QM 1.

Me

Introduction QM

Definition according to DIN EN ISO 9000:2015

Quality

Degree to which a set of inherent characteristics fulfils requirements.

section 3.6.2

Quality Management

Coordinated activities to direct and control an organization with regard to quality.

section 3.3.4

Process

Set of related or interacting actions of the inputs used to achieve an intended result

section 3.4.1

Quality Management System

Part of a set of interrelated or interacting elements of an organization related to quality in order to establish policies, objectives and processes for achieving these objectives

section 3.5.4

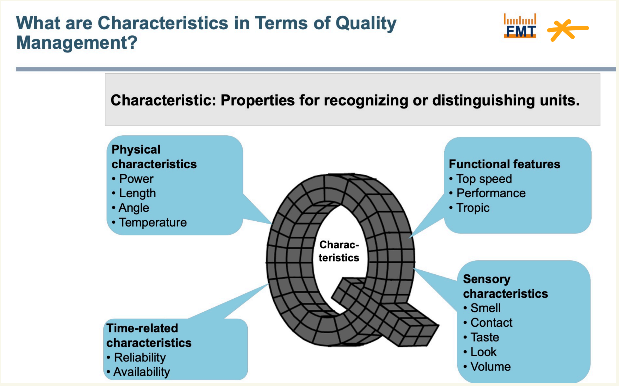
Quality Interpretation

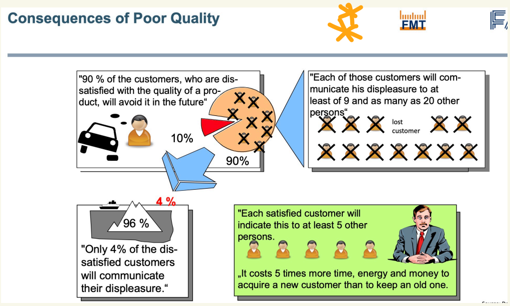
DIN 55350 (1995)

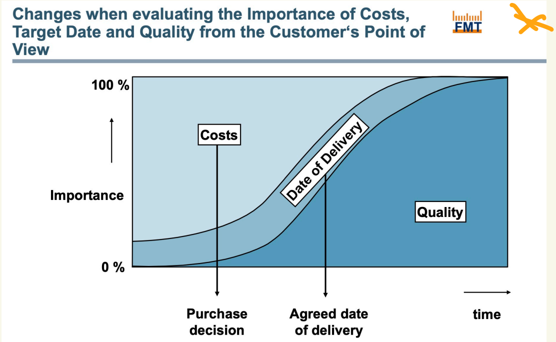
The totality of the characteristics and characteristics values of an object under consideration - be it of a material or immaterial nature - with regard to its suitability to fulfill specified and assumed requirements.

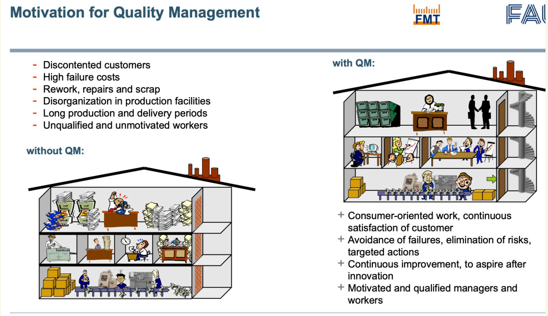
What does Quality science deals with.

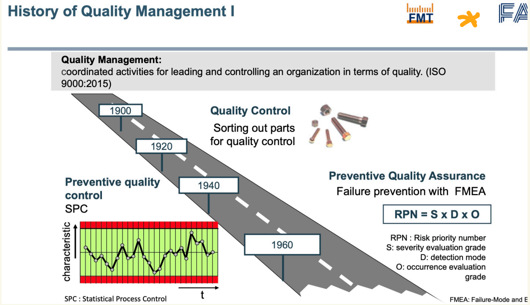
It includes collecting experience systematizing findings, searching for laws and methodological procedures, and defining uniform terms in the field of quality.

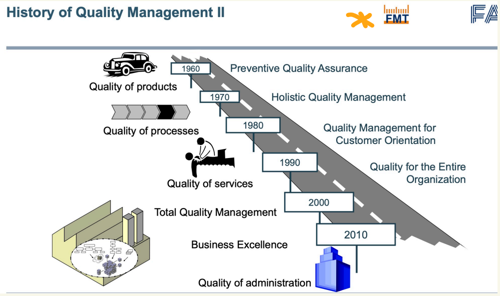












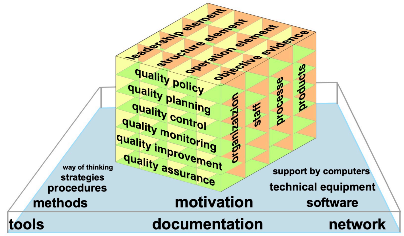
Quality Management System

Management Responsibility
+ quality policy und quality objectives
+ customer orientation
+ organisation of quality management, responsibilities
+ instructions, information flow, internal communication
+ methods and techniques of quality management
+ staff, facilities, technical equipment and work environments
+ standardized quality data base, data analysis
+ motivation and training, skill improvement
+ complete documentation regarding to quality
+ continuous improvement

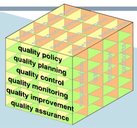
= QUALITY MANAGEMENT SYSTEM

Quality Management System: Part of a set of interrelated or interacting elements of an organization related to quality in order to establish policies, objectives and processes for achieving these objectives. (DIN EN ISO 9000:2015)

Quality Management



Quality Management System Requirements



Quality Policy
overall intentions and direction of an organization with regard to quality, as formally expressed by top management

Quality Planning
activities that establish the objectives and requirements for quality and for the application of quality system elements

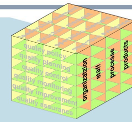
Quality Control
operational techniques and activities that are used to fulfil requirements for quality

Quality Monitoring
continuous monitoring and verification of the status of an entity and analysis of records to ensure that specified requirements are being fulfilled

Quality Improvement
actions taken throughout the organization to increase the effectiveness and efficiency of activities and processes in order to provide added benefits to both the organization and its customers

Quality Assurance
all the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfil requirements for quality

Scope of Quality Management



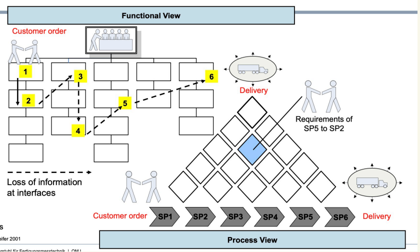
Staff
- staff qualification
- staff motivation
- staff achievement

Products
- methods
- quality characteristics
- quality index
- product analysis

Organization
- company structures
- hierarchies
- responsibilities
- connecting up

Processes
- methods
- quality index
- process index
- process analysis

From Function oriented to Process oriented Perception



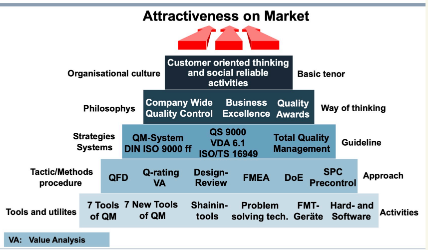
SP: Subprocess

source: according to Pfeifer 2001

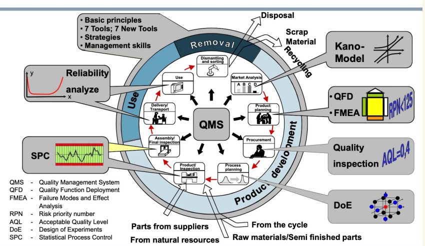
Overview of Quality Gurus

	Goals	Content	Methods
Deming † **1950**	Continuous improvement of products and processes	Process orientation, statistical methods	PDCA-Cycle
Juran † **1954**	Process of a systematic and continuous quality improvement	Quality planning, Quality check, Quality improvement	Pareto-Principle, focus on meaningful problems
Taguchi **1951**	(statistical) Design of experiments	Go off the tolerance mindset	Quality loss function, statistical methods
Crosby † **1961**	Zero-defect program, conformance of requirements	Measure for quality: price of non-conformance	Four rules of Crosby
Feigenbaum **1961**	Value oriented view on quality, Total Quality Control	Quality costs are a measure for quality	Structuring of processes
Ishikawa † **1968**	Companywide quality control	Network of customer-supplier-relationships	Ishikawa-Chart
Shainin † **1980**	Design of experiments for the continuous production	Concentration on the significant factor (Red X)	7 tools of Shainin

Five Levels of Approaches in Quality Management



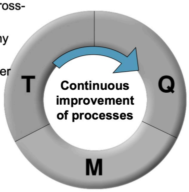
Enhanced Quality Loop



QMS - Quality Management System
QFD - Quality Function Deployment
FMEA - Failure Modes and Effect Analysis
RPN - Risk priority number
AQL - Acceptable Quality Level
DoE - Design of Experiments
SPC - Statistical Process Control

Content and Components of Total Quality Management (TQM)

- Cross-divisional and cross-functional
- Inclusion of all company employees
- Entire customer-supplier chain
- Customer focus
- Internal customer orientation



- Quality of products and materials
- Quality and capability of processes and systems
- Quality of work
- Quality of the company

- Company policy, goals
- Quality policy, goals
- Leadership structure and quality
- Teamwork and learning ability
- Responsibility

Quality Management Quotes

"If you stop getting better, you have stopped being good"
Philip Rosenthal, *1916 entrepreneur

"Do it right the first time"
Philip B. Crosby, *1926 quality guru

"Quality is everyone's job"
Armand V. Feigenbaum, *1920 quality guru

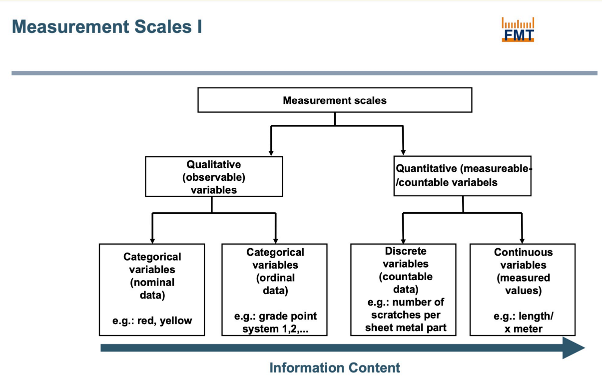
"Quality is not a coincidence, but always the result of hard thinking"
John Ruskin, *1819 English social scientist

"The customer is the most important part of the production line "
W. Edwards Deming, *1900 quality guru

"Quality is when the customer comes back and not the product"
Dr.-Ing. Karl Grund, head of development at Hewlett-Packard

"Quality exists , when the price is long forgotten "
Frederick Henry Royce, *1863 entrepreneur

Basic Tools



Measurement Scales II

Categorical variables : Nominal variables
Nominal variables, also called categorical variables, represent the lowest level of measurement. The values of their characteristics can't get prioritized. The data does not possess an orientation. Examples: Red / yellow / green, etc.

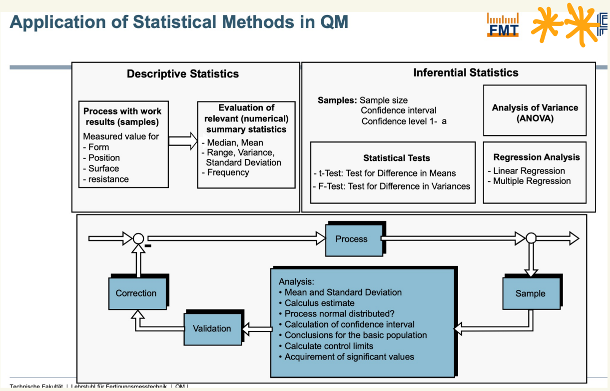
Categorical variables : Ordinal variables
Ordinal variables, like nominal variables, classify persons or objects but also rank them in terms of the degree to which they possess a characteristic of interest. The values of their characteristics can get prioritized. The distances between the values can be arbitrary and are therefore not interpretable. Examples: Grade points; sailor / captain / admiral etc.

Discrete variables : Countable data
The surveillance provides integer values; an intermediate value is not possible between two incidents. Examples: paint flaws per sheet, etc.

Continuous variables : Measured values
Each observation is assigned a value, which assumes continuous values.
Examples: diameter of shaft, length of a bolt, etc.

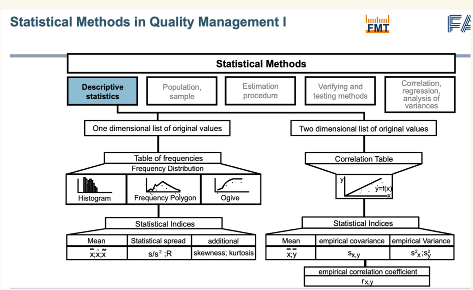
Information Content

↳ Q. Example of Each categories.



What are statistics needed for in QM?

- Destructive testing (product charac.)
- Inferences from a sample to populatⁿ (E.g. market analysis)
- Reduction of (financial) Effort for decision making.



- As far as technically possible and Economically reasonable, a full inspection (100% inspection) is often preferred to a sample inspection (Especially with automated Control.

Descriptive Statistics: Measures of Central Tendencies

Given:
Sample with a size of n = $x_1, x_2, x_3, x_4, \ldots, x_n$

Searched:
Measures of central tendencies.

Arithmetic Mean:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Median:

$$\tilde{x} = \begin{cases} x_{((n+1)/2)} & \text{If odd number of scores} \\ (x_{(n/2)} + x_{(n/2+1)})/2 & \text{If even number of scores} \end{cases}$$

Root Mean Square:

$$Q = \sqrt{\frac{1}{n}\sum_{i=1}^{n} x_i^2}$$

Mode (modula value)

D = most common value in the sample

Descriptive Statistics: Measures of Variability

Given:
Sample with a size of n = $x_1, x_2, x_3, x_4, \ldots, x_n$

Searched:
Measures of Variability for indication of how much scatter there is in the sample

Variance:

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(\bar{x} - x_i)^2$$

Standard Deviation:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\bar{x} - x_i)^2}$$

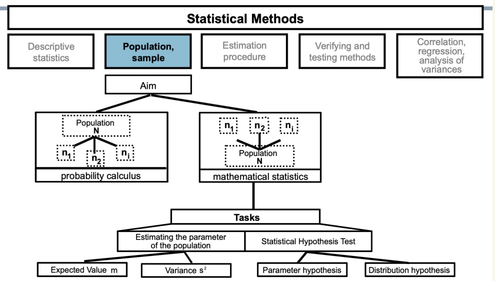
Range:

$$R = x_{max} - x_{min}$$

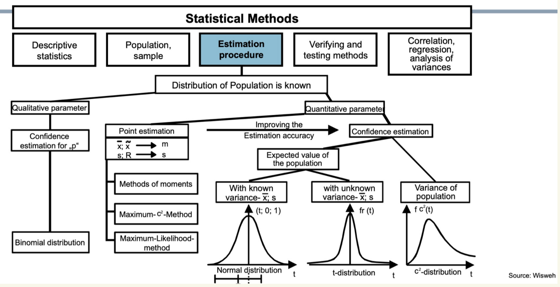
x_{min} - smallest measurement

x_{max} - biggest measurement

Statistical Methods in Quality Management II



Statistical Methods in Quality Management III



Introduction to Probability Distribution

The **probability of a characteristic** is the relative frequency, with which this characteristic appears within the population. It's defined as:

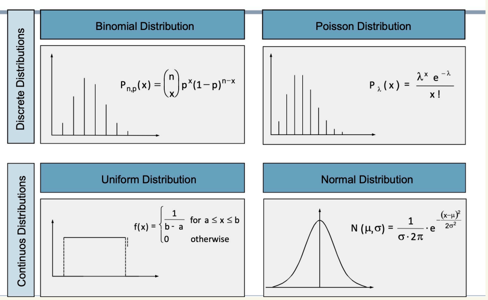
$$P(x) = \frac{\text{Number of elements with the characteristic x}}{\text{Number of all elements in population}} = \frac{n_x}{N}$$

For tests with samples there are two basic approaches:

- The **counting test** distinguishes two antithetic (discrete) attributes of a characteristic like e.g. good/bad, existent/not existent.
- The **measuring test** regards an attribute which can embrace continous (steady) values.

Against the form of the characteristic values (discrete or steady) there are used different probability distributions for describing the interrelationship between a measurement value and the frequency respectively the probability of its appearance.

Probability Distributions



Binomial: $P_{n,p}(x) = \binom{n}{x} p^x (1-p)^{n-x}$

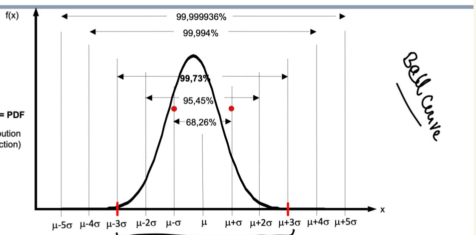
Poisson: $P_\lambda(x) = \frac{\lambda^x e^{-\lambda}}{x!}$

Uniform: $f(x) = \begin{cases} \frac{1}{b-a} & \text{for } a \le x \le b \\ 0 & \text{otherwise} \end{cases}$

Normal: $N(\mu,\sigma) = \frac{1}{\sigma \cdot 2\pi} \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}}$

↳ No. need to remember formular remember graph.

Normal Distribution



f(x) = PDF

(Probability Distribution Function)

μ = Mean
σ = Standard Deviation
σ² = Variance

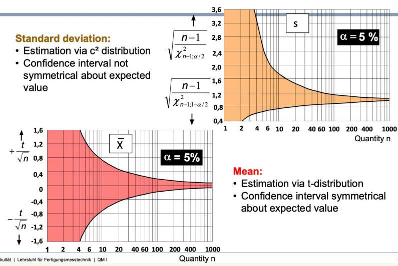
$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Source: DGQ

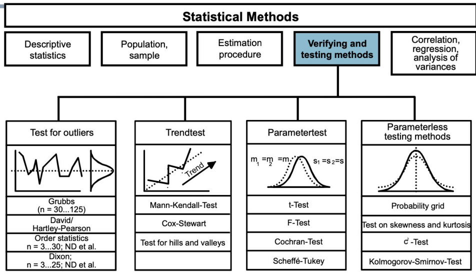
Confidence Region of Mean and Standard Deviation for a Confidence Level 1 - a = 95 %

Standard deviation:
- Estimation via c² distribution
- Confidence interval not symmetrical about expected value

Mean:
- Estimation via t-distribution
- Confidence interval symmetrical about expected value



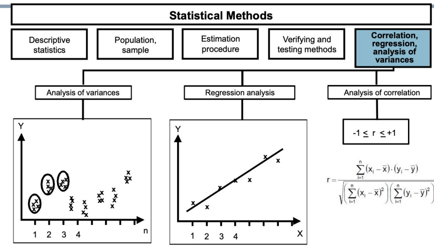
Statistical Methods in Quality Management IV



ND: Normal Distribution

Source: Wis

Statistical Methods in Quality Management V



$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})\cdot(y_i - \bar{y})}{\sqrt{\left(\sum_{i=1}^{n}(x_i-\bar{x})^2\right)\left(\sum_{i=1}^{n}(y_i-\bar{y})^2\right)}}$$

Source

Analysis of Variance I

Aim:
The goal of Analysis of Variance (ANOVA) is to test for significant differences between means

Approach
For the simple ANOVA the samples are classified to k groups. The number of groups are according to the k levels of the factor A.

Group (factor levels)	Samples	Means
Group 1	$y_{11} \cdots y_{12} \cdots y_{1\nu} \cdots y_{1n}$	$\bar{y}_1$
...	....	...
Group i	$y_{i1} \cdots y_{i2} \cdots y_{i\nu} \cdots y_{in}$	$\bar{y}_i$
...	....	...
Group k	$y_{k1} \cdots y_{k2} \cdots y_{k\nu} \cdots y_{kn}$	$\bar{y}_k$
	total	$\bar{\bar{y}}$

Parameters
Mean and empirical Variance of the i-th Group:

$$\bar{y}_i = \frac{1}{n}\sum_{\nu=1}^{n} y_{i\nu} \qquad s_i^2 = \frac{1}{n-1}\left(\sum_{\nu=1}^{n} y_{i\nu} - \bar{y}_i\right)^2$$

Overall-Mean and Overall-Variance:

$$\bar{\bar{y}} = \frac{1}{k}\sum_{i=1}^{k}\bar{y}_i \qquad s^2 = \frac{1}{k}\sum_{i=1}^{k} s_i^2$$

k: number of experimental lines n: experimental runs

Analysis of Variance II

The analysis of variance examines samples as an estimate for the basic population at correlation. Therefore, the sums of the squared deviations are applied, where one refers to the deviations from the overall mean.

Sum of the squared deviations

$$Q = \sum_{i=1}^{k}\sum_{\nu=1}^{n}(y_{i\nu} - \bar{\bar{y}})^2$$

Disjoint the sum into two parts

$$Q = n\sum_{i=1}^{k}(\bar{y}_i - \bar{\bar{y}})^2 + k(n-1)s^2 = Q_A + Q_R$$

Q_A: Dispersion due to the change in the level of factor A

Q_R: Residual dispersion of the test, regardless of the factor level

Regression Analysis I

Goal:
The goal of regression analysis is to determine the values of parameters for a function that cause the function to fit best a set of data observations.

$$\hat{y} = f(x_i)$$

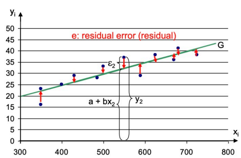
Assumptions:
In the linear regression model, the dependent variable is assumed to be a linear function of one or more independent variables plus an error introduced to account for all the other factors:

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i$$

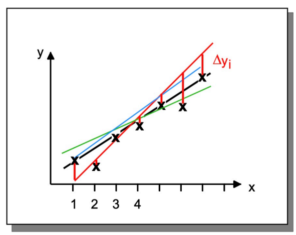
With:

$$E\{\varepsilon_i\} = 0$$
$$V\{\varepsilon_i\} = \sigma^2$$

β_i: Regression parameters
ε_i: Error term
E: Expected value
V: Variance



Regression Analysis II



Model: $\hat{y} = b_0 + b_1 x$

The usual model of Estimation for the regression model is Ordinary Least Square (OLS)

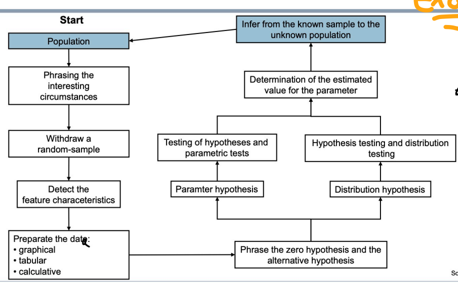
$(y_i - \hat{y}) = \Delta = f\,(b_0, b_1)$

Request:
$\sum(\Delta y_i)^2 = \text{Min}$

Criteria:
$\sum(\Delta y_i)^2 = \text{Min}$

Basic Model of Statistical Methods in Quality Management

** Exam

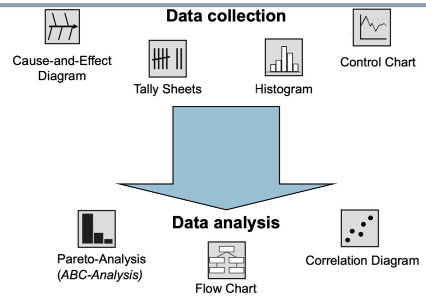


Source: Peters

Seven tools of quality ** Exam

- Cause-and Effect Diagram (Ishikawa Daigram)
- Pareto analysis
- Tally sheets.
- Control Chart
- flow chart
- Histogram
- Coorelation Diagram.

The Basic Tools of Quality Management



Cause-and-Effect Diagram (Ishikawa-Diagram) I

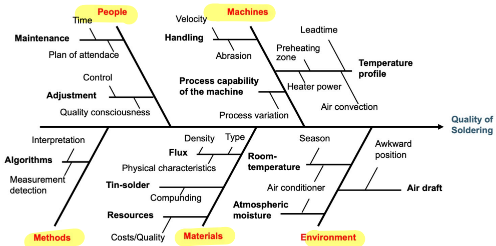
Description:
The cause-and-effect diagram displays all relevant factors of an arbitrary process. Junctions with detailed characteristics incur through the main knotsof the individual categories, e.g. „abrasion“ by „machines“.

Goal:
The Cause-and-Effect Diagram (Ishikawa Diagram, Fishbone Diagram) is responsible for the analysis of a defined problem regarding its possible causes. Possible and well-known causes and influences are displayed graphically in connection with possible effects and problems.

Application area:
- Complete overview of possible and actual causes
- Graphical display of verbal connections
- Tools for interdisciplinary teamwork
- Determining the accumulation of faults and analyzing the causes

Boundary conditions
- The analytical problem must be clearly defined
- Causes must be described in a short und precise way
- The 5 M or 7 M help group causes together

Cause-and-Effect Diagram (Ishikawa Diagram) II



Frequency Distribution (Tally Sheet)

Description of the basic tool frequency distribution:
The frequency distribution demonstrates the frequency of the occurence of several failure classes respectively the frequency of appearance of numerical data in certain intervals.

Field of application:
- Determining the accumulation of faults and analyzing the causes.

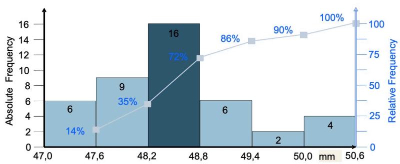
Type of failure	Aug. 23	Aug. 24	Total
Scratch	𝍸 𝍸 |||	𝍸 𝍸 𝍸 ||||	32
Dent	|||	𝍸 ||	10
Corrosion	||||	𝍸	9
Staining	𝍸 𝍸 ||	𝍸 𝍸 𝍸 |	28
Part missing	|	|||	4
Assembly error	𝍸 ||	|||	10
Other	||	|	3

Histogram

Description of the basic tool histogram:
For the histogram the range of a characteristic is classified in partial intervals (categories) and the frequency of appearance of every partial interval is graphically shown. On the basis of the chart one can read the probability distribution of the characteristic with its mean.

Boundary conditions:
- Current and representative data has to be available
- A large amount of data increases the statistical informational value of the histogram
- Reasonable choice of the number of intervals k

n: number of measurements



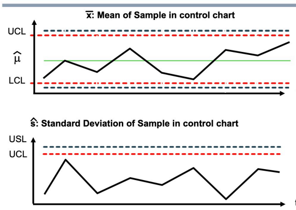
Control Chart

Goal:
Quality control charts are forms to collect and graphically display measurement data and/or statistical values or discrete variables derived from production processes in order to compare them with pre-defined action control limits. When exceeding these pre-defined action control limits, measures for improvement must be introduced.

Field of application:
- Graphical display of production process data
- Monitoring and controlling continuous production processes
- Verification of the capability of self-control of the production process

Boundary conditions:
- Information on the calculation and interpretation of statistical values such as mean value and standard deviation are necessary

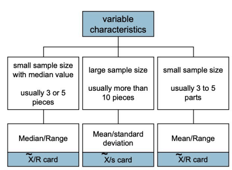
Example: Control Chart



UCL = Upper Control Limit
USL = Upper Specification Limit
LCL = Lower Control Limit
LSL = Lower Specification Limit

Types of Control Charts with variable Characteristics

Selection tree for control charts with variable characteristics



Formulas for variable characteristics

Kartentyp	stat. Gesamtwert der k Stichproben (Prozessdurchschnitt)	Eingriffsgrenzen
$\bar{X}$/R-Karte	$\bar{\bar{X}} = \frac{(\bar{X}_1 + \bar{X}_2 + \ldots + \bar{X}_k)}{k}$	OEG = $\bar{\bar{X}} + A_2\bar{R}$ UEG = $\bar{\bar{X}} \cdot A_2\bar{R}$
	$\bar{R} = \frac{(R_1 + R_2 + \ldots + R_k)}{k}$	OEG = $D_4\bar{R}$ UEG = $D_3\bar{R}$
$\bar{X}$/s-Karte	$\bar{\bar{X}} = \frac{(\bar{X}_1 + \bar{X}_2 + \ldots + \bar{X}_k)}{k}$	OEG = $\bar{\bar{X}} + A_3\bar{s}$ UEG = $\bar{\bar{X}} \cdot A_3\bar{s}$
	$\bar{s} = \frac{(s_1 + s_2 + \ldots + s_k)}{k}$	OEG = $B_4\bar{s}$ UEG = $B_3\bar{s}$
$\tilde{X}$/R-Karte	$\bar{\tilde{X}} = \frac{(\tilde{X}_1 + \tilde{X}_2 + \ldots + \tilde{X}_k)}{k}$	OEG = $\bar{\tilde{X}} + \tilde{A}_2\bar{R}$ UEG = $\bar{\tilde{X}} \cdot \tilde{A}_2\bar{R}$
	$\bar{R} = \frac{(R_1 + R_2 + \ldots + R_k)}{k}$	OEG = $\tilde{D}_4\bar{R}$ UEG = $\tilde{D}_3\bar{R}$

Pareto Analysis

Description of the basic tool Pareto Analysis
The Pareto principle says that a problem, that can have many causes, in reality only has very few relevant causes. For this reason, it is advisable to find out these causes and to analyze them in detail.

The Pareto Analysis (ABC Analysis) structures the causes (influences) according to their importance.

Procedure:
- List all causes
- Allocate and assign data
- Display graphical (ranking)

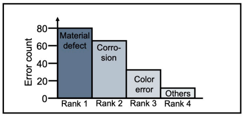
Goal:
The goal of the analysis is to create a statement, which problems should be attended primarily and which methods for improvement can be expected by solving these problems.

Example: Pareto-Analysis I

Step 1: Collection of Data

Failure report	Week 1	Week 2	Total	Ranking
Material defect	40	40	80	1
Color error	20	12	32	3
Corrosion	30	35	65	2
Others	5	7	12	4
Total	**95**	**94**	**189**	

Step 2: Development of a Pareto-Graph

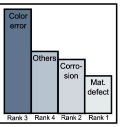


Source:

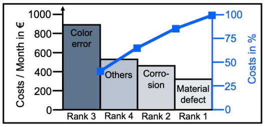
Example: Pareto-Analysis II

Step 3: Allocation of values "Costs"

Type of error	Costs/ Failure		Fre- quency		Euro/ Month
Corrosion	7,10	x	65	=	461,50
Color error	27,81	x	32	=	889,92
Others	44,00	x	12	=	528,00
Mat. defect	4,00	x	80	=	320,00
Sum:					**2199,42**



Step 4: Determine the progress graph



Flow Chart

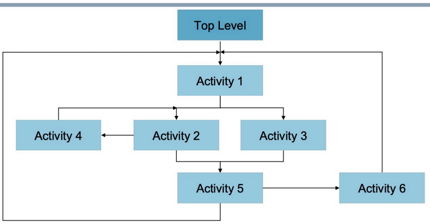
Goal:
Flow diagrams graphically describe sequences of action. Beginning at a starting point, the instructions are clearly structured with the help of symbols.

Application area:
- Graphical display of action sequences and action possibilities
- Verification of complex action sequences regarding completeness
- Tool for interdisciplinary teamwork

Boundary conditions
- Action sequences and action possibilities must be described briefly and concisely.

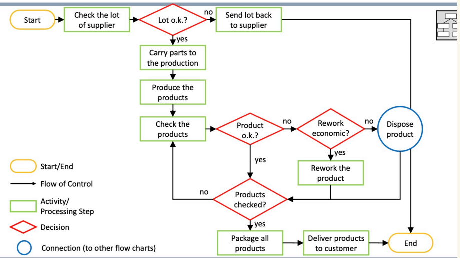
Benefits
- Complicated activities can be checked for completeness.
- Possibilities of action become manageable.
- Logical inconsequences can be detected while creating the flow chart.
- Flow charts are representing a compressed documentation.

Flow Chart



Visualization of
- Connections
- Gradients
- Divisions

Example: Flow Chart



Correlation Diagram

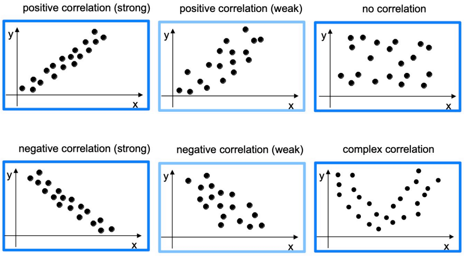
Aim:
Correlation diagrams describe graphically whether there is a correlation between two variables

Application area:
- Graphical display of the nature of the correlation between two factors (strong or weak)
- Deduction of information on the nature of the correlation between two factors (positive or negative)
- Calculation of the correlation coefficient from the numerical data

Boundary conditions:
- Up-to-date and representative data must be made available
- Causal connections cannot be derived from the correlation diagram.

Example: Correlation Diagram

***



→ Need to know graph

Advanced Tools

What are 5 steps of 5S? #1 imp

Fundamentals I
5S

5S is a method for introducing and standardizing workplace organization. Work efficiency, productivity and occupational safety are improved, search times are reduced and employees are motivated. With little effort and cost, errors can be avoided and deviations can be discovered before they cause errors.

Seiri Select	Seiton Sort	Seiso Clean	Seiketsu Standardize	Shitsuke Self-discipline
Throw away or remove waste and materials not needed at the workplace.	All required materials should have a suitable place for quick reuse and storage.	Clean the workplace, each person should be a "caretaker" for his or her place.	Standardize maintaining cleanliness and order.	Practice 5S daily. Make it a way of life.

Fundamentals II
The 7-W-Questions

The 7-W-Questions help to structure data and information acquisition, as well as problem solving:

- Why?
- Which?
- How Many?
- Where?
- Who?
- When?
- With what?

Example: Describe quality problems
Which failure or defect occurred?
Where did the failure or defect occur first?
When was the problem identified?
How many units are affected?

Example: Plan Data Acquisition
Which data will be necessary?
Why is the data acquired?
How much data is necessary?
Where should the data be acquired from?
Who is responsible for the data acquisition?

Example: Eliminate quality problems
Which measures are necessary?
How much personnel, material and time is necessary?
When can the measures be implemented?
Who will carry out the measures?

Fundamentals III
Deming`s PDCA-Cycle (Systematic Procedure)

What is it about? Where is the benefit?
A systematic procedure leads to efficient problem solving.

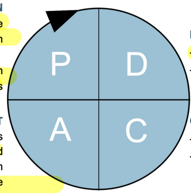
How should I proceed?

PLAN
- Identify and analyze problem
- Find and evaluate approach
- Institute measures

DO
- Determine action plan
- Realize action plan

ACT
- Codify changes
- Document results and present them
- Use experience

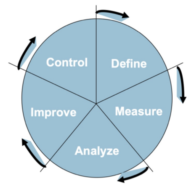
CHECK
- Evaluate measures
- Evaluate results



PDCA - Cycle

what are 5 step of 6 σ.?

Fundamentals IV - DMAIC Cycle (approach from SixSigma philosophy)



Goal
Measurable and verifiable improvements

Define
- Goal of the project defined (measurable and verifiable)
- Record boundary conditions

Measure
- Describe the current situation using appropriate data
- Collect relevant data

Analyze
- Analyze data to determine root causes of the problem
- Identify possible starting points for a solution

Improve
- Develop improvement measures
- Implement improvement measures

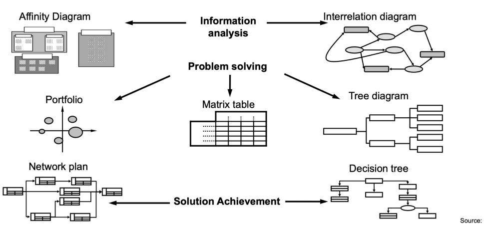
Control
- Check the results of the improvement measures
- Depending on the result: look for alternative solutions or establish an improved approach

what are 7 new tools?

The Seven Management Tools

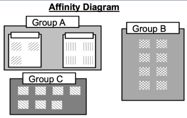
What's tree of quality.

The basic tools of QM are insufficiently effective when complex problems and incomplete data collections are involved.
The seven management tools have been defined in order to supplement the basic QM-Tools:

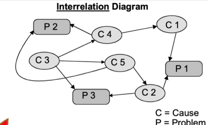


Management Tools for Information Analysis

Affinity Diagram



Interrelation Diagram



Summarization of information by:
Collection and arrangement of the data
Summarization in chief groups

\+ Clarify the problem
\+ Encourage the formation of consensus within group

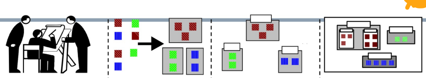
\- Results subjective; dependant on the team
\- Often difficult when problems are demanding

Display of reciprocal influence values for: Determining problem-relevant factors and their reciprocal relationships

\+ Clarification more complex
\+ Problem includes reciprocity

\- Results subjective; dependant on the team
\- Danger of high complexity
\- Danger of misinterpretation

Affinity Diagram

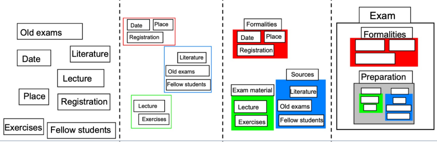


Creative Phase
Collection of articles, thoughts, ideas etc. according to the rules of brainstorming

Grouping
Establishing groups (clusters) of topics for contents that belong together

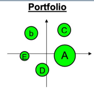
Heading
Finding headings for the individual groups

Summarization
Eventually summarizing certain groups

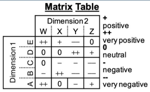


Management Tools for Finding Solutions

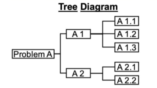
Portfolio



Matrix Table



Tree Diagram



Summarization and Processing of information by display of correlation

\+ Data reduction
\+ Concentration on main components
\+ Products/Company comparison possible
\- Hardly possible manually

Clarification of the main points and relationships by: Matrix-type display from two or more viewpoints

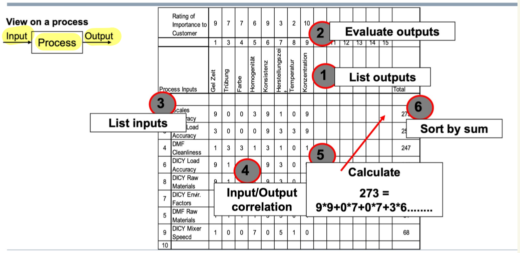
\+ Clarity
\+ Matrix easily adjustable
\+ Relationships can be weighted
\- Weighting of factors subjective
\- Time consuming

Overview of all measures for solving a problem by: Substructure and sorted graphic display

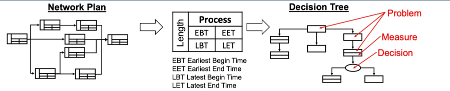
\+ Processing complex problems
\+ Presenting a solution
\- Quality of tree structure strongly dependant on knowledge of the team

Example: Cause-effect matrix

View on a process



Management Tools for Problem Solving



Network Plan

Showing time critical relationships and mutual reciprocity by:
Determining and showing individual processes of a project including length of time dependency

+ Determining the time needed for the entire project and individual processes
+ Determining the "critical path"
- Results strongly dependant on the knowledge of theteam
- Danger of high complexity

Decision Tree

Display of logical correlations with decision criteria by:
Collection and graphical display of possible difficulties and counter measures

+ Prevention of non-logical decisions
+ Shortening decision making process

– The result depends heavily on the respective team
– Insufficient knowledge can lead to wrong decisions

Network Plan

Length	Process	
	EBT	EET
	LBT	LET

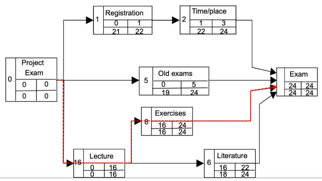
EBT = Highest EET of all direct predecessor

EET = EBT + procedure period

LBT = Lowest LET of all direct successors

LET = LBT – procedure period

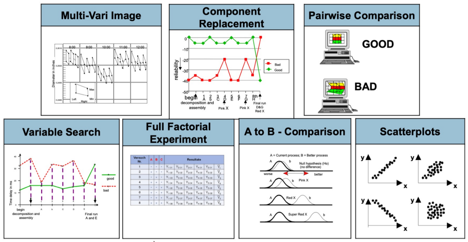
EBT Earliest Begin Time
EET Earliest End Time
LBT Latest Begin Time
LET Latest End Time



The Seven Shainin-Tools

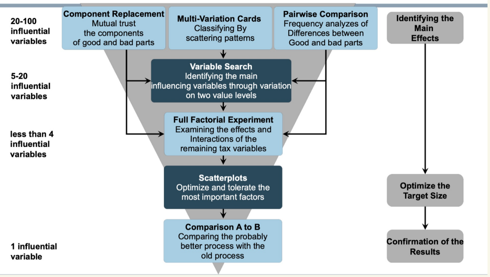
Name Shanin 7 new tools?

Philosophy: *"The vital few, the trivial many."*

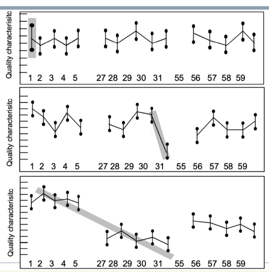


Goal: Find "Red X" (Red X®).

Shainin



Shainin-Tool: Multi-Vari-Chart - Possible Variations



Positional variation (variability on a single piece)

Cyclical variation (piece to piece variability)

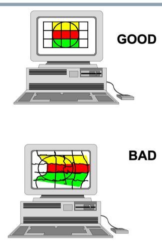
Temporal variation (time to time variability)

Shainin-Tool: Pairwise Comparison

Objective:
Provide clues to determine the Red X by using a paired comparison of good and bad parts

Approach:
- Several Pairs (e.g. five or six) of a good and a bad type series are compared
- Visualization of the frequency of differences gives a clue to the main factors

Boundary conditions:
- Appliance predominantly for type series which can't be disassembled.

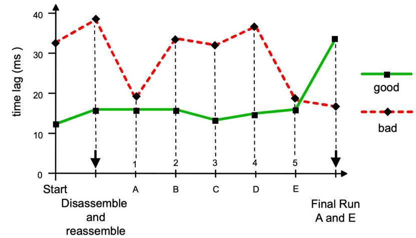


Shainin-Tool: Variable Search - Example of Use I

Experiment number	Compared components	Module high grade	Result in ms	Module low grade	Result in ms
Initial test	-	Components all „good"	13	Components all „bad"	34
Disassemble and reassemble	-	Components all „good"	16	Components all „bad"	38
1	A Silica	$A_B R_G$	16	$A_G R_B$	19
2	B Microprocessor	$B_B R_G$	16	$B_G R_B$	35
3	C Transistor	$C_B R_G$	14	$C_G R_B$	33
4	D Capacitor C_2	$D_B R_G$	15	$D_G R_B$	37
5	E Capacitor C_1	$E_B R_G$	16	$E_G R_B$	18
Pilot run	A and E	$A_B E_B R_G$	33	$A_G E_G R_B$	17

R: Rest

Shainin-Tool: Variable Search - Example of Use II



Shainin-Tool: Full Factorial Experiment

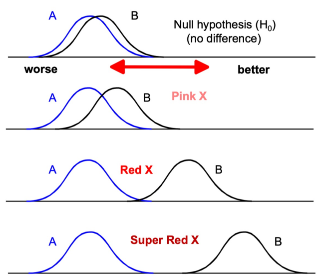
Experimental design

Experiment No.	A	B	C	D	Results
	Main Effects				
1	-	-	-	-	Y_1
2	-	-	-	+	Y_2
3	-	+	-	-	Y_3
4	-	+	-	+	Y_4
5	-	-	+	-	Y_5
6	-	-	+	+	Y_6
7	-	+	+	-	Y_7
8	-	+	+	+	Y_8
9	+	-	-	-	Y_9
10	+	-	-	+	Y_{10}
11	+	+	-	-	Y_{11}
12	+	+	-	+	Y_{12}
13	+	-	+	-	Y_{13}
14	+	-	+	+	Y_{14}
15	+	+	+	-	Y_{15}
16	+	+	+	+	Y_{16}

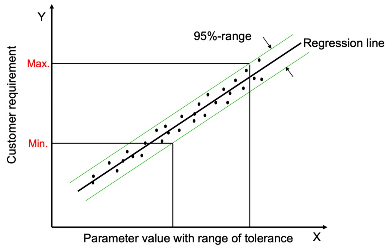
\- = low Level
\+ = high Level

Shainin-Tool: A to B – Comparison

B = Better Process ⇔ C = Current Process



Shainin-Tool: Scatterplots



Further selected Quality Management Tools: Check List

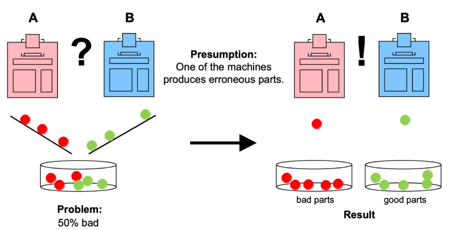
Goal:
To ensure the full adherence and completion of the planned systematic sequence of work steps

Procedure:
- To list all necessary work steps (i.e. action or testing instructions) in chronological order
- Documentation of accomplished work steps by checking off points in check list

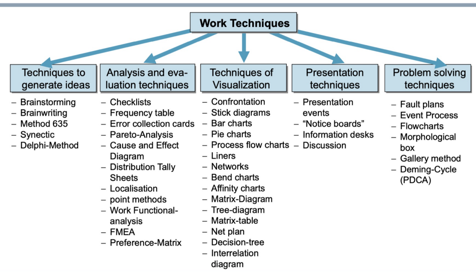
Boundary conditions:
- Application of check lists, especially for repetitive procedures
- If check lists are very extensive, individual positions can be grouped according to adequate characteristics or attributes (i.e. time, place etc.)

Further selected Quality Management Tools: Stratification

Goal:
Separating of data by specified characteristics of differentiation for analysis.

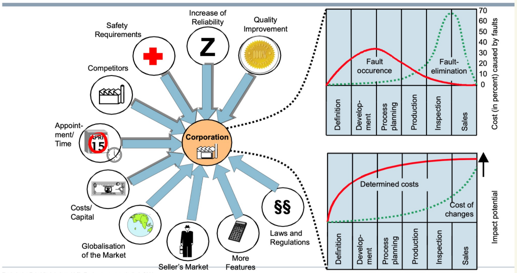


Summary of often used Work Techniques



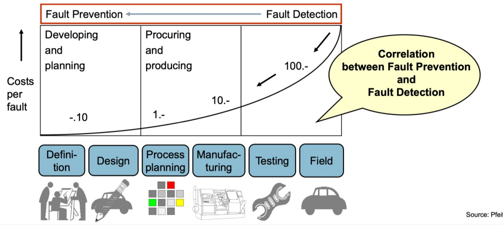
Quality function Deployment (QFD)

Situation of Corporations: Internal and External Influences on Product Development



Factor 10 Rule for Fault Costs

Factor 10 Rule for Fault Costs
A frequently confirmed fact, that the costs of fault prevention or fault detection increase by a factor of 10, when faults are not avoided or eliminated in the development phase, where they occur, but in the next stage.



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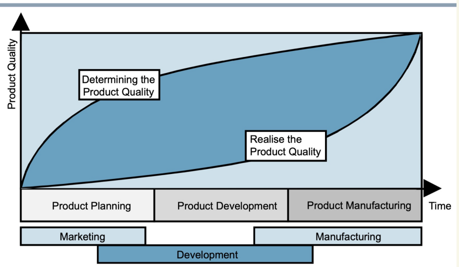
Influence of Product Planning and Development on Product Quality



QM-Tools for Product Planning

Motivation for Utilization of QM in Product Planning
- A large amount of faults have often originated in this phase
- Product planning results from external and internal information
- The basis for common future products are developed in this phase

#

Aim of QM in Product Planning
- Requirements of the customers, enterprises, environmental protection are transformed into product specifications
- Product finding
- Pursuance of product planning during product realisation
- Product monitoring and controlling for product sales

QM-Tools for Product Planning
- Quality of product and manufacturing practice are included
- Customers' quality requirements are included, compared and evaluated
- Quality Function Deployment

Task of Quality Management in Product Planning

The task of quality planning is to identify customer needs, implement them into new or improved products and services, and design the processes that need to be provided to create the products and services.

#

- **Accuracy**: The needs and expectations of customers should be accurately met by the product or service.
- **Robustness**: Products, services and the underlying processes should be robust, i.e. not susceptible to disturbances that cannot be influenced.
- **Faultlessness**: Errors should be avoided throughout the entire product development process.

Systematic recording of Customer Requirements

Secondary survey

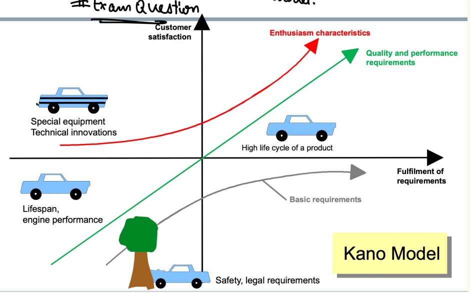
Internal company sources
- Inquiries and offers
- Order and sales statistics
- Complaints
- Warranty and customer services
- Intranet
- Etc.

Sources external to the company
- Official statistics
- Analysis of competing products
- Business information services
- Documentation centers
- Sources of supply
- Trade journals
- Internet
- Etc.

Primary survey
- Interviews with test subjects
- Technical discussions
- Surveys (telephone, written)
- Panel investigation
- Observation of market behavior
- Competitor research
- Etc.

Kano Model

Draw the Kano model.
Exam Question



Quality Function Deployment (QFD)

品質	機能	展開
HIN SHITSU	KI NO	TEN KAI
Qualität Merkmale Attribute Gütekennung	Funktion Mechanisierung Tätigkeit	Aufstellung Verteilung Entwicklung Evolution
Quality	**Function**	**Deployment**

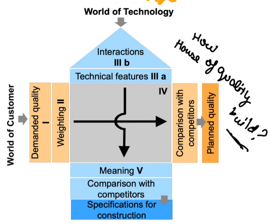
Definition of "Quality Function Deployment"

What is QFD

QFD is the systematic survey of customers' requirements and their conversion into technical specifications in order to define market-friendly quality demands for the product.

Example

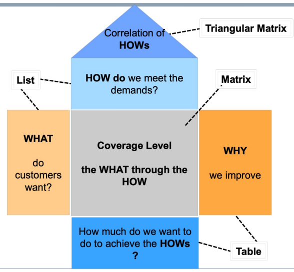
Customer requirements for their mobile phone:
- light
- reliable
- long battery life
- robust housing
- high sound quality
- modern design
- easy usability
- …



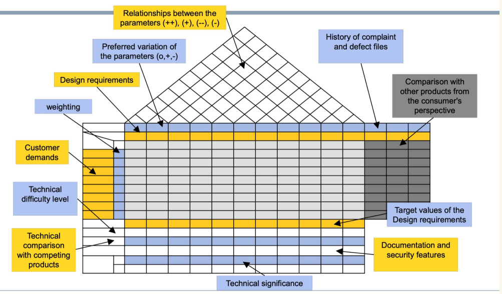
Translating Customer Requirements into Quality Characteristics

Customer Demands "Language of the Customer"	➡	Quality Characteristics "Language of the Engineer"
Simply to carry around	➡	Weight / dimensions / shape / portability
Small enough to get it simply to carry around	➡	Dimensions /Shape/ Portability
Light enough to get it simply to carry around	➡	Weight / portability
Stable	➡	Weight / center of gravity / angle of inclination
Stable if it turned off	➡	Shape/ center of gravity / stability
User friendly for beginners	➡	Position of buttons and switches / touch sensitivity
…	➡	…

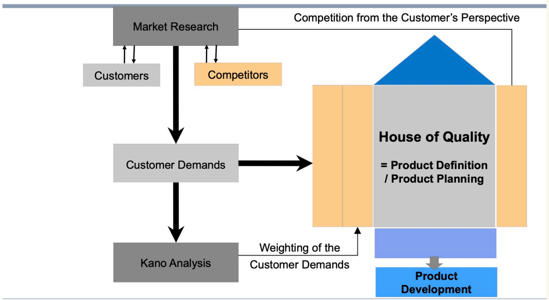
Building the House of Quality (HoQ)



House of Quality (HoQ) / QFD Form



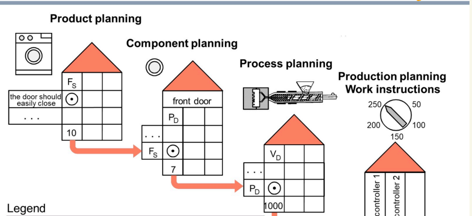
Integration of QFD into the Product Planning Process



Approach to QFD

1 Forerun	• Create a cross-departmental QFD-Team with a QFD-Moderator
2 Market Analysis	• Determine the requirements of the customer in the customer's language • Translate the requirements of the customer into the language of technology or of the company • Weight the customer requirements • Assessment of the competitors in terms of meeting the customer requirements • Set market goals
3 Product Analysis	• List the product features • Define the optimization directions of the product features • Evaluate the trade-offs between product characteristics • Assessment of the feasibility of the optimization • Assessment of the competitor products in technical terms • Define product targets and evaluate the technical importance
4 Measures	• Determine critical quality characteristics of the products to be optimized • Creating the process flow chart and deduce inspection plan • Create work instructions and inspections instructions for critical work and inspection activities in the "language of the workshop"

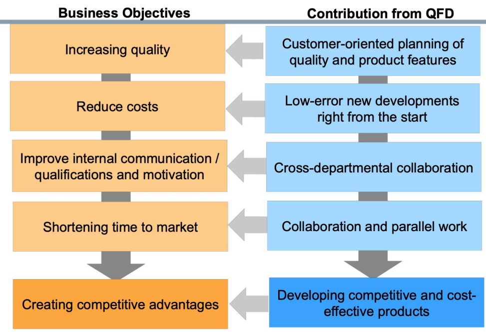
Breaking down Customer Requirements with Quality Function Deployment (QFD)



Legend

F_S	locking pressure of the door in N
P_D	real pressure at the front door in N/mm²
V_D	dose volume for the barrel extruder in cm³
controller 1	tool temperature in °C
controller 2	dwell pressure in bar

Contribution of QFD to meet the Business Objectives



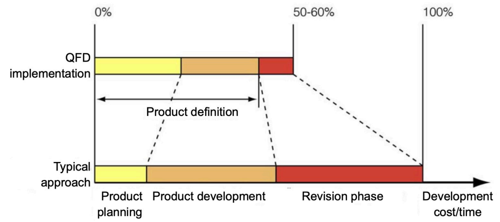
Benefits of the QFD Method

- System-oriented planning of the production
- Tools for the reengineering
- Consistent listening to the customer and the market
- Preventing departmental thinking
- Avoid fail developments by prevention

But:

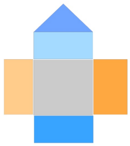
- **High temporal and financial investment worthwhile only for complex structures**
- **Quality of the result depends crucially on the correct implementation**

Reduction of Development Time and Costs through QFD



Requirements for the Application of QFD

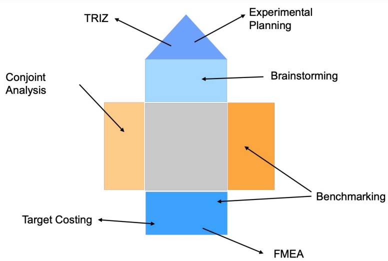
- Support and commitment from company management
- Training of those involved on the method
- Team-oriented employees with personal qualifications
- Suitable environment
- Competent composition of the team
- Regular participation in work meetings
- A moderator trained in the method
- TQM and QFD must be understood and wanted by everyone involved



Principle of QFD

- When developing products and services, the voice of the customer is often not heard and features are developed that no longer meet actual customer requirements.
- Quality Function Deployment (QFD) supports the systematic, multi-stage capture and implementation of customer requirements into technical specifications.
- The central medium is the so-called House of Quality (HoQ), a complex planning matrix in which customer requirements and performance specifications are compared.
- Systematic cascading across several planning stages ensures that all features are derived from specific customer requirements or can be traced back to them at any time.

More Auxiliary Tools and Methods for QFD



TRIZ Method

Excursion

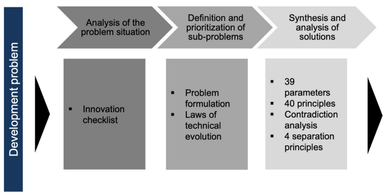
Teorija Rezhenjia Izobretatel`skich Zadach (TRIZ)

Theory of Inventive Problem Solving (TIPS)


GS Altschuller (*1926 - †1998)

TRIZ Procedure

Excursion

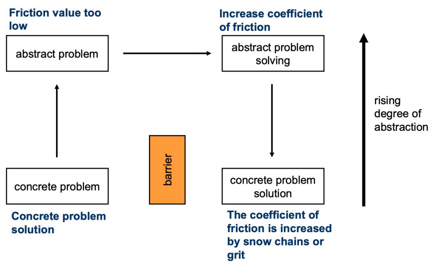


Basic of the TRIZ Philosophy

Excursion

1. Abstracted problems and their solutions are repeated in various branches of science and industrial applications.
2. The evolution of technical systems always follows a similar pattern.
3. Real innovations are only triggered by bringing together different areas of knowledge.

Principle of Analogy Formation / Progressive Abstraction



Source: Teut

4 Separation Principles

1. **Separation in Space:**
A problem is solved by the local separation of components or by dividing a component into several components, whereby the same result is achieved overall.

2. Separation in Time:
A process is divided into several operations that take place one after the other without affecting the overall function.

3. Separation through System Transition :
Transferring a system under consideration into the supersystem (superior system) or into a subsystem (subordinate system).

4. Separation through Change of Condition :
Changing the contradictory conditions so that there is no longer any mutual influence. This can be done by converting the system under consideration into a different state (e.g. solid - liquid - gaseous).

Example: 4 Separation Principles

Separation in Space:
Progressive lenses with bifocal lenses (i.e. different areas of the lens are ground differently) combine reading and far-vision glasses
→ Division of the component

Separation in Time:
Pivoting wings on an aircraft create ideal conditions for take-off and landing
→ Processes that take place one after the other in time

Separation through System Transition
Links in a bicycle chain are rigid, but the chain as a whole is elastic
→ Subsystem is rigid, upper system is elastic

Separation through Change of Condition :
A protective gas is used to change the environmental conditions during inert gas welding.
→ Transferring the system under consideration into one others Condition

QM Development and Construction (FMEA)

Quality Management in Development and Construction

FMT

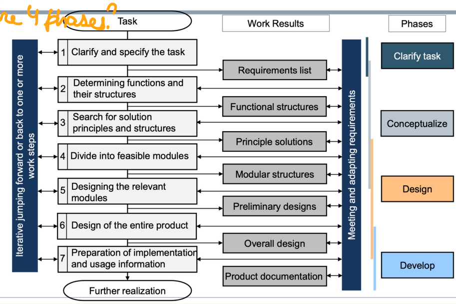
Quality in Development and Construction

- Methodical Construction
  - VDI 2221
  - …
- Preventive QM Methods
  - FTA
  - ETA
  - WA
  - FMEA
  - …
- …

Methodical Development and Construction According to VDI 2221

FMT

What are 4 phases? *



Main Guidelines for Ensuring and Maintaining Quality

FMT

What are main Guidlies for Ensuring & maintaining quality

Robust Construction

With robust designs, production errors do not immediately occur in the production process if small parameter deviations occur

3RoRe

Reliable Testability

Already at the construction should on it respected become that _ requested Customer characteristics in the production checked become can . Become like this potential Mistake secure recognized.

Reliable material

Through use more qualitative Raw materials and auxiliary materials as well as Standard parts becomes a higher Quality level guaranteed . From this results the demand for parts suppliers with complete and correct Quality specifications to supply.

DIN 1725 T2

DIN EN 1706

Quality Improvement through reduced Number of Parts

FMT

Reduction the Number of Parts

Direct effects		**Impact on product quality**
fewer drawings	→	fewer drawing errors
fewer characteristics	→	easier to maintain quality level
fewer missing parts	→	fewer disturbances
easy assembly	→	fewer assembly error

Further approaches: Reduction of complexity, platform concepts, ...

Selected Quality Management Methods

FMT

- Quality Function Deployment
- Quality assessment
- Design review
- FTA and ETA
- Value analysis
- Error possibility and influence analysis

Product planning → Development and construct. → Production planning → Production → Test → Mission

Definition of Quality Assessment

FMT FAU

*

Quality assessment is a method that records and evaluates all quality-relevant findings at certain points in the development project. She accompanies the entire development process from the design to series release .

Representatives from all affected company areas are included in a team in the quality assessment. By systematically querying the areas involved, the development status is viewed from different perspectives.

Characteristics of Quality Assessment

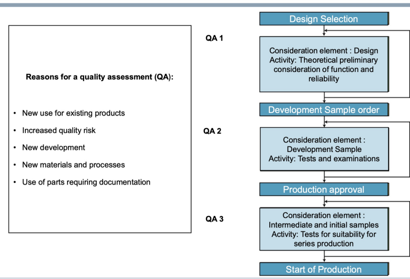
FMT

*

When?	From the product idea to the start of series production - The quality assessment is cross-phase.
How?	What has been developed is checked using systematic queries within a team with all those affected. Aids can be checklists, for example.
Why?	Assessment regarding the fulfillment of the desired quality.
Goal	Through staggered, multiple applications, weak points become visible in good time. Errors can be avoided through early corrective measures.

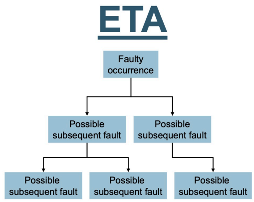
Reasons for a Quality Assessment

FMT



Definition of Event Tree Analysis (ETA)

ETA



Event Tree Analysis
assesses events that can develop as a result of the functional structure within technical systems based on the assumption of possible faults.

Main Emphasis:
describe and evaluate sequences of events.

Question:
what are the consequences of a fault?

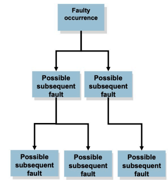
Source: DIN 25419

Event Tree Analysis

Precondition
- Unique, complete knowledge of the functioning of individual parts of a system and their behavior at the events to be analyzed

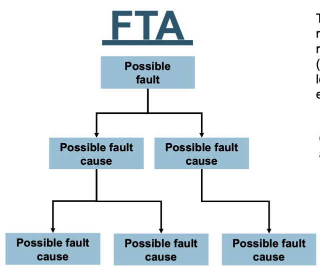
Aim
- Provide a comprehensible scheme to calculate the probabilities (bifurcation probabilities of fault tree analysis) of different event sequences

Approach
- Visualizing the logical interrelationships between the function by means of graphical symbols.



Definition of Fault Tree Analysis (FTA)

FTA



The **Fault Tree (FTA)** is a graphical representation of the logical relationships between failure inputs (= failure of a function element), leading to a given and undesirable event.

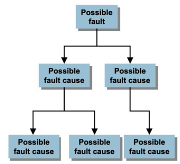
Question : What reasons/causes are there for a possible fail?

Fault Tree Analysis

Precondition
- Complete system description regarding system function, environmental conditions, resources, system components and organization / system behavior

Aim
- Systematic determination of the causes of an event
- Determination of reliability parameters quantities such as occurrence rating or unavailability

Approach
- Analyze system exactly
- Define the undesirable event and the failure criteria
- Define the reliability parameters and the time intervals to be considered
- Reflections on the failure modes of the components
- Setting up the fault tree
- Assemble the parameters of the fault tree inputs (failure mode and time)
- Evaluation of the fault tree
- Validation of the results



Definition of "Design Review"

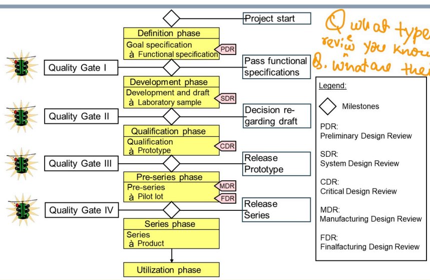
Design Review

= **Formal, documented, systematic and critical evaluation of design results** in order to determine problem areas and deficiencies that may influence the purpose and requirements of a product. Furthermore, correctional measures should be introduced to ensure that the final design and its appendant specifications correspond to consumer demands.

Three most important Types of Design Review

Input	Design Review	Output
- Functional specifications - Supporting documents - Check lists	Preliminary Design Review	- Improved functional set of specifications - Project proposal - Interface specifications - Maintenance and logistic concept - Report
- Test specifications - Supporting documents - Reports - Check lists	System Design Review	- List of deviations for functional specifications - Report
- Technical documentation - Check plan, check specifications - Test results - Variation list of functional specifications - Maintenance concept - Check lists	Critical Design Review	- List of deviations for functional specifications - Revised functional specifications - Prototype - Documentation - Report

Design Review Phase Model parallel to Product Development



Q what types of design review you know & what are their usage.

Source: Pfeifer 200

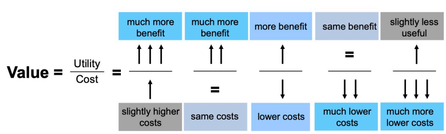
Value Analysis

Value analysis is a QM procedure with the aim of saving costs.

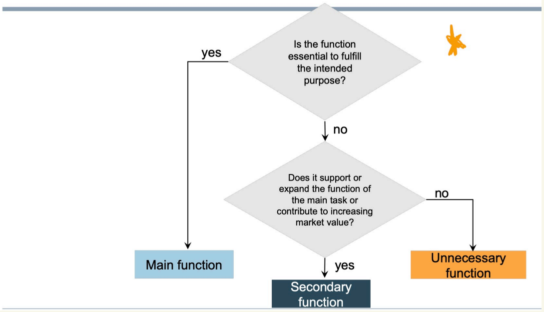
Application of various methods for cost recording and assessment with the aim to further develop and improve products.

Application of teamwork and function-oriented cost decisions.

Types of increasing value:



Determination of the Function as Part of the Value Analysis



The Systematics of Value Analysis

Work Schedule	Solution	Aims	Basic Questions
Information Phase	Define functions & evaluate	Obtaining basic information; functional analysis; cost analysis	What is it? What does it do? What is it supposed to do? How much does it cost?
Creative Phase	Use creativity methods; develop alternatives	Generate as many ideas as possible; value goal; combine ideas	What could accomplish the same task?
Assessment Phase	Investigate	Check ideas cost-wise, compare ideas with each other	What are the best ideas? How much do they cost? What ideas to suggest?
Planning Phase	Plan	Create a schedule; prepare change proposal	How much time for redesign ? For new tools? For long-term delivery parts?
Proposal Phase	Suggest alternatives	Compilation of an alternative proposal including precise cost calculations	How do you present alternatives? What is the motivation for management to accept the proposal?

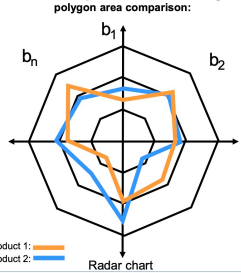
Product Comparison through a Quality Vector

Quality Vector

$$\bar{q} = \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{pmatrix} \quad \text{with } b_i = \sum_{j=1}^{m} M_j \times G_j$$

M_j = measure in a quality circle element
G_j = weighting of the measure M_j
j = 1,2,3…n

Multi-criteria product evaluation through polygon area comparison:



FMEA – Failure Mode and Effect Analysis

FMEA = The Failure Mode and Effect Analysis (FMEA) is a development- and planning-concomitant system and risk analysis. It is integrated within the business departments and includes the system optimization and risk reduction.
As an important methodological tool the FMEA attends for the early detection of possible errors, to avert their appearance previously. The FMEA is applied for new concepts and developments as well as for the further development of products and processes. During the development and planning phase their maturity is methodically scrutinized and evaluated. The FMEA shows on all critical areas appropriate measures, to reduce risks with their implementation.

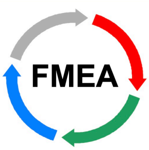
What is a FMEA?

Definition
The Failure Mode and Effects Analysis (FMEA) is a method of the product development phase to support evaluation of product design, construction and the process steps in the development stages. It is derived from the DIN 25448 "Ausfalleffektanalyse" (Failure effect analysis).

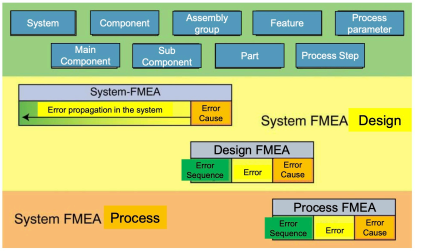
Aim
The implementation of FMEA aims to detect potential faults in the development of a product or a manufacturing process during the planning of a product or process and to avoid those faults through appropriate measures. The main feature of the FMEA is the **risk priority number RPN**, which is formed from the product of **occurrence rating**, **importance for the customer (severity rating)** and **detection rating**.

Benefit
The FMEA supports the systematic documentation of failure relations and quality influences as well as the effort to avoid failures, given that 80% of all failures in use are based on weaknesses in the design.

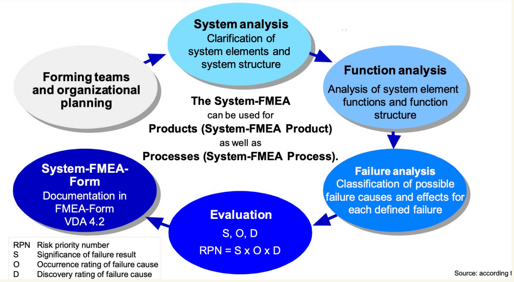
Varieties
System-FMEA Examine product components or complete systems
Design-FMEA Checking the fulfillment of sub-functions of a particular component
Process-FMEA Checking the process to achieve a certain sub-function



Classification of the FMEA in the Product Hierarchy



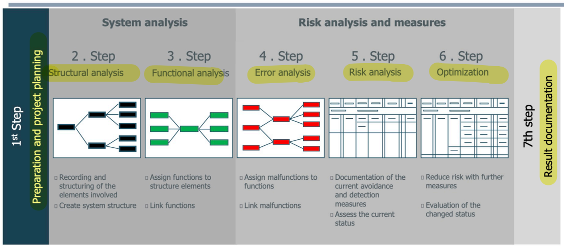
Principal Sequence of a System-FMEA according to VDA 4.2 (1996)



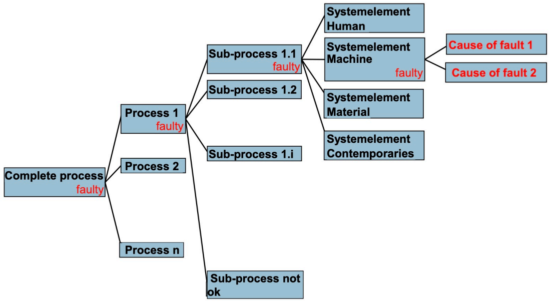
Source: according t

7 NEW STEPS TO CREATE FMEA

According to the AIAG & VDA FMEA-Handbook 2019



System-FMEA Process: System Structure with Malfunction



Selected Variants of FMEA

- **Design Review Based on Failure Mode (DRBFM)** The DRBFM change-focused FMEA method was developed by Toyota. The DRBFM is intended to eliminate the separation between the development and quality process and to involve the development engineer more directly in the quality process.
- **Hazard Analysis and Critical Control Points (HACCP)** The HACCP concept (German: Hazard Analysis and Critical Control Points) is aimed at food. Originally developed by NASA together with a supplier to ensure the safety of astronaut food, it is now developed by the US National Academy of Sciences as well as from Food and Agriculture Organization of the UN recommended. In the European Union, HACCP has been mandatory for trade/production of food since 2006.
- **Failure Mode, Effects , and Criticality Analysis (FMECA)** The FMECA is an extended FMEA for analyzing and evaluating the probability of failure and the expected damage. This is now 100% reflected in an FMEA and therefore no longer needs to be created explicitly. (see AIAG Potential Failure Mode and Effects Analysis Fourth Edition)
- **Failure Mode, Effects , and Diagnostic Analysis (FMEDA)** The FMEDA quantitatively examines all electronic components for their reliability (random errors as a supplement to the systematic errors of an FMEA). The FMEDA also determines Safe Failure Fraction (SFF) as an evaluation variable for the functional Safety management according to IEC 61508.

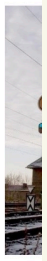
Poka Yoke

Examples of Poka Yoke

- Acetylene cylinders have a unique clamp connection to prevent dangerous confusion with other gases.
- CEE plugs have different colors and contact arrangements to avoid confusion.
- Every component to be installed must be approved via barcode or RFID scan before installation.
- Depending on the valid work plan, only the appropriate component compartments are opened.
- A pick-by-light facility prevents picking errors.
- TAE telephone plugs cannot be inserted upside down.
- ATMs in Germany only issue money once the card has been removed. This prevents you from forgetting the card.
- Due to their shape, SIM cards can only be inserted in the SIM card slot in the correct orientation.
- USB plugs can only be inserted in a certain direction.
- Position sensors on a press only allow the pressing process to start when the component is correctly inserted

Fail Safe

Signals in railway operations generally indicate two terms: stop and travel. Your task is to only let one train run on a section of the route. A signal is constructed in such a way that in the event of an error it does not indicate travel, but rather a stop. In addition, effective train control systems are now linked to the signals, which automatically leads to rapid braking if a stop signal is exceeded. In the event of an error, no train will travel into the closed section of the route.



Mechanical signals were designed in such a way that the signal wing in a horizontal position signals stop, and a wing pointing diagonally upward signals drive. If a cable breaks or other mechanical faults occur in the signal, the sash automatically falls into the stop position.

This is the construction in the fail-safe method.

This principle also applies to railway brakes: while driving, they must be under pressure in order not to brake. If a clutch breaks and with it the brake line, the brakes on both parts of the train are vented and rapid braking occurs.

Redundancy

Redundancy is the additional presence of functionally identical or comparable resources in a technical system when they are not normally required for trouble-free operation. Resources can e.g. B. redundant information, motors, assemblies, complete devices, control lines and power reserves. As a rule, these additional resources serve to increase failure, functional and operational reliability.

There are different types of redundancy: Functional redundancy aims to design safety systems in parallel so that if one component fails, the others guarantee service. In addition, attempts are made to spatially separate the redundant systems from each other. This minimizes the risk that they will suffer from a common fault. Finally, components from different manufacturers are sometimes used to avoid a systematic error causing all redundant systems to fail (diverse redundancy).

Hot redundancy means that several systems in the system execute the function in parallel. A voter evaluates the results based on the majority decision (min. 3 parallel systems). It must be ensured that the probability of two devices failing at the same time approaches 0.

Cold redundancy means that several functions exist in parallel in the system, but only one is working. The active function is evaluated and, in the event of an error, a switch switches over to the function that exists in parallel. It must be ensured that the switching time is permissible for the overall task and that the system works with predictable tasks. The reliability of the switch must be far greater than that of the functional elements.

Standby redundancy (passive redundancy) Additional resources are switched on/provided, but are only involved in the execution of the intended task in the event of a failure or malfunction.

N+1 redundancy means that a system consists of n functioning units that are active at a time and one passive standby unit. If an active unit fails, the standby unit takes over the function of the failed unit. If an active unit fails again, the system is no longer fully available and is usually considered to have failed.

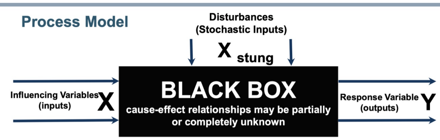
DoE - Basics Planning and Optimization

Historical Development of DoE

1920	RA Fisher	The idea arises to carry out experiments systematically and define the principles. Use in agriculture.
1924	RA Fisher	First experimental plan (according to Fisher)
1935	RA Fisher	First edition of "The design of experiments"
1948	E. Weber	"Outline of biological statistics"
1951	GEP Box & KB Wilson	"On the experimental achievement of optimal conditions" Experimental plans for 1st and 2nd order optimization tasks
1953	A. Linder	"Planning and evaluating experiments"
1958	H. Scheffé	"Experiments with mixtures" Experimental plans to investigate Multi-component systems
1958	G. Taguchi	"System of experimental design"
1959	J. Kiefer	"Optimum experimental designs" theoretical basis for the construction and comparison of experimental plans
1969	GEP box	"Evolutionary operations (EVOP)" Process optimization method based on the evolution strategy
1974/1997	E. Scheffler	"Introduction to the practice of statistical experimental design" Treatment of factor plans, mixture and response surface plans
1988	D. Shainin	"World Class Quality" by KR Bhote Experimental planning for ongoing production according to D. Shainin

Definitions - Design of Experiments (DoE) ** *

Process Model



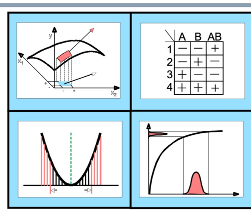
Definitions:

- **VDI 2247 draft (1994):** "Statistical test planning serves to uncover the effect of metric or attributive influencing parameters on a (usually metric) quality characteristic."
- **Douglas C. Montgomery (1991):** "A designed experiment is a test in which some purposeful changes are made to the input variables of a process or system so that we may observe and identify the reasons for changes in the output response."
- **ISO 3534 (1985):** "The arrangement in which an experimental program is to be conducted, and the selection of the levels (versions) of one or more factors or factor combinations to be included in the experiment."

Terms of DoE

Response Variable	Size that characterizes the result of an experiment
Influencing Variable	Can change the target size
Response Function	Relationship between influencing variables and response variables
Random Variable	A quantity influenced by chance
Disturbance Variable	An uncontrolled, unintended influencing factor
Factor	A controlled, variable influencing factor (qualitative or quantitative)
Level	Specific setting value for a factor
Step Combination	The levels of all variable influencing variables defined for an experiment
(Main) Effect	Influence of a factor on the response variable
Interaction	Influence each other two or more factors in their effect on the response variable

Targets of Design of Experiments (DoE)



- Determination of influencing variables that will significantly influence response variables
- Extraction of information on products, processes and machines
- Optimization of quality of products and processes
- Acceptance of machines, work pieces and processes

Phase 1: System Analysis and Phase 2: Modelling

** What are 6 phases #Exam question

Phase 1: System analysis

- Establish a project team
- Problem and job definition
- Describe the product or process to be examined
- Phrase the purpose
- Determine possible response, influencing and disturbance variables

Phase 2: Modelling

- Election of the response variable
- Determine known and supposed interrelations (interactions)
- Define the factors
- Define the levels of factors

Phase 3: Experiment strategy

Phase 4: Realization of experiments

Phase 5: Evaluation of experiments

Phase 6: Validation

Phase 3: Experiment Strategy and Phase 4: Realization of Experiments *+

Phase 1: System analysis

Phase 2: Modelling

Phase 3: Experiment strategy

- Selecting and generate an experimental design
- Define the evaluation process
- Define necessary boundary conditions
- Review the plan for feasibility
- Plan subsequent phases

Phase 4: Realization of experiments

Provide experiment logistics

- Set up written experiment printouts
- Explaning and distributing the printouts to involved
- Assign the rooms (experiment room, test field)
- Provide resources (machines, ...) and materials

Carrying out the experiments

- Monitor experimental progress
- Mind runaway values and threshold (if necessary cancel)
- Document experiment results and surveillance instantly

Phase 5: Evaluation of experiments

Phase 6: Validation

Phase 5: Evaluation of Experiments and Phase 6: Validation

Phase 1: System analysis

Phase 2: Modelling

Phase 3: Experiment strategy

Phase 4: Realization of experiments

Phase 5: Evaluation of experiments

- Frequency distributions, Pareto Analysis
- Test for normal distribution, calculate confidence interval
- Graphical and numerical effect evaluation
- Analysis of variance (ANOVA)
- Regression analysis
- If necessary, planning further experiments
- Deduce of optimal parameter setting

Phase 6: Validation

- Realization of validation experiments
- Documentation
- Provide the knowledge for subsequent experiments and freze for the future

Overview of the Results of the Experimental Methodology

Screening Experiment
- Factorial designs [2k]
- Plackett-Burman Designs
- Linked factorial designs
- Group screening plans
- ...

Reduction of Influencing Factors

Experimental Optimal Search
- Single factor method
- Steepest climb method
- Simplex method
- Evolutionary process
- ...

Starting Point for Investigations in the Optimal Area

Investigation in the Optimal Area
- Factorial designs [3k]
- Box-Behnke experimental plans
- Centrally assembled experimental plans
- ...

Regression Approach to Describe the Response Variable

Different experimental plans to find solutions in the respective phase

Full Factorial Designs
Practical Significance of 2^k-Designs

	A	B	AB
1	-	-	+
2	+	-	-
3	-	+	-
4	+	+	+

- Full factorial designs on two levels with the least possible experimental effort:
  - completely interpretable and
  - can be evaluated without restrictions (the effects and interactions are independently recognizable and calculable)
- Linear correlations are completely recognizable
- Testing of non-linear correlations via:
  - Serial connection of designs
  - Expansion to full factorial designs with central points
- 2^k-Plans can identify trends and therefore also the direction of further experiments
- For measurable factors a direct correlation exists between the regression coefficient and the effects of the factors and interactions
- 2^k-Plans are the basis for the fractional factorial design with which influencing variables can be examined without increasing the experimental effort

Construction of a Full Factorial Design

Plan Matrix

	A	B	Results		
1	-	-	y_{11}	y_{12}	y_{13}
2	+	-	y_{21}	y_{22}	y_{23}
3	-	+	y_{31}	y_{32}	y_{33}
4	+	+	y_{41}	y_{42}	y_{43}

Standard sequence :
- Begin with (-)
- The first factor varies the algebraic sign in every line
- The second factor varies the algebraic sign in every second line
- The third factor varies the algebraic line in every $2^{(k-1)}$ line

Interaction Columns

A•B	=	AB
-•-	=	+
+•-	=	-
-•+	=	-
+•+	=	+

The algebraic sign in the interaction column is the result of the multiplication of the algebraic sign of the columns belonging to the factors.

Evaluation Matrix

	A	B	AB	Results			$\overline{y}_N$
1	-	-	+	y_{11}	y_{12}	y_{13}	$\overline{y}_1$
2	+	-	-	y_{21}	y_{22}	y_{23}	$\overline{y}_2$
3	-	+	-	y_{31}	y_{32}	y_{33}	$\overline{y}_3$
4	+	+	+	y_{41}	y_{42}	y_{43}	$\overline{y}_4$

The evaluation matrix is comprised of all examined factors and all possible interactions.

Full Factorial 2^k Experimental Designs – Setup

This is the only thing that can be adjusted

	Influencing Variables (plan matrix)			Interaction Matrix				Response			
Attempt	A	b	C	AWAY	AC	B.C	ABC	y 1	y 2	y 3	$\overline{y}$
1	-	-	-	+	+	+	-				
2	+	-	-	-	-	+	+				
3	-	+	-	-	+	-	+				
4	+	+	-	+	-	-	-				
5	-	-	+	+	-	-	+				
6	+	-	+	-	+	-	-				
7	-	+	+	-	-	+	-				
8 (=N)	+	+	+	+	+	+	+				
Effect	E_A	E_B	E_C	E_{AB}	E_{AC}	E_{BC}	E_{ABC}				

The influencing variables **A, B, C** (factors) correspond to process settings at the lower (-) and upper (+) levels

Each process setting provides a different answer (response variable)

The **main effects A, B, C** are the mean change in the response variable **y** when the setting of a factor is changed

The interactions **AB, AC, BC** and **ABC** in their combination influence the response variable **y**

Plan Matrix for Full Factorial Designs

2⁴- Design / 2³- Design / 2²- Design

Run	X_1	X_2	X_3	X_4
1	-	-	-	-
2	+	-	-	-
3	-	+	-	-
4	+	+	-	-
5	-	-	+	-
6	+	-	+	-
7	-	+	+	-
8	+	+	+	-
9	-	-	-	+
10	+	-	-	+
11	-	+	-	+
12	+	+	-	+
13	-	-	+	+
14	+	-	+	+
15	-	+	+	+
16	+	+	+	+

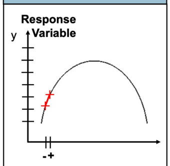
Number of attempts:
N = 2^k with k: number of factors

- = lower factor level
+ = upper factor level

Sou

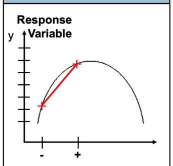
Selection of Factor Levels

Too small level distance



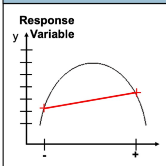
No substantial change of the response variable (effect) is possible

Reasonable level distance



Great effect, linear relationship, but rough approximation

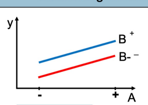
Too great level distance



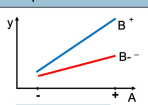
Small effect shown, although a strong dependence between y and x exists

Interactions in Design of Experiments (DoE)

Interaction is the combined influence of two or more influencing variables on the response variable

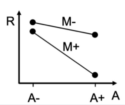


no interaction



strong interaction

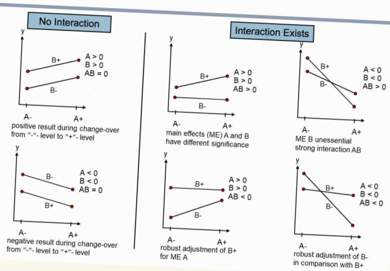
Example:
Effects of alcohol (A) and medication (M) on reactivity (R)



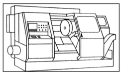
A-: without alcohol
A+: with alcohol

M-: without medication
M+: with medication

Case Study on 2-Factor-Interactions



Matrix Plan and Chart Plan



Response variable: Surface roughness R_t in µm
Factors:
Rotary frequency **A**: "-" 500 rpm "+" 1000 rpm
Feed **B**: "-" 30 mm/min "+" 40 mm/min

Matrix Plan

		Rotary frequency (A) -	Rotary frequency (A) +
Feed (B)	-	100	10
Feed (B)	+	120	30

Calculation of Effects

$$Effect_{R.freq.} = \frac{\sum R_t(A+)}{N/2} - \frac{\sum R_t(A-)}{N/2} = \frac{10+30}{2} - \frac{100+120}{2} = -90$$

$$Effect_{Feed} = \frac{120+30}{2} - \frac{100+10}{2} = +20$$

Chart Plan

Nr.	Rot.freq.	Feed	R_t
1	-	-	100
2	-	+	120
3	+	-	10
4	+	+	30

Rotary freq.	Feed
-100	-100
-120	+120
+10	-10
+30	+30
-180/2 = -90	40/2 = 20

Integration of Interactions into Chart Plan

Experimental Design | **Calculation of Interactions**

Matrix Plan

		Rotary frequency (A) -	Rotary frequency (A) +
Feed (B)	-	100	10
Feed (B)	+	120	30

Interaction = Effect of A (on B when "+") – Effect of A (on B when "-")

$$AB = \frac{(30-120)}{2} - \frac{(10-100)}{2} = -45-(-45) = 0$$

Chart Plan

No.	A	B	AB	R_t
1	-	-	+	100
2	-	+	-	120
3	+	-	-	10
4	+	+	+	30

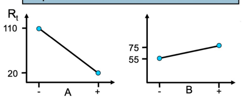
Interaction
+100
-120
- 10
+ 30
0

$$\frac{0}{2} = 0$$

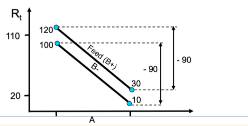
Graphical Representation of Effects

Nr.	A	B	AB	R_t
1	-	-	+	100
2	-	+	-	120
3	+	-	-	10
4	+	+	+	30

Representation of Main Effects A and B

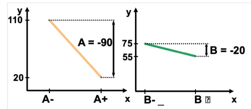


Representation of Interaction AB

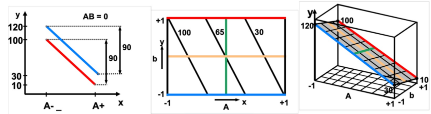


Graphical Representation of Effects – Response Surfaces without Interaction

	A	b	AW AY	y
1	-	-	+	120
2	+	-	-	30
3	-	+	-	100
4	+	+	+	10



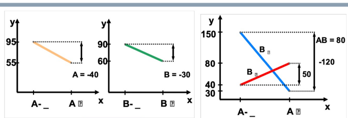
Main Effects



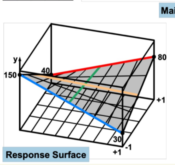
Interaction Effects | Contour Lines | Response Surface

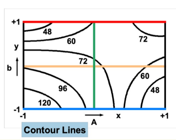
Graphical Representation of Effects – Response Surfaces with Interaction

	A	b	AW AY	y
1	-	-	+	150
2	+	-	-	30
3	-	+	-	40
4	+	+	+	80



Main Effects | Interaction Effects





Response Surface | Contour Lines

Fractional Factorial Experimental Designs - Practical Significance of 2^{k-p}

- Fractional factorial experimental designs only contain some of the possible factor-level combinations.
- The ideal area of application are systems with exclusively negligible interactions or precisely known ones Interactions.

Advantages:

- With the help of a fractional factorial experimental design,
  - more factors can be examined with the same number of experiments or
  - the same number of factors
  can be examined with fewer experiments than with a full factorial experimental design.
- Same evaluation and interpretation rules as for full factorial tests.
- Extension to full factorial plans possible.

Disadvantages:

- Mixing of effects - all effects become ambiguous.
- Reduction in sensitivity or resolution.
- Limitation of interpretability.

The appropriate experimental design must be selected for each individual situation, which has the advantages and largely excludes the disadvantages.

	A BD	B AC	C AB
1	-	-	+
2	+	-	-
3	-	+	-
4	+	+	+

Fractional Factorial Design - Developing a 2^{k-p} fractional Factor Plan by Assigning and Mixing

Developing a 2^{k-p} **fractional** factor plan by assigning and mixing

1. Choosing an interaction with presumably little effect from basic plan
2. This sign vector is assigned an additional factor **= Assign**
3. Transferring the sign vector into the plan matrix as a setting rule
4. Sign vectors of the additional interactions Multiplying the sign vectors of their components

Additional interactions with the identical sign Enter vectors into the matrix of independent variables **= Mix**

Only mix significant effects with negligible effects

Fractional Factorial Design - Example of Creating a fractional Factorial 2^{3-1} Design from a 2^2 Design

FULL FACTORIAL DESIGN

Plan Matrix			Evaluation Matrix			
Nr.	A	B	Nr.	A	B	AB
1	-	-	1	-	-	+
2	+	-	2	+	-	-
3	-	+	3	-	+	-
4	+	+	4	+	+	+

FRACTIONAL FACTORIAL DESIGN

Plan Matrix				Evaluation Matrix			
Nr.	A	B	C	Nr.	A +BC	B +AC	C +AB
1	-	-	+	1	-	-	+
2	+	-	-	2	+	-	-
3	-	+	-	3	-	+	-
4	+	+	+	4	+	+	+

- In order to place another factor C with the same number of lines, the only option in a 2² test plan is to neglect the interaction AB
- Higher-order interactions are particularly suitable for mixing, as the effects determined here can often no longer be distinguished from experimental scattering.
- **The designation of the fractional factorial plans as 2^{k-p} has the following meaning:**

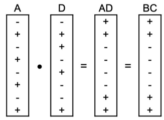
- k = number of factors in the fractional factorial factor plan
- p = number of factors that were added by mixing .

Fractional Factorial Test Plans - Determination of the Mixing of Effects in fractional Factor Plans using the Example of a 2^{4-1} Plan

Additional Factor D

	A	B	AB	C	AC	BC	ABC
1	-	-	+	-	+	+	-
2	+	-	-	-	-	+	+
3	-	+	-	-	+	-	+
4	+	+	+	-	-	-	-
5	-	-	+	+	-	-	+
6	+	-	-	+	+	-	-
7	-	+	-	+	-	+	-
8	+	+	+	+	+	+	+

Determination of aliases by comparing signs



	A BCD	B ACD	AB CD	C ABD	AC BD	BC AD	D ABC
1	-	-	+	-	+	+	-
2	+	-	-	-	-	+	+
3	-	+	-	-	+	-	+
4	+	+	+	-	-	-	-
5	-	-	+	+	-	-	+
6	+	-	-	+	+	-	-
7	-	+	-	+	-	+	-
8	+	+	+	+	+	+	+

The effort required to find the aliases increases as the number of factors increases

Results of Unacceptable Confounding

A baker wants to determine the influence of "yeast", "water" and "clothing" on the "height of the cake" by means of design of experiments.

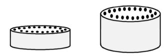
	-	+
Yeast	20 g	40 g
Water	200 g	400 g
Clothing		

Conclusion:
- Yeast has no influence
- Water has no influence

But
- The baker should wear a tie!

Response Variable

- Height of the cake



5 cm 15 cm

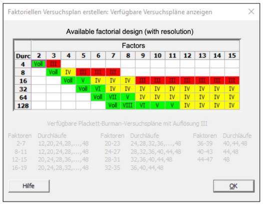
	Yeast (A)	Water (B)	Clothing (C = AB)	Height in cm
1	-	-	+	15
2	+	-	-	5
3	-	+	-	5
4	+	+	+	15
Effect	0	0	10	

Experimental designs

Characteristics

Full factorial designs
Perfect analyzability, but with a high number of parameters the amount of experiments becomes too large (number of trials: 2^k with k = number of factors).

Fractional factorial designs
Half the amount of experiments, but interactions cannot be fully analyzed - resolution decreases (number of experiments: 2^{k-1}).



Faktoriellen Versuchsplan erstellen: Verfügbare Versuchspläne anzeigen

Available factorial design (with resolution)

Durc	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Voll	III												
8		Voll	IV	III	III	III								
16			Voll	V	IV	IV	IV	III	III	III	III	III	III	III
32				Voll	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Voll	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Voll	VIII	VI	V	V	IV	IV	IV	IV

Verfügbare Plackett-Burman-Versuchspläne mit Auflösung III

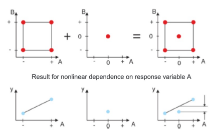
Faktoren	Durchläufe	Faktoren	Durchläufe	Faktoren	Durchläufe
2-7	12,20,24,28,...,48	20-23	24,28,32,36,...,48	36-39	40,44,48
8-11	12,20,24,28,...,48	24-27	28,32,36,40,44,48	40-43	44,48
12-15	20,24,28,36,...,48	28-31	32,36,40,44,48	44-47	48
16-19	20,24,28,32,...,48	32-35	36,40,44,48		

Hilfe OK

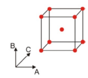
Factorial Experimental Designs with a Central Point

- The dependency between influencing variables and response variables is viewed as linear in plans in which factors are only implemented at two levels (2^k-, 2^{k-p}- experimental plans).
- This assumption is checked by adding a third stage, the central point.

Construction of a 2^2 plan with a central point:

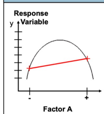


Principle of a 2^2 factor plan with a central point:



Retrospect:

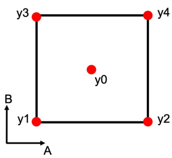
Too great level distance



Small effect shown, although a strong dependence between y and x exists

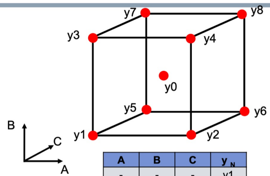
Source: Pfeifer 1991

Factorial Experimental Designs with Central Point - Experimental Arrangement and Experimental Plan



A	B	y_N
-	-	y1
+	-	y2
-	+	y3
+	+	y4
0	0	y0

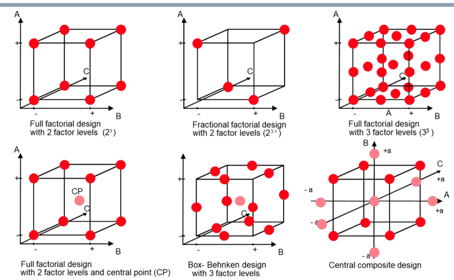
2^2 – Experiment Design with Central Point



2^3 – Experiment Design with Central Point

A	B	C	y_N
-	-	-	y1
+	-	-	y2
-	+	-	y3
+	+	-	y4
-	-	+	y5
+	-	+	y6
-	+	+	y7
+	+	+	y8
0	0	0	y0

Experimental Designs with 3 Factors



Further Analysis of Experimental Results

$$F_{Factor,WW} = \frac{s^2_{Factor,WW}}{s^2}$$

$$F_{critical} = F(f_{Factor,WW}; f; \alpha)$$

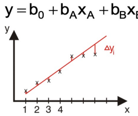
Tabulated with
$f_{factor,WW}$: degree of freedom of the factor
f: total degrees of freedom
a: significance level

$F_{Factor,WW} < F_{critical}$
Effect is not significant

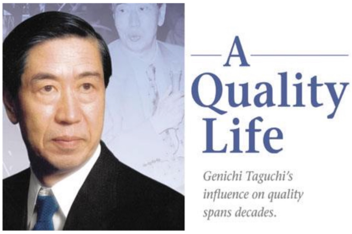
$F_{Factor,WW} \geq F_{critical}$
Effect is significant

Regression Analysis (determination of the response function)

$$y = b_0 + b_A x_A + b_B x_B + \ldots + b_{AB} x_A x_B + \ldots + b_{ABC} x_A x_B x_C + \ldots$$



Genichi Taguchi - Robust Design



Parameter Test Planning :

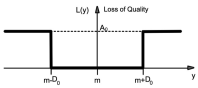
With the help of parameter test planning, product and process parameters are optimized and made as insensitive as possible, i.e. **robust** against disruptive influences.

Loss Function:

It means that the characteristics that lie within tolerance limits are not qualitatively equivalent. Accordingly, there is a "global loss" (loss for society). This loss increases quadratically with the deviation from the response variable and the scatter (loss function parabola).

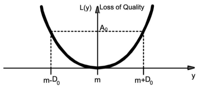
Taguchi - Quality Loss Function

Stair Function



$$L(y) = \begin{cases} 0 & \text{if } |y-m| \le D_0 \\ A_0 & \text{otherwise} \end{cases}$$

Quadratic Loss Function

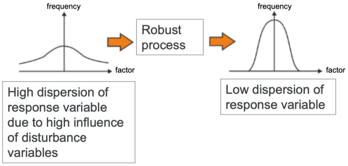


$$L(y) = k(ym)^2$$

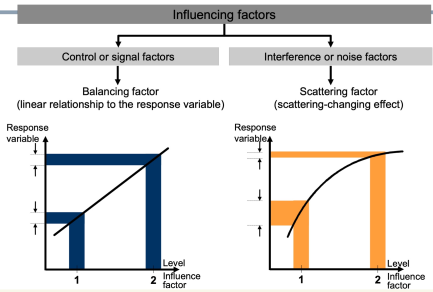
with k: loss of quality coefficient

Taguchi - Experimental Methodology and Objectives

- At the heart of Taguchi's experimental planning is the requirement for robust processes
- A robust process has the property that the result and the creation of results are influenced as little as possible by influencing factors and therefore the experimental variation is very low.



Taguchi - Influencing Factors



Taguchi - Procedure

1st step **System Design:**
Applying technological know-how to product and process design to fulfill requirements.
Preliminary determination of product and process parameters.

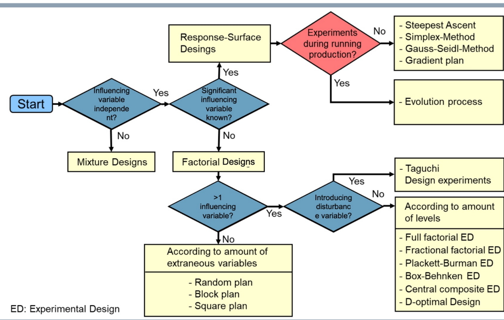
2nd step **Parameter Design:**
Applying experimental methodology to determine optimal ones Parameter combinations (also from a cost perspective) for the design of products and processes that are opposite are insensitive to interference that cannot be influenced.
Response varibale orientation and scatter reduction.

3rd step **Tolerance Design:**
In addition to the parameter design, in the case of further optimized determination of tolerances from a cost-benefit perspective .

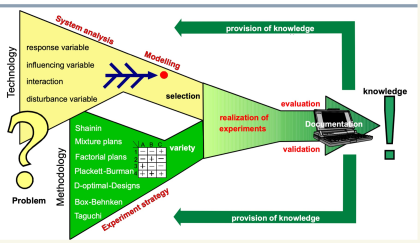
Dorian Shainin – Red X

- **The vital few, the trivial many**
  Only a few of the influencing factors have a dominant influence (Pareto principle, Red-X)
- **KISS – Keep It Statistically Simple**
  Statistical methods that are understandable to laypeople
- **Let the parts do the talking**
  Don't trust the experts – let the parts do the talking
- **Principle of Elimination**
  Exclusion of influencing factors
- **Principle of Comparison**
  Comparing parts with each other, not with given specifications

Decision Making Aid regarding the Type of Experimental Design



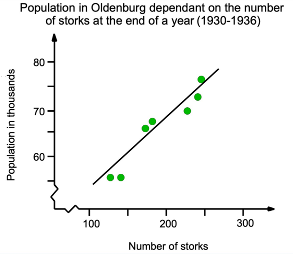
Methodical Approach for Design of Experiments



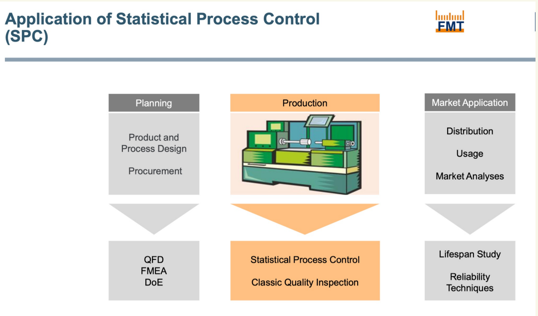
Limitations of the Experimental Methodology

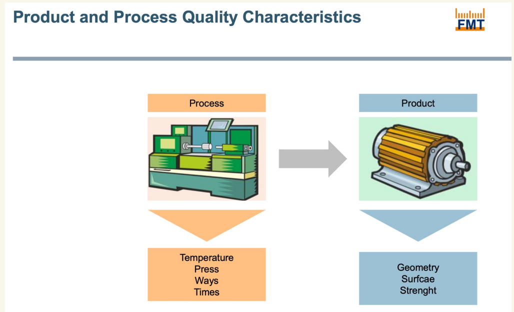
- Fields in which the test methodology is only partially applicable:
  - Basic experiments in which connections are based on natural laws
  - In principle, test methodology can only be used for stationary processes.
  - There is no need for the test methodology if many tests can be carried out in a very short time and therefore reducing the test effort offers no advantage.
- Another danger when using the experimental methodology is when false connections are assumed

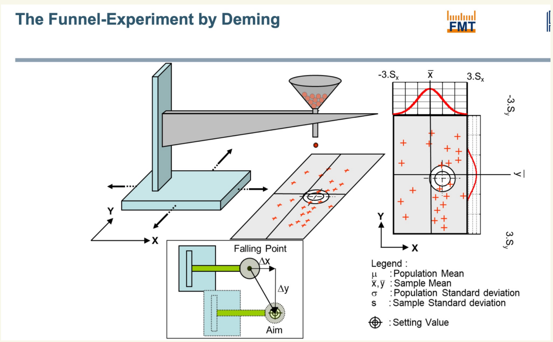
The experimental methodology is one method among others and has limitations and disadvantages

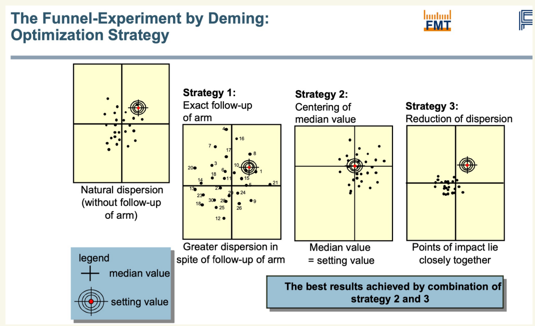

Population in Oldenburg dependant on the number of storks at the end of a year (1930-1936)
80
70
60
Population in thousands
100
200
300
Number of storks

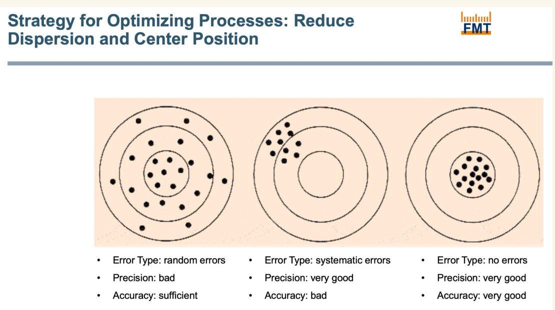
Statical Process Control

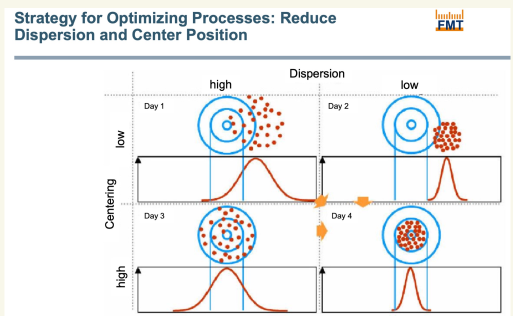


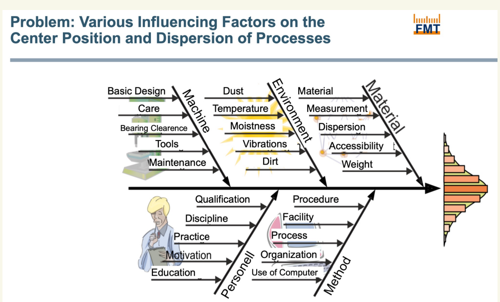












Random and Systematic Influences

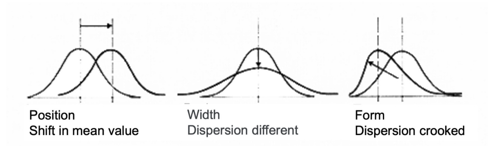
Random Influences

- Sum of many small individual influences
- Independent of each other
- Always present
- Predictable

Systematic Influences

- Few, specific causes
- Causing changes and shifts in the process
- Cause process instability
- Unpredictable

Effect of Random and Systematic Influences on the Quality Characteristics of the Process

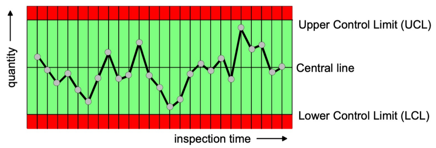


Random or Systematic Influences?

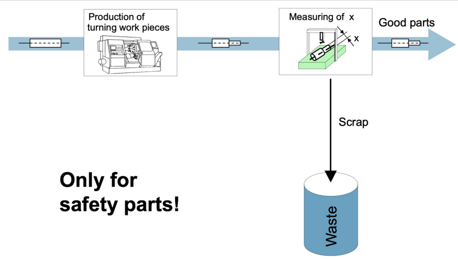
Definition of Statistical Process Control - SPC

SPC

is a procedure for monitoring process characteristics according to position and dispersion by statistical methods and devices, in order to control production processes

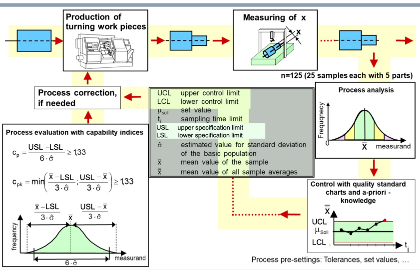


Example of Quality Control without SPC

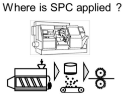


Only for safety parts!

Example of Quality Control with SPC

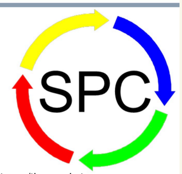


Application of Statistical Process Control



Where is SPC applied ?
- unit load processes
- flow processes
- company units: mainly
  + acceptance department
  + manufacturing
  + assembly
  + test field

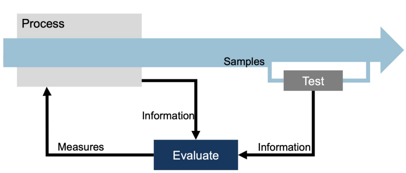
What is SPC used for ?
- Inspection of quality feature:
  + process-
  + product-
  + measurement unit features



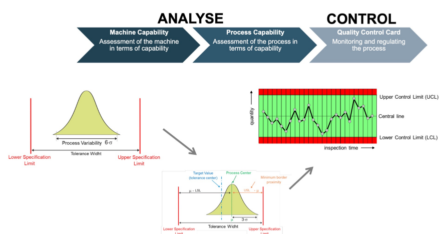
What are quality feature ?
- features demanded from the customer/the market
- important features for the functionality of a part
- attributive and measurable features
- controllable features, whose values have to be observed for the following steps
- features, that enable a economical manufacturing with small dispersion (entire evaluation)

Examples
- attributive features (bad/good)
- discreet features (diameter in mm,…)
- numeric features (amount of non-conformant parts in sample,..)

Principle of Statistical Process Control



Phases of Statistical Process Control: Machine and Process Capability Analysis, Quality Control



Machine and Process Capability Analyses

#Exam

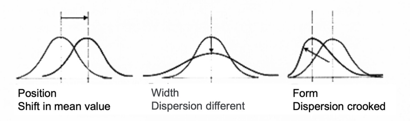
The aim of machine and process capability analyzes is to provide evidence that the machine or manufacturing process is safely able to meet the specification (i.e. the specified limit values).

Machine Capability Studies can be carried out on the occasion of a machine acceptance test or as part of a release process for a new product (or a new process).

Process Capability Studies are carried out before the start of series production to release a new product (process) and during series production.

The results are determined statistically using random **samples**. The ability is assessed using determined statistical parameters in the form of capability indices and the associated proportions of exceedances (error proportions), namely by comparing them with the specifications.

Searched: Frequency Distribution of Quality Characteristics



What does the distribution (position, dispersion and shape) of the population, i.e. the manufacturing process, looks like?

Tests for Normal Distribution

The following methods are used to check whether data is normally distributed:

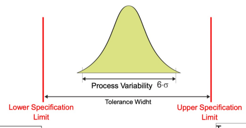
- **Chi-square Test**
- **Kolmogorov-Smirnov Test**
- **Anderson-Darling Test (modification of the Kolmogorov-Smirnov test)**
- **Lilliefors Test (modification of the Kolmogorov-Smirnov test)**
- **Cramér-von Mises Test**
- **Shapiro-Wilk Test**
- **Jarque-Bera Test**
- **Q-Q Plot (descriptive review)**
- **Maximum Likelihood Method (descriptive verification)**

The tests differ in their insight into the nature of the deviations from the normal distribution. For example, while the **Kolmogorov-Smirnov Test** detects deviations in the middle of the distribution as deviations at the edges, the **Jarque-Bera Test** reacts sensitively to strongly deviating individual values at the edges ("heavy tails").

With the help of **Quantile-Quantile Plots** (also normal quantile plots or Q-Q plot for short), a simple graphical check for normal distribution is possible.

The **Maximum Likelihood Method** can be used to estimate the parameters of the normal distribution and to graphically compare the empirical data with the fitted normal distribution.

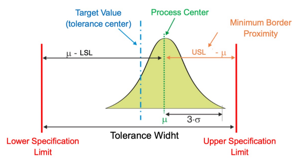
Calculation of Process Capability: C_p Value for Normally Distributed Populations



$$C_p = \frac{T}{6\cdot\sigma} = \frac{USL - LSL}{6\cdot\sigma}$$

T	Tolerance Widht
USL	Upper Specification Limit
LSL	Lower Specification Limit
σ	Standard Deviation

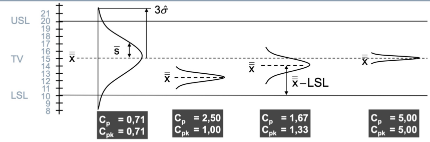
Calculation of Process Capability: C_{pk} Value for Normally Distributed Populations



$$C_{pk} = \min\left\{\frac{USL - \mu}{3\cdot\sigma}; \frac{\mu - LSL}{3\cdot\sigma}\right\}$$

USL	Upper Specification Limit
LSL	Lower Specification Limit
σ	Standard Deviation
µ	Process Mean

Comparison of Process Capability Parameters C_p and C_{pk}



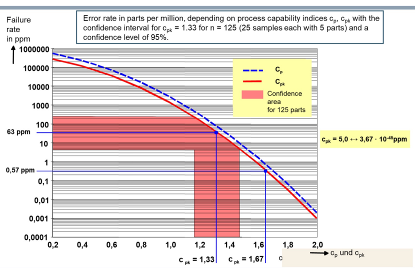
$$C_p = \frac{\text{Tolerance Widht}}{\text{Process Variability}} = \frac{USL - LSL}{6\hat{\sigma}}$$

$$C_{pk} = \frac{\text{Min. Border Proximity}}{\text{Half Process Variability}} = \frac{|\bar{\bar{x}} - LM|_{min}}{3\hat{\sigma}}$$

$\bar{s}$: Mean standard deviation of the samples
$3\hat{\sigma}$: Estimation of dispersion of the population
$\bar{\bar{x}}$: Mean of sample means

USL	Upper Specification Limit
LSL	Lower Specification Limit
LM	Limit Value
TV	Target Value

Confidence Area of Process Capability Indices

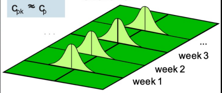
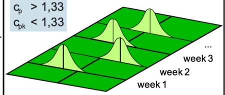
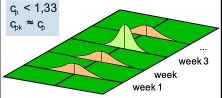
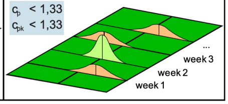


Measures Depending on the Process Capability C_{pk}, taking into Account Feature Classes

Tolerance Dispersion	Error-Free Manufacturing	Possible Additional Actions
> 1,33	Unproblematic	Continuous quality improvement while taking economic efficiency into account
1 – 1,33	Problematic	Optimize Process
< 1	Impossible	100% sorting inspection and process improvement required at the same time

Characteristic Classes		
	Critical Characteristic	$C_{pk} > 1{,}33$
	Main Characteristic	$C_{pk} > 1{,}17$
	Secondary Charateristic	$C_{pk} > 1{,}00$

Four-Field-Table according to Kirstein n > 125 measured Values have approximate Normal Distribution

Process is	Controlled	Not Controlled
Capable	$c_p > 1{,}33$ $c_{pk} \approx c_p$ stable  	$c_p > 1{,}33$ $c_{pk} < 1{,}33$ 
Not Capable	$c_p < 1{,}33$ $c_{pk} \approx c_p$  	$c_p < 1{,}33$ $c_{pk} < 1{,}33$ 

c_p, c_{pk} Process capability index (long-time efficiency)
n number of measured value per week