in the lot is	20%	then, accept the lot;
	> 20%	then, reject the lot.



Assume, you have inspected 100 items out of a lot of 10000 an no defective item was observed. Then, it seems that the lot is good. However, you are not sure about it. If you check a sample of size 1000 and again you could not find any defective. You are even more sure than the whole lot is good and that the percentage of defective is much below 20%. However, you are not sure. There remains a small but non-null probability that the lot is bad. The only way to be 100% sure consists in inspecting the lot completely.

complete inspection

However, this is often too expensive. Or it could simply be impossible (when the test is destructive, for example). In practice, a sample is inspected, that is a small number of units. By inspecting this sample only, properties on the complete lot are derived..

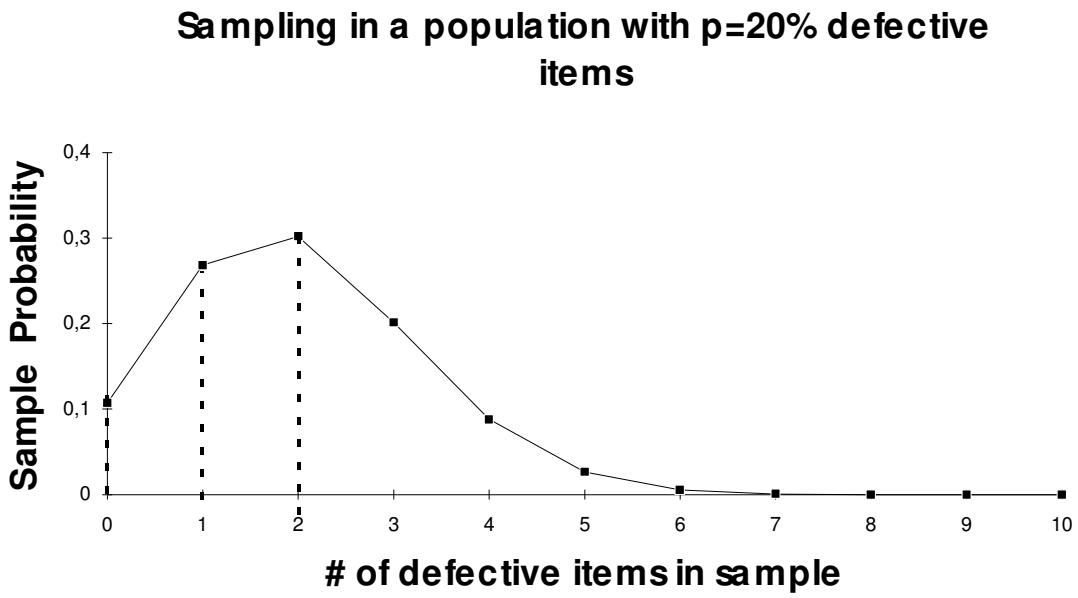
Sampling plan (n, c):

Inspect n units; if the number of defective items is:	c,	then accept the lot;
	> c,	then reject the lot.

However, by choosing a sampling plan, we introduce two risks: the risk of rejecting a good lot (because we unluckily picked a rather bad sample) and the risk of accepting a bad lot (because we luckily picked a rather good sample). Let us try to determine both risks.

Sampling Plan (n, c)

Assume you have a large lot with exactly 20 % bad items.
According to our definition, we want to reject the lots with more than 20 % defectives. In this case, the lot with exactly 20% defectives is still acceptable.
We take a sample of size 10 (n=10) and we decide to accept the lot if we find 0, 1 or 2 bad items (c=2) and to reject the lot if we find 3 or more bad items.
Here are the exact probabilities of taking a sample with 0, 1, ...or 10 bad items.



The probability of picking a sample with 0 bad items is the probability of picking 10 times a good item. It is 0.8^10 = 0.107. Thus with a probability 0.107, the sample will have no defectives. We can similarly compute the probability of taking a sample with 1, 2, ...10 bad items. The general formulas are given on a later page.

Prob[accept the lot | defective percentage p = 0.2] =
Prob[finding exactly **0, 1, ..., c** bad items | p = 0.2]

The probability of accepting the lot is therefore (0.107 + 0.268 + 0.302 = 0.677).
This means that with a probability of 0.323, the lot will be rejected although it was , by definition, good. This is thus the probability of rejecting a good lot.

n	c	Prob of accepting the lot	Error I
10	2	0.677	0.323

Error I = Probability of rejecting a good lot
= Producer's risk
=

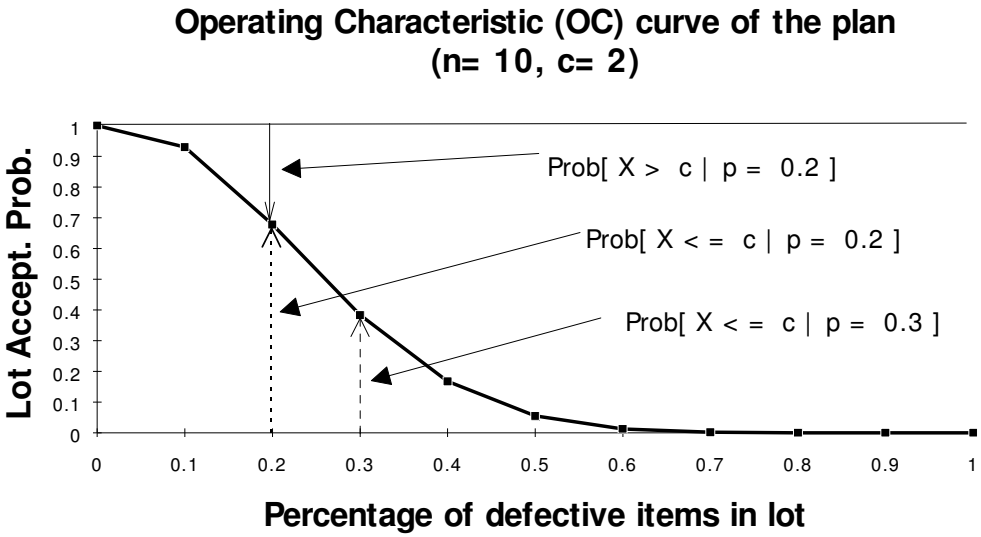
This error is called producer's risk since the producer will in this case reject a lot which should have been accepted.

Sampling plan (n, c)

But we could raise the more general question: what is the probability of accepting/rejecting the lot if the defective probability is not 20% but more or less?

By repeating this computation for all p: OC curve

Here is the plot we obtain.



For p = 0.2, we obtain the value as follows. If p = 0.2, we can compute the probability of getting a lot with 0, 1 ...10 bad items. Knowing c, we can derive the probability of accepting the lot f(0.2)=Prob[$X \leq c \mid p = 0.2$]=0.677. This is the couple we plot (0.2; 0.677). Repeating for all the p values, the obtained the above curve. Here we only computed this probability for some p values and we interpolated.

Sampling Plan (10,2)			
p	Probability of accepting the lot	error I	error II
0.1	0.93	0.07	
0.2	0.68	0.32	
0.3	0.38		0.38
0.4	0.17		0.17

Below the curve is the probability of accepting the lot. For p=0.3, we see that we accept the lot with probability 0.38 (the second vertical dotted arrow). In this case, it will also be a mistake since the lot is bad (p=0.3) and it will be accepted. This is a type 2 error or consumer's risk.

How to select n and c ?

The question is then how to best select b and c. Which objectives do we select and how do we translate them in n and c.

Sampling Plan Development

Practically, the producer select a percentage of defective items, called AQL or p_0, which is, in his opinion, acceptable. That is, in his opinion, if there are AQL percent of defective items in the production lot, this lot should be accepted. However, a sampling plan cannot perform a perfect discrimination. The producer therefore specifies the risk he is accepting to run: α. He states: "A lot which has AQL or less percent of defectives should be rejected in at most α percent of the cases (with probability at most α)". Similarly, the consumer (the buyers of the products) define a percentage of defective items, called LTPD or p_1, which is, in his opinion, not acceptable. He also define a risk, β, and states: "A lot which has LTPD or more percent of defectives should be accepted in at most β percent of the cases (with probability at most β)"

Producer's cost :	Consumer's cost :
Producing a bad item versus Inspection to assure the desired quality	Accepting a bad item versus Assuring the desired quality by inspection
Producer specifies :	Consumer specifies :
Acceptable quality level AQL = p_0	Unacceptable quality level LTPD = p_1 Lot tolerance percent defective
Risk (α) of having AQL quality or better rejected $\alpha = prob[X > c \mid p = AQL]$	Risk (β) of having LPTD quality or worse accepted $\beta = prob[X \le c \mid p = LTPD]$

↘ ↙

Sampling Plan (n,c):

Remember that n is the size of the sample and c is the maximum number of defective in the sample to accept the lot.
Let us consider a practical example.

Example: Derive a sampling plan for the following data:

We assume the following data.

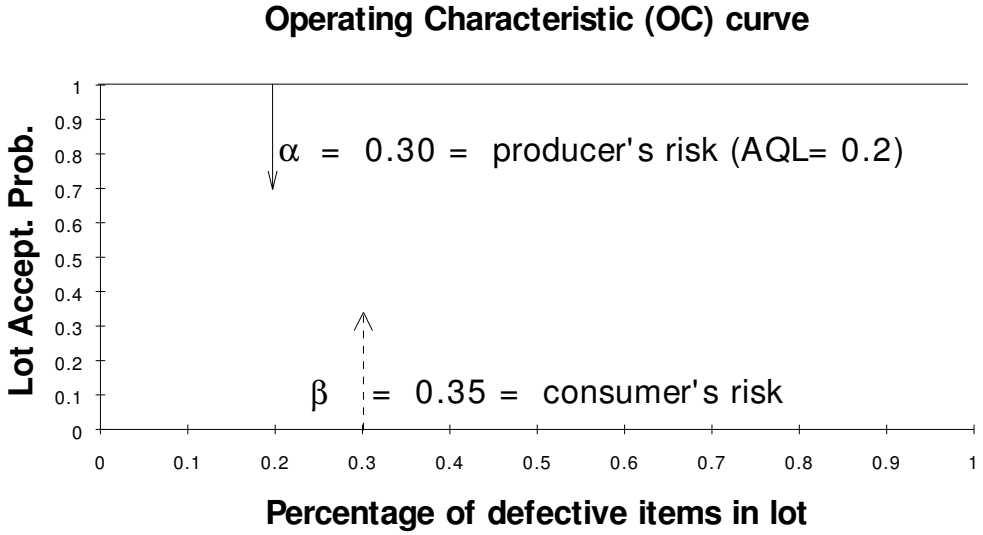
! Producer: Acceptable quality level AQL = 0.20
Risk α = 0.30

! Consumer: Unacceptable quality level LTPD = 0.30
Risk β = 0.35

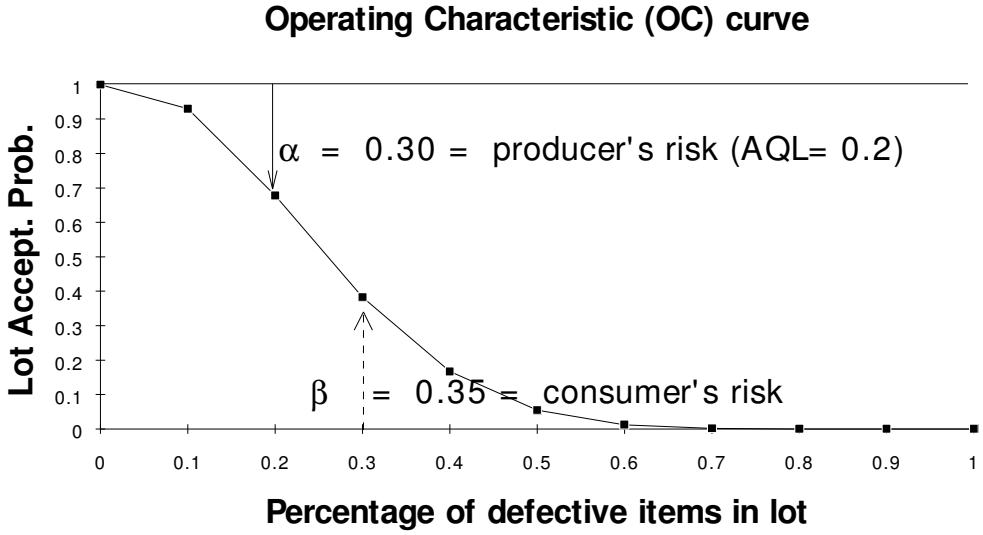
Sampling plan (n, c)

AQL = 0.20; α = 0.30; LTPD = 0.30; β = 0.35

The problem is now to find a sampling plan (n,c) whose OC curve go through precise points. The curve always goes through the points (0,1) and (1,0) since, whatever n and c are, we will always accept a lot which does not contain any defect and refuse a lot which is only composed of defect. With the above objectives, we aim at a plan which goes above the point (AQL=0.2; 1-α=0.70). Similarly, we would like the curve to go below the point (LTPD=0.3; β=0.35).



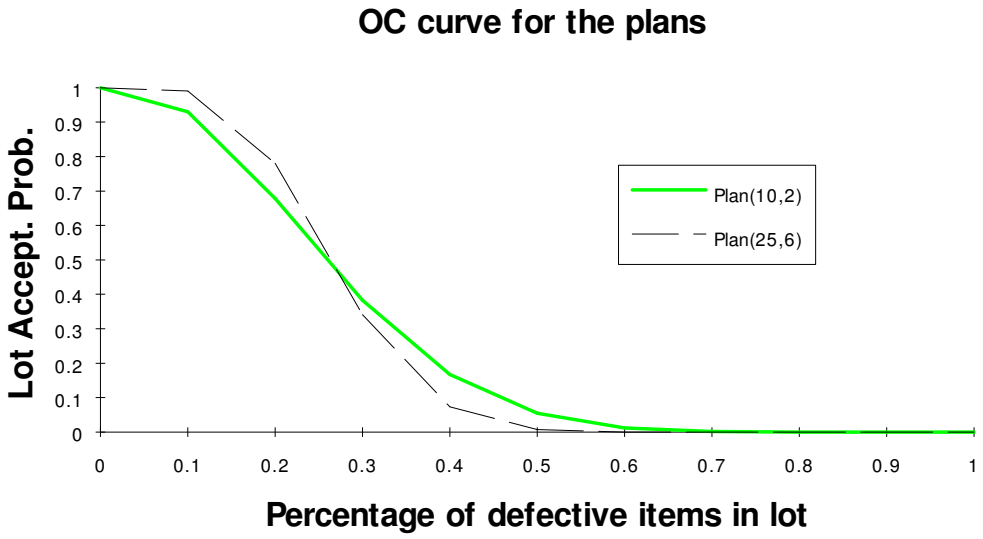
Let us try with the plan (n=10, c=2). We see that none of the risks is satisfied. The curve shows a error I of 0.32 that is more than the 0.30 allowed; and an error II or 0.38 which is also more than allowed. This plan is not acceptable!



Sampling plan (n, c)

Sampling Plan (10,2)			
p	Probability of accepting the lot	error I	error II
0.1	0.93	0.07	
0.2	0.68	0.32	
0.3	0.38		0.38
0.4	0.17		0.17

The question is then what should we do: change c ? increase the sample size n ? or both ?
Try as an exercise to understand how the OC curve would evolve if you increase c and if you decrease c?
Do you have any chance of satisfying the objectives of the plan?



It should be obvious than increasing n (and c proportionally) leads to a more steeper OC curve in the region p=c/n.

n separation

Imagine what would happen if you increase n so much that sample size would approach the lot size ?

X, the number of defective items

Here are some formulas which could be used to determine the probability that a sample of size n contains exactly m defective items. In most cases, we use the binomial approximation (2).

N = lot size	M = # of defective items in lot
n = sample size	m = # of defective items in sample

In the first model, we assume we draw without repetition, n units out of a lot of size N which contains M defectives.

1) exact computation : X is hypergeometric

$$\text{Prob}[X = m] = \frac{C_M^m \quad C_{N-M}^{n-m}}{C_N^n}$$

$$\alpha = \text{Prob}[X > c \mid p = p_0] = \sum_{m=c+1}^{n} \text{Prob}[X=m \mid p = p_0]$$

$$\beta = \text{Prob}[X \le c \mid p = p_1] = \sum_{m=0}^{c} \text{Prob}[X=m \mid p = p_1]$$

In this second model, we assume the population to be infinite. The value p is then the percentage of defective p=M/N.

2) approximation : assume N infinite, X is binomial

$$\text{Prob}[X = m] = C_n^m \; p^m (1-p)^{n-m}$$

In order to avoid computing these combinatorics, you could assume the distribution to be continuous and Poisson. Again, p is the percentage of defectives and here, np is the average number of defectives in a sample of size n.

3) approximate the binomial by Poisson

if (n > 25 and np < 5)

$$\text{Prob}[X=m] = \frac{e^{-np}(np)^m}{m!}$$

Here we assume the distribution to have the shape of a normal distribution.

4) approximate the binomial by Normal[np,sqrt(np(1-p))]

if np (1-p) > 5

Double Sampling Plan for Attributes

The following acceptance plan is said to be double in the sense that if the number of observed defectives falls in a central zone]c1 - c2[, then a second sample is taken. We can understand the method as follows. First, 3 zones are determined: the good, the fuzzy and the bad zone. If the sample is in the good zone, then the lot is accepted. If it is in the bad zone, then the lot is rejected. If it is in the critical zone, then one cannot immediately decide. We take then a second sample in order to be more precise.

Sampling plan (n_1, n_2, c_1, c_2, c_3)

1) Extract n_1 items

2) If the number of defective items is <= c_1 ,then accept the lot;

3) If the number of defective items is > c_2 ,then reject the lot;

4) Otherwise, extract n_2 additional items;

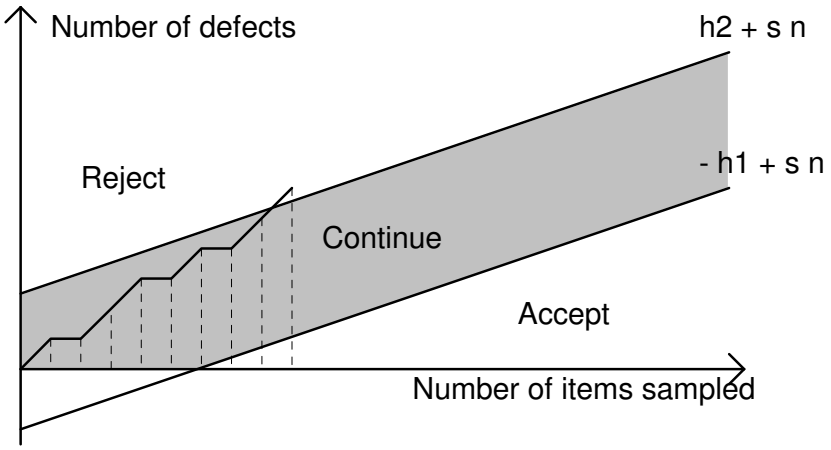
5) If the number of defective items in ($n_1 + n_2$ <= $c_{3)}$, then accept the lot;

6) Otherwise, reject the lot.

Sequential Sampling Plan for Attributes

The double plan can be generalized to the sequential plan. Here, we plot the curve (number of items checked - number of defective items). If the curve crosses the upper limit (the line with equation f(n) = h2 + sn), then the lot is rejected. If the lower limit is crossed, the whole lot is said to be acceptable. Otherwise, we are in a fuzzy zone and we proceed picking items and checking them.

Sampling plan (h_1, h_2, s)



Here are the formulas which allow the parameters (h1, h2 and s) of the sampling procedure to be related to the parameters: p0=AQL, p1=LTPD, α and β.

$$h_1 = \frac{\log \frac{1-\alpha}{\beta}}{\log \frac{p_1(1-p_0)}{p_0(1-p_1)}}$$

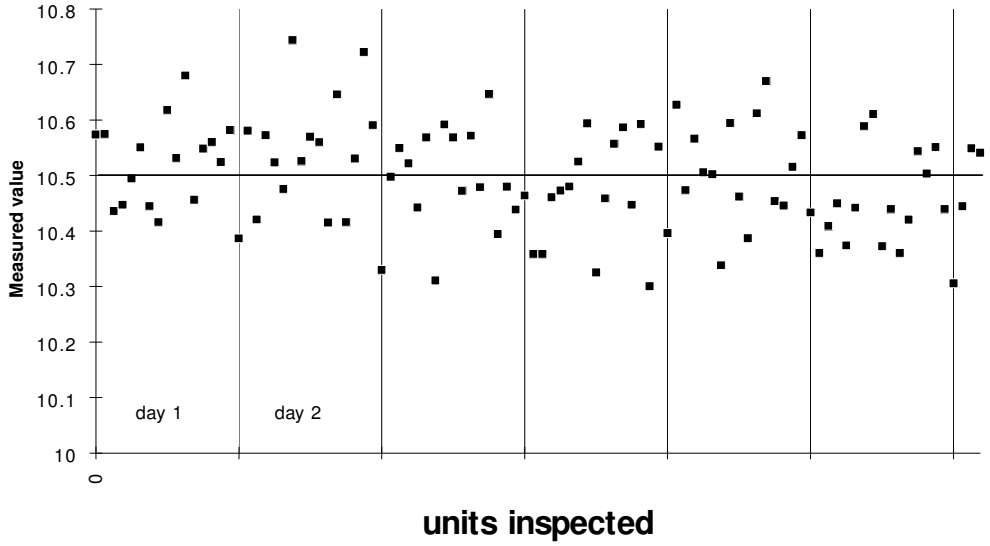
$$h_2 = \frac{\log \frac{1-\beta}{\alpha}}{\log \frac{p_1(1-p_0)}{p_0(1-p_1)}}$$

$$s = \frac{\log \frac{(1-p_0)}{(1-p_1)}}{\log \frac{p_1(1-p_0)}{p_0(1-p_1)}}$$

This plan allows the specifications, in terms of risks (α and β), to be exactly met.

Stochastic Process Control

Here we will use our observations to determine properties of the process. Our goal is to know whether a production process in still under control or not. This technique is called stochastic process control. Here are the data.



Everyday, we extract some items and perform some measurements. Assume we measure the length of the products. We plot these data as above. By analyzing these data we would like then to know whether the process is still under control.

If (μ, σ) are unknown

The first step is to estimate what the mean and variance ofthe process should be, assuming that Xi represents the ith observation.

$\Rightarrow$ best estimator:

$$\overline{X} = \frac{1}{r} \sum_{i=1}^{r} X_i \qquad s^2 = \frac{1}{r-1} \sum_{i=1}^{r} (X_i - \overline{X})^2$$

However, the computation of s^2 has two drawbacks. First it strongly depends on the mean. If there are slight changes in this mean, one could think that the variance becomes unacceptable while it is perfectly stable. The second drawback is that it is hard to compute. The remedy consists in using another estimator of the variance which is less sensitive on the mean. This estimator is the range of observed values. The range is defined as the difference between the largest and the smallest observed values.

$\Rightarrow$ in practice:

- Y_j the mean of the sample (of size n) taken on day j
- R_j the range of the sample (of size n) taken on day j

This does not change anything for the mean. Whether we take the average of all observations or the average of the daily averages, gives the same result. The variance is now estimated from the range and no longer from the average squared deviation.

$$\overline{X} = \frac{1}{m} \sum_{j=1}^{m} Y_j \qquad s = \frac{\overline{R}}{d_2(n)} = \frac{1}{d_2(n)} \left(\frac{1}{m} \sum_{j=1}^{m} R_j\right)$$

We assume here that m samples have been taken and that each sample is of size n.

SPC: Charts

Now we are in position to check whether the process does change or not. We use the expression "under control" to qualify a process which does not change.

Process under control

$$\Rightarrow \quad (\overline{X}, s)$$

$$\Rightarrow \quad Y_j \in [\overline{X} - \varepsilon; \overline{X} + \varepsilon] = [LCL\ ; UCL]$$

If the process is under control, it should then produce units whose lengths are distributed as before, that is with an average Xbar and some standard deviation s. If we now take a sample of known size, the average of this sample Yj should be close to Xbar. In fact we can compute an interval around Xbar in which the observed range Yj should fall with some predetermined probability. We can for example compute the interval [LCL-UCL] which will contain an observed sample average with probability 0.995 (corresponding to 3 sigma's).
Now if the observed range does not fall in this interval, then two cases are possible. Either we are very unlucky and got this very seldom case (with probability 0.005) where the process is still under control but produces a sample average out of the computed interval or, what most likely happened, the process is no more under control.

If $Y_j \notin [LCL\ ; UCL]$

$$\Rightarrow \quad \text{process } \underline{\textbf{is}}\ \underline{\textbf{not}} \text{ under control}$$

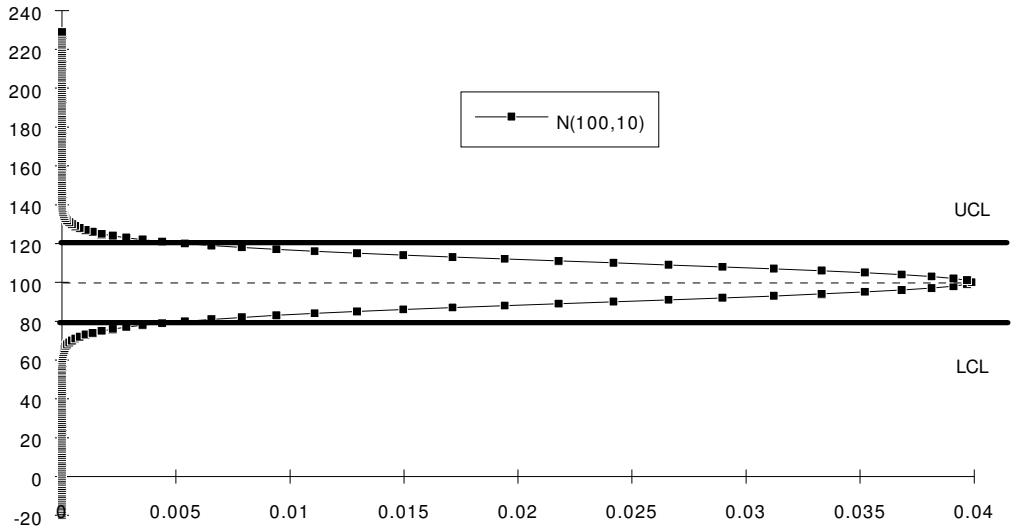
In the above case we are not sure that is went out of control but it most likey did.
LCL stands for lower control limit and UCL for upper control limit.

This reasoning can be generalized to any characteristic of any process. It is used in real life. Here is another example. Assume we compute for each exam the probability of success of a student. We could for example determine that passing and failing 6 exams has a very small probability if "everything is under control". Now, if it happens, we should start an investigation because "something is no more under control".

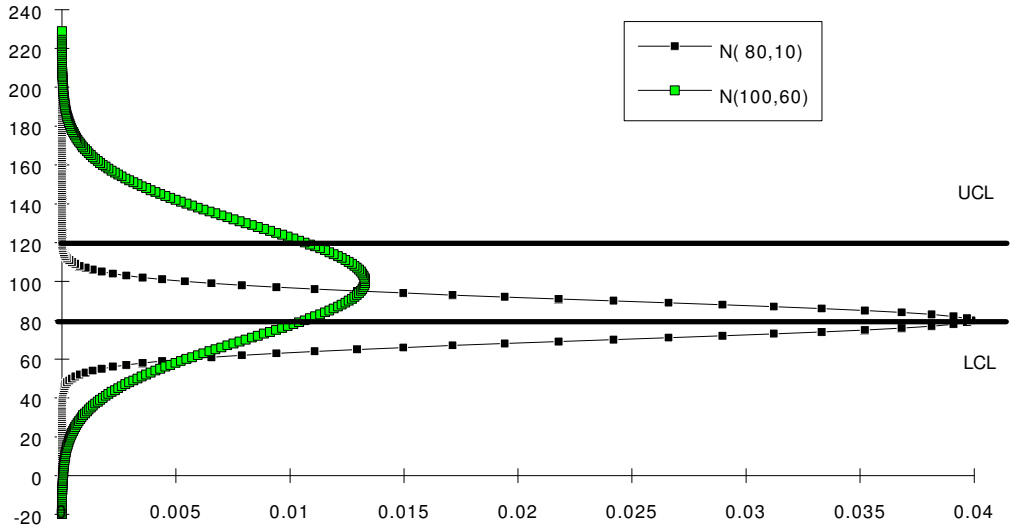
SPC: Charts

Here is an example. Assume that the average of the sample should be distributed as a N(100,10). This means that the probability of finding a sample with an average smaller than 80 or larger than 120 is about 5%. We could use this as a control test. Take a sample and check its average. If it fall within the limits, then we assume that the process is under control.

If the process is under control:



If it does not, then start an investigation.



In this case again, there are two types of errors. Either the process is under control but we were unlucky and picked a bad sample. Or the process is not but the sample did not show it.

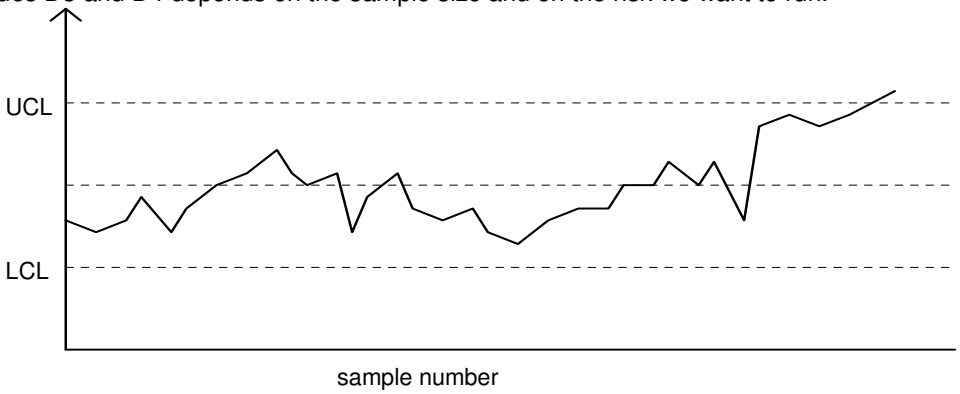
SPC: X and R Charts

Practically, we compute an interval [LCL-UCL] for the average and for the range of the sample. We will check first the range and if it is acceptable, then the average since the check of the average can only be done when the variance has been proven stable.

1. Check whether a shift in the **range** has occurred

   [LCL = $D_3(n,k)\overline{R}$ UCL = $D_4(n,k)\overline{R}$]

The values D3 and D4 depends on the sample size and on the risk we want to run.



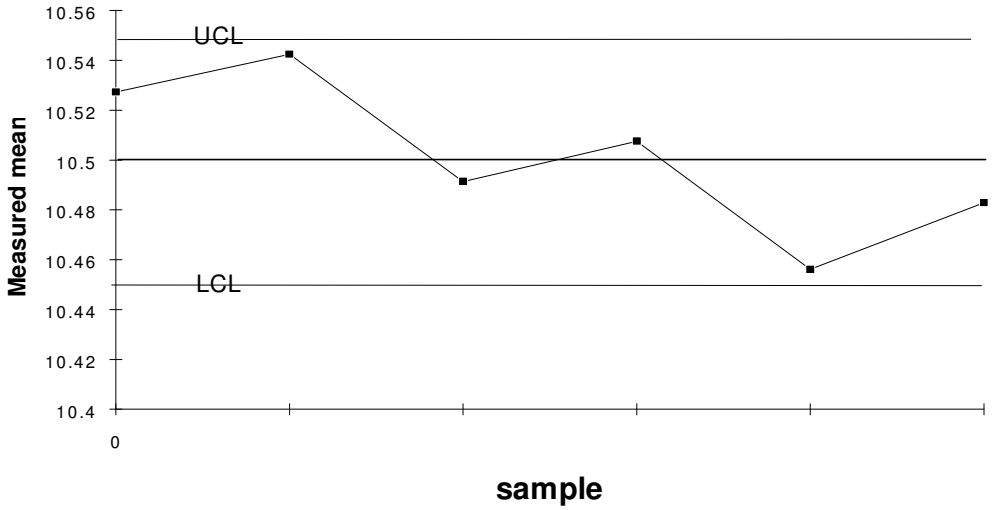
For example, for n=20, 59% below and above the average range.

If LCL ≤ Rj ≤ UCL, then, X-chart
else, start an inquiry.

If the observed range becomes too large, then some re-setting is necessary. On the other hand, if it becomes too small, something abnormal but good happened. It is also important to look for the reasons which explain why the process got more stable.

2. Check whether a shift in the **average** occurred

   [LCL=$\overline{X} - A_2(n,k)\overline{R}$ UCL=$\overline{X} + A_2(n,k)\overline{R}$]



If LCL ≤ Xj ≤ UCL, then OK
else, start an inquiry.

SPC: X and R Charts

Here are the values of the parameters. Note that they vary with the size of the sample. They have been determined with the 3-sigma's rule. This means that the probability of finding a value out of the interval while the process is under control is 0.005.

n	$A_2(n,3)$	$D_3(n,3)$	$D_4(n,3)$
5	0.58	0	2.11
8	0.37	0.14	1.86
15	0.22	0.35	1.65
20	0.18	0.41	1.59

Note how these values do change with n and try to understand why.

Conclusion

Here is a brief summary that is given without comments. The students are required to draw their own synthesis of this section.

Quality requires:

- planning
- spirit
- participation
- formation