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Six Sigma^{+Lean} Toolset

Mindset for Successful Implementation of Improvement Projects

Second Edition

Translated by Astrid Schmitz

Springer

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Table of Contents

Forewords 1

INTRODUCTION 5

– Six Sigma+Lean – a Global Success Story Are 25 Years Enough? 7

– Six Sigma versus Lean Management – Competition? 8

– From Toolset to Mindset: What Does This Mean in Business Practice? 9

– Business Excellence as a Key for Sustainable Success 10

– Excellence Mindset in Project Work 14

DEFINE – What is the Problem? 17

– Summary DEFINE Phase 19

– Road Map DEFINE Phase 20

– Tool Overview DEFINE Phase 21

– Project Charter 23

– Benefit Calculation 28

– Project Frame 31

– Multi Generation Plan 33

– SIPOC 35

– Dependency Assessment 37

– Project Management 38

– Work Breakdown Structure 40
– Network Plan 42
– Time Plan 44
– Resource Planning 46
– RACI Chart 48
– Budget Planning 50
– Risk Management 52
– Stakeholder Management 54
– Kick-off Meeting 57
– Project Communication 59
– Customer Needs Table 61
– Kano Model 63
– Tool 1_CTC/CTB Matrix 66
– Gate Review 69
– Gate Review DEFINE 71

MEASURE – How Big is the Problem? 73
– Summary MEASURE Phase 75
– Road Map MEASURE Phase 76
– Tool Overview MEASURE Phase 77
– Tool 2 79
– Collect Data 82
– Operational Definition 83

– Data Source 86
– Data Type 87
– Data Collection Forms 89
– Sampling Strategy 91
– Measurement System Analysis (MSA) 97
– Gage R&R for Discrete (Binary) Data 102
– Measurement System Analysis Type I 105
– Measurement System Analysis Type II 106
– Linearity Study and Systematic Measurement Deviations 108
– Test the Quality of Available Data 110
– Data Collection Plan 112
– Understanding Variation 114
– Pie Chart 115
– Bar Chart 116
– Pareto Chart 117
– Dot Plot 119
– Histogram 120
– Box Plot 123
– Run Chart 125
– Control Charts 128
– Scatter Plot 130
– Probability Plot 131
– Location Parameter Mean Value 133

– Location Parameter Median 135

– Spread Parameter Variance 137

– Spread Parameter Standard Deviation 138

– Spread Parameter Range 140

– Spread Parameter Span 141

– Process Performance 142

– Defects per Million Opportunities (DPMO) 143

– Parts per Million (ppm) 145

– Defects per Unit (DPU) 146

– Yield 147

– Span, Percentile Distance 149

– Data Transformation 151

– Process Capability and Process Stability 153

– C_p and C_{pk} values 155

– Gate Review MEASURE 158

ANALYZE –

What are the Root Causes of the Problem? 159

– Summary ANALYZE Phase 161

– Road Map ANALYZE Phase 162

– Tool Overview ANALYZE Phase 163

– Cause-Effect Diagram 165

– FMEA 168

- Tool 3 ___ 175
- Process Analysis ___ 178
- Spaghetti Diagram ___ 182
- Process Flow Chart ___ 184
- CFD ___ 186
- Value Stream Map ___ 188
- Value Analysis ___ 191
- Time Analysis ___ 195
- Process Efficiency ___ 199
- Capacity Analysis ___ 200
- Process Flow Analysis ___ 202
- Analyze Data ___ 204
- Data Stratification ___ 206
- Confidence Interval ___ 208
- Hypothesis Tests ___ 211
- ANOVA/One Way ANOVA ___ 217
- ANOVA/Two Way ANOVA ___ 222
- Correlation Coefficient ___ 226
- Simple Linear Regression ___ 228
- Multiple Linear Regression ___ 233
- Logistic Regression ___ 236
- Design Of Experiments (DOE) ___ 240
- Full Factorial Design ___ 245

– Fractional Factorial Designs 250
– Variation Reduction 254
– Response Surface Methods 256
– Further Experimental Designs 257
– Derive Main Causes 260
– Gate Review ANALYZE 263

IMPROVE –
What are the Solutions for Eliminating the Causes? 265

– Summary IMPROVE Phase 267
– Road Map IMPROVE Phase 268
– Tool Overview IMPROVE Phase 269
– Conceive Solutions 271
– 5 S 272
– Poka Yoke 276
– Workplace Layout 280
– Theory of Constraints 282
– Setup Time Reduction 284
– Total Productive Maintenance (TPM) 288
– Generic Pull System (GPS) 294
– Replenishment Pull System (RPS) 297
– Two Bin Replenishment Pull System 300

– Determination of Batch Size 301
– Process Flow and Process Logic 302
– Brainstorming 303
– Anti-Solution Brainstorming 305
– Brainwriting 307
– SCAMPER 309
– Analogy Brainstorming 311
– Affinity Diagram 313
– Must Criteria 314
– Effort Benefit Matrix 316
– N/3 Method 317
– Nominal Group Technique 319
– Pugh Matrix 321
– Tool 4 324
– Should be Process Map 327
– Cost Benefit Analysis 329
– Prepare Process Control 331
– Reaction Plan 333
– Pilot 335
– Implementation Plan 338
– Risk Analysis 341
– Rollout 342
– Gate Review IMPROVE 343

CONTROL –
How can the Improvement's Sustainability be Ensured? 345

– Summary CONTROL Phase 347
– Road Map CONTROL Phase 348
– Tool Overview CONTROL Phase 349
– Process Documentation 351
– Visual Management 355
– Control Charts 358
– Dashboard 367
– Process Control Team 370
– Glass Wall Management 372
– Audits 374
– Project Documentation 377
– Project Closure 379
– Gate Review CONTROL 382
– Continuous Improvement Process 383
– Lean Workout 385

APPENDIX

– Abbreviations 389

– Index 392

– Process Sigma Table Including 1.5 Sigma Shift 399

– Bibliography 400

Foreword to the Second Edition

During the past five years, i.e. since the publication of the first english edition, the deployment and scope of Six Sigma^{+Lean} has continually developed. This fact, our own numerous experiences and suggestions by users of the methodology has inspired us to add a number of content-related supplements and upgrades to the book. More importantly, we were also inspired to a paradigm change: from Toolset to Mindset.

In addition to this, we are increasingly aware of the danger that tools and templates frequently dominate project work, even though most tools and checklists utilized do not necessarily ensure good project results and/or acceptance within the organization. Furthermore, it cannot be denied that a, certain over organization of project work exists. Not every problem that we see, justifies the organizational effort that is applied. For these reasons, we developed the tool based approach into a question-based one.

It has in fact become apparent that systematic questioning is the best filter for selecting the suitable tools. Experience shows that this leads to quicker and better results. Tools are just the means to the solving of the problem. No more, no less.

The acceptance among stakeholders can also be significantly increased by a question based approach. This target group is not confronted with a multitude of tools and the detailed information contained within them, but is provided with insights and answers.

We thus provide you an optimization approach going far beyond the classical toolset. Nevertheless, we did not want to rename the book as a mindset, keeping the known and proven chronological structure, but adding the described questions and providing further relevant tips for practical application.

In our opinion, the result is a book, which is even more suitable for fulfilling the requirements of practical improvement work. We are looking forward to your feedback.

Apart from the authors, who invested innumerable nights and weekends in the realization of this book once again, I would also like to take this opportunity to thank the UMS team. Dear colleagues, you continuously contributed your enormous experiences to the book.

Thank you for this. I would especially like to mention my colleagues Martin Funk, Felix Reble and Marc Török, who provided excellent support especially for the Lean tools, statistics and the Measurement System Analysis. Thanks too, to Alastair Gardner for working to improve the reader's experience, and Mariana Winterhager, who, just as in previous editions, worked again around the clock on the graphic design.

I wish readers good luck in the application and further development of this "Best Practice" approach.

Frankfurt am Main, January 2013
Stephan Lunau

Foreword to the First Edition

Six Sigma has established itself globally over the last 20 years as a best practice concept for optimizing processes. Many renowned companies from a diverse array of business branches successfully deploy Six Sigma and profit from the benefits of Six Sigma-inspired projects, significantly improving their net income. Focusing on customer needs and measurability is at the forefront of this approach.
In the course of its long history the Six Sigma approach has undergone many developments and upgrades and these have been incorporated into the original concept. One very important step is the integration of Lean Management tools into the classical Six Sigma concept. Along with reducing process variation – which is achieved through classical quality tools and statistical analysis, these tools contribute decisively to achieving a significant acceleration in process speed and a reduction of inventories and lead times.
As practiced by UMS GmbH, in its applications, the Six Sigma^{+Lean} approach thus combines the tried-and-tested tools of both worlds, which are linked together systematically in the proven DMAIC process model. Effective tools exist for every problem, ensuring that excellent and sustainable project results are achieved.
We took the chance to update the book with respect to the latest developments of the method and incorporated the customer feedback of the last years.
Here we focused especially on an improved Define phase, the incorporation of the OEE measurement in the Measure phase and a revised Lean Toolset.

The present Six Sigma^{+Lean} Toolset takes into account the described developments by serving as a practice-oriented reference book for trained Master Black Belts, Black Belts, and Green Belts. It contains all key Six Sigma^{+Lean} tools, which are depicted in clearly structured graphs, charts and highlighted with examples. The book follows the successive phases of a project and deals with the tools according to their respective place in the Define, Measure, Analyze, Improve, and Control phases. This enables the expert to work through his projects chronologically, with the Toolset acting as a guideline.

I am indebted to members of the UMS team; their detailed expertise and rich wealth of experience contributed to realizing this Toolset. In particular my co-authors Alexander John, Renata Meran, Olin Roenpage, and Christian Staudter. I would like to thank Astrid Schmitz for her effort in the translation and adaptation process. Finally, my thanks go to Mariana Winterhager for her continuous effort in incorporating all the changes and the improvements into the Toolset.

I wish readers good luck with their projects.
Frankfurt am Main, July 2008
Stephan Lunau

SIX SIGMA^{+LEAN}
TOOLSET

INTRODUCTION

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Six Sigma+Lean – a Global Success Story

Are 25 Years Enough?

Six Sigma has been known for more than 25 years in business practice and has proven its value all over the world.

- Isn't it time that something completely new was tried and tested?
- Does the concept still fit in with modern times or has it become superfluous?

Before we start dealing with these questions, here is some background information on the terms of Six Sigma and Lean:

Six Sigma is the name for a quality assurance and quality increase initiative introduced at Motorola at the end of the 80's. For the company's success Motorola received the renowned award "Malcom Baldrige National Quality Award". The ideas and components of the program were taken up and applied by further companies such as e.g. Texas Instruments. Similar results were achieved. General Electric transferred the concept also to service processes. The successful application in the entire company and the consistent support by Jack Welch (CEO General Electric from 1981 to 2001) contributed to the fact that the Six Sigma concept became renowned internationally and was applied in many further companies.

In its origins the term "Six Sigma" stands for the description of a statistical quality goal: the customer specifications are fulfilled in 99.99999976% of the cases (six standard deviations on the left and on the right side from the process mean value).[1] The statistical term "Sigma" (for the standard deviation) in itself shows which importance the data analysis and the statistical analyses had for this methodology.

The central element of Six Sigma is the combination of an approach based on phases, which is tool-oriented and structured. However, Six Sigma stands for more than just an established analysis tool based on scientific statistics. Since the beginning it has represented a systematic and strict methodology for the optimization of business processes, with the goal of fulfilling all critical customer and business requirements completely and in a profitable way.

At the beginning of the Six Sigma application the defined tools were applied in a relatively inflexible way. This means, that each phase required the application of so-

1 The specialized literature generally assumes a 1.5 Sigma shift. This is why the frequently quoted target value of 99.99966 percent actually corresponds to a Sigma value of 4.5.

called must or obligatory tools. This strict procedure was the key to success in many projects around the world. Because it helped to drive ahead a cultural change: Decisions were no longer taken based on gut feeling but rather made based on figures, data, facts. However, Six Sigma project leaders often gained the reputation of scientists, which was especially due to the partly complex statistical methods. This often led to the perception that Six Sigma was complex and bureaucratic.

This changed over time. On the one hand, statistics was designed in an increasingly application-oriented way and on the other hand, it has turned out that the DMAIC cycle is suitable for integrating proven tools, similar to an open platform.

DMAIC is systematic, structured common sense. The letters stand for five consecutive project phases,
DEFINE (define problem and goal)
MEASURE (measure current performance)
ANALYZE (analyze and verify causes)
IMPROVE (identify and implement improvement actions)
CONTROL (ensure sustainability of results).

Six Sigma versus Lean Management – Competition?

The Lean Wave was introduced in companies at the beginning of the 90's. This led to the fact that Lean tools gradually became an integral part of the DMAIC toolbox. Certain question formulations for which no standard tools existed in the classical Six Sigma Toolset, could be solved in this way.

For instance, the process lead time can be significantly reduced by the application of pure Lean analysis and improvement tools. Furthermore, the elimination of waste is among the essential goals in process improvement projects today. Here, the proven Lean methods show their full effectiveness.

Any discussion about which methodology represents the guiding methodology and which only a tool, is superfluous in our opinion. At the end of the day it is the result that counts and the success of the entire program. How and with what tools this has been achieved, is – strictly speaking – of minor importance. This also means that the further development of the toolbox is not impossible but to be welcomed at every opportunity.

Nor is it about the strict application of obligatory tools or the quantity of used tools. It is rather an intelligent questioning of the key to success. The tools are the means to the end: They are simply intended to help us find the right answers to the questions.

This new approach, which is question instead of tool-oriented, leads to the fact that Six Sigma^{+Lean} enjoys more and more understanding and acceptance particularly among executives and management. The same also applies to the work done in project teams, projects and workshops run faster, more efficiently and generate greater acceptance among Stakeholders. The reputation of Six Sigma^{+Lean} as a complex and bureaucratic concept is thus gradually eliminated.

Therefore, we understand this book as a further development of the Toolset to the Mindset.

From Toolset to Mindset:

What Does This Mean in Business Practice?

Many improvement projects generate significant benefit within the organization. But is the impact really perceivable by the external customer in the aspired degree?

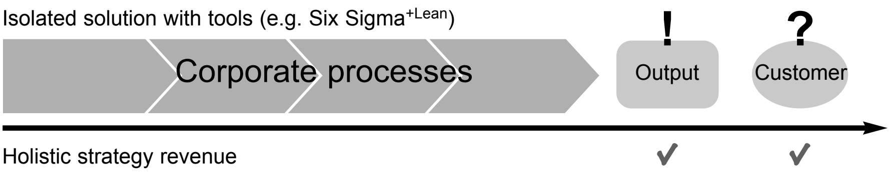


Illustration 1: Are the efforts of the organization for the improvement of processes visible for the customer?

Project managers are often reproached for being diligent but not making results visible at the end of the process chain. Requirements of customers, products and markets are so dynamic and short-lived that it doesn't suffice any longer to work on individual processes and/or sub-processes in an isolated way. Moreover, the tendency that initiatives can wear out over the years must also be taken into consideration. Their impact often subsides and the employees and/or the organization require new impulses continuously in order to work on the goal of continuous improvement. This is difficult and actions such as name changes or the initiative's addition by a "+" do not solve the problem of decreasing effectiveness.

Unfortunately, this usually leads to the something-completely-new-should-be-tried-and-tested phenomenon mentioned earlier which does not contribute to maintaining the acceptance of employees and the alignment of executives towards the respective goal in the long run. A holistic approach which is comprehensible for everyone helping the company to become and remain successful in the long run is required. This concept should be directly linked to the corporate strategy, thus having the requested long-term character, irrespective of tools and methods.

An idea to describe this development is the need to continuously strive for excellence in all matters. But what does this mean for the design of such an Excellence Program on the corporate level and in the project work?

Business Excellence as a Key for Sustainable Success

Business Excellence serves the purpose of achieving maximum performance in all areas of economic activity. It should be possible to measure all actions and improvement projects by this goal.

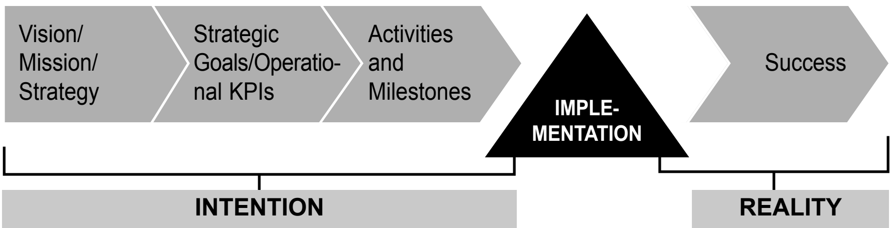


Illustration 2: Implementation – The deviation between intention and reality

The above illustration shows the process of strategy implementation. Planning is located on the left. The achieved result is on the right side. A gap exists in between, the red triangle, which is to be minimized.

We are always concerned about fulfilling all critical customer and business requirements completely and economically. It is important not to think of oneself as the best problem solver within the triangle – in contrast to the approach practiced by many Six Sigma programs in the past.

It is more about deriving the relevant fields for action for the improvement projects directly from the strategy and/or the goals. This means in practice that the activity field of Business Excellence orients itself specifically towards the strategy implementation process rather than only towards the implementation triangle. The Business Excellence model practiced by us thus creates the connection between intention and reality. More than tools are required for this. It is about the mindset of strategy implementation.

Strategy implementation as a mindset has complex dimensions and concerns the entire organization. In order to approach this task as a company in a sensible way, without getting bogged down in the complexity of the task, a structured procedure in several steps is required which can be derived from the observation of our customers over the last 15 years.

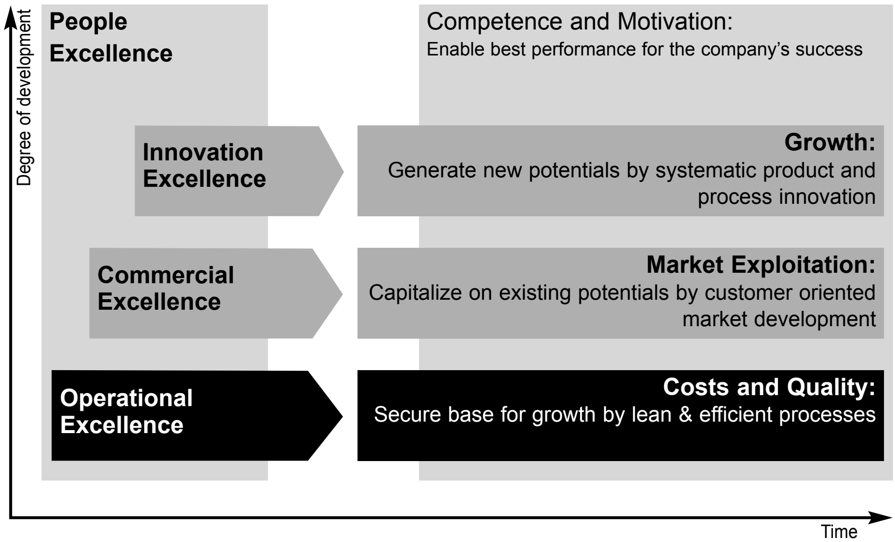


Illustration 3: The UMS Business Excellence Model

In the beginning companies embarking on the journey to Excellence focus too strongly on securing existing scope of action by efficient processes with the focus on costs and quality. This focus is frequently directed inwards. The operative processes, of whatever type, are optimized and/or designed in an excellent way. It makes no difference here whether production or service processes are concerned.

In the sense of the classical Six Sigma language this focus can also be referred to as fulfillment of CTBs (Critical to Business). We refer to this phase as **Operational Excellence**, which we support with a specifically tailored mix of tools, methods and concepts (cf. following illustration).

Process Management Lean Office **Production Systems** **Supply Chain Management** **Potential Analysis** **Measurement Systems** Experimental Procedure **Key Figure Systems** **Rapid Process Design** Project Management

After a certain period of time it is rather cross-sectorial topics that become the focus of the improvement work. This usually involves the fulfillment of external customer requirements, the CTCs (Critical to Customer), i.e. projects into which suppliers and customers must be integrated. Apart from sales and marketing topics also topics concerning Supply Chain are dealt with. Here, the motto is: Capitalize on existing potential by customer oriented market cultivation. For this purpose, further, additional concepts and methods are required. We refer to this Excellence Field as **Commercial Excellence.**

Channel Management Customer Service **Market Cultivation** **Value Proposition** **Sales Processes** **Market Entry** Customer Touch point Management **Segmentation** **Customer Value Management** Opportunity & Pipeline Management

At the third level of maturity new potential is generated by systematic product and process innovation. Research and development areas, Marketing etc. are strongly involved. The mix of concepts, tools and methods, which hide behind the term referred to us as **Innovation Excellence**, come above all from Innovation Management.

Innovation Management Fuzzy Front End **Blue Ocean** **Trend Analysis** **Innovation Processes** **Design for Six Sigma** Market/ Competition Analysis **Feasibility Analysis** Early 6 Just Enough Prototyping

All of the previously mentioned Excellence Fields are based on **People Excellence**. It ensures the competence and motivation of employees and in this way enables best performance for the company's success in all areas. For this, suitable employees must be identified, selected, qualified and supported. For each of the mentioned phases respective concepts must be applied in order to support the target achievement. One of these is for example the development of a culture for continuous improvement.

Change Management Recruiting **Skills & Training** **Culture Diagnosis** **Employee Selection** **Group Work** Improvement Culture **Maturity Level Analysis** **Agenda Setting** Employee Development

For us the fact is interesting that companies deploying Six Sigma^{+Lean} as well as companies which have so far not dealt with the topic of continuous improvement, all react very positively to the concept of Business Excellence. Many questions arise during discussions as to how the idea can be implemented in the respective context.

Each application of the Business Excellence concept must be designed individually. However, 5 success factors have emerged whose consideration contributes to designing a Mindset which is lived on the basis of the concept. The following questions emerge if it is transferred to Operational Excellence:

Focus	• Which goals are pursued with Business Excellence ? • How is the target achievement measured?
Process	• What does the process look like – from the identification of need for action to the benefit realization? • How is the process controlled?
Tool	• Which tools are used? • How are old and new methodologies and tools linked?
Skill	• What do roles and responsibilities look like? • What knowledge, and which skills, must role owners have, and how should these be developed?
Structure	• Have the roles and responsibilities been anchored in an appropriate way in the corporate structure? • Are they accompanied by sufficient power and resource?

The idea of Business Excellence, designed along the five success factors enables the development of a company-wide concept ensuring continuous strategy implementation.

Excellence Mindset in Project Work

The compilation of the tools, methods and concepts used in the Excellence Fields goes far beyond the tools described in this book. Although many of the tools and methods included in this book are applied in all Excellence Fields, the focus here is on **Operational Excellence**.

The Mindset of Business Excellence can be found in each of the five DMAIC project phases and even in each individual tool: Question-based approach and focus on the aspired result.

With respect to DEFINE, the following applies:

DEFINE: What is the problem?		
D.1	**Set Project Goals** What is to be the project's result?	Project Charter Benefit Calculation
D.2	**Scope the Project** What is part of the project? Which process is tested?	Project Frame Multi Generation Plan (MGP) SIPOC Dependency Assessment
D.3	**Ensure Project Success** Which work packages must be completed in which time? Which Stakeholders must be addressed? Which risks can occur and how are they managed?	Project Management Work Breakdown Structure Network Plan Time Plan Resource Planning RACI Chart Budget Planning Risk Management Stakeholder Management Kick-Off Meeting Project Communication
D.4	**Specify Customer Requirements** Which requirements does the customer have for the process output? Which requirements does the Business have for the process output?	Customer Need Table Kano Model Tool 1: CTC-CTB Matrix

Typical questions for process improvement will be asked in the following chapters for each phase and tools will be presented with which the questions can be answered systematically and in a structured way. The question-based procedure ensures that you will identify and apply the relevant tools for your action from the great number of offered tools not only quickly but also securely.
In this way a comprehensive integration of Six Sigma^{+Lean} and project management will come into being which in itself makes a contribution to completing improvement projects OTOBOS: on time, on budget and on specification.

In the end only the project result counts: Tools are just the means to the end.

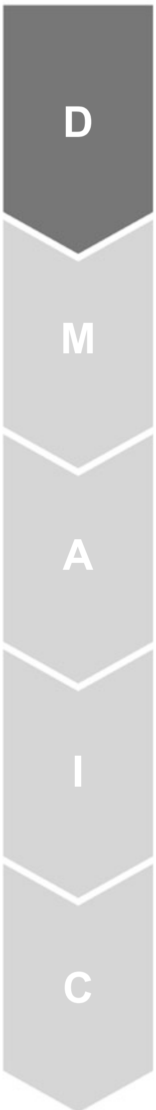
SIX SIGMA+LEAN TOOLSET

DEFINE

What is the Problem?

R. Meran et al., *Six Sigma+Lean Toolset: Mindset for Successful Implementation of Improvement Projects*, Management for Professionals, DOI 10.1007/978-3-642-35882-1_2,

Summary DEFINE Phase



Objective and Scope of Phase

- The DEFINE phase answers the question: "What exactly is the problem?" i.e. where is the pain, why does it have to be addressed, which customer requirements are to be focused on and what exactly does the road to the solution look like?
- The problems and objectives should be clearly defined. The project and process should be clearly scoped. Analysis of the causes of the problem or suggestions for solutions do not happen at this time

The Meaning of the DEFINE Phase

- Clearly defined goals provide the direction for the team
- A clearly scoped project and a well, defined process provide context and determine focus for team activities.
- As a result of these two points a common understanding is achieved which is of great importance when communicating externally.

Procedure in the DEFINE Phase

- Project goals are set and defined in a SMART way
- Project and process is clearly scoped
- A comprehensive project management approach (including change and risk management) is established
- Customer and business requirements (CTCs/CTBs) are identified and linked with the project goal

Road Map DEFINE Phase

D
M
A
I
C

D.1 Set Project Goals

What will the project deliver?

D.2 Scope the Project

What is part of the project scope?
Which process is to be analyzed?

D.3 Ensure Project Success

Which work packages must be undertaken and how long will they take?
Who are the stakeholders we should take into consideration?
What are the risks to the project and how are they to be managed or mitigated?

D.4 Specify Customer Requirements

What requirements does the customer expect of the process?
What requirements does the business expect of the process?

D Gate Review/Phase Closure

Tool Overview DEFINE Phase

D.1 Set Project Goals

Project Charter	Benefit Calculation

D.2 Scope the Project

Project Frame	Multi Generation Plan (MGP)	SIPOC	Dependency Assessment

D.3 Ensure Project Success

Project Management	Project Structure Plan	Network Plan	Time Plan	Resource Planning	RACI Chart
Budget Planning	Risk Management	Stakeholder Management	Kick-off Meeting	Project Com-munication	

D.4 Specify Customer Requirements

Customer Needs Table	Kano Model	Tool 1 CTC/CTB Matrix

D Gate Review

Project Charter

Term
Project Charter, Team Charter, Project Contract

When
Before the start of the project
Revisited the at any stage during the project

Goal
- Define project clearly
- Map the initial situation, the problem and project goals in a concise and clear way
- Focus on the (sub) process to be improved
- Name the most important people involved in the project
- Formalize the sponsor contract for the improvement team

Procedure
- A draft of the Project Charter is to be drawn up by the sponsor/client in cooperation with the project leader (Black or Green Belt)
- Clarify contents of the Project Charter with people directly and indirectly involved at soon as you can

Initial Situation
The business environment and the background of the problem should be described. The context and the importance of the project must be emphasized. Explain why the project must be carried out now and indicate the consequences if the project is not carried out now

Problem and goal
Describe the problem and goal in clear, precise, and measurable terms. The **SMART** rules apply:

- **S**PECIFIC: In which product, service or process does the problem occur? What defect or breach of customer requirements is occurring?

- **M**EASURABLE: Formulate the problem statement in such a way that at least one operational measurement is used; estimates can be used at this time

- **A**GREED TO: Same understanding of problems and goals among Sponsor and team

- **R**EALISTIC: The project goal can be achieved within the defined time period

- **T**IME BOUND: The time period during which the problem has occurred and/or was measured and date for target achievement

The problem description is a formal description of the AS IS situation and should contain no causes or apportionment of blame. The goal statement should describe the desired final outcome and should not contain solutions.

Project Scope
Focus on, and map the major elements that are IN and OUT of the activity frame. Map the underlying process and its exact start and stop points. In the event of a longer or phased project, goals should be described using a Multi Generation Plan (MGP) in order to break them into smaller, more manageable steps.

Project Benefit
Articulate the financial benefit of the project and if applicable further non-quantifiable benefits (cf. "Benefit Calculation").

Roles
Name the involved persons and estimate the resource needed. Among the most important roles are the Project Sponsor, the Project Leader (Black Belt/Green Belt), team members, the Process Owner as well as the Master Black Belt if required.

Milestone
Set dates for the beginning and end of the project. This should be broken down into separate time plans detailing the most important activities.

Tip

- Convey the "level of pain" being experienced during the initialization of the Project Charter in order to reinforce to all readers the necessity of conducting the project; the Project Charter is the calling card of the project
- Follow the SMART rule and focus on the essentials when formulating the contents; many projects fail because problem and goal statements are not specific enough
- Explain the necessity of SMART formulation to the Sponsor especially if problems and goals cannot be formulated in a measurable way immediately; support the idea of creating a common understanding of the problem
- Small teams (three to five members) make it easier to get resources and facilitate cooperation; decisions are faster and it is easier to make joint appointments; you can involve process experts on an ad hoc basis if, and when required
- When forming the team consider whether the project leader can delegate important tasks immediately and without having to consult others
- Discuss the essential points of the Project Charter with the team members before the Kick-off Meeting in order not to lose too much time during the meeting itself
- Use the standard template for the Project Charter of your organization even if it deviates partly from the suggested version
- The Project Charter is a living document. Amend it with any new insights as they arise and update it on the completion of each phase

See example on the following page.

Example: Car Dealer

Avoidance of customer defection

Initial Situation/Project Background
The company is a car dealer selling many different brands and providing repair services. 80 employees work at the headquarters, in addition to that, 20 employees work at each of the company's two branches. Turnover in the repair services/spray-painting departments has decreased during the last two years with turnover slumping €384,000. Moreover, the number of customer complaints about the quality of the spray-painting has increased. The costs in this area are no longer in line with the market.

Problem:
During the period from January to December 2010, 30% of the 480 spray-painting orders had to be redone owing to customer complaints. This rework caused additional costs of €57,600. Four employees completed the 480 spray painting orders.

Goal:
Reduce rework to a maximum of 5% of jobs by the end of 2011. Increase of output of the four employees to at least 700 orders per year by the end of 2011.

Project Scope/Project Focus

In: Acceptance of order, final control of vehicle, preparation of spray-painting

Out: Expenses for personnel, warranty work, recalls by manufacturer

MGP

Generation I: Headquarters

Generation II: Branch I and II

Monetary Benefit
€148,000

Additional Benefit
Increase of customer satisfaction, reduction in customer defection

Dependencies
None

Project Status/ Milestones		Beginning DD.MM.YY	End DD.MM.YY	Status ✓
1	Kick-off / Project Contract signed	2/25/2011	2/25/2011	✓
2	Phase DEFINE	2/25/2011	3/5/2011	
3	Phase MEASURE	3/5/2011	4/15/2011	
4	Phase ANALYZE	4/15/2011	5/5/2011	
5	Phase IMPROVE	5/5/2011	9/1/2011	
6	Phase CONTROL	9/1/2011	9/1/2012	

Project team:

Name	Role	Business unit	Agreed time commitment for the project	Approved by Manager
Goldbach	Black Belt	Spray-painting	45 MD	Vetter
Vetter	Sponsor	Customer-Relationship-Management	1,5 MD	Vetter
Stolle	Team member	Paint shop	15 MD	Vetter
Rimac	Team member	Paint shop	10 MD	Goldbach
Calabrese	Team member	Paint shop	15 MD	Vetter

Benefit Calculation

Term
Benefit Case, monetary and/or non-monetary benefit, qualitative and quantitative benefit

When
When drawing up the Project Charter
To be updated on completion of each DMAIC phase

Goal
- Determine monetary benefit in coordination with the Sponsor and financial controllers
- Indicate non-monetary benefit to make the case for the project more persuasive

Procedure
- Map AS IS performance, described by the problem statement in the Project Charter
- Outline TARGET performance, described by the goal statement in the Project Charter
- Calculate the difference in performance between TARGET and AS IS
- Break the financial impact down by each change in accordance with the financial policies of the organization
- Adjust the project benefit in the course of the project on the basis of new and further insights; this should be done by the team and Sponsor

Tip
- Determine the project benefit with the help of current guidelines in your company
- Get approval from financial control for the calculated benefit. In this way, you create credibility and transparency for the project
- Define the non-monetary benefit as precisely as possible
- At the beginning information on expenses/investments will not be known, you will identify them at the latest during the IMPROVE phase with a Cost Benefit Analysis and then you can include them in the Project Charter

- In case the project goal is one of cost reduction the operation on the following page will be +, -; in case it is a turnover increase the operation will be -, +

Example of measurements for the three main drivers of monetary benefit

NET BENEFIT

Turnover increase	Reduction of operating costs	Reduction of capital expenditure
• Reduction in process lead time • Increase of quality	• Reduction of rework or scrap rate • Reduction of material or energy use • Reduction of process lead time	• Reduction of open-items • Reduction of risk costs

See example of a Monetary Evaluation on the following page.

Example of a Monetary Evaluation

+1) Situation before implementation (one year period)

\# of KPI units
x base units/KPI
x costs of base unit

e.g. rework:
1,500 parts x 2 hours
x €200/hour

-1) Situation after implementation (one year period)

\# of KPI units
x base units/KPI
x costs of base unit

e.g. rework:
200 parts x 2 hours
x €200/hour

- Operating costs divided by project implementation (one-year period)

e.g. rent for equipment: €6,000

- Required investments for the implementation (one-year depreciation)

e.g. annual depreciation of equipment: €3,000

- Direct project costs

e.g. project team: 300 hours x €60/hour

Net Benefit of project (one-year period)

Examples of non-monetary strategic values

- Technical developments and innovations in line with strategy
- Improvement of aspects with respect to environment, safety, health
- Improvement of customer and employee retention e.g. through improvement of consulting and support quality

Project Frame

Term
IN/OUT of Frame, Project Frame, Scoping

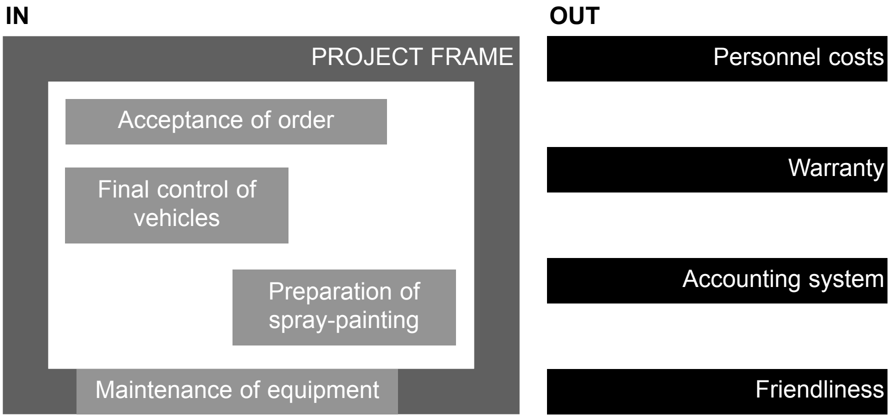
When
DEFINE, ideally during the first project meeting

Goal
- Scope content and alignment of project clearly
- Identify and define topics which are in scope and out of scope
- Create a common understanding of the project scope among all team members
- Set basis for clear communication

Procedure
- Visualize the Project Scope in the form of a picture frame
- Define topics together with the team, which are to be addressed within the frame of the project (IN)
- Scope topics which are to be expressly excluded from the project (OUT)
- Define open and/or topics to be discussed (on the frame)

Tip
- Create clarity about open topics (on the frame) with respect to IN/OUT up to the closure of the DEFINE phase
- Using this distinction you can identify the topics which remain to be clarified in the further course of the project
- Discuss the relevance of "OUT" aspects for potential follow-up project generations
- Use the Project Frame during the course of the project for continually securing project alignment

Example Project Frame



Multi Generation Plan

Term
MGP, Multi Generation Plan

When
DEFINE, ideally during the first project meeting

Goal
- Establish the milestones in order to reach a long-term project goal in smaller steps and/or identify follow-up project generations early on
- Guarantee a uniform understanding of the process to be improved

Procedure
- Assign the agreed focal points (IN/OUT Frame) to the first generation of the project
- Assign the topics excluded explicitly from this (OUT) to a potential second and/or third project generation and/or use this as a basis for a further specification of potential follow-up projects

Tip
- Use the Multi Generation Plan in order to cut the project into "smaller manageable slices" yet maintain sight of the long term project goals
- Make use of the Multi Generation Plan to identify potential follow-up projects early on in the course of the discussion with the Sponsor ("think forward"), e.g.
  Gen I: Machine A, product Z at site K
  Gen II: All machines for product Z at site K
  Gen III: All machines for product Z throughout Germany
- Use the Multi Generation Plan in the further course of the project for continually securing the project alignment

See example Multi Generation Plan on the following page.

Example Multi Generation Plan

GENERATION I — Carry out the first step	**GENERATION II — Improve the achieved position**	**GENERATION III — Take over the leadership position**
Generation I aims at cutting off urgent problems and at filling gaps	Generation II extends the result of Generation I	Generation III strives for a quantum leap with effective success
Machine A, product Z at site K	All machines for product Z at site K	All machines for product Z throughout Germany

SIPOC

Term
SIPOC (Supplier, Input, Process, Output, Customer)

When
DEFINE, ideally during the first project meeting

Goal
- Determine the start and stop signals of the process under scrutiny
- Determine the relevant process outputs and identify their recipients i.e. customers
- Guarantee a uniform understanding of the process to be improved

Procedure
- Articulate start and stop signals of the underlying process as an "event", i.e. passively and highlight them with the help of colors – this helps to avoid misunderstandings with respect to IN/OUT
- Map the process to be optimized in five to seven process steps using actions
- Describe individual process steps with one, brief, sentence consisting of nouns and verbs in the correct sequence
- Identify essential inputs of the process, relevant suppliers of the input and the most important process outputs
- Describe important customers i.e. recipients of the main outputs
- This element is the basis for the next tool – Tool 1/CTC Matrix

Tip
- Please use facilitation cards or Post-its® for drawing up the SIPOC – this allows for changes and enables a "clean" picture of the elements as you create it.
- Check that the output is consistent with the content of the Project Charter: Has the project been "cut" in the right place?
- Maintain the altitude (high level process) but take into account that a SIPOC is prepared to generate a common understanding
- Highlight the outputs relevant for the project with color

- Pay attention to the fact that the input and the supplier are not yet a focus for observation
- Check the result of the SIPOC by considering the defined In/Out Frame

Example: SIPOC

Supplier	Input	Process	Output	Customer
Customer	Vehicle	Vehicle accepted		
Customer ser-vice	Order	Prepare vehicle		
Spray-painting supplier	Paint	Carry out spray-painting		
		Complete vehicle	Order report and invoice	Accounting
		Vehicle handed over	Spray-painted vehicle	Customer

Start Stop

Dependency Assessment

Term
Dependency Assessment

When
DEFINE or before the project is instigated

Goal
Check other company projects (internal and external) to check their potential influence on the new project e.g. overlap or resource availability or repetition etc.

Procedure

Focus internal projects:
- Get an overview of projects with a similar focus and check the transferability of the results to the new project
- Get an overview of other projects carried out in the company at the same time in order to leverage their information in the new improvement project
- Check the influence of other projects with respect to any constraints they might create e.g. resources
- Define forms of documentation and communication in order to ensure an effective and efficient exchange of information among the employees of different projects

Focus external projects:
- Get an overview of projects at suppliers or customers in order to check their potential influence on the new project

Tip
- Also take into consideration current and concluded projects in other plants or branches
- Apart from the "formal" information sources such as your Program Office and Intranet you should also pay attention to "informal" sources

Project Management

Term
Program Management, Project Management

When
Throughout the course of the project

Goal
Control project activities actively in order to reach the project goal with the available resources without exceeding the budget or the time frames (OTOBOS = **o**n **T**ime, **o**n **B**udget, **o**n **S**pecification)

Procedure

1. Derive all necessary work packages and activities and find out linkages, connections and dependencies

2. Plan derived work packages/activities based on the likely duration of activity and the activity effort

3. Find out the budgets for the implementation of the individual work packages/activities and distribute the total budget

4. Form the project team, find out resource availability, assign resources and responsibilities

5. Set up project communication, identify risks, develop plans to mitigate and contingency plans to respond

6. Develop Change Management concept, derive communication strategy

Mapping Project Management Elements

Work Breakdown Structure

Term
Work Breakdown Structures, Project Structure Plan, Activity Plan, Action Plan

When
- DEFINE, after the project has been scoped
- IMPROVE, during piloting and final implementation

Goal
Breakdown of project into sub tasks that can be planned and controlled (work packages) and are required for the implementation of the DMAIC project or for the solution to be implemented in IMPROVE

Procedure

Compositional Procedure (Bottom-up)
- Collect work packages
- Analyze relationships with the help of the question "What is part of what?"
- Set up and put together project structure in the form of a hierarchy (cause-effect-chain)
- Add unmentioned but obviously required tasks and/or project components

Decomposition Procedure (Top-down)
- Determine the project and implementation phases and break down into main tasks
- Break down the main tasks into sub tasks
- Define tasks in smaller and smaller work packages, describing them in detail

Mapping Decomposition Procedure

DEFINE	MEASURE	ANALYZE	IMPROVE	CONTROL
Set project goals	…	…	…	…
- Define problem and goal - Find out Benefit - Draw up Project Charter	…	…	…	…
	…	…	…	…
	…	…	…	…
Scope the project	…	…	…	…
				…
…	…	…	…	…

Tip

- A robust and realistic time plan can only be created by breaking the work into small enough pieces
- Bear in mind that each work package must be assigned to only one responsible person
- Ensure that all technical, material and organizational prerequisites are available for completing the work package
- In order to check completeness you should ask yourself the question: "If I have carried out all these things, can I successfully complete the phase?"

Network Plan

Term
Program Evaluation and Review Technique, Critical Path Method, Network Plan

When
- DEFINE, in the course of project planning
- IMPROVE, in the course of the implementation planning

Goal
- Visualize logical relationships/dependencies between the activities and their sequence in the course of the project and in particular with the planning of more complex flows/projects
- Find out the critical path, i.e. the shortest period of time in which the project can be concluded
- Minimize project duration and make it controllable

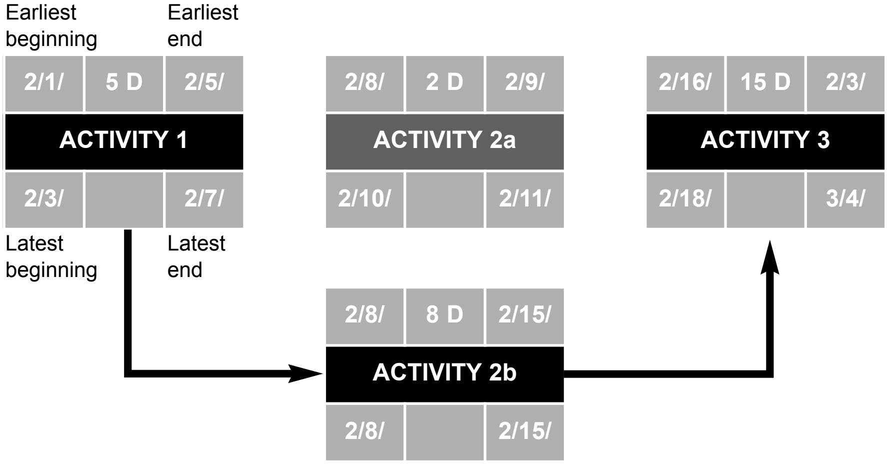
Procedure
1. Map work packages in a logical sequence; parallel steps are possible

2. Map the earliest beginning, the duration and the earliest end (Best Case Scenario) as well as the latest beginning and the latest end (Worst Case Scenario) of all work packages

3. Find out and mark the shortest period of time by adding all the best case durations

Tip
- Bear in mind and take into consideration that a difference can exist between the effort for carrying out an activity and its real duration until completion
- With respect to the level of detail you should always focus on which activities can be carried out at the same time when dependencies have an influence on the project duration
- Use different colors/shading to visualize finished and pending activities and also to recognize the critical path

Mapping Network Plan



Time Plan

Term
Gantt Chart, Time Plan

When
- DEFINE, in the course of planning the project
- IMPROVE, during implementation planning

Goal
- Define and visualize duration and effort for individual milestones/phases/ work packages
- Make sure that the project is led to success on time

Procedure
1. Include work packages from the Activities Plan and Network Plan

2. Set start and end dates for each activity

3. Additionally dates (start-end) and responsibilities for the implementation need to be fixed

4. If required, further information can be added such as implementation status, % complete, effort/benefit etc.

5. Continually update the Time Plan for the ongoing TARGET-AS IS comparison with respect to the implementation status, effort/benefit etc.

6. Resources need to be actively managed, adjusted and controlled in the event that the project deviates from the plan

Tip
- If you are unsure about the planning of your milestones get support e.g. from your coach
- Plan time buffers for activities in order to be able to compensate for unknowns or a big difference between planned duration and the actual effort required

- Use suitable software packages to track the current status of the activities and the timeline in order to be able to react quickly to deviations

Example Rough Time Plan

DMAIC phases		DEFINE	MEASURE	ANALYZE	IMPROVE	CONTROL
February	1					
	2	GR				
	3		GR			
	4					
March	1					
	2					
	3					
	4			GR		
April	1					
	2					
	3				GR	
	4					
May	1					
	2					
	3					
	4					
June	1					
	2					
	3					
	4					
July	1					
	2					
	3					
	4					
August	1					
	2					
	3					GR
	4					
September	1					
	2					
	3					
	4					
until September 1 of following year	1					
	2					
	3					
	4					
Work packages		• Provisional problem description • High level process mapping • Identified process and quality indicators • Project Plan mapped	• Data Collection Plan developed and implemented • Problem description finally defined • Improvement goals finally defined • Base Line found out	• Possible causes collected and verified • Main causes confirmed • Solution opportunities quantified	• Benchmarking of Best Practices • Counter Measures Matrix • Cost-Benefit Analysis presented • Action Plan drawn up for implementation • Main causes eliminated	• Continuous Monitoring System implemented • Improvement shown

Resource Planning

Term
Resource Planning

When
- DEFINE, in the course of planning the project
- IMPROVE, during implementation planning

Goal
- Find out the resources needed
- Identify necessary resources and ensure availability for the project

Procedure
1. Determine and/or check team composition and answer the following questions:
   - Which sub-processes are involved? Who are the people involved?
     – Use the SIPOC for this purpose
   - Which specialists and methodology experts are required for completing the project?
   - How much time is required for the team sessions and for work between the sessions?
   - Who are the team members from the Six Sigma organization (MBB, BB, GB)?
   - Are the right people in the team? Functional? Hierarchical?

2. Work out the effort need per team member from the activities and time planning and link with the requested resources. Ensure availability of resources and control actively

3. Set realistic time frames with the help of the following questions:
   - To what extent can the team members be released from everyday activities?
   - Apart from the core team, who else is needed and to what extent?
   - Who is the contact partner?
   - What, if any, external support is required?
   - When are vacation periods?

- Who is on vacation and when?
- Who is absent when (conferences, sales activities, etc.)?
- What is the running time for the DMAIC project (90 to 180 days)?

4. Define responsibilities (RACI Chart)

Tip
Use a RACI Chart in order to determine the roles and responsibilities of those touched by the project work.

RACI Chart

Term
RACI Chart

When
- DEFINE, in the course of project planning
- IMPROVE, during implementation planning

Goal
Determine roles and responsibilities in the course of the project work and create transparency

Procedure
1. Identification/listing of all activities as well as of involved roles/persons

2. Clarification and determination of RACI roles for each activity
   a. Responsible
   b. Accountable
   c. Consulted
   d. Informed

3. Clarification of responsible person per activity; only one Accountable per activity/task

4. Elimination of responsibility overlaps and identification of "responsibility gaps"

Tip
Draw up the RACI Chart during the Kick-off Meeting at the latest – this proven tool prevents communication problems arising during the course of the project.

Mapping of RACI Roles

RESPONSIBLE (R)	**"The Doer"** • Person(s) who complete(s) a task • Responsible for an action and/or for introducing an action • The responsibility is set by the accountable person • Projects can have multiple R's
ACCOUNTABLE (A)	**"Vouches for the others"** • Person bearing ultimate responsibility for completing a task and who can be held accountable • This person possesses a veto • Every task can only have one "A"
CONSULTED (C)	**"Consultant"** • The person(s) who is/are consulted before a final decision is made
INFORMED (I)	**"Information obligation"** • The person(s) who has/have to be informed about a decision or a proposed action

Example RACI CHART

Activity / Name	Employee training	First talks with customers	Identify potential measurements
Mr. X	R	I	I
Ms. Y	I	R	
Mr. Z	I		R
Management	C	I	I
…			
…			

Budget Planning

Term
Budget Planning

When
- DEFINE: in the course of scoping and planning the project
- IMPROVE: in the course of estimating costs related to implementing solutions

Goal
- Plan and derive the required project budget including labour, machine and equipment costs etc.
- Actively manage the project budget

Procedure
1. List of all budget and non-budget related cost categories

2. Write a statement regarding the skill sets (individuals) required and how much of their time and talent will be needed in order to successfully complete the project

3. List the estimated date(s) when any given cost will be incurred or appear on the books

4. Total the costs per category

5. Tracking real costs against planned or budgeted costs

Tip
- Take into consideration the project costs as it relates to your Six Sigma+Lean Organization
- Work together closely with your Sponsor during budget planning

Example Budget Planning Table

					Planned (TARGET)			
	Category	Details What? What for? Why?	DMAIC phase	Project activity	Cost period	Net amount €	Before tax €	Total amount €
Budget related (BR)	1. External services							
	2. Materials and tools							
	3. Travel expenses							
	4. Investments							
	5. Additional costs (e.g. rent, software licenses)							
Non-(BR)	6. Internal costs (according to ICR*)							
					Sum:			

* ICR Internal Cost Rate

Risk Management

Term
Risk Management

When
- DEFINE: anticipating risks at the beginning or the planning stage of the project
- Should continue for the duration of the project

Goal
- Identify potential risks that might affect the project's success
- Continually manage risks
- Identify actions and implement to mitigate risks

Procedure
1. Identify the risks

2. Evaluate and prioritize each risk with respect to it's impact and probability of occurring

3. Relative impact on the project success and occurrence are mapped in a matrix comprising of nine fields

4. Depending upon the field, a standard strategy is pursued when dealing with the risk

5. Take appropriate actions and/or add activities, if required, and put them into a timeline.

Tip
Bear in mind that "Soft Risks" exist, e.g. unexpected resistance, unidentified Stakeholders, conflicts within the team, poor or missing communication etc. as well as the "Hard Risks", e.g. external events, delay of preceding project tasks, personnel changes, by the Sponsor or by Management, unexpected resource constraints.

Risk Management Matrix

Occurrence probability	Impact on project success: Low	Medium	High
High	Clarify before project start	Significant risk	Show Stopper
Medium	Proceed with caution	Clarify before project start	Significant risk
Low	Proceed with caution	Proceed with caution	Clarify before project start

Stakeholder Management

Term
Stakeholder Management

When
Analyze potential instances of resistance with respect to the implementation of improvements before the project starts and throughout the entire project, in particular, during the DEFINE and IMPROVE phases

Goal
- Determine the attitude of leaders and of the team members, then take action and win them over
- Generate support for the project
- Identify resistance and overcome it

Procedure
1. Create a list of individuals for the Stakeholder Analysis with the help of the following questions:
   - Who is affected by this project? Which departments and interfaces are involved? Looking at individuals outside the project, who might be interested in its outcomes?
   - Who feels positive about this project?
   - Who will profit by the success of the project?
   - How can the Stakeholders contribute to the project success? Can certain relationships be used in a positive way?

2. Determine the attitude of each respective Stakeholder to the project

3. In case of resistance, determine the type of resistance (TPC analysis: technical, political or cultural) which may cause a negative attitude. Do this for each Stakeholder

4. Assess the actual or expected behavior for each individual; note the perceived viewpoint of each person (o) as well as of the target area (x); visualize the gaps; find links between the players: Who influences whom?

5. Create an effective system for communication and strategy to influence others

Tip

- Conduct Stakeholder Analysis with the Project Sponsor – he/she will support you in identifying and analyzing the relevant Stakeholders and in identifying the appropriate actions
- Document the Stakeholder Analysis for future use in the project; However, the Stakeholders' names and the analysis should be kept confidential – it could lead to misunderstandings and increased resistance
- Update the Stakeholder Analysis frequently during the course of the project: Always check the success of the planned actions and examine if "new" stakeholders are to be added
- Stakeholders can be identified not only within but also outside the organisation

Example Stakeholder Analysis Template

	Opinion towards project					Type of resistance		
Stakeholder	--	-	0	+	++	**Technical (I can't do that!)** Lack of abilities, lack of critical resources	**Political (I'm not allowed to do that!)** Concerns with regard to power or authority	**Cultural (I don't like that!)** Norms, mentality, habits, language

Example Influencing Strategy

Stakeholder	Topics/concerns	Levers	Influenced (by whom)
Mr. A	SAP introductiong	Resources	Sponsor
Ms. B	Works council	Company agreement	Sponsor
Mr. C	Training	Training	Sponsor

Mapping Communication Plan

Con-tent	Purpose	Recipient	Respon-sible Person	Media	Times	Status
Mess-age	Why is this mess-age to be sent to the recipient?	Who is to receive the mess-age? (RACI)	Who is respon-sible for the com-munica-tion? (RACI)	What media will be used?	When or how often is the communi-cation to be sent?	Was the message sent as planned?
				Examples: Email, Gate Review, posting, orally, newsletter, "Elevator Speech"		

Kick-off Meeting

Term
Kick-off Meeting, Start Workshop

When
At the beginning of the project work

Goal
- Active introduction of team members to the project
- State importance and significance of the project topic to the company
- Formalize the project's start
- Each team member knows his/her role and his/her tasks and can fulfill them

Procedure
1. Coordinate dates with the Sponsor
2. Develop the agenda with input from the Sponsor and the MBB
3. Invite participants (team members can include other invested stakeholders)
4. Prepare the room(s)
5. Conduct the meeting following the agenda
6. Take notes and publish them after the meeting

Tip
- Let the Sponsor present project, problem, goal, team etc. – he/she should create a "Sense of Urgency" and show his/her appreciation of the project team
- Make sure that suitably sized rooms and IT (technology) is available
- Send the agenda to the participants before the Kick-off
- Ask the team members to bring along their calendars in order to discuss follow-up dates and note absences (e.g. due to vacation)
- Bring with you all the necessary facilitation material

Example Kick-off Agenda

Name of Meeting	Kick-off DMAIC-Project						Facilitator	Black Belt
Participants of meeting							Minute taker	
Date of Meeting	DD.MM.YYYY	Beginning	10:00 AM	End	15:00 PM	Location	Room 1	

No.	Topic	Beginning	Duration	Expected result	Who
1	Welcoming	10:00 AM	15 min.	All participants are introduced to each other, expectations explored with respect to the Kick-off and goals are established	Black Belt
2	Introduction and project presentation	10:15 AM	15 min.	All participants know the background and the necessity of carrying out the project	Sponsor
3	Presentation of the Project Charter	10:30 AM	30 min.	Common understanding of all elements of Project Charter	Black Belt/ Sponsor
4	Six Sigma^{+Lean} introduction	11:00 AM	30 min.		Black Belt
5	Determine roles and rules; planning of meetings/vacations; organizational matters	11:30 AM	60 min.	Roles, tasks and responsibilities within the project are supported by all participants; basics for project planning and project work	Black Belt
6	Lunch with the group	12:30 AM	60 min.		
7	Development of SIPOC	13:30 AM	60 min.	Scoping of project and/or process with the group with uniform understanding	Black Belt
8	Determination of next steps (first steps to VOCs)	14:30 AM	30 min.	All participants know the next steps and their specific tasks	Black Belt
9	Closure and Feedback	15:00 AM	15 min.	Summary of results and feedback round	All

Project Communication

Term
Project communication

When
At the beginning of the project work and during the entire project

Goal
- Ensure regular and structured communication within and between the project team and individual sub-teams
- Continuous communication with the Sponsor about the project's progress
- Regularly inform employees working in the project domain and create transparency

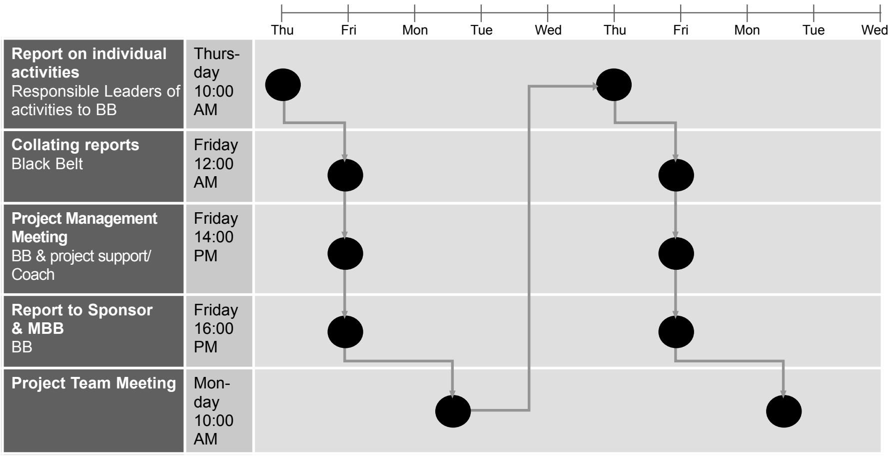
Procedure

1. **Internal:**
   a. Define necessary communication frequency for the project
   b. Plan the timing with the team members and the Sponsor during the Kick-off Meeting

2. **External to the project environment:**
   a. Set communication goal and determine recipients
   b. Set contents and media methods

Tip
- Use the Kick-off date in order to set the communication pace for the project team.
- Develop an Elevator Speech with your team. The so-called "Elevator Speech" will enable you and your team to describe the necessity and the goal of the project in a concise and clear way: Problem, benefit, current status including desired support

Example Project Communication Pace



Example Weekly Report for Sponsor

Lead	Last name, first name	Report no.	7	Date	1/22/2012	CW	08
		Time	● ● ●	Budget	● ● ●	Risk	low

Activities CW 08			Next steps CW 09	Necessary decisions
• xxx	planned	closed	• xxx	
	YES	YES		

Communication Map

Content	Purpose	Recipient	Person responsible	Meda	Times	Status
Mess-age	Why is this message to be sent to the recipi-ent?	Who is to receive the message? (RACI)	Who is respon-sible for the com-munication? (RACI)	Which media are to be used?	When is communi-cation to take place?	Was the message sent as agreed?
				Examples: Email, Gate Review, posting, orally, newsletter, "Elevator-Speech"		

Customer Needs Table

Term
Customer Needs Table

When
DEFINE, to ensure customer focus

Goal
Identify actual customer needs

Procedure

1. Collect genuine customer and business opinions ("Voice of Customer" – VoC, "Voice of Business" – VoB)
   - Customers have already been identified in the SIPOC
   - Collect customer views (usually by interviews or surveys, or during the Customer Interaction Study ["Gemba" study]) Value verbatim statements

2. Organize the collected statements (VoC and VoB) into complaints, solutions, specifications etc. Subgroup by theme if necessary e.g. timeliness, accuracy

3. Derive the "true" customer needs

4. Articulate each customer need. Remember that customer needs …
   - … are a statement of the benefit to the customer,
   - … don't contain solutions, and
   - … have a positive focus, i.e. "I would like …" instead of "I don't want any …" or "It must …"

Example Customer Needs Table

Voice of Customer/ Business	Complaint	Solution	Cause	Specification	Other	"True Need"
"I'm cold!"	X					I want a pleasant temperature
"Turn up the heating!"		X				
"Turn up the temperature to 72°!"				X		
"The window is draughty!"			X			
…						

Tip
Discuss the derived need with the customer and/or the Sponsor and let them confirm you correctly understood.

Kano Model

Term
Kano Model[1], Kano Analysis

When
DEFINE; ensure customer focus

Goal
- Classify customer needs into delighters, satisfiers and dissatisfiers
- Recognize needs that must be guaranteed/fulfilled, and recognize which needs can be guaranteed?

Procedure
1. Every need is tested by asking the customer a positively and a negatively phrased question:
   - "How would you feel if this need was not fulfilled?" (negative)
   - "How would you feel if this need was fulfilled?" (positive)

2. The customers can choose between four answers:
   - "I like that"
   - "That’s normal"
   - "I don't care"
   - "I don't like that"

3. Based on the answers to the negatively and positively phrased questions the need can be categorized with the help of a table.

4. Based on the customer responses the needs can be classified into:
   - **Basic needs** (Dissatisfier), i.e. features which are expected by the customer
   - **Performance factors** (Satisfier), i.e. features which enable the customer to measure/assess the quality of the system

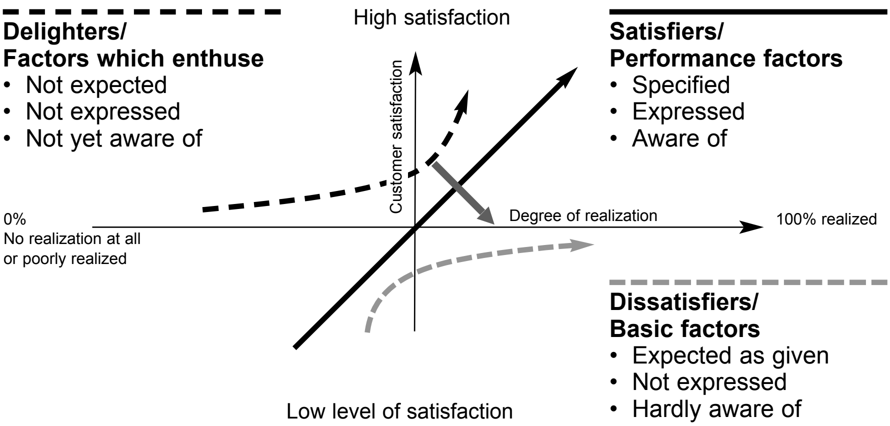
[1] This classification is based on the model by Professor Dr Noriaki Kano (Rika University, Tokyo), developed in 1978.

- **Buzz factors** (Delighter), i.e. features which exceed the customer's expectations

The following matrix helps with the assignation of the needs

		Answer to a negatively formulated question			
		I like that	Normal	I don't care	I don't like that
Answer to a positively formulated question	I like that		Delighter	Delighter	Satisfier
	Normal				Dis-satisfier
	I don't care				Dis-satisfier
	I don't like that				

Mapping Kano Model



Tip
If an item has been assigned to an empty cell then this hints at contradictory answers. Ask the questions again and, if necessary, discuss with the customer in order to resolve the contradiction. Rephrasing the original question may help.

Tool 1

Term
CTC/CTB Matrix, Tool 1

When
DEFINE, to ensure customer focus

Goal
- Specify critical to customer and business requirements which are connected with the stated problems
- Formulate clear and measureable customer requirements ("critical to customer" – CTCs) in the language of the process
- Translate business requirements ("critical to business" – CTBs) into the language of the process

Procedure
- Collect Voice of the Customer and of the Business
- Derive the needs from the Voice of the Customer and the Business (VoC and VoB) (Customer Needs Table)
- Understand the needs, evaluate them with the help of the Kano Model and prioritize them
- Create specific and measurable requirements (CTCs and CTBs)

Tool 1 Template

Voice of Customer/ Business	Complaint	Solution	Cause	Specification	Other	"True" need	CTC/CTB

Example

Voice of Customer/ Business	Complaint	Solution	Cause	Specification	Other	"True" need	CTC/CTB
"I can see that the car had an accident."					X	I want my car to look good.	Each paint application has to correspond to the original paint with respect to coloration, thickness and density: • Paint thickness LSL = 100 µm; USL = 180 µm • No formation of drips and runs • Color: No visible transition.
"The paint has drained away."	X						
"I'm here to pick up the car and it hasn't been completed yet."	X					I want good service.	Each order is completed by the agreed date. (*)
"The service could be friendlier."		X					The question on friendliness in the CSI questionnaire must have been answered with a score of at least eight. (*)
"I don't want to be called because of my invoice."				X			Each order is ready after the final check and the invoice can be issued immediately. (*)

(*) These CTBs should be dealt with in a follow-up project because they are beyond the scope of the Project Frame.

**CTCs
(Critical to Customer)
are critical, measurable customer requirements**

i.e., CTCs …
- describe the customer requirement, not the solution
- are measurable, precise and formulated positively
- are formulated for a unit of the product or service

**CTBs
(Critical to Business)
are critical, measurable business requirements**

i.e., CTBs …
- describe the business requirement, not the solution
- are measurable, precise and formulated positively
- usually correspond to the target/goal (of the project)

Tip
- In a DMAIC project you should focus on one to three CTCs and one or two CTBs at the most.
- Indicate which CTCs and CTBs will not be pursued in the existing project in order to avoid misunderstandings
- Projects that have too many CTCs/CTBs will struggle to be delivered in the expected time frame of 6 months. If a project is targeting improvements in quality, speed and inventory level, then it would be better split into smaller more manageable projects.
- Note also that you often have projects where some of the CTCs are already being correctly fulfilled. You may need to monitor these to ensure that improvement work on the under performing CTCs does not negatively impact them.
- Commencing a CTC/CTB with the words "Each" or "Every" helps focus on the unit level

Gate Review

Term
Gate Review, Tollgate Review, Phase Check, Phase Closure, Phase Transition

When
At the end of each DMAIC phase

Goal
- Inform the Sponsor and other key stakeholders about the results the team achieved in the phase
- Communicate the progress of the project to the Sponsor
- Guarantee the timely delivery of goals and the project closure by setting and tracking critical milestones
- Increase the acceptance of the project work within the entire organization by including key stakeholder groups throughout the project
- Acknowledge the work of the team
- Coordinate tasks and actions and, if necessary, adjust the Project Frame together with the sponsor and risk management experts. Identify any risks that need addressing
- Determine what support is required of the sponsor early on; decide whether the project is to continue (Go/No-go)

Procedure
- Conduct a phase closure with the MBB (this should ensure that all DMAIC criteria have been fulfilled)

- Confirm the Tollgate date with the Sponsor

- The following participants should be invited as soon as possible
  - **Required:** Project Leader (Black/Green Belt) and Sponsor
  - **Recommended:** Process Owner
  - **Optional:** Project team, Quality Leader, Master Black Belt, Management, Controller, internal customers, works council, further Stakeholders

- Prepare presentation
  - Starting point and/or results of the previous phase
  - Goal of the phase
  - (Short) overview of the activities under taken in this phase
  - Insights and results of phase
  - Next steps

- Conduct the meeting

- Discuss the Project Charter and make adjustments if necessary

- Coordinate next steps

- Go/No-Go decision: In case of a Go decision the next phase is introduced; in case of a No-Go decision, outline the required steps needed to continue with the project – if neither of the above the project should be cancelled

Tip

- Present the results as simply as possible: Think of your listeners and prepare the presentation with the target audience in mind
- Coordinate the dates for the phase closures with all involved
- Use phase checklists for the project leader (Black/Green Belt) and the Sponsor – you provide the facilitation for discussions
- Give your team members a platform where they present specific parts of the review; this leads to a stronger commitment by the project team and shows your appreciation towards colleagues
- Plan enough time for open and honest discussions
- Brief the Sponsor before the Meeting with respect to the current status of the Stakeholder Management – a Gate Review Meeting is a good opportunity for creating transparency and for exerting a positive influence
  Avoid being side tracked by minor technical questions

Gate Review DEFINE

- **Set Project Goals**
  - Has the starting point been described in a suitable way?
  - Has the problem been stated in a SMART way?
  - Have goals of the project been set in a SMART way?
  - What exactly is the benefit of the project? How great is the monetary benefit? Was Financial Control involved in the estimation of the cost benefit?

- **Scope the Project**
  - Has the project been scoped clearly? Which aspects are IN and which are OUT? Has an MGP (Multi Generation Plan) been drawn up?
  - Has the process to be improved been defined clearly? (high level/SIPOC)
  - Are other projects influenced by this project? If so which?

- **Ensure Project Success**
  - Has a detailed project plan been drawn up (activities and timeline)?
  - Who are the team members and why were they selected?
  - Have all necessary personnel been given time to work on the project, i.e. have they been released from other tasks so they can work on the project?
  - Was a budget calculated for the project? How much is it? What are the underlying assumptions?
  - Which tools were used to achieve acceptance of the project and to overcome resistance?
  - What are the potential risks?
  - Does everyone involved in the project know his/her role and responsibilities? Which tools were used in order to determine their roles and responsibilities?

- **Specify Customer Requirements**
  - How did we collect the Voice of the Customer and the Business?
  - How were the needs derived from the Voice of the Customer and Business? How have we ensured that they describe the true needs?
  - Are we sure we aren’t working on the improvement of "nice-to-have" features without fulfilling the basic requirements first?
  - Have the critical customer and business requirements been formulated in a measurable way?

SIX SIGMA^{+LEAN} TOOLSET

MEASURE

How Big is the Problem?

R. Meran et al., *Six Sigma^{+Lean} Toolset: Mindset for Successful Implementation of Improvement Projects*, Management for Professionals, DOI 10.1007/978-3-642-35882-1_3,

Summary MEASURE Phase

D M A I C

Objective and Scope of Phase

- The MEASURE phase answers the question: "How big is the problem?" i.e. how well are the CTCs and CTBs being fulfilled by the current process?
- For this only the output of the identified process is observed; the process itself and the associated inputs are dealt with in the ANALYZE phase

The Meaning of Measurability

- With observations in the form of measurements a problem can be formulated and developed with statistical methods
- These methods make changes and relationships in the output measurements apparent
- The ability to measure things is therefore an essential pre-requisite for statistically based process optimization

One can only improve something if it can be measured!

Procedure in the MEASURE Phase

- The characteristics of the output are described by collecting corresponding measurements
- The identified customer and business requirements (CTCs/CTBs) are used to select the relevant output measurements
- The data collection in the MEASURE phase is restricted to these output measurements; input and process measurements can be collected in the ANALYZE phase
- Of central importance is the four step procedure which ensures a high quality of data collection
- Using the collected output measurements, results can be re-presented graphically and the stability and capability of the process can be evaluated

Road Map MEASURE Phase

D
M
A
I
C

Result DEFINE

Problem and goals have been clearly defined ; process has been precisely scoped, project management has been set up, relevant customer and business requirements (CTCs and CTBs) have been identified

DEFINE

MEASURE

M.1 Derive Measurements

Which measurements are relevant? measured

M.2 Collect Data

What is to be measured, how is it to be measured and by whom, when and where?

M.3 Understand the Process

How does the process run in reality?

M.4 Calculate Process

How well does the process fulfill the requirements of customers and of the business?

M Gate Review/Phase Closure

Tool Overview MEASURE Phase

M.1 Derive Measurements

Tool 2 Output Measurement Matrix

M.2 Collect Data

Collect Data	Operational Definition	Data Source	Data Type	Collection Forms
Sampling Strategy	Measurement System Analysis (MSA)	Data Collection Plan		

M.3 Understand the Process

Understand Variation	Visual display	Location and Spread Parameters

M.4 Calculate Process

Process Performance	Process Key Figures	Data Transformation	Process Capability and Stability

M Gate Review

Tool 2

Term
Output Measurement Matrix, Tool 2

When
MEASURE, for selecting suitable output measurements

Goal
- Make sure that at least one good output measurement is found for each CTC/CTB which shows the degree of fulfillment of customer and/or business requirements
- Prioritize and select relevant output measurements (three to five)

Procedure
1. Transfer the customer and business requirements (CTCs and CTBs) from Tool 1, which was discussed in the DEFINE phase, verbatim to the rows of Tool 2

2. Write down the available output measurements (which are already being collected e.g. by an existing measurement system)

3. Evaluate the validity of these measurements inside the matrix based on how well they describe the degree of fulfillment of customer or business requirements. There are four categories for you to choose from:
   - Strong relationship between the metric and the degree of fulfillment (●)
   - Medium relationship between the metric and the degree of fulfillment (O)
   - Weak relationship between the metric and the degree of fulfillment (Δ)
   - No relationship between the metric and the degree of fulfillment (/)
   Figures can be used as an alternative although this is not a mathematical exercise: 9 (strong), 3 (medium), 1 (weak), 0 (no validity)

4. Select the best measurement for each CTC and CTB,

5. If a CTC or CTB doesn't have a metric graded as strong then a new measurement must be identified

Tip

- Use measurements which are already being collected in the table first; if they turn out to be strong then you will save time and effort
- Use specific questions when evaluating the validity: "How well does this measurement describe the degree of fulfillment of this CTC/CTB?"
- The fulfillment of each CTC/CTB should be measured at least by one output measurement with strong validity – pay attention to at least one "full moon" per table row
- Output measurements with weak or no validity are unsuitable when multiple strong metrics are available and the choice of which one of those to use will be based on effort and time required to collect
- Complement the Tool 2 with further, precisely described output measurements, if necessary
- The output measurement should be sensitive to changes in the level of fulfillment of the CTC/CTB, – thus only one "full moon" is necessary per column in the table

TOOL 1

Complaint	Solution	Specification	Cause	Other	"True" need	CTC/CTB
…	…			…	…	CTC_1
	…	…			…	CTC_2
…		…			…	CTB_1

TOOL 2

	Output measurements			
Customer and/or business requirements (CTCs/CTBs)	y_1	y_2	y_3	…
CTC_1				
CTC_2				
CTB_1				

Example

Customer and/or business requirements	Output measurements: Are there sags and/or runs (yes/no)	Coloration: visible differences (yes/no)	Paint thickness (micrometers)	Paint durability (months)	Gross turnover of department (€)	Proportion of rework (in %)	Deviation between current and target date for handover (h)
Each paint application has to match the original paint with respect to coloration, thickness and density:							
• Paint thickness: LSL=100µ; USL=180µ	0	1	9	3	0	1	0
• No sags or runs	9	0	0	0	0	1	0
• Coloration: No visible transitions	0	9	0	0	0	1	0

The proportion of rework indicates the degree of fulfillment of a CTC and a CTB at the same time; it is not as good as the first three measure as it is less specific; also it only has a strong relationship if all rework is correctly identified.

Collect Data

1

Clarify the Goals of Data Collection

1.1 Relevant Measurements: Clarify Goals. This will depend on which phase you are in

2

Develop Definitions and Procedures for the Execution

2.1 Operational Definition
2.2 Data Sources
2.3 Data Types
2.4 Data Collection Forms
2.5 Sampling methods & Sample Size
2.6 Measurement System Analysis

3

Begin Data Collection

3.1 Data Collection Plan

4

Improve Measurement Consistency

4.1 Monitoring

Operational Definition

Term
Operational Definition

When
When the selection of a measurement has been concluded. At any time a new measurement is identified e.g. ANALYZE

Goal
- An Operational Definition ensures each person carrying out a measurement has the same understanding of the measurement and of the measurement method, i.e. the measurement method is replicated exactly regardless of who does it, and when it is done
- By detailing exactly how measurements are to be taken eliminate ambiguities that otherwise would distort the measurement result

Procedure
- Write an Operational Definition for each measurement i.e. a precise description of what is to be measured and in what way?

WHAT	Measurement	A detailed description of the object to be measured and of the measurement (what exactly is measured?)
HOW	Measurement instrument	A detailed description of the measurement instrument (measurement device, visual inspection, units e.g. kgs etc.)
	Measurement method	A detailed description of the measurement procedure i.e. position of object and measurement device, lighting, if required operation of measurement device
	Criteria for decision	In cases of discrete measurement criteria for good or bad parts should be stated. Examples can be provided to help. Occasionally gauges can used in a discrete way

- Check if the Operational Definition provides a good common understanding with the help of Measurement System Analysis

Tip

- Use sample parts and/or sample cards or other visual aids to help
- Keep the Operational Definition as short as possible but as detailed as necessary – descriptions which are too detailed are often overlooked

Example: Proportion of Internal Rework

Description of measurement	The percentage of spray-painting hours for the rework, i.e. correction and improvement work after the undercoat, the base varnish or the varnish have dried Percentage = (spray-painting hours rework)/(spray-painting hours total)*100
Measurement instrument	Visual inspection
Measurement method	Parts are examined in full lighting in the drying cabin when the drying process is complete; for the examination of the paint coverage and the comparison between the old and the new paint use card XColor35, for the identification of the formation of sags, runs and scratches use color card defect sizes G38
Criteria for decision	Rework will be defined as all spray-painting orders which do not meet the quality criteria which were described by the paint shop i.e. paint thickness, formation of sags, runs, and paint match between old and new

Proportion of sags and runs

Description of measurement	The percentage proportion of parts displaying formation of sags and runs Proportion = (Number of parts with formation of sags and runs)/(Total number of parts)*100
Measurement instrument	Visual inspection
Measurement method	Parts are examined in full lighting in the drying cabin when the drying process is complete; for the examination of sags and runs use cf. comparison card defect sizes G38
Criteria for decision	Maximum size of sags and runs: F2 on comparison card for defect sizes G38; if any sag is bigger than this the part is to be reworked

Example paint thickness

Description of measurement	The paint thickness is recorded in µm
Measurement instrument	Paint thickness – measurement instrument DFT-Ferrous (PosiTest DFT)
Measurement method	The completed vehicle is examined after the varnish has dried; the device is put on the middle of the painted surface at an angle of 90 degrees and the paint thickness is read
Criteria for decision	Not applicable

Data Source

Term
Data Source

When
MEASURE, ANALYZE, IMPROVE, CONTROL, i.e. whenever data is to be collected

Goal
The Analysis of Data Source shows if measurements or data already exist or if effort must be expended to create, collect or calculate the desired measurement

Procedure
- Check the prioritized measurements for their data source
- If existing data sources exist then these are preferred and should be tested to see if the data quality is acceptable.

		Measurements	
		Existing	New
Sources	Existing	**PRIO 1a**	**PRIO 1b**
	New	**PRIO 2a**	**PRIO 2b**

Tip
If the effort for collecting defined measurement is enormous you should check to see if you can revert to existing sources by adapting the Operational Definition

Data Type

Term
Data Type – Continuous, Discrete

When
MEASURE, ANALYZE, IMPROVE, CONTROL, within the scope of each data collection, with each new piece of data analysis

Goal
- Determine the data type based on the measurement description.
- Depending on the data type the following will vary:
  – the amount of data for a meaningful statement
  – the Measurement System Analysis procedure
  – the choice of graphical display
  – the nature of statistical analysis

Procedure
1. Determine the data type for each measurement

2. Recognize the consequences of this type of data
   - The data collection, the graphical display of data and the data analysis differ depending on the different data types (e.g. the sample sizes are calculated differently, pie charts can only be used for discrete data etc.).
   - Continuous data is preferred to discrete (nominal or ordinal) data: Continuous data offers a better basis for information. It can provide information about the location (mean value) and the spread (standard deviation) of the measurement. Discrete data is not capable of doing this e.g. paint thickness, non-defective or defective (discrete) vs. exact paint thickness (continuous).

3. It may be necessary to rewrite the operational definition to obtain the required data type

	Metric		Nominal	
Discrete	Ordinal and/or scaled to rank e.g. age, grade, quality class	Cardinal e.g. number of children 3,4,5 …	Binary e.g. male/female, head/tail, nondefective/ defective	Nominal and/or categories e.g. colors, party, method, telephone num-ber
Continuous	Cardinal e.g. temperature, weight, length, time		Not possible	

Tip

- Prefer continuous data to discrete data: continuous data provides a richer source of information continuous data facilitates a wider choice of statistical testing but;
  Example paint thickness:
  - discrete: paint thickness OK/not OK (just information about the amount of parts in/out of specs)
  - continuous: paint thickness measured in micrometers (information about the location and spread of the whole process)
- In many cases discrete data is what is available and is sufficient for the needs of the project

Data Collection Forms

Term
Data Collection Forms

When
Within the scope of each data collection activity

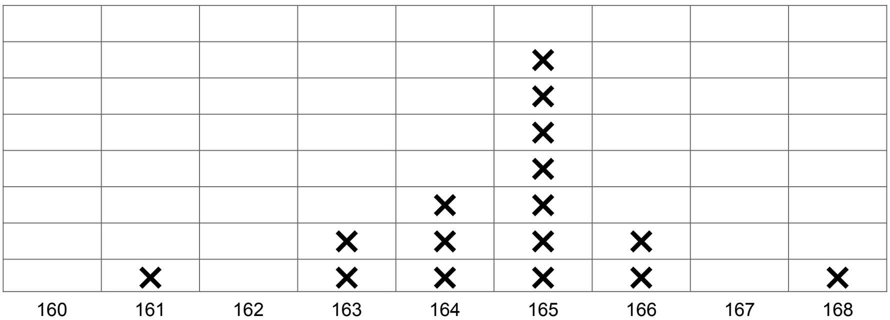
Goal
- Develop clear and easily comprehensible Data Collection Forms which facilitate smooth and accurate collection of data
- A common standard guarantees that different people collect the data in the same way and that the results are consistent
- Forms enable the traceability of data

Procedure
1. Development of a form that saves time, is simple and user friendly accord-ding to the Operational Definition

2. Provides tips and guidance for filling out the form

3. Test the form in practice and adjust it if required

Example



Order	TARGET	AS IS	Employees	Causes
10272930	Wed 3:00 p.m.	Wed 6:00 p.m.	BJ	Spray-painting dept. overloaded
10272931	Wed 6:00 p.m.	Wed 6:00 p.m	HP	
10272932	Thu 12:00 a.m.	Thu 03:00 p.m.	CG	Order cancelled
10272933	Thu 03:00 p.m.	Thu 05:00 p.m.	BJ, BS, RB	Employee ill
10272934	Thu 03:00 p.m.	Thu 07:00 p.m.	CG	Spray-painting dept. overloaded
10272935	Thu 06:00 p.m.	Fri 6:00 p.m	CG	Panel beating not sufficient

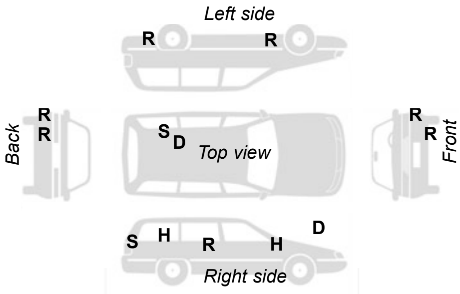
Example: Collection of defect frequency

Reason	Frequency	Comments
Formation of sags and runs in spray-painting, base varnish	~~IIII~~ ~~IIII~~ ~~IIII~~	
Incomplete paint coverage	~~IIII~~ IIII	
Erfasser: Hr. Meyer, Datum: 18.02.2010		

Example: Collection of damage location and type

Date: 1/18/2008	Time: 12:15 p.m.	Location: Paint shop
Name: A. Meyer	Forwarding agent: UPS	

Type of damage	Dent	Rust	Scratch	Hole
Sign	**D**	**R**	**S**	**H**



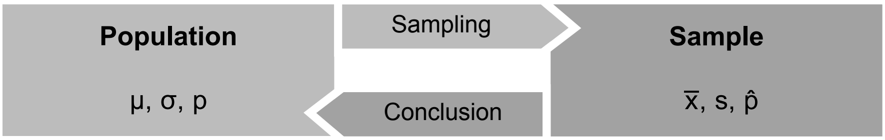
➪ **Tip**
Check each Data Collection Form before the data collection takes place in order to make sure that everyone has the same understanding with respect to what has to be collected and in what way

Sampling Strategy

Term
Sampling Strategy

When
Within the scope of each data collection

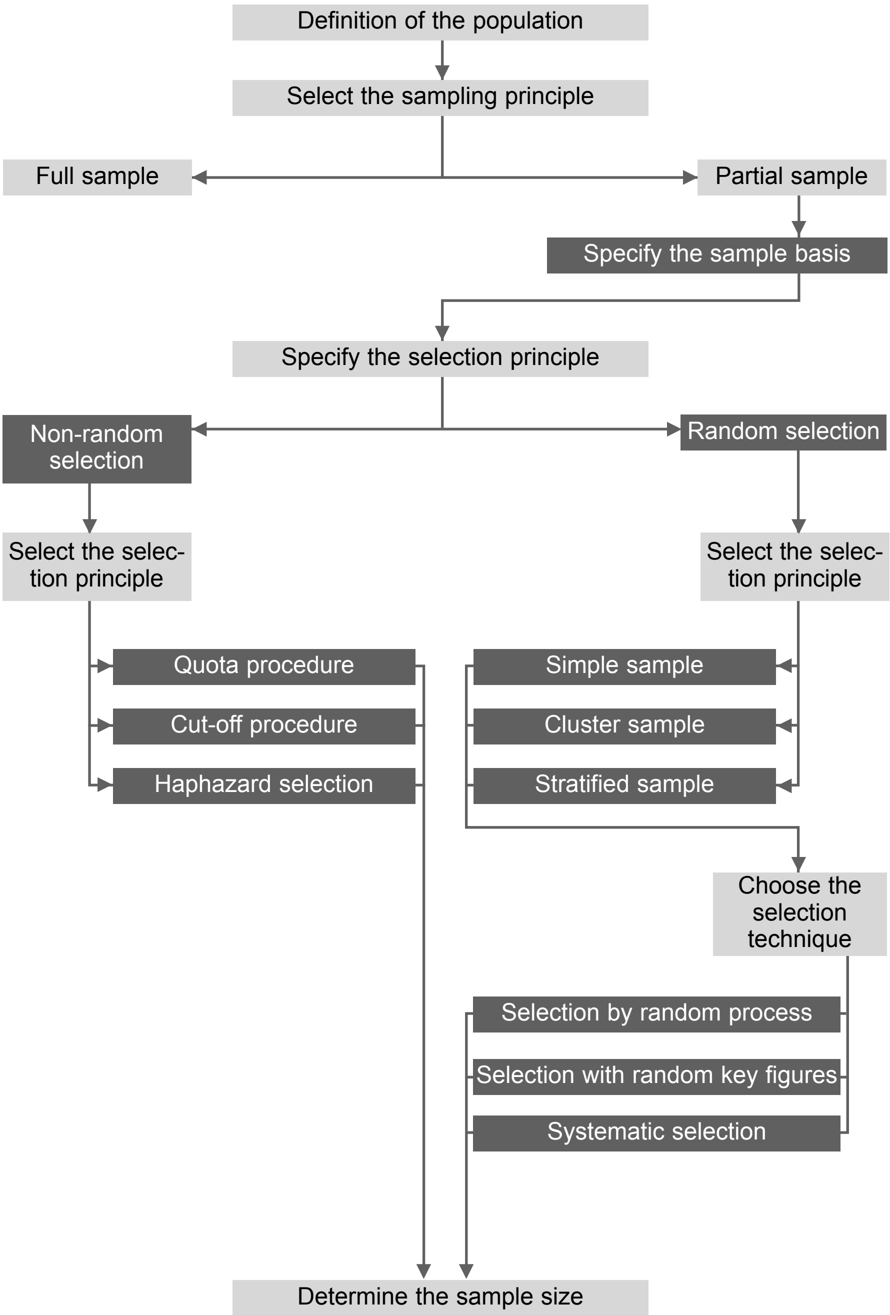
Goal
- Samples save time and effort when data is collected,
  - when it is impractical, impossible or too expensive to collect all data
  - when the data collection is a destructive process
- Derive a sampling strategy, which provides the most accurate level of information about the process being measured so meeting the goals of data collection but optimizing the effort and cost



Procedure
The sampling strategy comprises the methodology for selecting samples as well as planning the sample size. This basic procedure can be divided into four phases with a great number of individual working steps:

1. **The selection of samples should be entirely random**

2. **Choose a selection principle and a selection type**
   - different types of selection and selection principles will be driven by cost and effort criteria
   - they vary depending on the question being asked


Definition of the population
Select the sampling principle
Full sample
Partial sample
Specify the sample basis
Specify the selection principle
Non-random selection
Random selection
Select the selec-tion principle
Select the selec-tion principle
Quota procedure
Cut-off procedure
Haphazard selection
Simple sample
Cluster sample
Stratified sample
Choose the selection technique
Selection by random process
Selection with random key figures
Systematic selection
Determine the sample size

3. Determine a selection technique in case of random selection

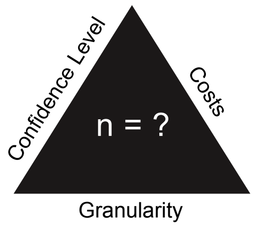
	Selection principle	
	Non-random Selection	Random Selection
Selection type	**Quota Procedure** Guideline of quotas e.g. accident repair, repair of rockfall ***Application:*** If only targeted information is needed	**Simple Sample** All units have the same chance of being drawn ***Advantage:*** No knowledge about population necessary ***Disadvantage:*** High effort
	Cut-off Procedure Only a part of the population is observed, e.g. accident damage ***Application:*** If only one aspect is to be examined	**Cluster Sample** The population is clustered in a logical way and one cluster is selected e.g. sites ***Advantage:*** Lower costs ***Disadvantage:*** Information can get lost
	Haphazard Selection Example: Only the information which can be obtained easily, is collected ***Application:*** If only a first impression is to be gained e.g. for estimation of proportion or standard deviation for more precise sample size calculation	**Stratified Sample** The population is stratified according to relevant criteria, e.g. spray-painting type, machine, location etc. Then a representative sample is removed from each stratum ***Advantage:*** Smaller sample ***Disadvantage:*** Information on the population must be available to start with

4. Determine the sample size

- The bigger the sample the greater the validity i.e. the quality of the statistical conclusion about the population
- One should therefore revert to available data (e.g. from IT systems): The data is treated like sample since the process to be improved hasn't yet been stopped
- When new data is collected (e.g. manual counting, surveys) an assessment of the cost of collection and desired level of confidence and precision must take place

All in all three factors play a role when the sample size is determined:

– the required **Confidence Level** which indicates the likelihood that the population mean lies within the given Confidence Interval. This value is normally a given for any organization e.g. 95%
– The **granularity** is an indication of how precise we want to be and is usually half the width of the Confidence Interval
– The **costs** and the duration of the data measurement increase with the sample size



- When the sample sizes are calculated it is important to consider whether the requested precision is worth the costs incurred

Rules of thumb for sample size

- Depending on the required information the minimum sample size can be indicated with the help of a rule of thumb
- It indicates the minimum sample size; additional data is often worth the additional costs

Discrete Data	100, at least 5 per category (e.g. OK/not OK)	**Continuous Data**	30

Example for determining the defect proportion

- In order to estimate the proportion of rework for paint repairs, at least 100 repairs have to be analyzed according to the rule of thumb
- If there are less than five repairs requiring rework or less than five non re-work repairs more repairs should be sampled until this criteria is fulfilled

Calculation via the Confidence Interval

- Samples sizes can be calculated knowing the Confidence Level, the required precision and the standard deviation or proportion of interest

Discrete Data	$n = \left\lceil \left(\frac{z}{\Delta}\right)^2 \cdot \hat{p} \cdot (1 - \hat{p}) \right\rceil$	**Continuous Data**	$n = \left\lceil \left(\frac{z\,s}{\Delta}\right)^2 \right\rceil$

- Δ is half the confidence interval width and $\pm\Delta$ expresses the confidence interval for which the range of values a statistical statement is valid (Granularity)
- z is a value relating to the normal distribution; a z value of 1.96 equates to a 95% Confidence Interval whilst a z value of 2.575 equates to 99% Confidence Interval. (Often 2 is used for ease of calculation)
- s is the estimated standard deviation from an initial sample
- $\hat{p}$ is the estimated probability that a part/unit of output is defective (also defect rate/defective rate); if the estimated probability is unknown 0.5 is assumed
- n is the calculated sample size; the symbol $\lceil\ \rceil$ means that the sample size n is rounded up to the next whole number
- The parameter s and $\hat{p}$ (p-hat) are found out by an initial sample

Example for determining the mean value (of a population)
- The drying time for the base varnish is to be tested
- An accuracy of ± 30 minutes is required
- The drying time has a standard deviation of 2 hours

$$n = \left\lceil \left(\frac{1.96 \cdot 2}{0.5}\right)^2 \right\rceil = \lceil 61.5 \rceil = 62$$

- The minimum sample size for this example is 62, i.e. the following statement about the mean value can be made from a sample of 62 spray-painting procedures: "We are 95% confident that the mean value of the population is ± 30 minutes around the mean value of the sample"

Example for determining the proportion (of a population)
- The correspondence between the new and original paint is to be tested. The defect rate amounts to approx. 25% ($\hat{p}$ = 0.25). It is to be estimated with an accuracy of 0.1% (Δ = 0.001)

$$n = \left\lceil \left(\frac{1.96}{0.001}\right)^2 \cdot 0.25 \cdot (1 - 0.25) \right\rceil = \lceil 3{,}841{,}600 \cdot 0.25 \cdot (1 - 0.25) \rceil = \lceil 720{,}300 \rceil = 720{,}300$$

- At least 720,300 samples are necessary to obtain the following statement on the proportion: "We are 95% confident that the proportion of the population is ±0.1% around the calculated proportion of the sample"

Tip

- In automated production the collection of a sample often appears to be unnecessary because an automatic measurement of the population takes place anyway; in this case you should check the quality of the system data in order to ensure that it is sufficiently accurate
- For DMAIC projects, however, the population is always the process to be improved; as soon as a process output is observed this is a sample because the process is ongoing
- Statistics programs enable the calculation of the sample size by taking into account the α- and the β-error; in the above rule of thumb $\beta = 0.5$ is assumed

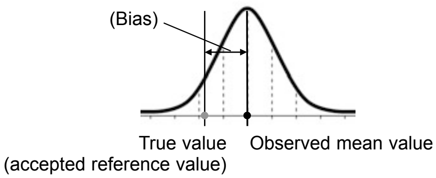
Measurement System Analysis (MSA)

Term
Measurement System Analysis, Gage R & R

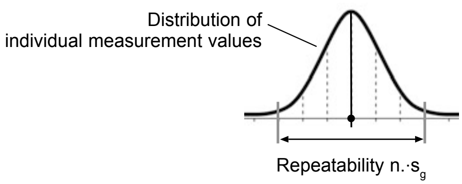
When
Within the scope of each data collection

Goal
- Recognize, understand and minimize variation sources which may influence the measurement result (man, material/measurement object, method, machine/measurement device/Mother Nature)
- Ensure high measurement quality i.e. a good measurement system must fulfill the following requirements:

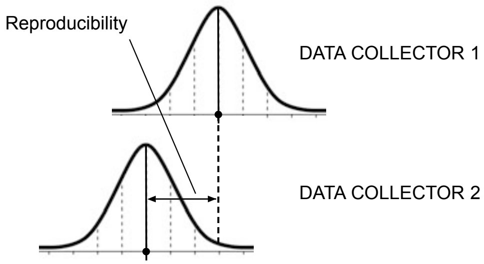
Accuracy describes the closeness of a measured value to an accepted reference value



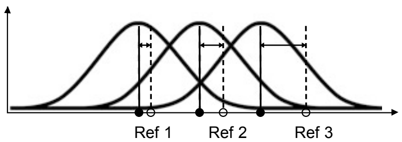
Repeatability/Precision): The Repeatability or Precision of a measurement system refers to how close individual measurement values are located to the true value (when individual values are collected and repeatable conditions exist)



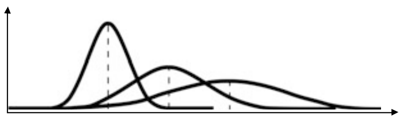
Reproducibility (also Traceability): refers to the influence of different evaluators on the measurement result (under otherwise identical conditions several evaluators measure the same part several times)



Linearity: The variation is sufficiently small and constant over the whole field of application in a good measurement system

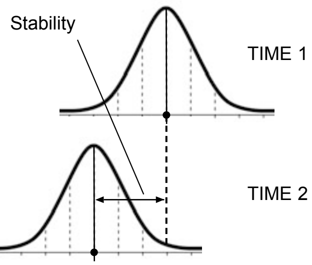


Systematic measurement deviation (Bias) is not constant

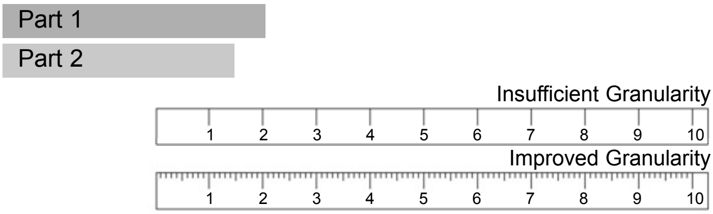


Repeatability/Precision – spread is not constant

Stability: A good measurement system produces stable measurement results over time, i.e. the variation over time is minimal

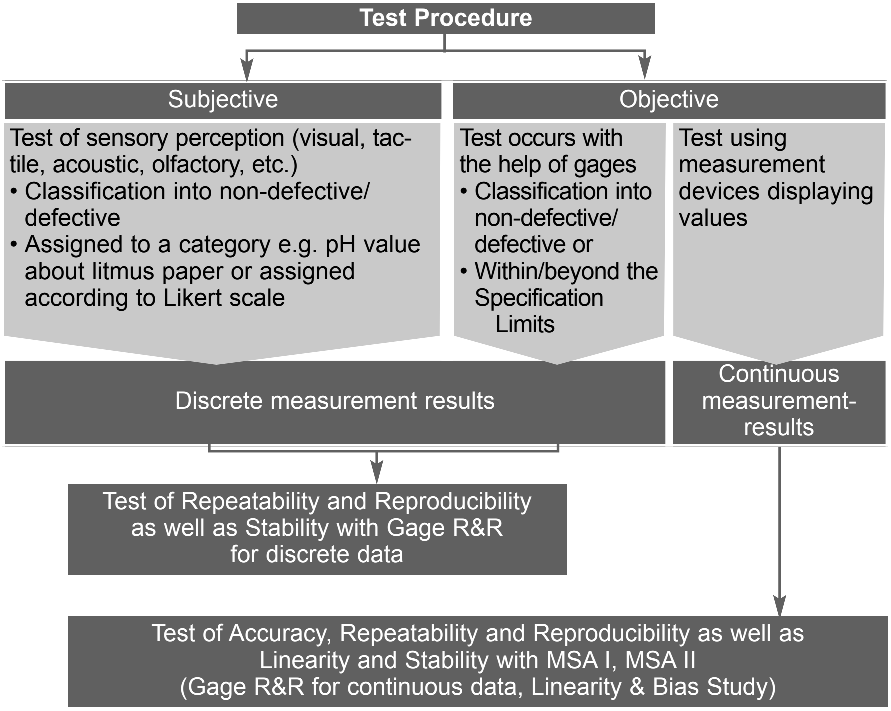


Granularity (also Resolution – Discrimination/Repeatability): The measurement system is capable of revealing differences in dimension between different parts



Procedure

1. **Preparation:**
   - Plan method by taking into consideration the test procedure (subjective/objective) and the type of the measurement result (continuous or discrete) as well as the parameters which are to be tested



  - MSA I: Test for Accuracy and Precision
  - MSA II: Test for Repeatability and Reproducibility, sufficient discrimination/granularity
  - Linearity and Bias Study: Test of Linearity and Accuracy
  - Stability test (over time)
- Number and type of test items (parts)
  - in case of discrete measurement results borderline pass/fail items should be chosen
  - in the case of continuous measurements the full range of the production spectrum should be tested
- Determine the number of data collectors and number of repetitions
- Prepare analysis, i.e. set Operational Definition, label parts, provide test lighting and other necessities etc.

2. Execution:
- Collect data making sure that as far as possible test results are blind to other operators and parts are randomized on subsequent measurements in order to reduce the chance an operator can remember the previous result.
- Record results in a correctly laid out spreadsheet/table

3. Analyse und Verbesserung:
- Analyze and interpret results
- Derive actions

Tip
- Remember to validate results with existing data (e.g. from SAP or other systems)
- In order to check the stability of the measurement system a time interval of twelve months usually makes sense; in case of subjective test procedures (discrete measurement results) shorter time intervals (three to six months) are frequently chosen
- Classically a resolution of a maximum of 5% of process tolerance is the prerequisite[2] – if e.g. when measuring the length of a part and the lower specification is 9.9 cm and the maximum specification is 10.1 cm the tolerance is 0.2 cm the measurement system must have a minimum resolution of 0.2*5%, i.e. ≤ 0.01

[2] According to Edgar DIETRICH, Alfred SCHULZE: "Prüfprozesseignung", Hanser Fachbuchverlag, 3rd Edition 2007

- An alternative rule of thumb for the resolution can be found in Breyfogle[3]: Thus the resolution is not to exceed 10% of the smaller value of either six times the estimated standard deviation of the process or of the tolerance
- The resolution can also be tested in a nested Measurement System Analysis in Minitab®; it is considered sufficient if a minimum value of 5 is achieved

[3] According to BREYFOGLE: "Integrated Enterprise Excellence, Vol. III – Improvement Project Execution", 2008

Gage R&R for Discrete (Binary) Data

Term
Gage R&R, Gage R&R for discrete (binary) data

When
During data collection, periodic reviews of the measurement system's stability/ accuracy when using discrete measurements

Goal
- Validate reliability of Operational Definition
- Ensure that the data collection is reproducible and repeatable

Procedure
- Determine the expert who sets the standard.
- Name the data collectors and make the parts/items to be examined available. Typically two operators but can be more, and typically 30 samples are required
- Select the parts to be tested, borderline pass/fail parts should be used to truly test the Operational Definition. Number them consecutively
- Set the standard with the help of the expert's visual inspection. Record results in the measurement form, e.g. OK and not OK
- Have the first operator inspect the parts and record results making sure that the other operator is not watching
- Have the second operator inspect the parts and record the results also
- Without losing the original part numbers randomize the parts so the order of the second inspection is different to the first
- Repeat the procedure without reference to the first round of results
- Check for matches. A match is where all results for one part are the same as the expert assessment. The goal of a good measurement system is 100% match
- A match of at least 90% can initially be regarded as acceptable
- Check the reasons for possible deviations
- If the result is below 90%:
  – Review the Operational Definition and redefine if necessary
  – Provide data collectors with more intensive coaching
  – Identify and eliminate noise factors in a targeted way

Tip

- Instead of consulting a single expert, it makes more sense in practice to call on a panel of experts (composed of customers of the process, e.g. final assembly, and the end user or at least an internal representative, e.g. quality management), which must evaluate the parts from the customer's perspective
- Check if the selected standards really correspond to the actual CTCs
- It is important to explain the goal of the Measurement System Analysis to the people involved in the process and to the project members: It is not that the data collectors are evaluated but the methodology!
  Bear in mind $R = (Q \times A)^M$!
- The lighting is especially important for visual inspections; make sure that it is consistent and can be controlled (e.g. by a light cabin)
- Objective test procedures with discrete measurement results can also be tested with the help Gage R&R (continuous characteristics e.g. drill or shaft diameter for fittings can also be evaluated by fixed gages e.g. plug gage or caliper gage, however, these two allow only for classification into good or bad within or beyond the tolerance)
- Ideally, it is better to have the whole test team involved in the Gage R&R and not just two data collectors (note though that the more people do the inspection the harder it will be to get high degree of match
- Afterwards ensure that results are made available, the expert’s view is disclosed, level of match is interpreted with data and graphical display and that statistical analysis is complete. List improvement actions considered necessary

Example Car Dealer on the following page.

Example Car Dealer

The parts 1, 2 and 29 are evaluated equally by the evaluators and the experts

Within the Evaluators
Repeatability is violated in part 3, data collector 1 evaluates this part differently in the first and second rounds. This could hint at an unspecific Operational Definition. If Repeatability is violated, Reproducibility is not possible either!

No.	Standard/ experts	Engers		Goldbach		Reproducibility (Y/N)
		Test I	Test II	Test I	Test II	
1	OK	OK	OK	OK	OK	Y
2	not OK	not OK	not OK	not OK	not OK	Y
3	OK	not OK	OK	OK	OK	N
4	not OK	OK	OK	OK	OK	Y
…	…	…	…	…	…	…
29	not OK	not OK	not OK	not OK	not OK	Y
30	OK	OK	OK	not OK	not OK	N
% correspondence with standard		86.67%		86.67%		
% Repeatability		96.67%		90.00%		
% Reproducibility						73.33%

Between the evaluators
With part 30 Reproducibility was violated, data collector 1 evaluates this part two times as OK, data collector 2, however, two times as not OK

Comparison with standard
With part 4 the evaluators arrive at the same result, however, it deviates from the expert standard. The evaluators Engers and Goldbach need training or the Operational Definition is flawed

Total result
Both evaluators have a correspondence with the expert for 26 out of 30 parts (=86.67%). Evaluator Engers can repeat his measurement result for 29 out of 30 parts (=96.67%), evaluator Goldbach only for 27 out of 30. For 22 out of 30 parts (=73.33%) the evaluators can reproduce the results

Measurement System Analysis Type I

Term

Measurement System Type I, MSA Type I

When

Within the scope of data collection for the one-time or periodic review of a measurement system which produces continuous data as measurements.

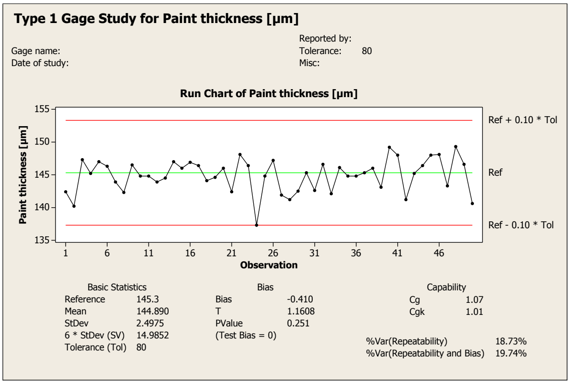
Goal

- Check accuracy and precision of the measurement system
- Gain insights about the capability and resolution of the measurement system

Procedure

One and the same reference part with a known characteristic (reference value) is measured under identical conditions (same measurement setup at the same location, identical conditions of environment, same evaluator) 30 to 50 times

Example



Control Limits are set based on reference value +/- 0.1* tolerance. Any point breaching the Control Limits hints at an unstable measurement procedure despite all measurement values being collected by one evaluator under the same conditions

Measurement System Analysis Type II

Term
Measurement System Type II, MSA Type II, Gage R&R

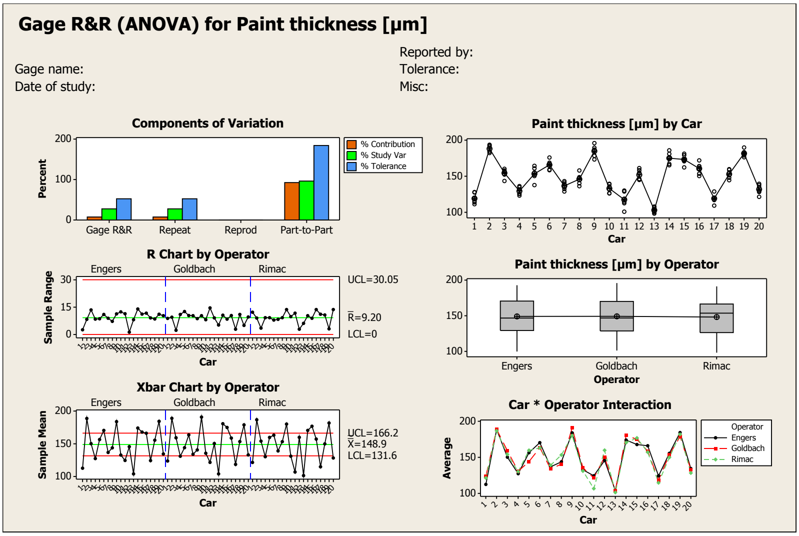
When
Within the scope of data collection for the one-time or periodic review of a measurement system which produces **continuous** data as measurements

Goal
- Check the Repeatability and Reproducibility of the measurement system
- Check the resolution of the measurement system

Procedure
- When a Gage R&R for continuous characteristics is carried out the rule is that the number of objects to be tested x number evaluators x number repeated measurements should be bigger than 30
- Classical approach: At least 10 test items (which should reflect the entire range of values in the production spectrum (this can also be parts beyond the Specification Limits) are tested by at least 2 evaluators on at least 2 occasions
- Interpretation of results:

	Standard Deviation		Variance
	% Study variation	% P/T-Ratio	% Contribution
	$\frac{S_{Gage}}{S_{Total}} \cdot 100\%$	$\frac{6 \cdot S_{Gage}}{Tolerance} \cdot 100\%$	$\frac{S^2_{Gage}}{S^2_{Total}} \cdot 100\%$
Measurement system is suitable	< 10%	< 30%	< 1%
Measurement system has – depending on measurement task and costs – limited suitability	< 30%	< 30%	< 9%
Measurement system is not acceptable	≥ 30%	≥ 30%	≥ 9%

Example



The Bar Chart shows the distribution of the observed spread. The goal is that the spread caused by the measurement system is significantly smaller than the spread between the parts. Analytical results complete the picture.. In the above example the measurement system's spread exceeds the permitted limit. The measurement system is not suitable or acceptable.

Tip

- The table lists the most common limit values for the capability of measurement systems; a "hard limit" exists (2nd/3rd column) with ≥ 30%; some authors (Dietrich/Schulze) recommend only this limit should be considered, although the limit value of ≥ 30% should apply for existing measurement systems and for new measurement systems ≥ 20%
- It is a good idea to agree limits of suitability in advance as the selection of test items can influence the outcome. % spread results and % tolerance results can be different. It happens that the measurement system can look suitable up until adding a tolerance value only then to find that it becomes unsuitable

Linearity Study and Systematic Measurement Deviations

Term
Linearity and Bias Study, Gage Linearity and Bias Study, Analysis of Linearity, Linearity Study

When
Within the scope of data collection for the one-time or periodic review of the measurement system which produces continuous data as measurements.

Goal
- Test systematic measurement deviation (Bias) of the measurement system i.e. on average how different from the true value is the actual value
- Test the linearity of the measurement system i.e. do we get equal accuracy for small and large dimension parts

Procedure
- The procedure is similar to Measurement System Analysis Type 1. Typically five test items are measured at least ten times each, these parts should cover the range of values expected in the process and certainly cover the tolerance range
- Once data is collected a Linearity Study is carried out to assess systematic measurement variation (Bias) A regression line is also calculated and tested statistically to determine how much systematic variation there is (slope) through the range of measurement system values (linearity)

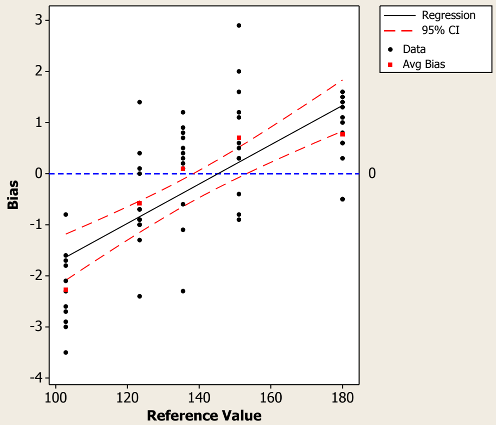
Results from both these tests will help us determine our measurement system acceptabiliy

Example

Gage Linearity and Bias Study for Paint thickness [µm]

Gage name:
Date of study:

Reported by:
Tolerance:
Misc:



Gage Linearity

Predictor	Coef	SE Coef	P
Constant	-5.5886	0.7188	0.000
Slope	0.038457	0.005098	0.000

S 1.02869 R-Sq 49.5%

Gage Bias

Reference	Bias	P
Average	-0.26000	0.044
102.8	-2.27500	0.000
123.4	-0.58333	0.109
135.5	0.09167	0.768
151.1	0.70000	0.061
180	0.76667	0.002

Here we see that 5 parts were tested 10 times each. Every result has been plotted and the means added (including the overall mean).
On average the bias is low (as it is < 0) but this is deceptive as we can see a strong slope with low value parts having a negative bias and higher value parts with a positive bias.
Statistical output confirms that this measurement system is not suitable or acceptable.

Test the Quality of Available Data

Term
Test the suitability of system data, Test the Quality of Available Data

When
Should be considered each time we undertake new data collection from existing systems and data banks

Goal
- Test the quality of data for MEASURE, ANALYZE, IMPROVE, CONTROL
- Make sure that any conclusions drawn from the collected data are valid and can be relied upon

Procedure
There are two methods to assess how reliable the data held in a system is:

- **Plausibility checks**
  – For time data: If the difference of end date/time minus start date/time is negative or implausible, this an indication that the data quality could be unreliable and further testing should be carried out
  – Production amounts: Commercial data and similar things can be compared e.g. last year v this year, one plant v another plant etc. Anything that looks unusual or unlikely might be an indication of unreliability
  – Random checks of the system data v the original paper records it was created from can be useful
  – Inventory reports can be validated (or not) from inventory audits with any anomalies being investigated to check whether a system issue or not

- **Evaluation of failure modes (based on FMEA, see ANALYZE Phase)**
  – For the evaluation of the quality of system data it is recommendable to consider the failure opportunities and their frequency when collecting, processing and providing data. This procedure corresponds basically to that of the FMEA (see ANALYZE Phase).
  – In the expert team possible failures are to be identified and described for the individual steps; the occurrence frequency is ideally determined with a sufficient sample size

– The reliability of the data in focus should be assessed through the entire process
– Experience has shown us that the following areas are often sources of failure:
  - System interfaces
  - Change of medium
  - Manual collection and subsequent entering of data
  - Multiple entry possibilities either by many operators or spread over longer periods of time
  - Poorly specified and/or apparently unimportant data fields (e.g. packaging sizes in product master data)

Tip
Always test data quality. Do not rely on the fact that just because data comes from a computer system that it is good data. This error can have severe consequences since bad data frequently leads to wrong conclusions

Data Collection Plan

Term
Data Collection Plan

When
Should be prepared each time we undertake data collection

Goal
- Bring together and summarize the work we have done so far in selecting, defining and quantifying the data to be collected
- Provide a structure for allocating tasks, time frames and responsibilities when carrying out the data collection activity. Describe how the data will be displayed once it has been collected

Procedure
1. Select measurements and draw up Operational Definition
2. Determine data sources and data type
3. Determine sampling strategy
4. Develop Data Collection Forms
5. Conduct Measurement System Analysis
6. Determine location/source, date, time and frequency for the data collection
7. Collect all relevant information in the Data Collection Plan
8. Conduct data collection

Example

WHAT				HOW	WHO	WHEN	WHERE
Measurement	Type of measurement (output/process/input)	Data type (continuous/discrete)	Operational Definition of measurement	Operational Definition of measurement method	Person responsible	Date, time and frequency	Data source; location of measurement
Proportion formation of sags and runs	Output	Discrete	The percentage proportion of parts displaying formation of sags and runs. Proportion = (number of parts with formation of sags and runs)/(total number of parts)	Visual inspection: parts are examined in full lighting in the drying cabin after the drying process has been completed. For the examination of formation of sags and runs comparison card G38	Spray-painter	Every part between January 27, 2010 and February 14, 2010	In the paint shop/ on the vehicle

Tip

- Inform the employees and managers and explain the goals of the project
- Train the data collectors and test the collection forms. Check frequently that data collection is being done and collected data is as expected e.g. at the beginning be there every hour. Once comfortable that data is being collected correctly then frequency of checks can be relaxed
- Carry out a pilot for data collection

Understanding Variation

Term
Understanding Variation

When
MEASURE, ANALYZE und CONTROL, always after data collection

Goal
- Quantify the level of variation in the AS IS process
- Visually display collected output data to highlight spread and location against specifications etc.
- Determine process stability – is there special cause variation present or is it just common cause

Procedure
1. Map data graphically

2 Analyze statistical key figures

3. Interpret variation

A great number of tools are available for testing and displaying variation:

	Variation at a specific point in time	Variation over time
Discrete data	• Pareto Chart • Bar Chart • Pie Chart	• Run Chart • Control Charts, e.g. - p-Chart - np-Chart - c-Chart - u-Chart
Continuous data	• Histogram • Frequency Chart • Dot Plot	• Run Chart • Control Charts, e.g. - IMR-Chart - Xbar-R Chart - Xbar-S Chart

Pie Chart

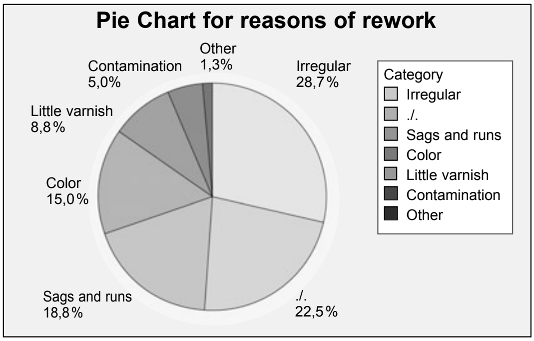
Term
Pie Chart

When
MEASURE, ANALYZE and CONTROL, always after data collection

Goal
Pie Charts display the results of discrete data at a specific point in time and show relative proportions

Procedure
Depict the frequencies of a discrete characteristic in a "pie"-shaped chart. This can be based on percentages, proportions or counts. The pie chart should include 100% of the data

Example



The size of the ‘pie pieces’ represents the proportional share of the totality. Pie Charts show the relationship between amounts by dividing the whole ‘pie’ (100%) into pieces or smaller percentages

Tip
Begin with the largest percentage segment at "12 a.m." and proceed in a clockwise direction. In order to avoid misunderstandings you should always indicate the size of the sample. If displaying defects and non-defects it is a good idea to show good product in green and poor product in red

Bar Chart

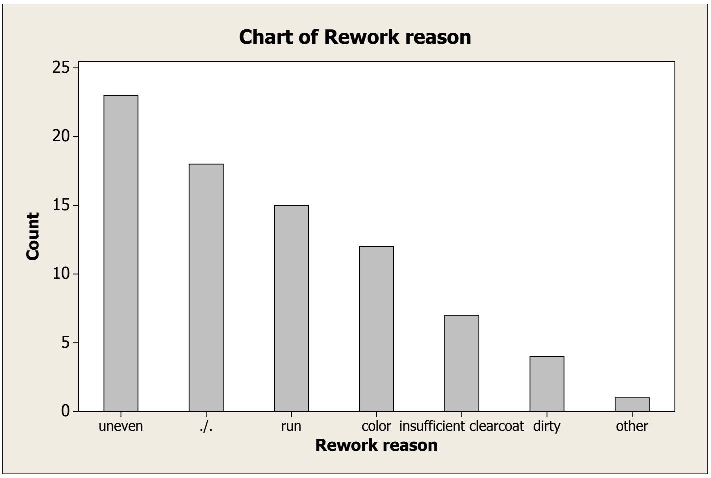
Term
Bar Chart

When
MEASURE, ANALYZE and CONTROL, always after data collection

Goal
Bar Charts are graphic comparisons of different categories (discrete data) at a specific point in time

Procedure
Map the frequency of occurrence of a discrete feature on a bar. The length of the horizontal or vertical bars (relative or absolute) represents the size of the values.

Example



Pareto Chart

Term
Pareto Chart

When
MEASURE, ANALYZE and CONTROL, always after data collection

Goal
- Display discrete data by category showing cumulative impact of each category
- Identify those categories that contribute the most to an issue and focus attention on these
- Demonstrate the existence of the 80/20 rule in the data.

Procedure
1. Depict the data in categories

2. Add up the frequencies of the individual categories in order to select the correct scale on the Y-axis in the Pareto Chart

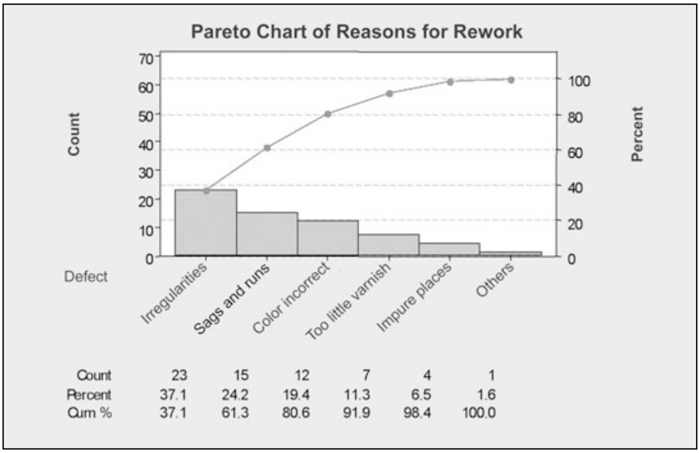
3. Depict the bars representing the categories true to scale: From left to right according to their frequency and in descending order

4. When multiple categories role up the last 5% of frequency into one category called "Other"

5. Depict the curve that shows the cumulative frequency as a percentage using Y2-axis

Example Pareto Chart of Reasons for Rework on the following page.

Example



Tip

- Occasionally the consolidated “Other” category may be larger than the next bar to the left of it. This is ok
- Sometimes the data will already have a category in it called “Other” and this can lead to confusion especially if it is large. If this does occur then investigation is required and reclassification may be necessary
- Focus on the most important categories with the greatest leverage effect. If the Pareto chart is flat then ask if a different classification factor might reveal the 80/20 effect we desire
- Focus on obvious problems

Dot Plot

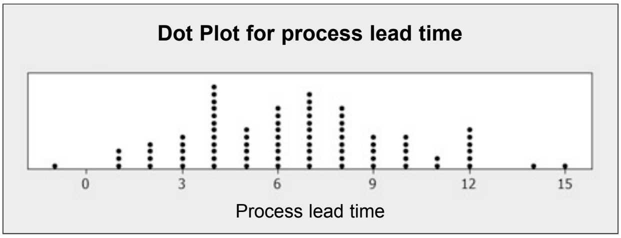
Term
Dot Plot

When
MEASURE, ANALYZE and CONTROL, always after data collection

Goal
- A Dot Plot shows the SHAPE of data distribution by mapping how often different individual values occur
- Helpful instrument for mapping data accumulations with quasi continuous data
- Display the spread and location of continuous data in a simple way
- Recognize outliers – especially in case of small data amounts

Procedure
- Depict the frequencies of the individual data points; (Minitab® automatically forms buckets for large data amounts with several decimal places)
- Each value is mapped as a single dot in the chart

Example



Tip
A Dot Plot can also be used to determine if the scope of the sample is large enough: An expert recognizes whether the whole data spread is depicted or if additional data is necessary.

DEFINE
MEASURE
ANALYZE
IMPROVE
CONTROL

Histogram

Term
Histogram

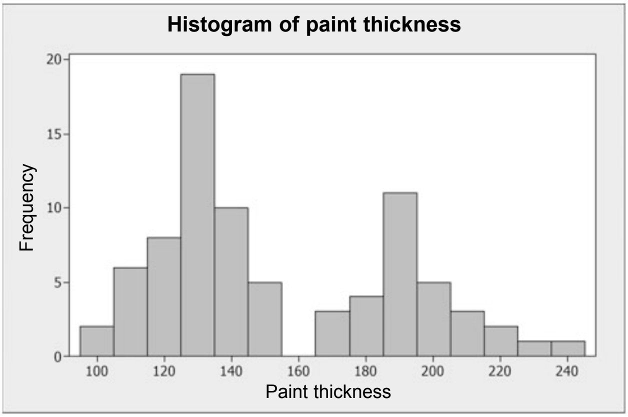
When
MEASURE, ANALYZE and CONTROL, always after data collection

Goal
- Display the shape / distribution of continuous data
- Show how process data relates to Customer Specifications in terms of spread and location

Procedure
1. Summarize continuous data into categories and/or classes. Rule of thumb: Number of categories (c) is $c = \sqrt{n}$

2. Plot the count of values allocated to each category as bars and to scale; the relevant interval for the data to be depicted is located on the x-axis; the frequencies are on the y-axis (absolute or relative percentage values).

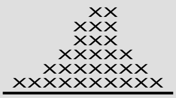
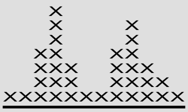
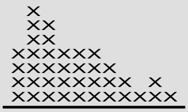
Example

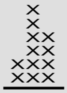
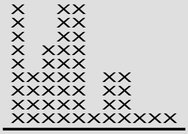
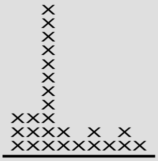
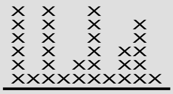
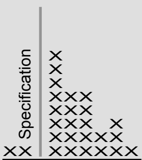


Tip

- Low levels of data can show misleading shapes/distributions. It is best to gather at least 100 data points in order to see the real shape emerging
- Several peaks in a Histogram may indicate that the data set is too small or that the data comes from different processes – in this case, the data set should be stratified and/or layered – see later chapters
- If you want to show variation over time you can connect the Histogram with the Run Chart or the Time Plot.

Interpretation help

Histogram	Description	Question formulation/ handling
	**Symmetrical, bell-shaped distribution** The data is symmetrical and distributed in a bell-shaped form. There are only very few outliers if any.	You can assume that the data is normally distributed.
	**Bimodal, two peaks** Potential cause: The data comes from two different processes.	Can the data come from several processes? Test before further analysis and if possible stratify the data in a way which makes sense e.g. by machine.
	**Long run asymmetry** Data is probably limited by a natural border to one side. Typical examples are durations (e.g. waiting times). It is possible that data was 'cut off' somehow.	Select suitable statistical procedure for analysis. Where does the measurement take place? Check collection process.

Histogram	Description	Question formulation/ handling
	**Insufficient dispersal** Five or fewer clear values. The measurement device is probably not sensitive enough – need more granularity	Improve measurement process.
	**Specific values are pre-ferred.** Large clusters of observa-tions around a minimum or maximum reading.	Is the measurement instru-ment capable of collecting the whole frequency range of the data? Extend the frequency range of the measurement.
	**Specific values are pre-ferred.** One value occurs extremely often.	Could the instrument be damaged? Seek physical reasons for this state and correct.
	**Saw-tooth pattern** Specific values occur more often.	Does the evaluator prefer specific values? Is rounding up inconsistent? Standardize the process for reading the measurement.
	**Observations cluster at the Specification Limit, only a few or no values outside the limit.**	invented so that the Specifi-cation Limit is not exceeded? Standardize the process for recording the data.

Box Plot

Term

Box and Whisker Plot, Box Plot

When

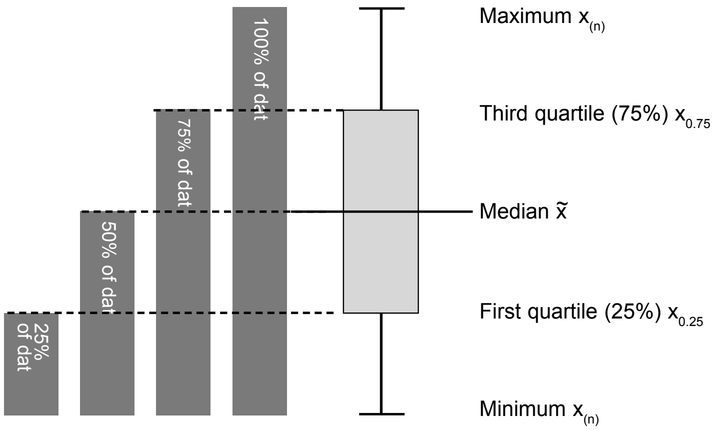
MEASURE, ANALYZE and CONTROL, always after data collection

Goal

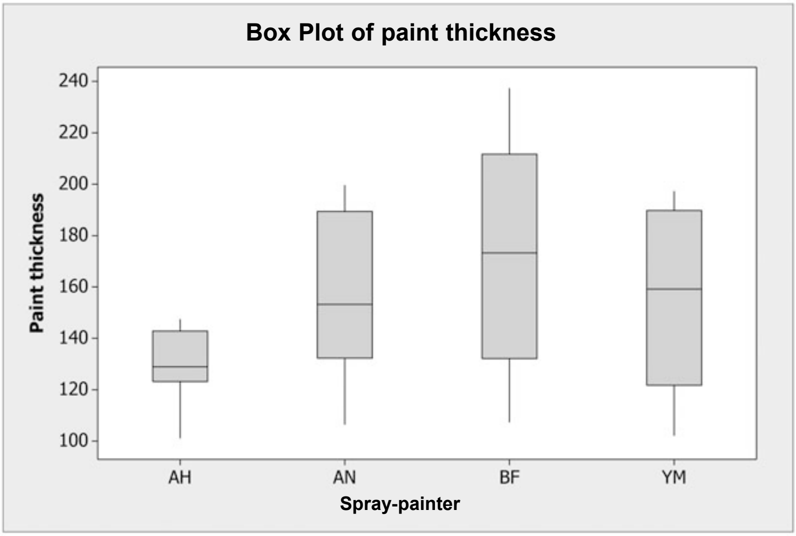
- Display spread and location of data with focus on quartiles
- Compare different data sets quickly and in a simple way (e.g. comparison of suppliers or machines)

Procedure

1. Map the maximum and minimum values true to scale and connect them with a vertical line
2. Map median as a horizontal line
3. Form a box between the first and the third quartile



Example



Tip
Statistics programs usually show outliers as "*"

Run Chart

Term
Run Chart, Time Series Plot

When
MEASURE, ANALYZE and CONTROL, always after data collection

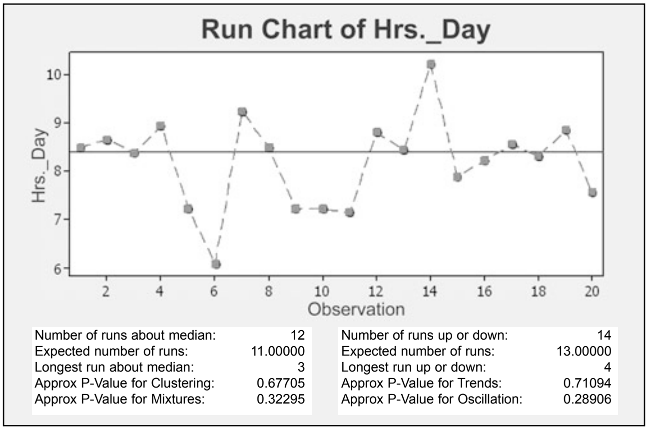
Goal
- Display data in time order thus revealing any patterns such as trends and shifts. Can be used for both continuous and discrete data
- Compare process performance before and after improvement

Procedure
1. Plot the relevant time period on the x-axis and the observed value of the process on the y-axis e.g. % failure or unit process lead time

2. Assign a corresponding value to every defined point in time

3. Connect plotted values with a (dotted) line

Example



Tip
You require a longer observation period for finding out special causes with Run Charts. At least 20 data points are required to be able to recognize a meaningful pattern. Customer specification limits can be added and also the median if required

Interpretation help

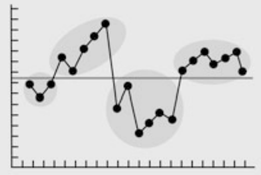
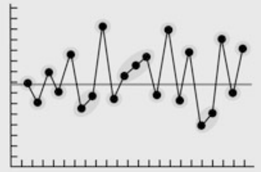
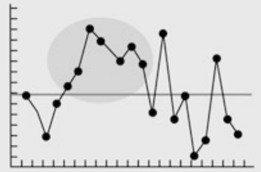
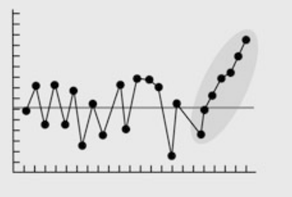
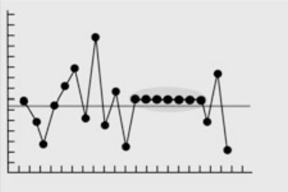
Diagram	Description	Question formulation
	**Few Runs** Few clusters of points (accumulation of points) above and below the median. Potential cause: **Cycles.**	What do the clusters below the median have in common and how do they differ from the clusters above the median?
	**Too many runs** Too many clusters above and below the median. Potential cause: **Overcompensation, s**amples drawn from **sev-eral sources**, data that was invented.	What distinguishes the measurements above from the ones below the median?
	**Shifts** 8 or more points in a row on one side of the medi-an. Potential cause: Shift in a central element of the process.	What was different in the process at the time when the shift took place?

Diagramm	Description	Question formulation
	**Trends** 6 or more points in a row that continuously rise or continuously fall. Potential cause: **Trend**.	What was different when the trend started?
	**Same values** A sequence of 7 or more points with the same value.	Did the measurement instrument "get stuck"? Was a batch processed?

Control Charts

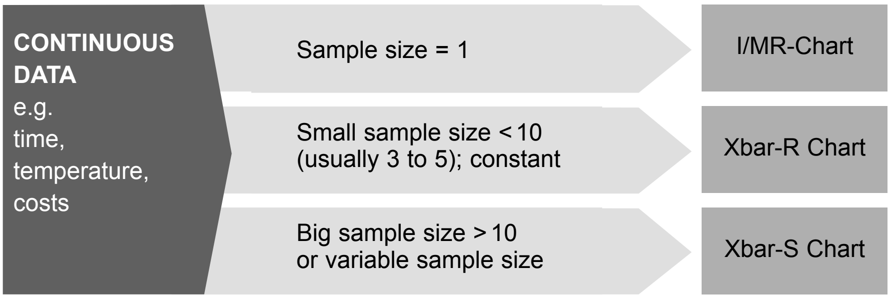
Term
Control Charts, Shewhart Charts

When
MEASURE, ANALYZE and especially in CONTROL, always after data collection

Goal
- Process monitoring: identify and track process variation, check if the process is stable/under control
- Understand the different types of variation within the process (i.e. common or special cause) and therefore the range of expected performance from the process

Procedure
A number of different Control Charts are available depending on the type and amount of measurements being gathered. The following diagram categorizes the choice of Control Charts:

Example



DISCRETE DATA e.g. defect, illness			
	Defects per part	Constant sample size (number of defects > 5)	c-Chart
		Variable sample size	u-Chart
	Defective parts	Constant sample size (> 50)	np-Chart
		Variable sample size (> 50)	p-Chart

COMMON VARIATION

E.g. Daily way to work:
- Traffic conditions
- Parking space situation

Graphic result

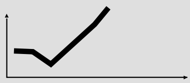
- Are expected
- Are normally distributed
- Are random

DMAIC PROJECT

SPECIAL VARIATION

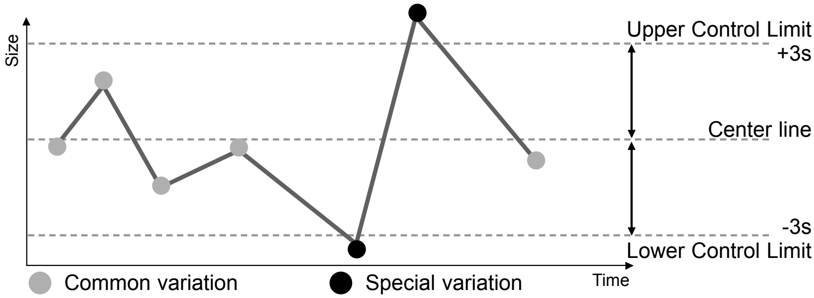
E.g. Daily way to work:
- Accident
- Police control

Graphic result



- Are unexpected
- Are not normally distributed
- Are non-random

TROUBLE SHOOTING



The Control Charts are presented in greater detail in the section "CONTROL"

Scatter Plot

Term
Scatter Plot

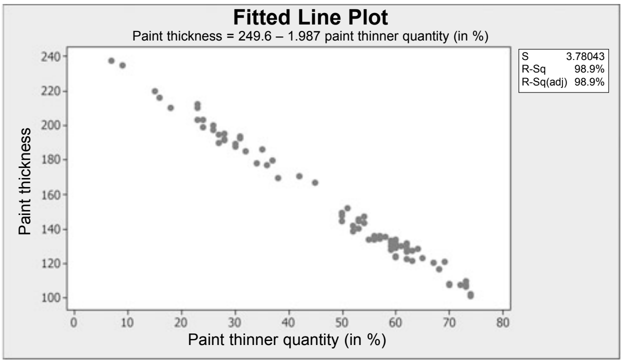
When
MEASURE and especially in ANALYZE, after data collection

Goal
Display the (linear or non-linear) relationship between two metric variables, usually continuous but possibly ordinal

Procedure
Enter data points in the coordinate system

Tip
- This is another way of verifying a suspected relationship identified in the Cause and Effect Diagram
- Scatter Plots do not validate that a causal relationship exists, merely that there is a relationship

Example



Probability Plot

Term
Probability Plot, Normal Probability Plot

When
MEASURE, ANALYZE and CONTROL, after data collection

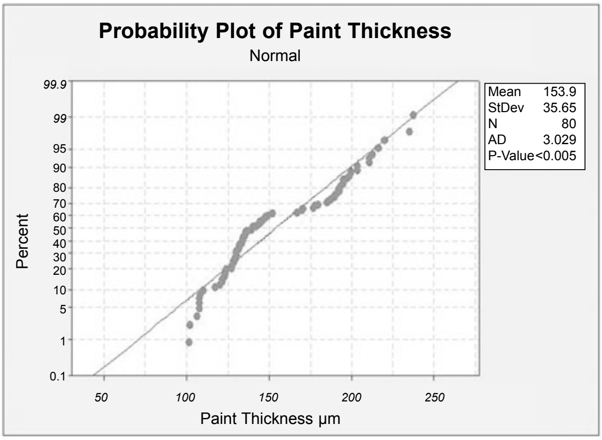
Goal
Check the data set for a specific distribution (e.g. normal distribution) most often in order to carry out the correct statistical analysis for this type of distribution e.g. which tests to turn on in a control chart

Procedure
- Based on the assumed distribution shape, select a transformation that should change the distribution shape into a straight line (given the complexity of this transformation, a Probability Plot should be drawn up with the help of statistical software.)
- Display the data points of the collected data set.
- Add Confidence Interval if required.
- If the data points lie on the straight line and/or within the Confidence Interval it can be assumed that your data matches the assumed distribution. Most often the assumed distribution is the Normal Distribution.

Tip
The result of the test for normal distribution presented in the statistics software Minitab® is based on the Anderson-Darling Test. The p value will be the final determinant of match or not

Example Probability Plot on the following page.

Example



This Probability Plot is based on the assumption that the distribution is Normal. In this example the data does not look straight. The more data you have the straighter it should look. The p value for the Anderson Darling Test is < 0.005 which is less than the typical Alpha level of 0.05. so we cannot assume that our data is normally distributed.

Location Parameter Mean Value

Term
Mean, mean value, arithmetic mean

When
MASURE, ANALYZE, IMPROVE and CONTROL, always after data collection

Goal
Find out the central location of a continuous data set

Procedure
Sum of all data points and divide by the number of data points (n). An $\bar{x}$ is used for the mean value of a sample. If the mean value of a population is determined it is written as μ.

$$\bar{x} = \frac{\sum_{j=1}^{n} x_j}{n} = \frac{(x_1 + x_2 + \ldots + x_n}{n}$$

Tip
The mean value is very sensitive towards outliers (extreme values). Checking the median at the same time makes sense.

Example on the following page.

Example

The average thickness of the applied varnish is tested in the paint shop. Six parts are tested:

255µm

89µm

110µm

152µm

324µm

199µm

Arithmetic mean

$$\bar{x} = \frac{255 + 89 + 110 + 152 + 324 + 199}{6} = 188.17$$

The tested parts have an average paint thickness of 188.17 µm.
CARE: No conclusions about all parts should be drawn from this result.

Location Parameter Median

Term
Median

When
MEASURE, ANALYZE, IMPROVE and CONTROL, always after data collection

Goal
Find out the central location of a continuous data set

Procedure
- Sort the data according to size, usually in ascending order
- In the event of an even number of data points; identify the middle two, add together and divide by two – this is the median
- In the event of uneven number of data points: identify the middle data point – this is the median

The median corresponds to the value at which 50% of the data is on either side

• In case of an **uneven** number of n observations the median is the middle value

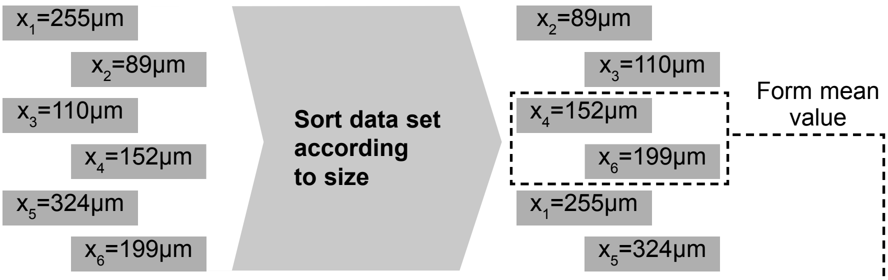
$$\tilde{x} = x_{\left(\frac{n+1}{2}\right)}$$

• In case of an **even** sample size (n) it corresponds to the mean value of the two middle values

$$\tilde{x} = \frac{x_{\left(\frac{n}{2}\right)} + x_{\left(\frac{n}{2}+1\right)}}{2}$$

Example on the following page.

Example
With random samples the thickness of the applied varnish is tested in the paint shop. 6 parts are examined:



$$\tilde{x} = \frac{x_{\left(\frac{n}{2}\right)} + x_{\left(\frac{n}{2}+1\right)}}{2} = \frac{x_{\left(\frac{6}{2}\right)} + x_{\left(\frac{6}{2}+1\right)}}{2} = \frac{x_{(3)} + x_{(3+1)}}{2} = \frac{152 + 199}{2} = 175.5$$

Tip
The median is less sensitive to outliers than the mean so maybe preferred in some situations.
For normally distributed data it would be expected that the mean = median.

Spread Parameter Variance

Term
Variance

When
MEASURE, ANALYZE, IMPROVE and CONTROL, always after data collection

Goal
Quantify the spread of a process using variance as a measure. The bigger the variance the bigger the process spread

Procedure
- Calculate the data set mean
- Deduct the mean from each individual data point and square it
- Total these values and divide by n-1
- You now have the average squared deviation from the mean

$$s^2 = \frac{\sum_{j=1}^{n}(x_j - \bar{x})^2}{n - 1} = \frac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_n - \bar{x})^2}{n - 1}$$

Example
The following results in micrometers are available from the random sampling of the paint thickness: 255, 89, 110, 152, 324, 199

$$s^2 = \frac{(255 - 188.17)^2 + (89 - 188.17)^2 + \ldots}{6 - 1} = \frac{40,286.83}{5} = 8,057.37$$

Tip
Due to the squared dimension it is difficult to evaluate the size of the variance. The bigger the variance the larger the process spread. A better description of the spread is the standard deviation.

DEFINE
MEASURE
ANALYZE
IMPROVE
CONTROL

Spread Parameter Standard Deviation

Term
Standard Deviation

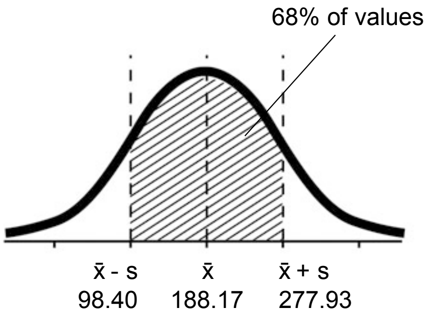
When
MEASURE, ANALYZE, IMPROVE and CONTROL, always after data collection

Goal
Quantify the spread of a process (the bigger the standard deviation, the bigger is the spread of the process)

Procedure
Calculate the square root of the variance. The resulting value Is the standard deviation

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

Example



From the variance of the paint thickness the following emerges

$$s = \sqrt{(8{,}057.37\,\mu m)^2} = 89.76\ \mu m$$

- With the help of the sample it is calculated that approx. 68% of the sample values are between 98.40 and 277.93 micrometers
- The spread in the spray-painting process is relatively enormous compared to the Specification Limits (100 and 180 micrometers)

Tip

- The standard deviation has the same units as the tested data and/or the mean value and is thus easier to relate to. Additionally the Normal Curve can be divided into standard deviations and certain assumptions made as follows:
- In a Normal distribution approx. 68% of the values are in the area ± 1 standard deviation (from the mean), approx. 95% in the area ± 2 s and approx. 99.7% are in the area ± 3 s.
- An s stands for the standard deviation of a sample, σ for the standard deviation of a population.

Spread Parameter Range

Term
Range

When
MEASURE, ANALYZE and CONTROL, always after data collection

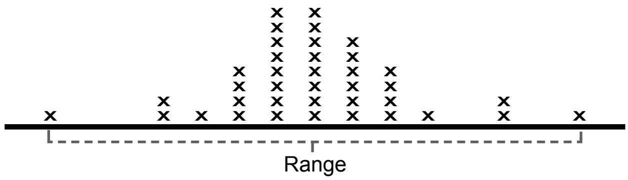
Goal
Quantify the spread of a process in the simplest way possible. (the bigger the range, the bigger is the spread of the process)

Procedure
Calculate range by deducting the minimum value of a data set from the maximum value of a data set

$$R = X_{MAX} - X_{MIN}$$

Tip
The range is very sensitive to outliers and should therefore be interpreted carefully; when in doubt use the span which, for example, might remove the top and bottom 1% of data points from the data set before doing the calculation

Example



$$R = 324 - 89 = 235$$

Spread Parameter Span

Term
Span, percentile distance

When
MEASURE, ANALYZE and CONTROL, always after data collection

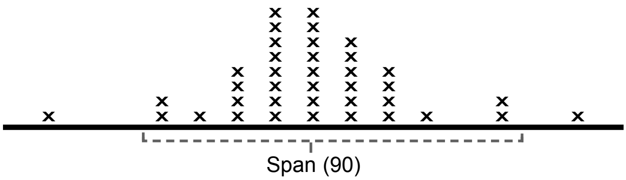
Goal
Quantify the spread of a data set which has outliers removed (Assumes that the outliers were believed to be an issue)

Procedure
- Sort the data according to size, usually in ascending order. Remove equal amount of data points from the top and bottom of the data set. How much you remove may vary but typically is 1% or 5%
- Span (90) is the range after 5% of data points have been removed from top and bottom of a sorted data set

$$\text{Span (90)} = x_{0.95} - x_{0.05}$$

Tip
The span is a good key figure for quantifying deviation from a target value. Form a new variable $Y = X_{AS.IS} - X_{TARGET}$ and calculate the interval width.
$\text{Span (90)} = Y_{0.95} - Y_{0.05}$

Example



n = 100, min = 100, max = 300, $P_{0.05} = 110$, $P_{0.95} = 255$

Span (90) = 255 - 110 = 145

Process Performance

Term
Process Performance

When
Closing MEASURE, continuously during ANALYZE and IMPROVE, especially during CONTROL

Goal
- Find out the performance capability of a process with respect to the customer requirements i.e. specifications
- Compare the ”before” and ”after” situations post improvements being made

Procedure
Among the most common quality key figures used in the world of Six Sigma^{+Lean} for assessing process capability are:

DPMO	Defects per Million Opportunities	• Quality from the company's perspective • Defects per 1 Million Opportunities • Basis for the sigma value calculation
ppm	Parts per Million	• Quality from the customer's perspective • Proportion of defective parts of all parts
DPU	Defects per Unit	• Average number of defects per unit
Yield	Yield	• Proportion of defective parts from production
Y_{RTP}	Rolled Troughput Yield	• Probability with which a unit runs through each individual step of the entire process without defects
Y_{Norm}	Normalized Yield	• Geometric mean of the Rolled Throughput Yield
Span	Percentile distance	• Spread of a data set excluding a small % of the data at each extreme, frequently used to quantify the deviations around a target
OEE	Overall Equipment Effectiveness	• Total effectiveness of plant

Defects per Million Opportunities (DPMO)

Term
Defects per Million Opportunities, DPMO

When
Concluding MEASURE, during ANALYZE, IMPROVE and CONTROL and after the completion of the project to confirm scale of improvement and sustain performance

Goal
Quantify process performance from an internal perspective with a view of minimizing the number of defects per produced unit

Procedure
- Define the produced unit (output of a process, e.g. spray-painting)
- Determine the defect opportunities (usually derived from the CTCs)
- Define the defects (every defect opportunity in a unit that corresponds to a defect)
- Determine the number of inspected units and count the defects; calculate the DPMO value:

DPMO = Defects per Million Opportunities

$$\text{DPMO} = \frac{D}{N \cdot O} \cdot 1{,}000{,}000$$

D = Number of defects
N = Number of processed units
O = Number of defect opportunities per unit

Tip
- Describe only the defect opportunities which are derived from CTCs and actually produce defects
- When counting the defects, ensure that the unit is checked for all defect opportunities

- The Sigma Conversion Table lists the process Sigma (Sigma value)
- In case calculations are conducted at different times during the project it is important to evaluate equal numbers of units in order to guarantee comparability of results – it is also important that the defect opportunities are consistent throughout
- The number of defect opportunities should match the number of the CTCs targeted by the project

Example

Calculation
"Car dealer example"

Number of units that were processed	N = 80
Number of defects made	D = 108
Number of defect opportunities per unit	O = 4
DPMO	$\frac{108}{80 \cdot 4} \cdot 10^6 = 337{,}500$
Process Sigma	1.95

Parts per Million (ppm)

Term
Parts per Million (ppm)

When
Conclusion of MEASURE, during ANALYZE, IMPROVE and CONTROL and after the completion of the project to ensure sustainability

Goal
Quantify process performance from the customer's viewpoint: A unit with one or more defects is still seen by the customer as a defective unit as it is, all in all, still useless to them

Procedure
- Determine the defect opportunities for which, when they occur, a whole unit is marked as defective
- Determine the number of inspected units and count the number of defective ones
- Calculate the ppm value: $\text{ppm} = \frac{\text{Number of defective units}}{\text{Total number of units}} \cdot 1{,}000{,}000$

Example

- Due to spray-painting defects requiring rework and/or the order was not ready on time, 63 out 80 orders were deemed to be defective at the main branch:

$$\text{ppm} = \frac{63}{80} \cdot 1{,}000{,}000 = 787{,}500$$

- We thus have a ppm rate at the main branch of 787,500

Tip
The DPMO value corresponds to the ppm value if there is only one defect opportunity per unit

Defects per Unit (DPU)

Term
Defects per Unit (DPU)

When
Conclusion MEASURE, during ANALYZE, IMPROVE and CONTROL and after the completion of the project to ensure sustainability

Goal
Determine the average number of defects per unit

Procedure
- Define the defects (every defect opportunity in a unit that corresponds to a defect)
- Determine the number of inspected units and count the defects
- Calculate the DPU value: $\text{DPU} = \frac{\text{Total number of defects}}{\text{Total number of units}}$

Example

• A total number of 108 defects were identified in 80 orders at the main branch:

$$\text{DPU} = \frac{108}{80} = 1.35$$

• We have a DPU rate of 1.35; this means that each produced part has 1.35 defects on average

Tip
The three quality key figures DPMO, PPM and DPU provide a comprehensive image of the process performance – it is recommended to use all three key figures

Yield

Term
Yield

When
Conclusion of MEASURE, during ANALYZE, IMPROVE and CONTROL and after the completion of the project to ensure sustainability

Goal
Determine the proportion of defect-free units and/or good parts in a process

Procedure

- Yield: Indicates the proportion of good, defect-free units

  $$Y = \frac{\text{Number of non-defective units}}{\text{Total number of units}}$$

- Rolled Throughput Yield: Determines the probability that a unit runs through the entire process without defects. This total yield is calculated by multiplying the single sub-process yields

  $$Y_{RTP} = Y_{Sub\,1} \cdot Y_{Sub\,2} \cdot \ldots \cdot Y_{Sub\,n}$$

- Normalized Yield: Determines the average yield per process step.
  ATTENTION: This measure can be misleading if the yields in the single process steps vary greatly

  $$Y_{NORM} = \sqrt[n]{Y_{RTP}}$$

Example 1 (Yield)

- Only 21 out of 80 spray-paintings were without defects

$$\text{Yield} = \frac{21}{80} = 0.2625 = 26.25\%$$

- We have a yield rate of 26.25%

Example 2 (Rolled Throughput Yield)

- The following yields were calculated for the individual process steps:

$$Y_1 = 92\% \rightarrow Y_2 = 82\% \rightarrow Y_3 = 84\% \rightarrow Y_4 = 82\% \rightarrow Y_5 = 95\%$$

- The probability that a unit runs through the entire process without defects is:

$$Y_{RTP} = 0.92 \cdot 0.82 \cdot 0.84 \cdot 0.82 \cdot 0.95 \cong 0.494$$

Example 3 (Normalized Yield)

$$Y_{NORM} = \sqrt[5]{0.494} = 0.87 = 0.87$$

The average yield per process step is 87%

Tip

- One can distinguish between two characteristics of the yield:
  1. Proportion of units that were produced without defects in relation to the total number of units (yield in classical production)
  2. Proportion of produced finished material in relation to the total amount of raw material (yield in chemical industry/pharmaceutical industry)
- The yield is usually identified before improvements and/or rework occurs (First Pass Yield)

Span, Percentile Distance

Term
Span, Percentile Distance (percentile distance of the deviations from the target value as a process key figure)

When
Conclusion MEASURE, during ANALYZE, IMPROVE and CONTROL and after the completion of the project to ensure sustainability

Goal
Determine the process performance when no Specification Limits are set (focus on attaining target value)

Procedure

- Transform all values (x) into a new variable X:
  $X = X_{AS\ IS} - X_{TARGET}$

- Calculate the interval range between $X_{AS\ IS}$ and X_{TARGET} without considering the outliers. Span (90) is usually used; the smaller the interval range the more effective is the span.
  Span (90) = $X_{0,95} - X_{0,05}$

- Optimize the process with the goal of attaining zero deviations (interval range = 0)

- The new variable X is the deviation (in days) between the agreed and the actual delivery date. The following data was collected for X:

X	= {-10, -9, -8, -7, -6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9}
$X_{0,95}$	= 8.05
$X_{0,05}$	= -9.05
Span (90)	= 8.05 - (-9.05) = 17.1

Tip

- The span is an excellent key figure for problems like delivery reliability
- The percentiles can be calculated with programs like MS Excel® – with MS Excel® "PERCENTILE(ARRAY,K)" is the syntax, whereby "Array" stands for the whole data set and "K" for the percentile (e.g. 0.95)

Data Transformation

Term
Data transformation

When
MEASURE, ANALYZE, CONTROL, when certain statistical tools are applied for the data analysis

Goal
Change the shape of the data using a statistically valid method that then allows the “transformed” data to be used in particular statistical tools. Usually this is transforming non normal data to normal which gives a wider choice of statistical tools to use.

Procedure

1. Ensure homogeneity of data, i.e. that data comes from one population (cf. data stratification)

2. Select transformation function
   - If the physical relationship is known a transformation can be selected that is easy to interpret for the Project Leader (e.g. if the relationship arises multiplicatively, the data becomes additive through logarithms [ln x])
   - In practice, however, a trial-and-error basis is frequently applied, since the relationship is usually unknown
   - The common transformation functions are:

Logarithm	log x, ln x
Exponential	exp x
Logit	$\ln = \left(\frac{x}{1-x}\right)$
Reciprocal	$\frac{1}{x}$
Square	x^2
Square root	$\sqrt{x}$
Root	$\sqrt[n]{x}$
Box-Cox	x^{λ}

- The Box Cox transformation is supported automatically by numerous statistics programs such as Minitab®. The transformation parameter λ (lambda) is estimated at the same time as other model parameters (e.g. mean value). Depending on the estimated λ value, the Box Cox transformation can correspond to one of the usual transformation functions (e.g. B. $\lambda = 2$ corresponds to x^2)

3. Test the data for normal distribution to see if the transformation has fulfilled its purpose

Tip
Please bear in mind that the statistical results must always be presented and accepted within the context of the project work.
It is usually recommended to relinquish working with transformed data once the project is complete. This is because explaining transformations and converting between transformed data and actual values is difficult and not always fully accepted by people unfamiliar with the technique.
As an alternative it may be worthwhile using the suitable distribution or the percentile method without distribution when the process capability (C_p and C_{pk} values) is to be identified.

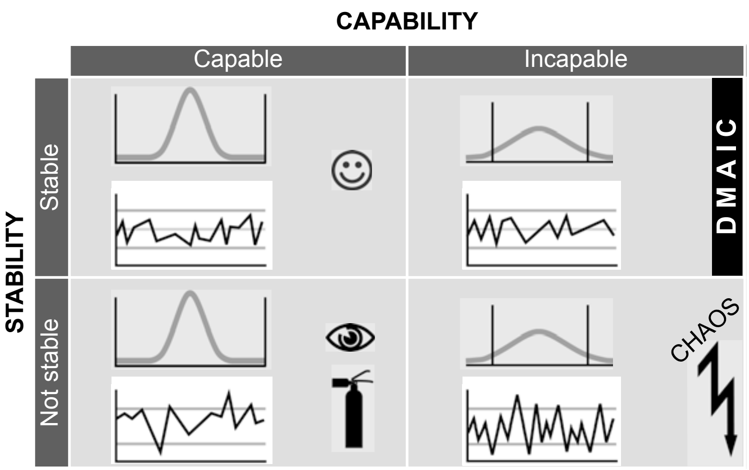
Process Capability and Process Stability

Term
Process Capability and Stability

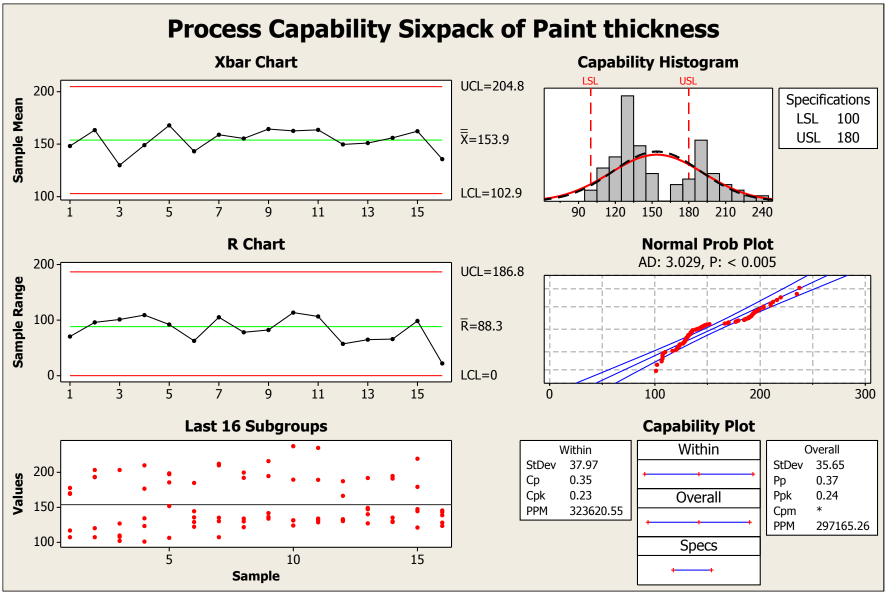
When
At the end of the MEASURE phase, monitor CONTROL process

Goal
- Determine the AS IS situation (Baseline) in terms of process capability and stability
- Identification of further work necessary in the project

Procedure
- Test process stability i.e. identify the causes of variation (special or common causes) – cf. understanding variation
- Test process capability i.e. identify the degree of fulfillment of the customer requirements – cf. calculate process performance
- Derive further procedures from the results



Example



The process in the above example is stable since the points seem to be distributed randomly in the X-bar and R-Chart i.e. the process indicates common causes for variation. The low C_p and C_{pk} values hint at an incapable process. In this case a project for process improvement is recommended.

Tip

- You should always test both perspectives: stability and capability
- If the process is capable, however, not stable, Emergency Management is required – rather than a process improvement project
- If the process is incapable and stable, a process improvement project is necessary
- If both criteria (stability and capability) are not fulfilled it must be questioned if a project for process improvement can start before the special causes have been identified and eliminated

C_p and C_{pk} values

Term

C_p and C_{pk} values

When

Concluding MEASURE, during ANALYZE and IMPROVE, especially during the CONTROL phase

Goal

- Determine the relationship between the customer specification limits (tolerance limits) and the natural spread of the process (C_p value)
- Also assess the centering of the process (C_{pk} value) with respect to specification limits

Procedure

C_p value:

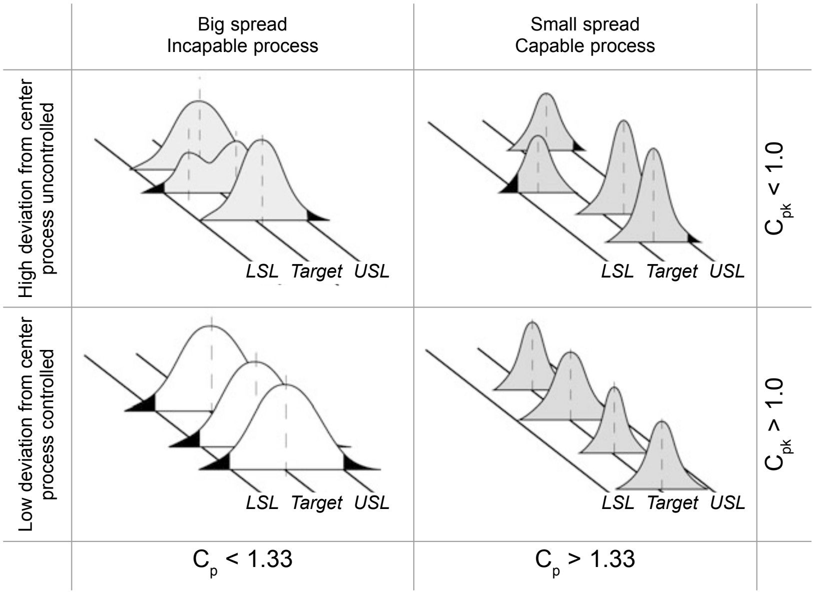
- Determine the upper and lower specification limit
- Divide the distance between the upper and lower specification limit (tolerance) by six times the standard deviation of the process
- If the data is not normally distributed: Divide the tolerance by the percentile range of +/- 3 standard deviations (corresponds to 99.73%)

With normal distribution	With non-normal distribution
$C_p = \frac{USL - LSL}{6s}$	$C_p = \frac{USL - LSL}{x_{0.99865} - x_{0.00135}}$

C_{pk} value:

- Divide the distance between the nearest specification limit and the mean value by 3 times the standard deviation of the process; this also takes the location of the process into consideration
- With non-normally distributed data: Divide the distance between the nearest specification limit and the median by half the percentile distance

With normal distribution	With non-normal distribution
$C_{pk} = \min\left[\frac{USL - \bar{x}}{3s}; \frac{\bar{x} - LSL}{3s}\right]$	$C_{pk} = \min\left[\frac{USL - \bar{x}_{0.5}}{x_{0.99865} - x_{0.5}}; \frac{\bar{x}_{0.5} - LSL}{x_{0.5} - x_{0.00135}}\right]$



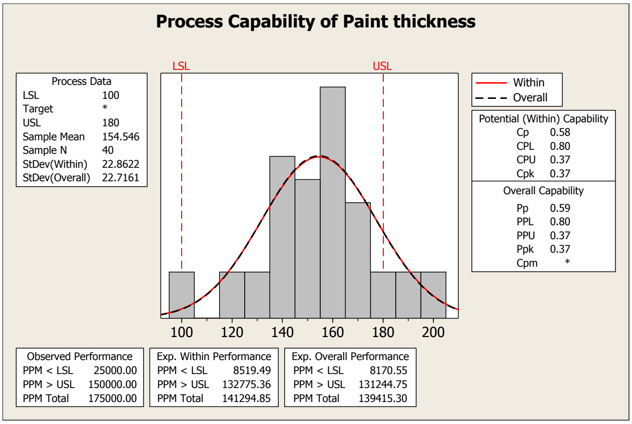
Example C_p and C_{pk} values

The Specification Limits for the spray-paintings are set at LSL = 100 and USL = 180. The collected data showed a mean value of 154.54 and a standard deviation of 22.86. Normal distribution is given.

$$C_p = \frac{USL - LSL}{6s} = \frac{180 - 100}{6 \cdot 22.86} = 0.58$$

$$C_{pk} = \min\left[\frac{USL - \bar{x}}{3s}; \frac{\bar{x} - LSL}{3s}\right] = \min\left[\frac{180 - 154.54}{68.58}; \frac{154.54 - 100}{68.58}\right] = \min[0.37; 0.79] = 0.37$$

Example: C_p und C_{pk} in Minitab®



C_p	= (USL-LSL)/(6s within)	→	>1 means: The process is narrower than the set limits
CPU=	(USL- m)/(3s within)	→	<1 means: The upper limit is exceeded.
CPL =	(m -LSL)/(3s within)	→	<1 means: The lower limit is exceeded.
C_{pk}	= min{CPU, CPL}	→	<1 means: The process passes both limits.
m	= midpoint between USL, LSL		

Graphic result:
The upper and lower specification limits and some statistical indicators from the sample:
The Histogram shows the distribution of data in relation to the specification limits. The curve depicts the normal distribution, taking into consideration the short and long-term observation. This example does not make such a distinction.

The C_p and C_{pk} values:
the bigger the values, the better is the process.
C_p = 2 and/or C_{pk} = 1.5 corresponds to a Six Sigma level.

Since no subgroups were given, the short and long-term process capabilities are identical.

Tip

- A high C_p value is a necessity but not indicative of a good process sigma value. Only by taking into account the process centering and attaining a good C_{pk} value, can a high process sigma be claimed
- In order to reach a Sigma level of 6 (Six Sigma process) C_p and C_{pk} must assume the value of 2 (at least 6 standard deviations fit in between the mean value and the customer specification limits). Due to the assumed process shift of 1.5 standard deviations Six Sigma+Lean companies such as Motorola have set C_p values of 2 and C_{pk} values of 1.5 as their goal.
- If the observation is long-term, the C_p and C_{pk} values are referred to as P_p and P_{pk}.

DEFINE
MEASURE
ANALYZE
IMPROVE
CONTROL

Gate Review MEASURE

- **Derive measurements**
  - Have meaningful measurements been identified for each CTC and CTB?
  - Can the degree of fulfillment of the customer and business requirements be identified?

- **Collect data**
  - Is the goal of data collection clear?
  - Have all relevant measurements been operationally defined?
  - Has the measurement system been tested and has it been ensured that the validity of the data is appropriate?
  - Has a sampling strategy including sample size been determined which enables an appropriate degree of granularity/precision?
  - Is the effort for the data collection justified in the sense of the project goal?
  - Has it been ensured that the quality of data collection fulfills the requested demands? Have people responsible for this been named?

- **Understand process variation**
  - Has the data been visualized with the help of meaningful graphical tools?

- **Calculate process performance**
  - Can the degree of fulfillment of the customer and business requirements be indicated by suitable key figures?
  - Has the Baseline been set for later comparison?
  - What type of variation is present in the process output? Is the process capable or not? Should the project continue based on the above information?
  - Have Quick Hits been identified and implemented?

- **Project Charter**
  - Has the Project Charter been reviewed and adjusted where appropriate?

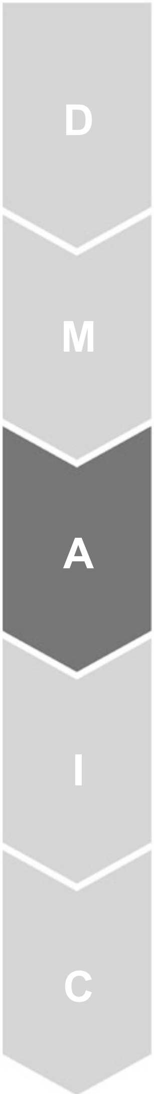
SIX SIGMA^{+LEAN} TOOLSET

ANALYZE

What are the Root Causes of the Problem?

R. Meran et al., *Six Sigma^{+Lean} Toolset: Mindset for Successful Implementation of Improvement Projects*, Management for Professionals, DOI 10.1007/978-3-642-35882-1_4,

Summary ANALYZE Phase



Objective and Scope of Phase

- The ANALYZE phase answers the question: "What are the root causes of the problem?" – Why is the current process not capable of fulfilling the customer and business requirements sufficiently?
- Potential causes are suggested which are analyzed by process analysis tools and/or data analysis methods – in this phase a focused analysis of the problem's potential causes takes place

The Meaning of the ANALYZE Phase

- Verification of potential causes is driven by figures, data and fact oriented methods
- Creation of a basis for secure but also creative decisions with respect to improvement actions

Procedure in the ANALYZE Phase

- Identification of potential causes
- Verification of identified potential causes with respect to their actual meaning/influence on the problem
- Prioritization/scoping of causes to few significant causes (root causes), which will be dealt with in the IMPROVE phase

Road Map ANALYZE Phase

D
M
A
I
C

M.4 Calculate Process Performance

AS IS state: How well does the process fulfill the requirements of customers and of the business?

MEASURE

ANALYZE

A.1 Collect Potential Causes

Why doesn't the process fulfill the customer requirements?
How can the potential causes be checked?

A.2 Analyze Process

What does the current process look like in detail?
Where are the interfaces; what are the weak points?
How does material and information flow?

A.3 Analyze Data

Can a significant influence and/or connection be proven with figures and data?

A.4 Derive Main Causes

What are the “vital few” root causes of the problem?

A Gate Review/Phase closure

Tool Overview ANALYZE Phase

A.1 Collect Potential Causes

Cause-Effect Diagram	Failure Mode and Effect Analysis (FMEA)	Tool 3 Input-Process Output-Measurement Matrix

A.2 Analyze Process

Analyze process	Spaghetti Diagram	Process Flow Chart	Swim Lane Diagram	Value Stream Map
Value Analysis	Time Analysis	Process Efficiency	Capacity Analysis	Process Flow Analysis

A.3 Analyze Data

Analyze data	Data stratification	Confidence Interval	Hypothesis tests	ANOVA
Correlation	Regression	Design of Experiments (DOE)	Further factorial designs	

A.4 Derive Main Causes

Derive main causes

A Gate Review

Cause-Effect Diagram

Term
Cause & Effect Diagram (CED), Fishbone, Fishbone Diagram, Ishikawa Diagram

When
ANALYZE, collecting potential causes, especially before conducting further deeper analyses (such as process analysis, data analysis)

Goal
- Provide a structured framework to help the team when it comes to brainstorming potential causes of the problem
- Visualize relations between potential causes
- Create a basis for further deeper analysis

Procedure
1. Formulate the specific problem as question and enter into a box on the right hand side of the diagram ("fish head") e.g. “Why are we late in deliveries?”

2. Ask the team this question and brainstorm potential causes. Look for plenty of ideas. If the team dry up consider prompting with more questions. Attach the potential causes to the “fish bone” using prime cause categories "i.e. the "6 Ms"- Method, Man, Machine, Material, Measurement, Mother Nature which have proven useful to many teams

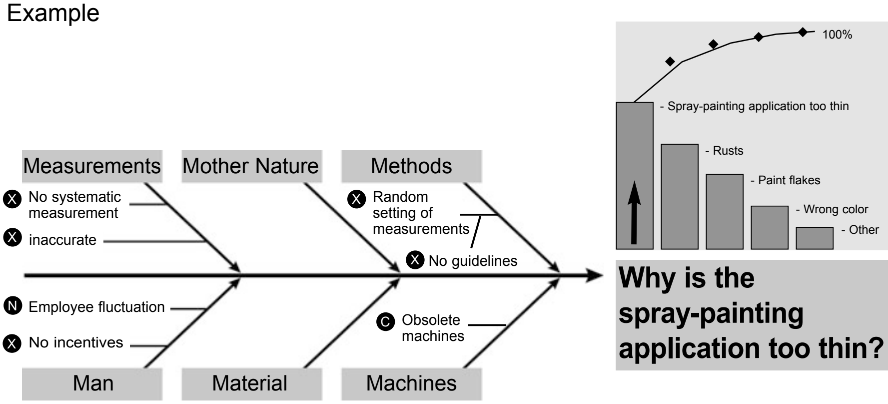
3. Clarify these ideas and commence an in depth review using the 5 “Why?” technique

4. Keep working on this until it is felt that the true potential causes have been revealed. Assess this by asking “If we stop this happening will the problem be eliminated or reduced?”

5. All causes are categorized afterwards as follows:
   C = Constant: invariable causes which are not alterable
   N = Noise: the causes which cannot be directly influenced which occur so to speak as "noise", e.g. lack of time

X = Variable: the decisive variables since they can be influenced by the project

Example



Tip

- Draw up a separate Cause-Effect Diagram for each individual CTC and CTB; this facilitates the focus and in this way makes the identification of root causes easier. NB: this is why too many CTCs are not desirable because of the work involved
- Formulate the question in the fish's head specifically and precisely. Ask team members to be as specific in their ideas as possible – this saves time later
- The Cause-Effect Diagram can be facilitated in different ways: general Brainstorming, analysis of branches step by step etc.; select the best method according to the employees' process knowledge
- The “bones” and/or branches are not always named according to the six standard Ms; for some teams it can also make sense to label e.g. a specific machine; if required only a few bones need be used; take into consideration the team dynamics
- The CNX evaluation is conducted from the project team’s perspective: "What can be changed or influenced from the team's point of view?" take into consideration the content of the Project Scope
- The Mind Mapping technique can also be used for developing a CED
- If very many potential causes are collected they can be prioritized with the help of the N/3 method; the goal is to reduce the verification effort:

  - Each participant gets as many adhesive stickers as the number of collected causes divided by three
  - The participants award their points according to their personal preferences
  - The potential causes with most points are verified first
- Quickly discuss the brainstorming rules and hang them up
- Also invite the expert(s) to the meeting if required
- Make sure enough space is available (usually two pin boards per fish bone)
- Plan approx. two hours for the first round – afterwards concentration and motivation among participants often decrease; test and add to the fish bone in a small group after the meeting and during the following team meeting

FMEA

Term
Failure Mode And Effect Analysis (FMEA)

When
ANALYZE: identification of potential causes for further detailed investigation; IMPROVE for the identification of risks and weak points in the target process

Goal
- Identify potential causes and weak points
- Score various aspects of failure to determine priorities for further analysis and action
- Assess the risks faced by the customer from a process
- Derive actions for reducing and mitigating risks

Procedure

Failure Mode and Effect Analysis				Last storage date:	
Customer:	1	Technical change status:		FMEA created on:	
Part name:		Production area/ step:		Responsible for FMEA:	
Customer part no.:		Part number:		Facilitator:	
Access no.:		Type of FMEA		Team:	
Defective part:		Status of FMEA		Revision status of FMEA:	
		File storage:			

Process-step	Potential failure	Consequences of failure	S	Causes of failure	O	Detection/ avoidance	D	RPN	Recommended action(s)	Responsible/ date	Realized action(s)	S	O	D	RPN
2	3	4	5	6	7	8	9	10							

FMEA Procedure ANALYZE Phase	
1	Record general information on the project in the documentation first
2	Describe the process steps and/or the product function precisely
3	Describe the potential failure modes: Why might the process/product not meet the requirements as specified at a particular step?
4	Describe the consequences of the failure mode or the failure on the process outcome
5	Estimate the scale of impact/severity as a consequence of the failure
6	List potential failure causes and/or mechanisms that could trigger this failure
7	Estimate the scale of occurrence of these potential causes
8	List existing ways of detecting or avoiding the occurrence of the failure cause
9	Estimate the likelihood of detection of a potential cause before handover to the following process step
10	RPN = S x O x D (the product of Severity, Occurrence and Detection; ranking the resulting RPN (Risk Priority Number) helps prioritize the fields requiring action; in case of high RPNs the analysis must be thorough)

Procedure IMPROVE Phase	
11	Define actions which reduce the rating numbers of Severity, Occurrence and/or Detection for the highest RPNs
12	Nominate people responsible and set closure dates
13	Describe completed actions and implementation dates
14	Estimate the new Severity effect of the potential failure mode on the customer after the improvement action
15	Estimate the new Occurrence frequency of the failure cause after the improvement action
16	Estimate the new Detection probability of a potential cause after the improvement action
17	Recalculate the RPN

Severity Scoring

- The severity of the failure's consequence is a "measure of the impact of the observed failure from the point of view of the customer(s)"[4]
- The scale of impact ranges from 1 to 10 with 10 being the most severe and 1 being the least. The team should determine specific criteria for each rating value beforehand
- The following rating scale demonstrates the nature of what is required.[4]

Rating	General evaluation criteria[4]
Very high 10-9	Very grave error violating safety requirements or fulfillment of legal regulations. It endangers the company's existence. Product cannot be delivered due to quality problems. Unacceptable excess of costs
High 8-7	Large delays in dispatch High proportion of rework, production standstill Tool wear/damage excessive High excess of costs Scrap proportion high
Moderate 6-5-4	Delayed dispatch Moderate proportion of rework Process interruption Tool wear/damage Moderate excess of costs Scrap proportion moderate
Low 3-2	Low proportion of rework Low level of process interruption Low excess of costs Scrap proportion low
Very low 1	Very low, acceptable excess of costs

[4] Cf.: (2008) DGQ Volume 13-11 FMEA – Fehlermöglichkeits- und Einflussanalyse. Ed. Deutsche Gesellschaft für Qualität e.V., Frankfurt, Berlin, Wien, Zürich: Beuth Verlag GmbH.

DEFINE
MEASURE
ANALYZE
IMPROVE
CONTROL

Occurrence Scoring

- The occurrence of the potential failure causes is estimated
- The estimation uses a scale of 1 to 10
- The existing preventative actions are taken into consideration
- This is not a mathematical probability but an estimate by a team of experts "to the best of their knowledge and judgment"
- The following rating scale serves the purpose of drawing up a process specific list

Rating	General evaluation criteria[4]
Very high 10-9	New process without experience i.e. untried and untested
High 8-7	New process with a known but problematic Procedure
Moderate 6-5-4	New process with known procedures Tried and tested process with positive experience of standard production under different conditions
Low 3-2	Changes of detail in tried and tested processes with positive experience of standard production under comparable conditions
Very low 1	New process under changed conditions with positive, conclusive proof of machine and process capability Tried and tested process with positive experience of standard production under comparable conditions in comparable plants

[4] Cf.: (2008) DGQ Volume 13-11 FMEA – Fehlermöglichkeits- und Einflussanalyse. Ed. Deutsche Gesellschaft für Qualität e.V., Frankfurt, Berlin, Wien, Zürich: Beuth Verlag GmbH.

Detection Scoring

- The probability of detecting a potential cause before handover to the following process step is evaluated (in case of a construction FMEA it can also refer to the failure's consequence. However, this should be marked.)
- The evaluation again follows a scale of 1 to 10
- The following rating scale serves is typical for a process

Rating	General evaluation criteria[4]
Very high 10-9	Very low probability that any failure would be detected since no detection method is known and/or no detection procedure has been set
High 8-7	Low probability that any failure would be detected since the detection method is unsafe and/or there is no experience with the adopted detection procedure
Moderate 6-5-4	Moderate probability of detecting any failure Tried and tested detection method from comparable processes although now in new situation or circumstances of use (machines, material, line)
Low 3-2	High probability of detecting any failure by tried and tested detection procedure The necessary capability of the measurement device for detection procedure to work has been confirmed
Very low 1	Very high probability of detecting any failure by tried and tested detection procedure from previous generation. The effectiveness for this product has been confirmed

[4] Cf.: (2008) DGQ Volume 13-11 FMEA – Fehlermöglichkeits- und Einflussanalyse. Ed. Deutsche Gesellschaft für Qualität e.V., Frankfurt, Berlin, Wien, Zürich: Beuth Verlag GmbH.

Failure Mode and Effect Analysis				Last storage date:	
Customer:		Technical change status:		FMEA created on:	February 2008
Part name:		Production area/ step:		Responsible for FMEA:	Mr. Goldbach
Customer part no.:		Part number:		Facilitator:	Mr. Goldbach
Access no.:		Type of FMEA		Team:	Stoll, Calabrese, Rimac, Engers
Defective part:		Status of FMEA		Revision status of FMEA:	
		File storage:			

Process-step	Poten-tial failure	Conse-quen-ces of failure	S	Causes of failure	O	Detection/ avoidance	D	RPN	Recom-mended action(s)	Respon-sible/ date	Realized action(s)	S	O	D	RPN
Mix color	Wrong color	Colora-tion wrong	8	Wrong in shelf	5	None	9	360							
	Wrong order	Colora-tion wrong	8	Incor-rectly filed	4	None	9	288							
	Wrong setting	Colora-tion wrong	8	No Training	9	None	9	648							

Tip

- The FMEA evaluation criteria are frequently company-specific. You should therefore check if your company has guidelines and/or a standard for evaluating the Severity, Occurrence and Detection probabilities
- Your facilitation of the FMEA should include the presentation and visualization of the evaluation criteria. This will shorten the decision process
- When you create the FMEA you should focus on specific parts of the process. Conducting an FMEA for a more complex process can mean a lot of effort. In case of complex FMEAs the effort v benefit relationship can be challenged often reducing the team's acceptance of the tool.
- The specialized literature frequently gives threshold values indicating which RPN evaluation requires need for action, e.g. 100 or 125. It is also recommended that any individual score of 9 or 10 is investigated regardless of the overall RPN. Discuss in your team when actions are needed in your process and don't be too driven by the figures.

Tool 3

Term
Measurement Matrix, Input-Process-Output-Measurement Matrix, Tool 3

When
ANALYZE, as part of the potential cause verification process

Goal
- Build a link between potential causes (X) to the output measurements (Y) attached to the CTCs/CTBs
- Confirm that some potential causes have been identified for each output measurement
- Identify measures that might confirm the link between the potential cause and the output measure and rate their strength

Procedure
1. Formulate specific hypotheses
   The collected potential causes (e.g. from the Fishbone or FMEA) need to be grouped and consolidated in a logical way and hypotheses must be formulated about how the potential cause might influence the output measurement

2. Fill out the Relationship Matrix
   Ask: "How strong is the assumed influence of X on Y?"
   - strong (9)
   - medium (3)
   - small (1)
   - none (0)

3. Decide how you will prove this
   - Is the influencing factor a constant or a variable?
   - What is the best input or process measurement for verifying the hypothesis?
   - Is the measurement discrete or continuous?
   - What is the best verification method and which tool is most suitable for verifying the hypothesis?
   - How exactly is will verification to take place?

4. Conduct the verification
   - The verification takes place iteratively (based on priorities)
   - The results are captured
   - The verified root cause is described in detail

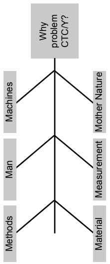
5. Quantify potential
   - How big is the impact on the output measurement? How was this measured and/or estimated?
   - Is the verified cause a main cause?

6. Close ANALYZE
   - Can the project goal be reached if all verified main causes are eliminated?
   - If this is not the case, other, not yet verified, and possibly not yet identified causes, must be tested

Tip

- Look closely at the variables marked with (X), challenge the causes evaluated as a constant (C) be prepared to test these as well – sometimes it makes sense to discuss this with the Sponsor; you should question entries which were evaluated as Noise (N); the goal is to find factors which can be controlled
- Develop the Relationship Matrix in the team and use tried and tested Post-its® and Meta Plan Boards for this purpose
- Complete Tool 3 on your own or in a small group (e.g. with experienced belt colleagues); filling out the methods, data types, tools etc. can appear to be laborious for some team members, if they have problems mastering the contents – the belts are the methodology experts
- As for some potential causes it can make sense to discuss the verification methods in the team and to gain creative hints in this way; present the current version of Tool 3 during each team meeting in ANALYZE in order to present the current status of the phase and to get your project team on board
- Use Tool 3 for continuously documenting your analysis results – this provides you with an overview of what has been done and you get a feeling for whether all important causes for the current project have already been found
- Consider the potential as contributions for achieving the goal; only if enough potential is available, can you close the ANALYZE phase; i.e. the project goal can be reached by eliminating the identified root causes

Example



Hypotheses to be verified	The training of the spray-painters is not sufficient	The spray-painting result depends on the spray-painter	The spray-painting result depends on the paint box	The spray-painting result depends on the amount of thinner	POTENTIAL FOR THE TARGET ACHIEVEMENT
Formation of sags and runs	3	9	3	3	90%
Coloration	3	9	3	0	90%
Paint thickness	1	3	9	9	100%
Prioritization for verification	7	21	15	12	
Constant or variable?	X	X	X	X	
Input/process measurement	Duration of training, number of trainings	Paint thick-ness/spray-painters	Paint thick-ness/paint box	Paint thick-ness/amount of thinner	
Data type	Discrete	Discrete	Discrete	Continuous	
Method	Process analysis	Data analysis	Data analysis	Data analysis	
	Comparison of training pro-gram and # days between spray-painter and benchmark	ANOVA, test for equal variances	2 sample t-Test; test for equal variances	Regression	
Result of analysis	Experience and training very different	P = 0.001; R^2 = 18%	P = 0.000; for location and spread	R^2 = 99%	
% influence (after verification) – optional	10%	10%	40%	30%	
Cause description	Quality of spray-painting depends strongly on human experience, since settings are not poka yoke		Nozzle of paint box 1 defective	Spray-painters take different amount of thinner; SOP not complete	
Main cause (Y/N)	Y	Y	Y	Y	

Process Analysis

Term
Process Analysis

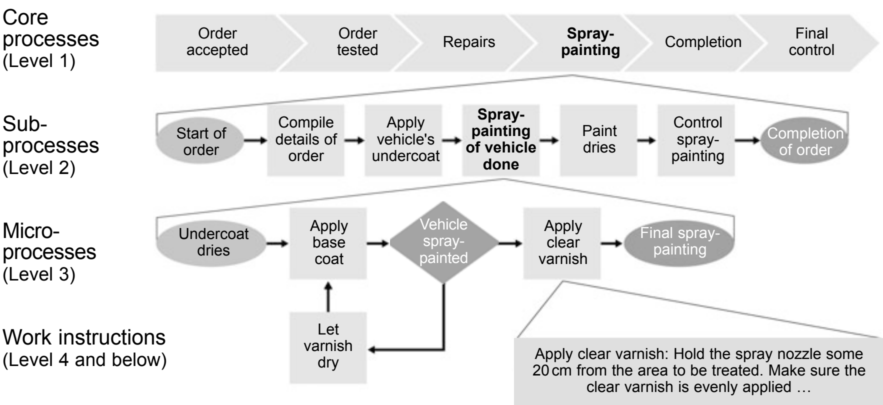
When
ANALYZE, usually after the identification of potential causes especially if the Process bone has a large number of causes attached

Goal
- Understand the AS IS process in detail
- Confirm or refute cause assumptions of people involved in, or customers of, the process
- Uncover improvement potential and previously unidentified causes

Procedure

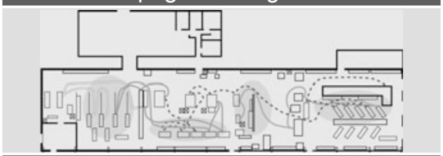
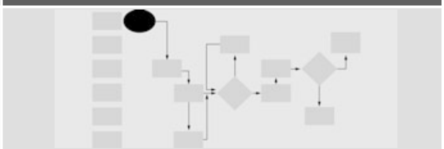
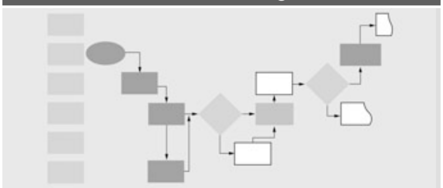
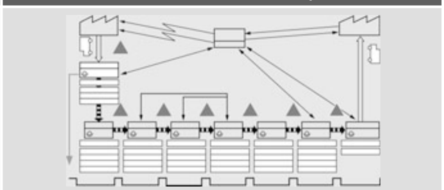
1. Set goals:
   a. Take up cause hypotheses from Tool 3 and check the process boundaries (are the SIPOC results still valid?)
   b. Choose the appropriate level of detail for the process visualization and analysis enabling the identification of further weak points (the process hierarchy used in the company may serve as an orientation point)
   c. If necessary focus on specific product families or product groups to reduce complexity

Example Process Hierarchies



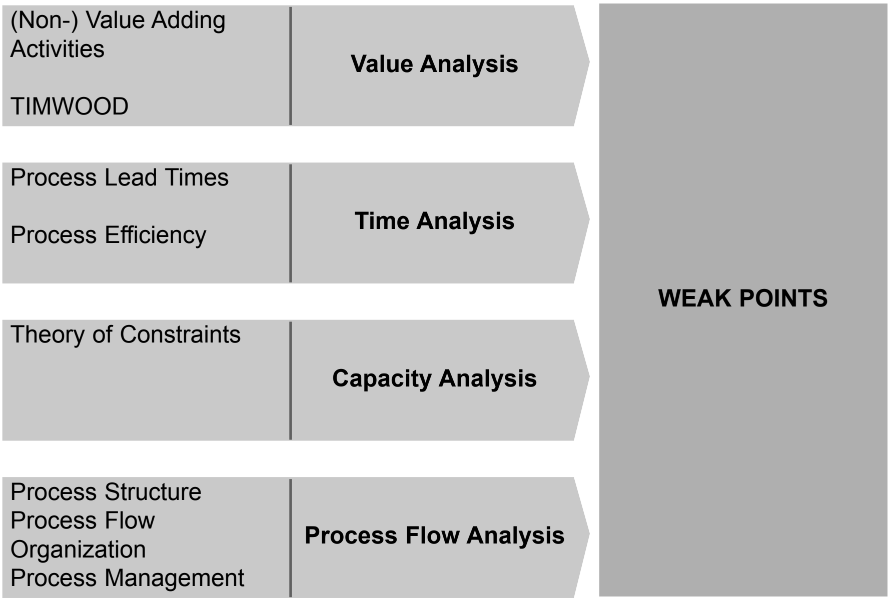
2. Describe and visualize process
   a. Select suitable visualization form; the form of process mapping depends on the objective of the process analysis: If the goal of the analysis is among others to analyze the interfaces, a mapping of the process in a Swim Lane Diagram makes more sense than in the form of a Flow Chart in which the interfaces are not immediately recognizable; the spatial arrangement of the analyzed area (layout) can be mapped with the help of the Spaghetti Diagram
   b. Record and visualize the defined process

Methods for process mapping at a glance

Spaghetti Diagram	Process Flow Chart
	
Swim Lane Diagram	**Value Stream Map**
	

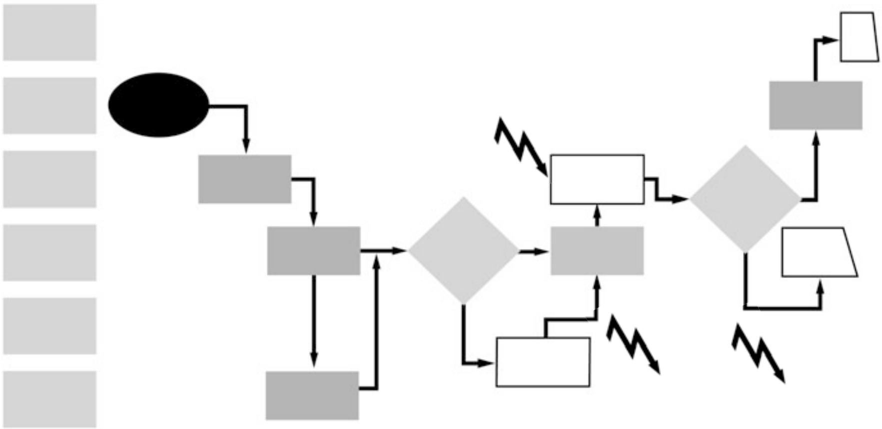
3. Analyze the process with the help of relevant analysis methods with respect to weak points; the different analyses are irrespective of each other and can be combined freely. The decision on which analysis to use usually takes place with the help of Tool 3 where the direction of testing potential causes is prescribed in the form of hypotheses.

Methods for process mapping at a glance



4. Summarize the analysis results visually and evaluate them finally; the identified weak points (non-value adding activities, long process times – e.g. by setup constraints, complex process structure) exemplify where in the process the potential causes occur for a specific problem and ultimately serve the purpose of verifying the causes from the process's point of view; it is documented which of the potential causes could be confirmed via the process analysis; Tool 3 can be used for documentation.

Summarizing Analysis of Weak Points



The individual tools are listed in detail in the following.

Tip

- The process analysis is not an end in itself but rather serves to prove potential causes; after having completed the analysis you should therefore always refer back to the Cause-Effect Diagram and/or the FMEA as well as Tool 3
- In the course of the process analysis you should focus on products and/or product groups or services which are characterized by typical operational procedures with high impact on the service quality or high quantities and costs
- When taking up the process you should proceed according to the rule: as easy as possible, as detailed as necessary – choose the observation level in such a way that the relevant information can be collected and used
- Before mapping any process you should be aware of which analysis form you want to apply afterwards since this may have an impact on the required space as well as tools used for inspecting the process
- When the process is inspected personal accusations should be avoided
- Make sure there is enough space for the visualization and enough facilitation material

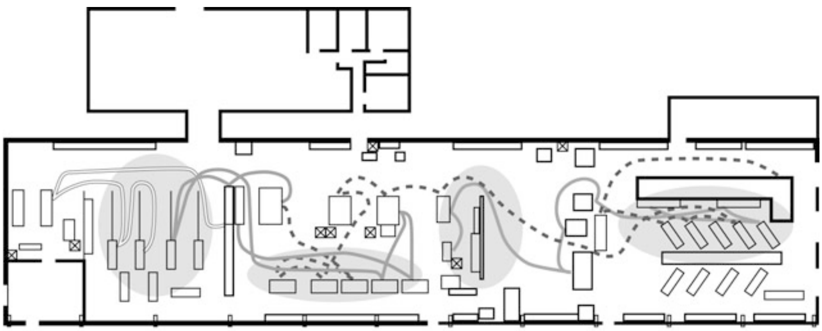
Spaghetti Diagram

Term
Spaghetti Diagram

When
ANALYZE, analyze the process; IMPROVE, consolidate solutions, mapping of TARGET process

Goal
- Identify suboptimal motion of raw material, half-finished products and people in the current process (ANALYZE phase)
- Optimize the layout in order to optimize value adding activities in the TARGET process and/or to minimize non-value adding activities in the TARGET process (IMPROVE phase)

Procedure
1. Draw the layout of the relevant area including all objects of furniture and facilities
2. Draw all movements of material, tools and employees and mark them as such (e.g. by different colors and symbols)
3. Already recognized weak points (waste) are to be marked, routes which are critical with respect to efficient procedure, e.g. because of intersections of foot paths and traffic ways, "traffic jam" or dangers are to be highlighted



Tip

- Make use of the layout for inspecting the process in order to record actual movements on site
- Use different colors for the ways of different product variants and/or different employees
- With a precise Spaghetti Diagram the total path length can be calculated and improvement potential can be quantified in this way
- Also include means of transportation in the graphic (e.g. fork lift) in order to identify areas with high accident risk; divide these areas further into primary and secondary areas according to the risk of accident
- Bear in mind that the Spaghetti Diagram can quickly become confusing for long processes with many variables (different materials, people); you should thus focus on the key questions which you want to analyze with this tool

Process Flow Chart

Term
Flow Chart, Process Flow Chart

When
ANALYZE, visualization and analysis of AS IS process; IMPROVE, consolidation of solutions, mapping of new TARGET process; CONTROL, basis for sustaining the improvements and controlling the process

Goal
- Visualize processes simply and quickly
- Verify potential causes
- Identify further potential causes
- Identify improvement potential

Procedure
1. Determine start and stop points by using a high-level map (e.g. a SIPOC) as a context, formulate them as an event and mark with color. ("order is established")

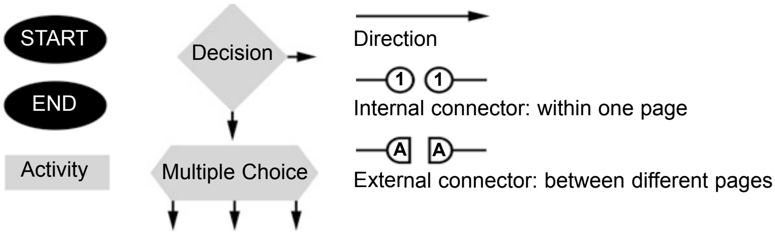
2. Identify the process steps with the help of brainstorming before drawing up the actual chart; each step consists of a noun and a verb (e.g. "collect orders", "check credit data")

3. Sort the process steps according to their actual sequence and include any information gained from process inspections or walk-throughs with respect to the process steps

4. Include decision steps, branches and any loops

5. Mark known weak points (waste etc.)

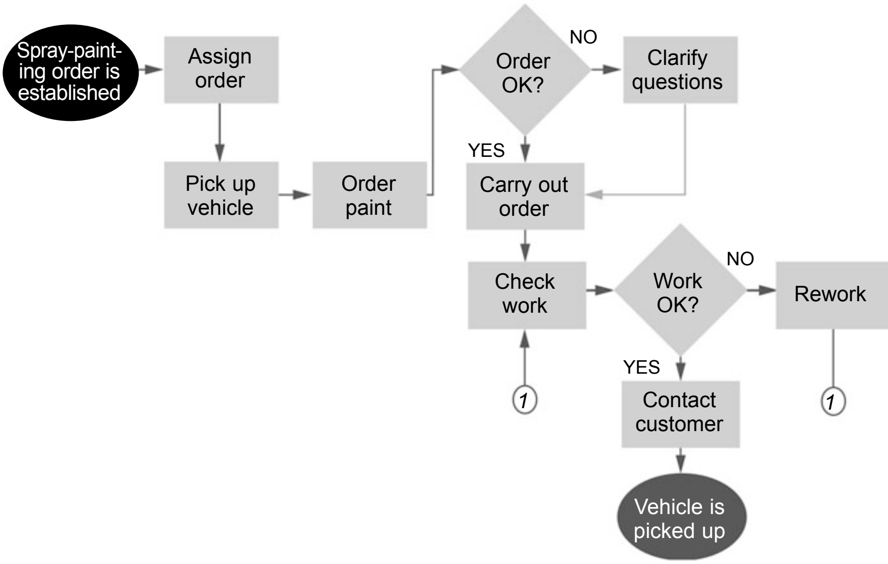
Symbols



Tip

Always draw the "No" branch in the decision diamond e.g. to the right hand side, the "Yes" branch always downward; this standardized procedure helps to avoid misunderstandings

Example



CFD

Term
Cross Functional Diagram (CFD), Swim Lane Diagram

When
ANALYZE, to visualize and analyze the AS IS process; IMPROVE, to map the new TARGET process

Goal
- Visualize processes displaying relevant interfaces and hand offs to;
- Verify potential causes
- Identify further causes
- Identify areas for improvement

Procedure
1. Identify people involved in the process, write down their functions on cards and organize them vertically on a wall or board

2. Mark start and stop points with colors

3. Formulate process steps as noun and verb (e.g. test order), start and stop points as an "event" (e.g. "parcel is available")

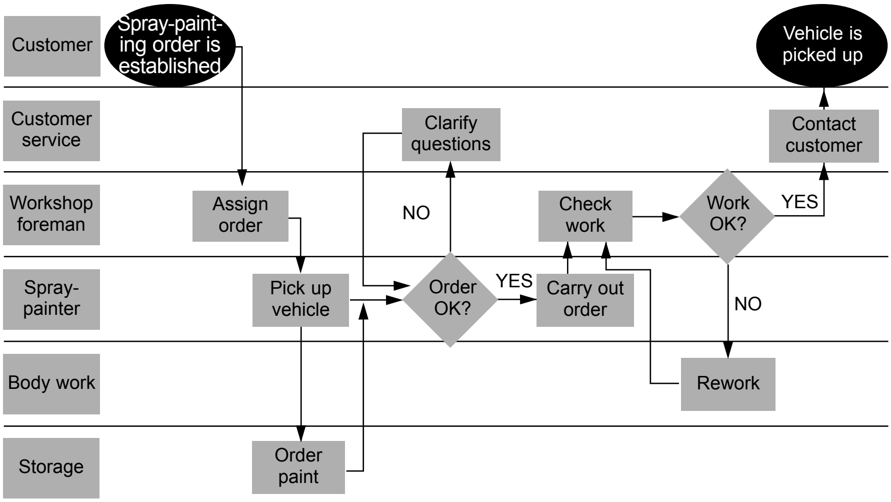
4. Sort the process steps according to their actual sequence and include any information gained from the process inspections and walk-throughs against the appropriate step

5. Assign the steps to their respective function

6. Map decisions and loops

7. Mark known weak points (waste etc.)

Example



Tip

- Before starting the mapping exercise the "swim lanes" should be marked as horizontal lines on the wall or board with a distance of just more than one card height between them
- Use Post-Its® or facilitation cards in order to ensure clarity, visual impact and to make sure handoffs between departments, team etc. are clearly marked.
- Always talk about functions and tasks rather than people
- In the TARGET process (IMPROVE phase) you should always map the process first, then the functions; the following rule applies: "organizational structure follows the operational structure"

Value Stream Map

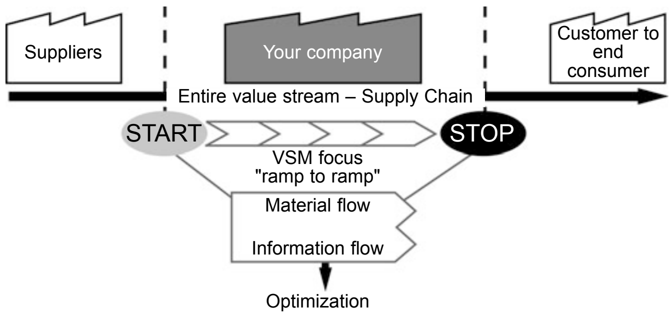
Term
Value Stream Map (VSM)

When
ANALYZE, visualization and analysis of AS IS process; IMPROVE, consolidating solutions, mapping of new TARGET process

Goal
- Identify sources of waste by mapping material flow, information flow and the other process relevant data (e.g. setup times, idle time, scrap, etc.)
- Identify improvement potential in order to reduce the process lead time

Procedure

1. **Define processes and products:**
   Draw up an overview of all relevant process information on a high level by using a SIPOC diagram; define the Process Scope by marking the start and stop events



Documentation of the AS IS state with the help of a top down process diagram; vertical division of core processes into individual sub-processes, assists identification of the right observation level for sketching the value steam; identify of customer relevant product groups or families in order to be able to focus on the areas in the Value Stream Map which have the greatest effect on the customer (ABC/XYZ Analysis)

2. **Visualize the process diagram:**
   Visualization of the entire value stream: The observation sequence takes place "upstream" starting from dispatch

Process step | Customers/ suppliers | Transport | Product to customer | 300 parts 7 days Inventory

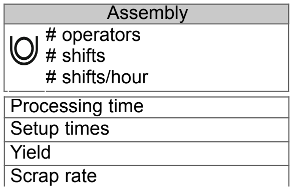
3. **Define material and information flow:**
   Mark directions in which the material flows in the process using push and pull arrows; include all inspections of goods received and quality checks

Push arrow | First-in-first-out sequence | Scrap | Rework | Pull Material flow

   Afterwards document the flow direction of the information, from incoming orders which have been released for production (type and frequency of customer orders, production releases, procurement of orders)

Electronic information: type, frequency, and method | Nonelectronic information: type, frequency, and method

4. **Define process data boxes and times:**
   Document all process relevant data (processing time, setup time, scrap rate, yield, machine availability, etc.); define the process related lead times and proportional, value adding and non-value adding times; calculate the metrics for determining the Process Efficiency.

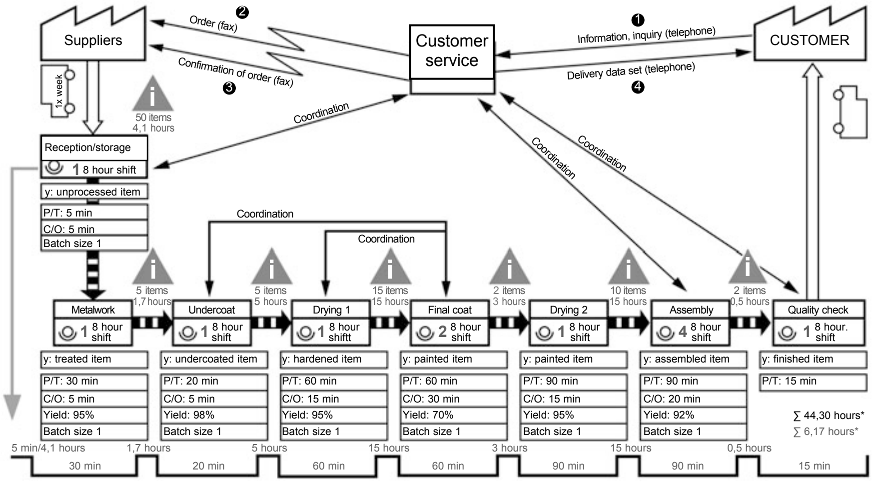


Process data

5. **Validate the AS IS state:**
   Has everyone involved in the process checked the draft Value Stream Map to validate, material and information flows and any interfaces identified?

Example

(* value adding, * non-value adding)



Tip

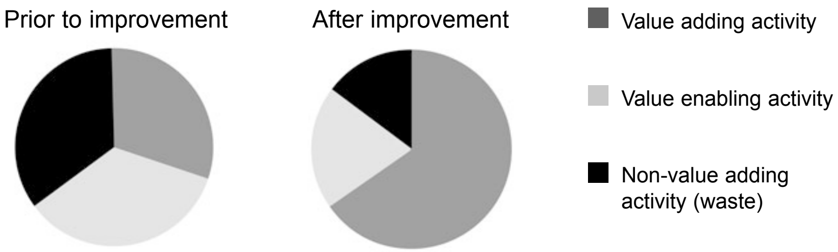
- Cross check the measurements noted down in the data boxes with the existing metrics and their operational definitions
- Check the information (process steps, information and material flow) on site
- Use uniform measurement units, e.g. minutes/hours

Value Analysis

Term
Value Analysis*, Analysis of Value Added, Waste Analysis (*not to be confused with the Function Analysis/Value Engineering in the product development process)

When
ANALYZE, after mapping the process (Process Flow or Swim Lane Diagram, Value Stream Map)

Goal
Describe the nature of work undertaken in order to maximize the proportion of value adding activities for the customer and minimize waste



Procedure
1. Use the process map created by the project team
2. Question each activity with respect to its value adding character and mark with color based on the nature of value attributed
3. Any non-value adding activities are to be assigned to one of the seven types of waste (TIMWOOD)

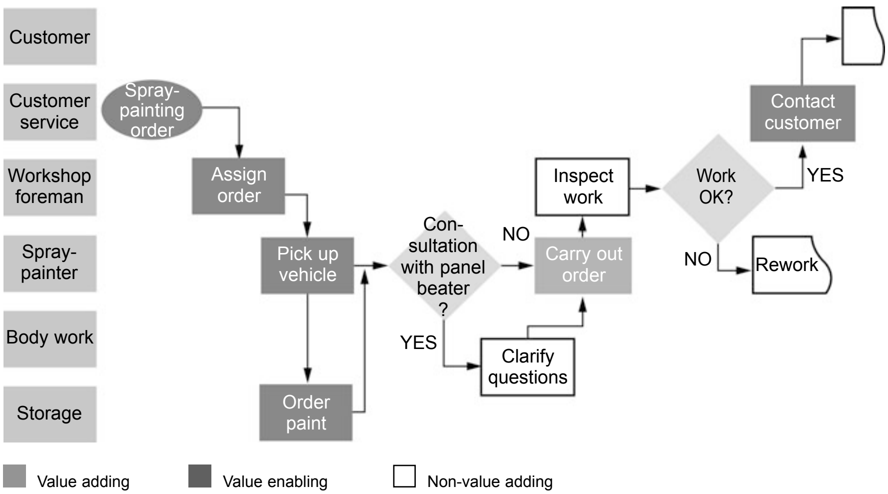
- **Value-adding activities:**
  Activities which, from the customer's viewpoint, have a positive effect on the product or service that raises its value the first time they are performed. Or put another way – the customer is prepared to pay for it, it materially changes the product and it is done right first time! In the end, these steps

alone, lead to a situation where the customer requirements are met completely and economically. The principle aim is to raise the share of these activities.

- **Non-value adding activity:**
  These are activities which are not regarded as essential, from the customer's point of view, and for which the customer would not be prepared to pay. Non-value adding activities are to be eliminated and/or reduced to a minimum within the scope of the process improvement. It is frequently not possible to relinquish non-value adding activities completely because sometimes they are an integral part of the process. Only a complete redesign might address these.

- **Value enabling activities:**
  These are activities which do not add value per se. Value enabling activities are usually required or at least supportive of, process performance. None the less it is best to minimize these activities

Example



Tip

- An evaluation of value adding and non-value adding activities requires a basic knowledge of the company's core competence, e.g. in the case of a transport company the transport from and to the customer is value adding, for a production company transport is non-value adding
- When you do Value Analysis you should be sensitive to the feelings of those involved. Labeling someone’s work as a non-value adding activity can create strong emotions, if their jobs are at stake, then, even more so.
- Marking the process steps with different colors has proven worthwhile in the past (with the help of adhesive stickers or a colored pencil): e.g. red = non-value adding activities, green = value adding activities, blue = value enabling activities
- In the event that a discussion develops about one process step then mark it as waste because clearly there seems to be potential for optimization

Seven Types Of Waste

In the 1970's Taiichi Ohno, father of the Toyota production system, defined "Seven Types of Waste" (abbreviation: TIMWOOD)

Seven Types of Waste in PRODUCTION		
T	**Transport**	• Movement of materials/products from one place to another • Repacking, transport on conveyor belts and bands, etc., unless paid by the customer
I	**Inventory**	• Material/product waiting to be processed • Storage, buffer, temporary stocks and non-authorized l stocks
M	**Motion**	• Superfluous movements or bad ergonomics • Workplaces are far away from one another, searching for materials, etc.
W	**Waiting**	• Delays within work flow • Waiting for material, releases, downtimes, etc.
O	**Overproduction**	• More is produced than necessary • By the avoidance of setup procedures • Exploitation of productivity as key control parameter
O	**Overprocessing**	• More value adding work than the customer is willing to pay for • Mis-understood and/or unknown customer needs etc.
D	**Defects**	• Items that must be corrected and/or scrap • Poor machine settings, materials, etc.

Seven Types of Waste in ADMINISTRATION		
T	**Transport**	• Unnecessary transport of information • Movement of documents and/or passing through hierarchies
I	**Inventory**	• Unnecessary inventories such as invoices, applications • Documentation of concluded projects, unused working aids, data banks and multiple filing
M	**Motion**	• Indirect routes, unnecessary journeys • Distance covered when searching for documents, consulting colleagues, ergonomic obstacles
W	**Waiting**	• Waiting times/idle periods • Waiting for decisions, returns, hand overs, warm-up time of office equipment
O	**Overproduction**	• Superfluous information, extra copies etc. • More information than the customer, the following processes or the current process phases require (emails, copies, memos)
O	**Overprocessing**	• Useless activities e.g. over elaborate power point presentations • Unread reports, statistics and protocols, unnecessary data entries and copies
D	**Defects**	• Misaligned document prints. • Illegible faxes and notes, incomplete information, inaccurate data entry

- In addition to the seven classic types of waste identified by Ohno others have also been suggested:
  – Unused human potential and/or talent (including creativity)
  – Inappropriate use of resources (high consumption of energy and water and/or material effort)

DEFINE
MEASURE
ANALYZE
IMPROVE
CONTROL

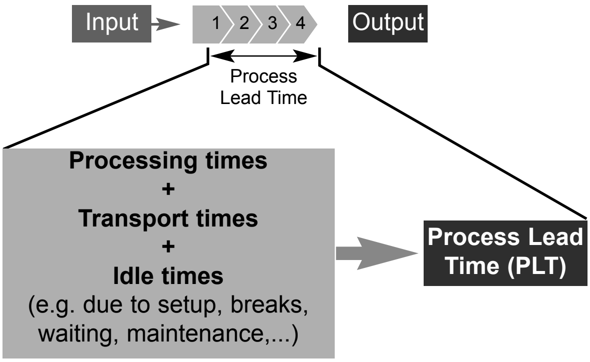
Time Analysis

Term
Time Analysis

When
ANALYZE, process analysis; after mapping the process (Process Flow or Swim Lane Diagram, Value Stream Map) and frequently based on Value Analysis

Goal
- Determine the factors influencing the process lead time and uncover potential for improvement
- Show the time impact of non-value adding and indeed value enabling process steps on process lead time and recognize approaches for change and/or improvements in this way

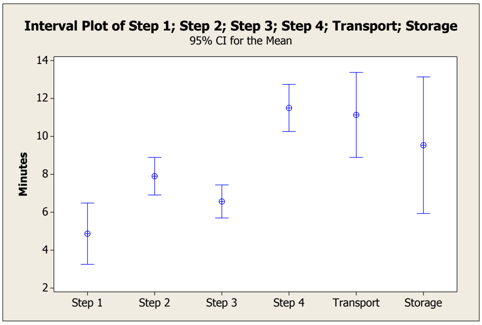
Procedure
1. Define operational start and stop points for process lead time



2. Record the individual components and/or collect them from reliable existing sources (e.g. time recordings, activity reports, shift logbooks, diaries, calendars, telephone messages, files) and verify them if required; the times for processing, transport and waiting are also part of this (setup times, time for breaks, idle and waiting times, etc.)

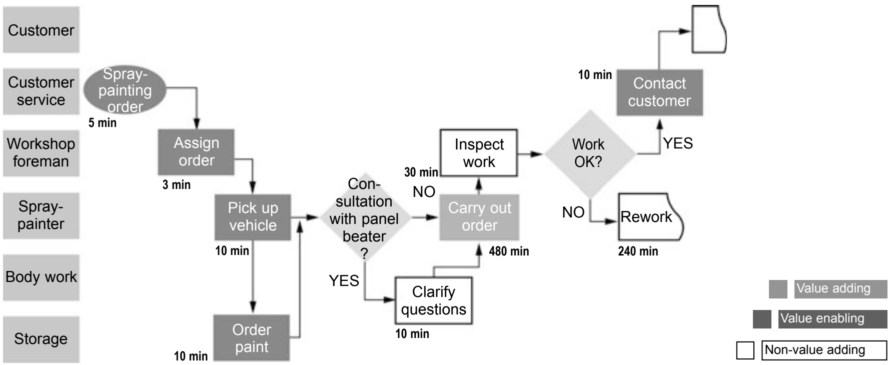
3. Document the times for each process step or summarize the times over several steps (sum of times) if very difficult to get individually
4. Given the relationship between WIP (Work in Process) and the Exit Rate of a process and process lead time levers for optimizing WIP and Exit Rate the Process Lead Time should be identified

Example 1: Time Analysis in the Interval Plot



- An Interval Plot indicates the average time (e.g. for each process step) and the corresponding Confidence Interval
- This gives a reflection of the spread as well as the mean
- Graphical representation helps identify the largest drivers of Process Lead Time and together with Value Analysis helps focus on those areas with greatest potential

Example 2: Mapping of time analysis in process diagrams



Determination of Process Lead Time using Little's Law*

$$\text{PLT} = \frac{\text{Work in Process (WIP) [Item]}}{\text{Exit Rate [Item/Time]}} \ \text{[Time]}$$

Little's Law says: The average Process Lead Time of a product in a (production) system (PLT), whose state is stable, equals the average amount of work in progress (WIP = Work in Progress) divided by the average exit rate, i.e. the number of finished products (output quantity) which leave the system during a specific time period.

- Little's Law is used in the ANALYZE phase in order to find out the average Process Lead Time by conducting a snapshot analysis
- It shows potential factors influencing the Process Lead Time: These might target either an increase in exit rate and/or a decrease of WIP

Example

- On average 5 vehicles in the process (WIP = 5 items)
- 10 vehicles are spray-painted on average per day (exit rate = 10 items/day)

Calculation of PLT according to Little:

$$\text{PLT} = 5 \text{ items}/10 \text{ hours/day} = 0.5 \text{ days}$$

Tip

- Please take into account that the processing time can also comprise non-value adding times since not every processing step is value adding per se
- Take into account the guidelines from the Measurement System Analysis when collecting times
- Time data does not need to be available for all process activities; in some cases cumulative times suffice
- If no data is available: Estimate the time first and measure it in the next step; it often suffices to calculate the mean value with just five measured times
- It is often sufficient to record only the total Process Lead Time and the processing times; idle and/or waiting times result from the time difference

* Little's Law, also known as Little's Theorem or Little's Formula, is a significant law in queuing theory. It was formulated and proven by John D. C. Little in 1961.

- Bear in mind that Little's Law always orients itself towards the average times and quantities; snapshot recordings can deviate from the law's results
- When discovering a wide variation in a process step’s time it may be that there are two different activities. Further investigation may be revealing

Process Efficiency

Term
Process Efficiency

When
ANALYZE, process analysis, analysis of AS IS process; IMPROVE, implement solutions, implementation of the improved or new process, e.g. of Pull Systems

Goal
Determine the current Process Efficiency in order to identify improvement opportunity by comparison with industry and other benchmarks

Procedure
1. Determine the average Process Lead Time of an output unit in the observed process

2. Evaluate the process steps as value adding, value enabling and non-value adding activities (cf. "Value Analysis")

3. Form the sum of times of all value adding activities

4. Identify the Process Efficiency

$$PE = \frac{\text{Value Adding Time}}{\text{Process Lead Time}} \ [\%]$$

Tip
- "Best Practice" values for the Process Efficiency are up to 25% with machine processing, 80% with assembly work stations; and the maximum Process Efficiency in administrative processes is usually 50%
- Most processes which are analyzed within the context of a DMAIC project frequently display a Process Efficiency of less than 10%; as described this has a negative impact on the Process Lead Time and thus the company's ability to react

Capacity Analysis

Term
Capacity Analysis, identification of constraints

When
ANALYZE, process analysis

Goal
- Determine the process's capacity
- Recognize constraints which lead to the fact that the quantity requested by the customer can't be produced

Procedure

1. **Determine the exit rate**
   The process step with the lowest capacity is the bottleneck of the process; each process has exactly one bottleneck; the bottleneck determines the exit rate of the entire process, i.e. the maximum capacity of the process

2. **Determine the amount requested by the customer**
   The amount per time unit requested by the customer and/or market is the takt rate, frequently referred to as customer takt; the reciprocal of the takt rate is the takt time – it indicates the maximum production time per unit for fulfilling the customer requirement

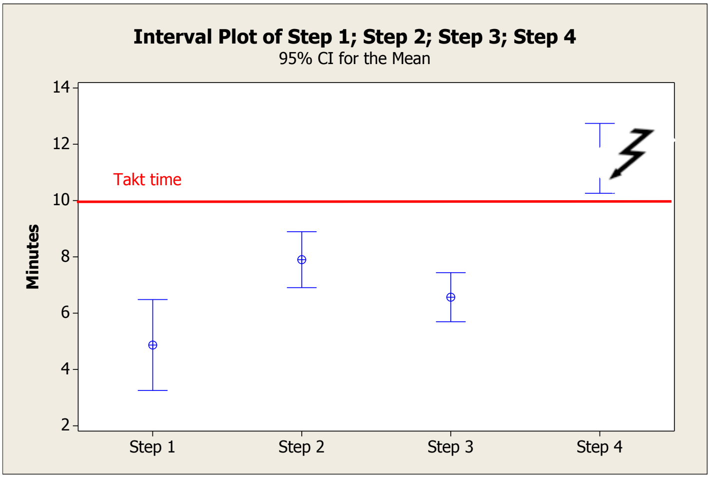
$$\text{Takt rate} = \frac{\text{Number of units to be produced (according to customer need)}}{\text{Available production time}}$$

$$\text{Takt time} = \frac{\text{Available production time}}{\text{Number of units to be produced (according to customer need)}}$$

3. **Compare exit rate and takt rate**
   - If the exit rate is **bigger** than the takt rate the process can satisfy customer demand; it is essential to check if over capacity is to be kept or not, e.g. due to seasonal fluctuations (overcapacity can also be a waste – Overprocessing)

- If the exit rate is smaller than the takt rate the demand cannot be fulfilled – a constraint exists
  In the short term this means a potential turnover loss; in the long run this can even lead to high customer dissatisfaction and loss of market share

4. Analyze further figures
Determine and analyze further potential constraints if necessary



NB: Takt time is the inverse of Takt rate so in this example we would expect to see times below the line. Step 4 is therefore a constraint.

Process Flow Analysis

Term
Process Flow Analysis, Analysis of Process Flow, Analysis of Weak Points

When
ANALYZE, process analysis, as part of process understanding, generally as a summary of process analysis

Goal
Identify any other weak points in addition to those identified in the Value, Time and Capacity analysis that has been carried out and to verify causes

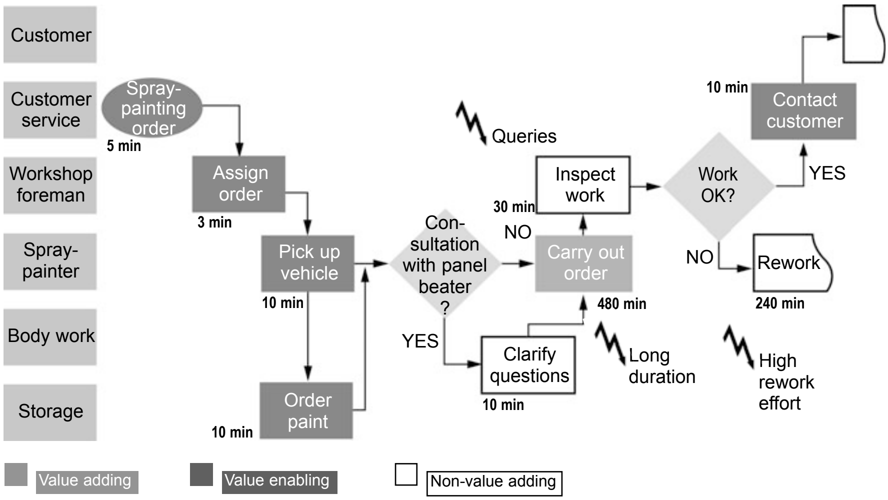
Procedure
1. Go through the visualized AS IS process step by step once again and check it with respect to the following questions:
   a. Does this conform to strategy
   b. Is there unnecessary complexity (interfaces, process loops, defect frequency, occurrence of waste, double work)
   c. Is the process flow logical with regard to: sequence, inputs and outputs, queries, transition times etc.?
   d. Is documentation and responsibility appropriately defined (effort, clear scoping)?
   e. Are materials suitable, ergonomically arranged and are machines, tools, IT applications available?
   f. Is the work environment clean, safe and tidy?

2. Highlight identified weak points (e.g. in the form of a flash symbol) and explain

Tip
- When conducting the process analysis you should also consult experts who know the actual As Is process well and who communicate openly about its' weaknesses

- Determine the weak points preferably after the process inspection has been completed; this has the advantage that the process inspection and the associated information flow are not interrupted and/or disturbed by discussing the weak points. Also it does not offend those who are actually carrying out the process at the time.

Example



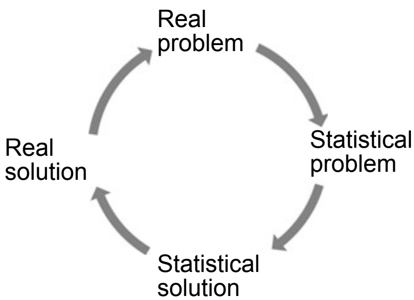
Analyze Data

Term
Data Analysis

When
ANALYZE, IMPROVE, CONTROL

Goal
- Test the impact of the potential influencing factors (Xi, Xp) on the process results (Y)
- Identify further potential causes
- Verify potential causes

Procedure
- Formulate a specific question based on the potential cause and the real observed problem
- Formulate the statistical problem, i.e. the statistical hypotheses. The formulation of the statistical problem will determine the statistical tool to be used.
- Apply a suitable tool and draw a statistical conclusion based on your data and the test result (statistical solution)
- Interpret the result and translate into a real solution or at least the requirements that the real solution has to deliver



Overview statistical methods

	Discrete output measurements	Continuous output measurements
Discrete influencing factors (X_i, X_p)	• Hypothesis tests 1. 1 Proportion Test 2. 2 Proportion Test 3. Chi-Square-Test	• Hypothesis tests 1. 1 Sample t-Test 2. 2 Sample t-Test 3. ANOVA 4. Test for equal variances 5. Non-parametric Tests • Design of Experiments
Continuous influencing factors (X_i, X_p)	• Logistic regression	• Correlation and regression • Design of Experiments

Data Stratification

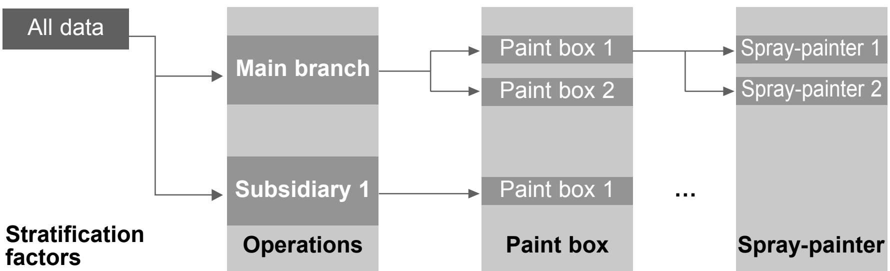
Term
Stratification, Data Stratification

When
ANALYZE, , analyze data, verification of potential causes

Goal
- Find graphical evidence that a potential cause may indeed be valid by splitting data into logical sub categories that represent the potential cause and displaying against each other hoping that a difference can be observed
- Identify previously unidentified potential causes that can be statistically assessed.
- Structure data in such a way that a problem can be demonstrated and/or explained, e.g. when a problem occurs at different times, at different places, or under different conditions

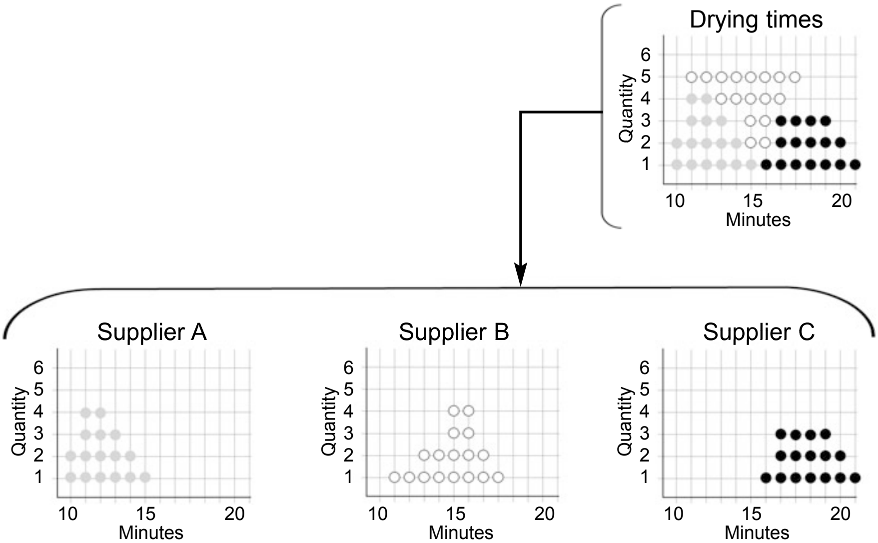
Procedure
1. Group data into meaningful categories e.g.
   - Who: People, departments, suppliers
   - What: Products, services
   - Where: Sites, regions
   - When: Weekdays, seasons
   - How: Machines, equipment, material

Example



2. Depict and analyze the stratified data graphically. If no relationships are recognizable, this can be due to the fact that:
   - the causes haven't been correctly identified: stratify the data further and in greater detail
   - the selected stratification factors are not causes after all and/or don't influence the result (Y); Sometimes no visible difference is also a result!

Example

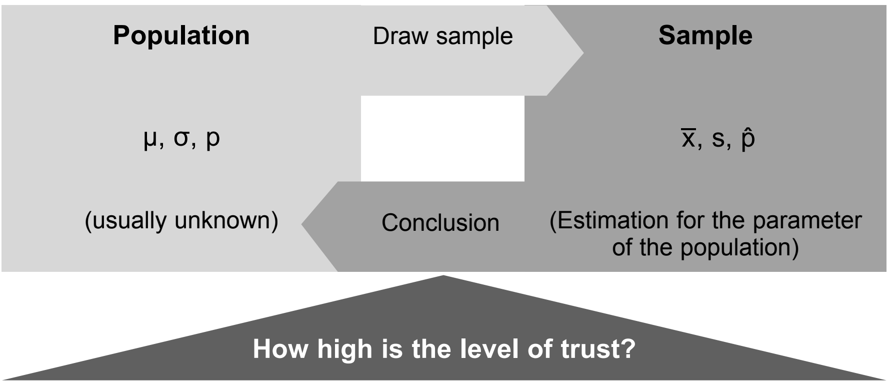


Confidence Interval

Term
Confidence Interval

When
ANALYZE, for the preparation of the data analysis

Goal
- Get information about the area in which a requested parameter is located with the required level of confidence.
- Quantify, based on a sample, a range for which the statement about the population parameter will be valid.



Confidence Intervals (CI)
...express confidence in an estimation that it actually corresponds to the correct value with a specific probability

DEFINE
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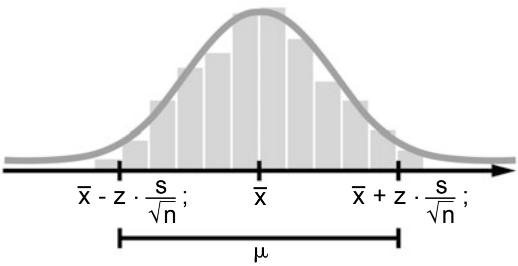
Procedure

From estimations of the mean value $\bar{x}$ and the standard deviation s, the Confidence Interval belonging to the z value is obtained together with the Confidence Level α.



$$\left[\bar{x} - z \cdot \boxed{\frac{s}{\sqrt{n}}};\ \ \bar{x} + \boxed{z} \cdot \frac{s}{\sqrt{n}};\right]$$

SE Mean (Standard Error of Mean)
The smaller the sample size or the bigger the standard deviation the less precise is the prediction of the mean value.

Quantile of normal distribution
If the SE Mean is multiplied by $\pm z_{0.975} = 1.96$, the CI around $\bar{x}$ displays the area for the mean value of the population (μ) in which it is located with a probability of 95%.

Tip

- Confidence Intervals (CI) reflect the quality of the collected data with respect to making the decision:
  - Narrow CIs provide better precision for decisions
  - If CIs are too wide bigger samples have to be collected
- Decisions of economic significance require a correspondingly big and reliable data basis
- ATTENTION: Uncertainty always exists!

Example

Calculate the SE Mean

Sample A

N = 10; $x = 14.07$

$s = 3.00333$

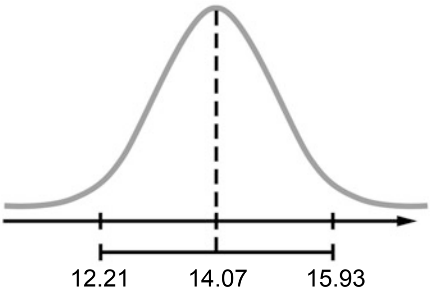
$$\text{SE Mean} = \frac{3.00333}{\sqrt{10}} = 0.95$$

Calculate the 95% Confidence Interval

$$\left[\bar{x} - z \cdot \frac{s}{\sqrt{n}};\ \ \bar{x} + z \cdot \frac{s}{\sqrt{n}};\right]$$

0[14.07 - 1.96 · 0.95; 14.07 + 1.96 · 0.95]
= [12.21; 15.93]

Graphic Illustration



DEFINE
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CONTROL

Hypothesis Tests

Term
Hypothesis Testing, Hypothesis Tests, Significance Tests, Statistical Tests

When
ANALYZE, IMPROVE, CONTROL

Goal
- Make objective decisions about the validity of assumptions made or to be made, e.g. about the parameters of a population
- Verify potential causes
- Check for statistical differences between two or more process outputs or against a target
- Show statistically significant improvements after their implementation

Procedure
A statistical test is a procedure quantifying the statistical significance of a hypothesis for one or more samples using a test statistic. Statistical tests are also called Hypothesis or Significance Tests.

Every statistical test involves the formulation of two complimentary assertions: the null hypothesis and the alternative hypothesis.

- **The null hypothesis (H_0)**
  describes the supposition that a tested parameter equals a given value or that different parameters are all equal when they are compared. The null hypothesis always describes the parity condition i.e. difference cannot be detected.

- **The alternative hypothesis (H_A)**
  on the other hand, describes the supposition that a tested parameter is unequal to a given value or that the comparison of different parameters will show that at least one of these is different. A significant difference can be detected i.e. parity does not exist with at least one of the parameters being tested.

Statistical tests can only identify differences but not correspondence. Thus, the null hypothesis is usually established in order to be rejected. The goal of the alternative hypothesis, also called working hypothesis, is to reject the null hypothesis as inapplicable.

Making decisions based on a statistical test entails a certain degree of uncertainty: One cannot be 100% sure that this decision is correct. However, statistical tests are designed in such a way that the probability of making the wrong decision is minimized.

The null hypothesis is rejected when the result of a sample shows that the validity of the established null hypothesis is unlikely. What is ultimately considered to be unlikely is determined by the so-called significance level. The most frequently used significance levels are 0.05 (=5%) and 0.01 (=1%). The significance level (α) indicates the maximum risk to which the organization is prepared to expose itself to making a mistake in rejecting the null hypothesis i.e. any statistical test that returns a probability* (of making a mistake in rejecting the null) of less than the level of significance will result in the null hypothesis being rejected and the alternative being accepted.

- Test decisions are based on sample values; depending on which parameter value is actually right (in the population) the decision can be either correct or incorrect; therefore two errors are possible:

		Reality	
		H_0	H_A
Decision	H_0	Correct decision	Type II error (β error)
	H_A	Type I error (α error)	Correct decision

  - Type I error (α error): Rejection of null hypothesis H0, although it is correct
  - Type II error (β error): Failure to rejecting the null hypothesis although it is wrong

* this is known as the p value and will be discussed shortly

DEFINE
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ANALYZE
IMPROVE
CONTROL

Example trial hearing

H_0	The accused is innocent
H_A	The accused is guilty
α error	The accused is pronounced guilty although he is actually not guilty
β error	The accused is acquitted although he is actually guilty

For a statistical test both α as well as β should be kept as small as possible (usually $\alpha = 0.05$ and $\beta = 0.10$). However, the following applies: The smaller the α value selected the larger β becomes!

The p value which is linked with the result of every statistical test, is calculated from the test statistic on the basis of the existing sample and thus indicates the empirical probability for a Type One Error. If the calculated p-value is smaller than the α value the null hypothesis can be rejected because the empirical error probability is smaller than the maximum acceptable risk.

The p-value corresponds to the level of risk you take, that Ho is actually true, when rejecting the null hypothesis.
Example: With $\alpha = 0.05$ the null hypothesis is rejected if $p = 0.01$. A residual risk of 1% remains that the null hypothesis is right after all.

Note that α and β are conditional probabilities of making a wrong decision and do not reflect the probability that the null or the alternative hypothesis apply.

A statistical test comprises the following steps:
1. Define problem and goal (What is being tested for what?)
2. Formulate hypotheses (H_0: parity condition, things are equal, the same as etc)
3. Set the significance level α (usually $\alpha = 0.05$ or $\alpha = 0.01$). Usually determined by the organization as a policy and not set on a test by test basis!
4. Select a suitable statistical test (e.g. Two Sample t-Test)
5. Conduct the test with the help of a statistics program (e.g. Minitab®)
6. Interpret the test statistic and p-value
7. Make a decision whether to reject the null hypothesis or not
8. If H_0 is not rejected check the level of β for your particular test using statistical software such as Minitab®!

There are a great number of statistical hypothesis tests. The most frequently used tests in practice are described in the following table:

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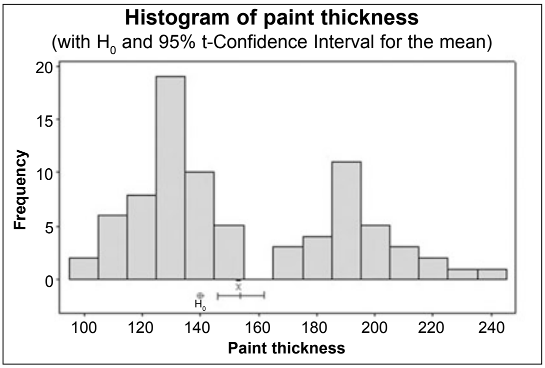
Test	Hypotheses	Prerequisites
Continuous data: Tests for mean value		
t-Test, 1 sample (One-sample t-test)	$\mathbf{H_0}$: $\mu = \mu_{Targetl}$ $\mathbf{H_A}$: $\mu \neq \mu_{Target}$	Independent and normally distributed data **or** $n \geq 30$
t-Test, 2 samples (Two-sample t-test)	$\mathbf{H_0}$: $\mu_1 = \mu_2$ $\mathbf{H_A}$: $\mu_1 \neq \mu_2$	Independent and identical normally distributed (iid) samples **or** $n \geq 30$
One Way ANOVA	$\mathbf{H_0}$: $\mu_1 = \mu_2 = \ldots = \mu_n$ $\mathbf{H_A}$: $\mu_i \neq \mu_j$ **for at least 1 pair i ≠ j**	i. Independent and identical normally distributed (iid) samples ii. $\sigma_1^2 = \sigma_2^2 = \ldots = \sigma_n^2$ **or** $\mathbf{n}_1 = \mathbf{n}_2 = \ldots = \mathbf{n}_n$
Wilcoxon Test	$\mathbf{H_0}$: $\tilde{\mu}_1 = \tilde{\mu}_{Target}$ $\mathbf{H_A}$: $\tilde{\mu}_1 \neq \tilde{\mu}_{Target}$	Independent and symmetrically distributed sample
Mann-Whitney Test	$\mathbf{H_0}$: $\mathbf{F}_1(Z) = \mathbf{F}_2(Z)$ $\mathbf{H_0}$: $\mathbf{F}_1(Z) \neq \mathbf{F}_2(Z)$ *	Independent and identically distributed (iid) samples
Kruskal-Wallis Test	$\mathbf{H_0}$: $\mathbf{F}_1(Z) = \mathbf{F}_2(Z) = \ldots = \mathbf{F}_c(Z)$ $\mathbf{H_0}$: $\mathbf{F}_i(Z) \neq \mathbf{F}_j(Z)$ *	Independent and identically distributed (iid) samples"
Continuous data: Tests for variance		
Tests for variance, 1 sample (χ^2-Test)	$\mathbf{H_0}$: $\sigma^2 = \sigma^2_{Target}$ $\mathbf{H_0}$: $\sigma^2 \neq \sigma^2_{Target}$	Independent and normally distributed sample
Tests for variance, 2 samples (F-Test)	$\mathbf{H_0}$: $\sigma_1^2 = \sigma_2^2$ $\mathbf{H_0}$: $\sigma_1^2 \neq \sigma_2^2$	Independent and identical normally distributed (iid) samples
Test for equal variance (Bartlett)	$\mathbf{H_0}$: $\sigma_1^2 = \sigma_2^2 = \ldots = \sigma_n^2$ $\mathbf{H_0}$: $\sigma_i^2 \neq \sigma_j^2$	Independent and identical normally distributed (iid) samples
Levene's Test	**for at least 1 pair i ≠ j**	Independent data
Diskrete Daten: Tests auf Anteile		
Test of proportions, 1 sample (1-Proportion Test)	$\mathbf{H_0}$: $\mathbf{p} = \mathbf{p}_{Target}$ $\mathbf{H_A}$: $\mathbf{p} \neq \mathbf{p}_{Target}$	i. Independent and binomially distributed data ii. $\mathbf{n} \geq 100$, $(\mathbf{n} \cdot \mathbf{p}) \geq 5$ **und** $\mathbf{n} \cdot (1-\mathbf{p}) \geq 5$
Test of proportions, 2 samples (2-Proportion Test)	$\mathbf{H_0}$: $\mathbf{p_1} = \mathbf{p_2}$ $\mathbf{H_A}$: $\mathbf{p_1} \neq \mathbf{p_2}$	i. Independent data, similar # and binomially distributed samples ii. $\mathbf{n} \geq 100$, $(\mathbf{n} \cdot \mathbf{p}) \geq 5$ **und** $\mathbf{n} \cdot (1-\mathbf{p}) \geq 5$
Chi-square test	$\mathbf{H_0}$: every sample has the same proportion $\mathbf{H_A}$: the proportion of at least one sample differs from the others	The expected cell counts are all ≥5
Continuous data: Tests for distribution		
Normal distribution	$\mathbf{H_0}$: the data is normally distributed $\mathbf{H_A}$: the data is not normally distributed	No prerequisites

Example

1.
Graphic result:
The difference between the target value and the mean value of the sample is statistically significant: The Confidence Interval around the mean value does not comprise the assumed value of 140 micrometers.



2.
Analytical result:
The observation is confirmed in the Session Window: Here $p < 0.05$. The hypothesis H_0 can be rejected assuming the significance level = 0.05.
There is a 0.1% chance of making a mistake in rejecting the null hypothesis.

```
One-Sample T: Paint thickness

Test of mu = 140 vs not = 140


Variable          N    Mean   StDev   SE Mean             95%-CI      T      P
Paint thickness  80  153.86   35.65      3.99  (145.92; 161.79)  3.48  0.001
```

Tip

- Non-parametric tests (Levene's, Wilcoxon, Mann-Whitney, Kruskall- Wallis) have the advantage that they don't require distribution assumptions; the big disadvantage of non-parametric procedures is that when distribution assumptions are satisfied the power is not as high as if you were using the

parametric test, i.e. the probability of detecting a difference if a difference exists is lower than in the case of parametric tests
- If the null hypothesis is rejected a breach of the distribution assumption in parametric tests can be ignored. However, if the null hypothesis cannot be rejected and a violation of the prerequisites exists the probability of making a beta error increases (the difference is not recognized). In this case it must be attempted to fulfill the test's prerequisites or to select a test requiring fewer prerequisites
- In order to reduce the complexity with regard to the selection of statistical methods and to ensure the acceptance of methods used we recommend you focus on the parametric tests

Sources of quotation:
Büning, H.; Trenkler, G.: Nichtparametrische statistische Methoden. Second Edition. Berlin, New York: de Gruyter; 485 pp., 1994

Rasch, D.; Teuscher, F.; Guiard, V.: How robust are tests for two independent samples? Journal of Statistical Planning and Inference 137 (2007) 2706 - 2720

Sachs, L.; Hedderich, J.: Angewandte Statistik: Methodensammlung mit R. Twelfth Edition. Berlin, Heidelberg: Springer; 702 pp., 2006

ANOVA/One Way ANOVA

Term

ANOVA, Analysis of Variances, One Way ANOVA, one-factorial variance analysis

When

ANALYZE, verify causes. One factor only – see Two Way ANOVA for two factors

Goal

- Facilitate decisions about the validity of assumptions made, e.g. about the parameters of a population
- Verify assumed causes
- Find out statistical influence of one factor (X) on the considered variable (Y)
- Test the relationship of a discrete, independent influencing variable and a continuous, dependent output measurement

Procedure

1. **Set the response (Y) and input factor (X) as well as the factor levels (X_1, X_2, …, X_n)**
   The independent variable is referred to as a factor, the individual characteristics of the factor as factor levels:
   - One factor: One-factorial variance analysis (One Way ANOVA)

2. **Establish a model and formulate hypotheses with respect to the effects**

The ij-th observation (y_{ij}) …

… and a random error (ε_{ij})

$$y_{ij} = \overline{y} + \tau_i + \varepsilon_{ij}$$

… the effect of the i-th factor level (τ_i), …

… is the result of the total mean value ($\overline{y}$), …

3. Conduct calculations

Basis for the Analysis of Variance is the variance decomposition:

Total variation	**=**	**explained variation**	**+**	**non-explained variation**
Sum of squared total deviation		Sum of squared deviations **between** the factor levels		Sum of squared deviation **within** the factor levels
$\sum_{i=1}^{a} \sum_{j=1}^{n_i} (y_{ij} - \bar{y})^2$	=	$\sum_{i=1}^{a} n_i \; (\bar{y}_i - \bar{y})^2$	+	$\sum_{i=1}^{a} \sum_{j=1}^{n_i} (y_{ij} - \bar{y}_i)^2$
SS_{Total}	=	$SS_{Factor\ levels}$	+	SS_{Error}

y_{ij} is the j-th observation value of the i-th factor levels
$\bar{y}_i$ is the mean value of the i-th factor level
a is the number of factor levels
n_i is the number of observations within the i-th factor level
$\bar{y}$ is the total mean value of all observed values

If the explained spread (between the factor levels) is significantly bigger than the non-explained spread (within the factor levels) it can be assumed that this factor has a significant influence on the response (on the result).

The above formulated null hypothesis $H_0: \mu_1 = \mu_2 = \ldots = \mu_l$
and the alternative hypothesis $H_A: \mu_i \neq \mu_j$
can be formulated alternatively as
$H_0: \tau_1 = \tau_2 = \ldots = \tau_l = 0$ and/or: $H_A: \tau_i \neq 0$ for an i.

Digression
By dividing the sum of squares by the correct number of degrees of freedom, a good estimate of the average spread within and between the factor levels is possible:

$$MS_{Total} = \left(\frac{SS_{Total}}{I \cdot J - 1}\right)$$

$$MS_{Factor\ levels} = \left(\frac{SS_{Factor\ levels}}{I - 1}\right)$$

$$MS_{Error} = \left(\frac{SS_{Error}}{I \cdot (J - 1)}\right)$$

The values $MS_{Factor\ levels}$ and MS_{Error} are measured in ratio to each other. This expression forms the test statistic for the ANOVA test for equal means.

$$F = \frac{MS_{Factor\ levels}}{MS_{Error}}$$

The bigger the average spread between the factor levels is compared to the average spread within the factor levels, the bigger the test statistic (F value) will be, and the more probable it will be to determine a significant difference between the mean values.

4. Analyze results

- Check the significance of factors (and their interactions)
  - Using the Main Effects and Interaction Plots it is possible to visualize the effect and interaction of factor levels
  - By analyzing the p-values it is possible to see the analytical result and measure the risk
- Test the proportion of explained variation
  - The question is how much variation in the data can be explained by the model; for this purpose the explained variation is set in relation to the total variation

$$R^2 = \frac{SS_{Factor\ levels}}{SS_{Total}} \cdot 100\%$$

  - The coefficient of determination (R^2) can assume all values between 0% and 100%; the bigger R^2 is, the bigger is the proportion of the total variation that can be explained by the model; values which are smaller than 80% are an indication of the fact that further factors are required for a fuller explanation of the variation witnessed

- The residuals (error terms) are checked
- The following prerequisites are tested:
  - Are the residuals normally distributed?
  - Is the variation of the residuals equally spread (homogeneous)?
  - Are the residuals independent?

Example

```
One-way ANOVA: Paint thickness versus Operator

Source     DF        SS      MS     F       P
Operator    3     19853    6618  6.24   0.001
Error      76     80571    1060
Total      79    100424

S = 32.56   R-Sq = 19.77%   R-Sq(adj) = 16.60%

                                Individual 95%-CIs for Mean
                                based on pooled StDev
Level   N     Mean   StDev   ---+---------+---------+---------+------
AH     20   129.23   14.30   (-------*------)
AN     20   158.92   31.03             (------*-------)
BF     20   172.83   44.29                    (------*-------)
YM     20   154.46   33.33           (------*------)
                             ---+---------+---------+---------+------
                              120       140       160       180

Pooled StDev = 32.56
```

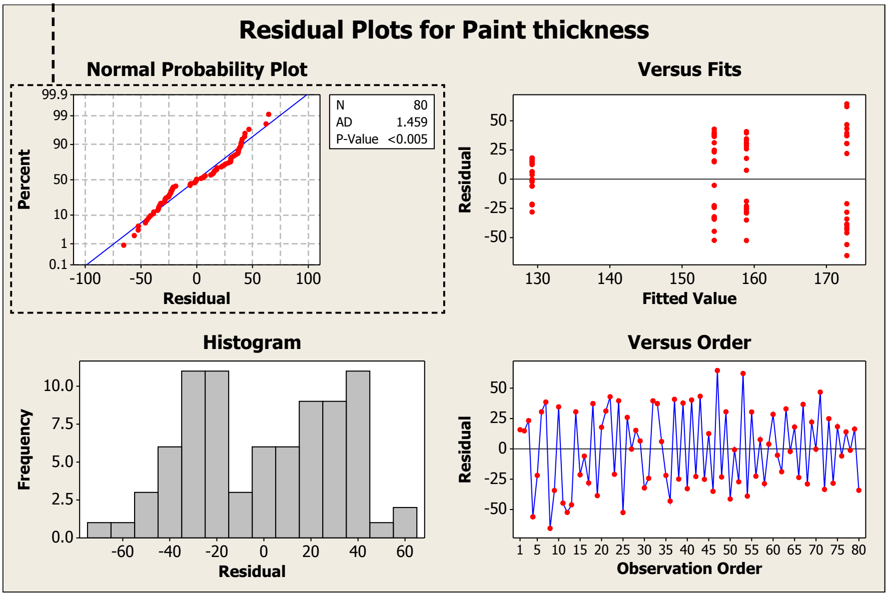
The p-value < 0.05 leads to the rejection of the null hypothesis.

The corrected R^2 of only 16.6% indicates that the model cannot explain the variation in the data well.

The Confidence Intervals confirm the result graphically: The CIs (just) do not overlap, equal mean values cannot be assumed.

The residual charts give important hints as to the goodness of model fit

The analysis of the residuals shows clearly non-normally distributed data. This is confirmed by the significance test (and the p-value belonging to it). The null hypothesis of normally distributed residuals must be rejected.



Non-normally distributed residuals are an indication of an incomplete model, i.e. important factors may not be considered in the model.

ANOVA/Two Way ANOVA

Term
Two Way ANOVA, two-factorial variance analysis

When
ANALYZE, verify causes. Two factors only – see One Way ANOVA for one factor

Goal
- Facilitate the decision about the validity of assumptions made, e.g. about the parameters of a population
- Verify potential causes
- Test the relationship of two discrete, independent influencing variables and a continuous, dependent output measurement

Procedure

1. **Set the response (Y) and input factor (X) as well as the factor levels ($X_1, X_2, \ldots, X_n$):**
   The independent variables are referred to as factors, the individual characteristics of these factors as factor levels
   - Two factors: Two-factorial variance analysis (Two Way ANOVA)

2. **Establish a model and formulate hypotheses with respect to the effects**

The k-th observation under the i-th factor level of factor A and the j-th factor level of factor B (y_{ijk}), …

… and of the random error (ε_{ijk})

$$y_{ijk} = \bar{y} + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk}$$

… is the result of the total mean value, …

… the effect of the i-th factor level of factor A (τ_i), …

… the effect of the j-th factor level of factor B (β_j), …

… the effect of the interaction between the i-th factor level of factor A and the j-th factor level of factor B (($\tau\beta$)ij) …

- The hypotheses for the **effect of factor A** are:
  H_0: $\tau_1 = \tau_2 = \ldots = \tau_I = 0$ (factor A has no effect)
  H_A: at least one $\tau_i \neq 0$

- The hypotheses for the **effect of factor B** are:
  H_0: $\beta_1 = \beta_2 = \ldots = \beta_J = 0$ (factor B has no effect)
  H_A: at least one $\beta_j \neq 0$

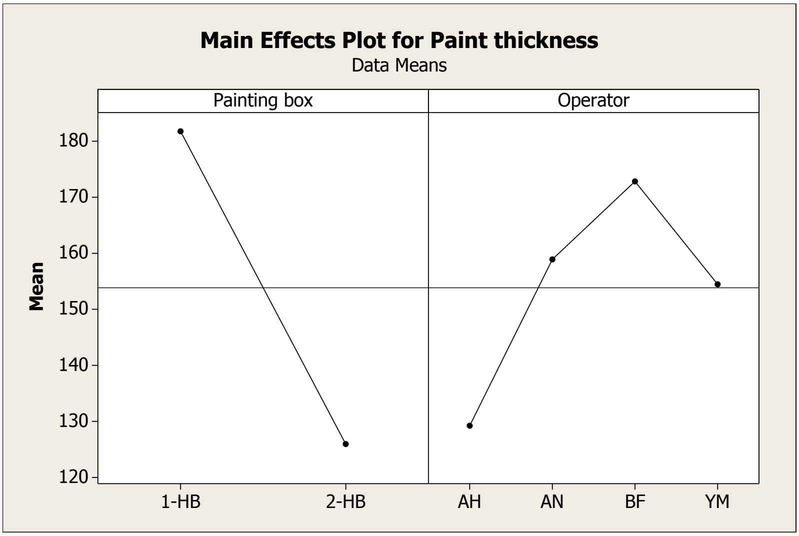
- The hypotheses for the **effect of the interactions** are:
  H_0: $(\tau\beta)_{ij} = 0$ for all i,j (there is no interaction between the factors)
  H_A: at least one $(\tau\beta)_{ij} \neq 0$

3. Conduct calculations and analyze the results

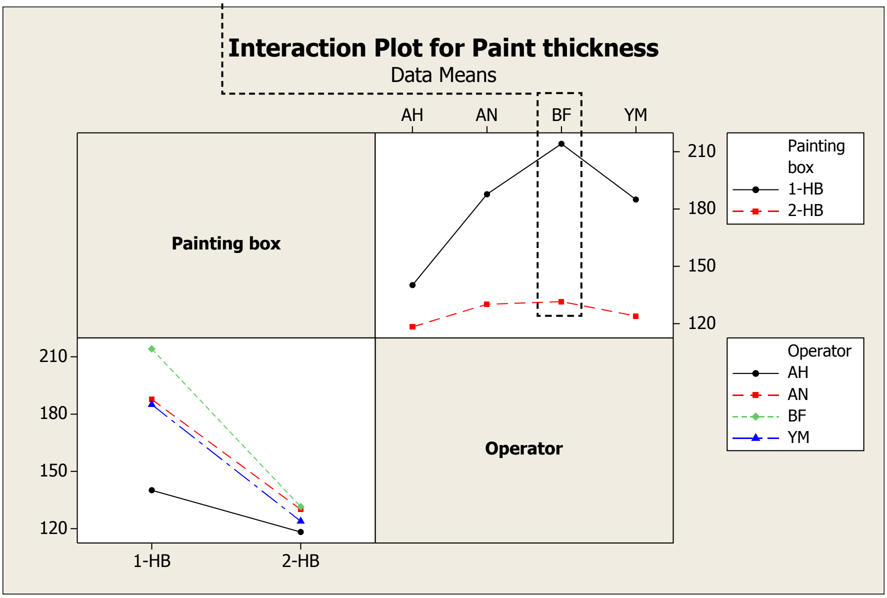
a. Visualize Effects

In paint box 1 a significantly higher level of paint thickness is achieved on average than in paint box 2.

The spray-painter AH generates the lowest level of paint thickness on average, while spray-painter BF generates the highest.



The spray-painter BF produces an unacceptable result in paint box 1, while the same spray-painter attains a completely satisfactory result in terms of paint thickness in paint box 2.
If possible, spray-painter BF should no longer work in paint box 1.



b. Analyze results

Two-way ANOVA: paint thickness versus Paint box; Operator

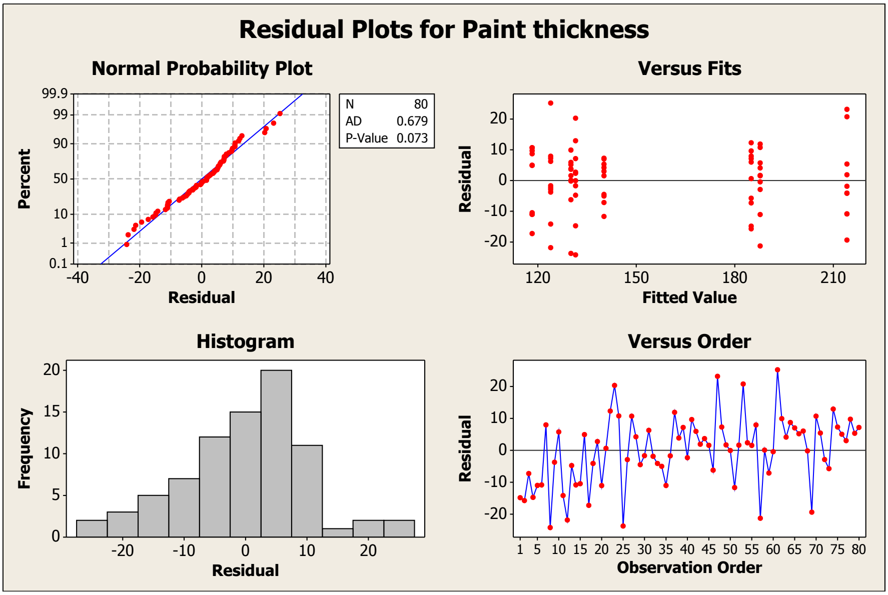
Source	DF	SS	MS	F	p
Paint box	1	62304	62303.9	512.58	0.000
Operator	3	19853	6617.8	54.44	0.000
Interaction	3	9515	3171.7	26.09	0.000
Error	72	8752	121.6		
Total	79	100424			

S = 11.02   R-Sq = 91.29%   R-Sq(cor) = 90.44%

The p-values are all nearly 0. Both factors and their interaction have a statistically significant influence on the paint thickness.

The corrected R^2 of 90.44% means that 90.44% of the total variation can be explained by the model.

The residual diagrams give important hints at the goodness of model fit



The null hypothesis of the residuals' normal distribution can be retained. As far as the sequence of residuals is concerned, a trend is partly recognizable. The present model explains most of the variation seen in paint thickness, nevertheless, further influencing factors might exist.

Tip

- In practice it is often difficult to apply Two Way ANOVA with existing data since the data needs to be balanced (balanced design).
- The necessary data can often be obtained by simple structured experiments involving relatively low sample levels

Correlation Coefficient

Term
Correlation coefficient

When
ANALYZE

Goal
Measure the strength of the linear relationship between two continuous variables

Procedure
The correlation coefficient as formulated by Bravais-Pearson is a measure for determining the strength of the linear relationship between two continuous variables:

$$r_{xy} = \frac{s_{xy}}{s_x \cdot s_y} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})\,(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \cdot \sum_{i=1}^{n}(y_i - \overline{y})^2}}$$

The correlation coefficient can range between -1 and +1:

$$-1 \leq r_{xy} \leq +1$$

The strength of the correlation can be classified roughly as follows:

$\lvert r_{xy} \rvert \approx 0$	→ No correlation, no linear relationship
$\lvert r_{xy} \rvert < 0.5$	→ Weak correlation
$0.5 \leq \lvert r_{xy} \rvert < 0.8$	→ Moderate correlation
$0.8 \leq \lvert r_{xy} \rvert$	→ Strong correlation
$\lvert r_{xy} \rvert \approx 1$	→ Perfect correlation

Tip

- The correlation coefficient is capable of recognizing a linear correlation. However, non-linear relationships are not considered here. The calculated correlation coefficient assumes a value around “0” in these cases. This only means that there is no linear relationship. It is recommended that you carry out a preliminary graphical analysis to check the shape of any possible relationship. Most likely you would use a scatter plot to do this!
- The correlation coefficient can only measure the strength of the relationship between two variables, not what drives the observed effect. What this means is that a correlation test cannot tell whether Factor A exerts influence on Factor B or the other way around only that there is a relationship. The influencing effect of one variable on another can only be determined by detailed process knowledge and not from the size of the correlation coefficient!
- If a high correlation exists between two characteristics which cannot be supported by process knowledge then the term pseudo-correlation is used. Pseudo-relationships might be generated by a third unknown or overlooked characteristic. This third characteristic would itself be correlated with both the other two characteristics!

Example

```
Correlations: Paint thickness; Paint thinner quantity (in %)

Pearson correlation of Paint thickness and Paint thinner quantity
(in %) = -0.987
P-Value = 0.000
```

Result: There is apparently a strong negative relationship between the proportion of the thinner and the paint thickness.
The p-value indicates that the null hypothesis (no correlation between the variables) must be rejected.

Simple Linear Regression

Term
Simple Linear Regression

When
ANALYZE

Goal
- Analyze the relationship between a continuous, independent variable and a continuous, dependent output
- Quantify this relationship in such a way as to explain as much of the change in the dependent output variable whilst minimizing the unexplained variation (residuals) through the range of the model.

Procedure
The Regression Analysis describes the relationship between a dependent and an independent variable as a function:

$$y = f(x)$$

The simple linear regression model has the form:

$$Y = b_0 + b_1 x + \varepsilon$$

Dependent variable
Axis intercept
Gradient of the regression line
Independent variable (regressor)
Error term (residuals)
Regression coefficients

The error term equates to the deviation that is not explained by the independent variable. These deviations are random and can be interpreted e.g. as material variations or measurement errors. The expected value of the error term is zero.
The regression coefficients are predicted by the least square method. The parameters are determined in such a way that the predicted line minimizes the sum of the squared deviations.

The predicted line has the following form:

$$\hat{y} = \hat{b}_0 + \hat{b}_1 x$$

The deviation between the observed value y_i and the predicted $\hat{y}_i$ is the residual ε_i:

$$\varepsilon_i = y_i - \hat{y}_i$$

1. **Formulate the model**
   The focus should be exclusively on content-related aspects:
   - Does the cause-effect-relationship really make sense?
   - Have all potential variables been considered and/or is the model complete?

2. **Predict the regression function with the help of statistical software**

3. **Test the predicted regression function:**
   - Do the predicted values make sense (sign test)?
   - Is the predicted model statistically significant?
   - Are the predicted coefficients statistically significant?
   - Does the predicted model fulfill the necessary model assumptions and/or prerequisites?

Test the predicted regression function

– **The coefficient of determination (R^2)**
  indicates the proportion of the explained spread with respect to the total spread, i.e. the percentage of variation from y which can be explained by the tested x

$$R^2 = \frac{SS_{Regression}}{SS_{Total}} = \frac{\sum_{i=1}^{n}(\hat{y}_i - \overline{y})^2}{\sum_{i=1}^{n}(y_i - \overline{y})^2}$$

– **The F-Test**
  answers the question if the the estimated model is valid for the population. The Null Hypothesis is: all regression coefficients in the population equal zero. If the Null Hypothesis can be rejected it means the model is statistically significant.

$$F = \frac{MS_{Regression}}{MSE_{Error}}$$

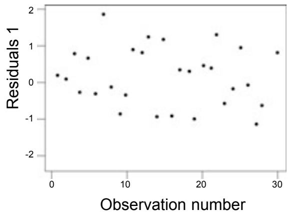
- **Regression coefficients:**
  T-tests are used to test the significance of the regression coefficients. The hypotheses are as follows:

  H_0: $b_0 = 0$ The line intersects the origin
  H_A: $b_0 \neq 0$ The line doesn't intersect the origin

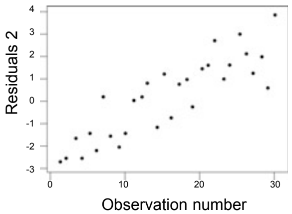
  H_0: $b_1 = 0$ There is no relationship between the independent variable x and the dependent variable y
  H_A: $b_1 \neq 0$ There is relationship between the independent variable x and the dependent variable y

- **Analysis of residuals:**
  The graphic analysis of the residuals provides important hints at how well the model fits; the existence of trends or the dependency of one variable indicates that the model is incomplete or false; furthermore, the model is based on the assumption that the residuals are normally distributed; the violation of this assumption is decisive: The test statistics and procedure are no longer applicable:

Residuals over time/observation number

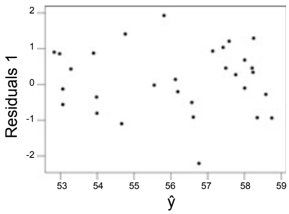


No trend!
Residuals do not change over time (no auto correlation).



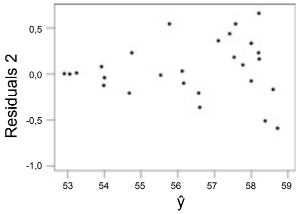
Trend!
Residuals increase over time (auto correlation). This hints at the fact that the factors which have not yet been collected change the result, e.g. machine wear, outside temperature.

Residuals vs. predicted model value (ŷ)



The standard deviation is independent of the y-value.

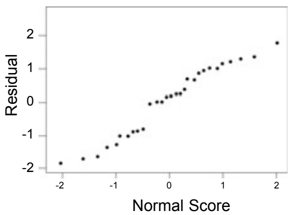
Standard deviation and variance are constant (Homoscedasticity).



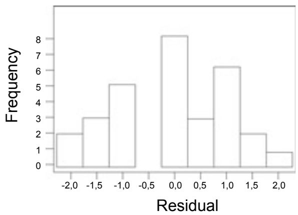
The standard deviation increases in line with the calculated y-value, the residuals are located in a funnel.

Standard deviation and variance are not constant (Heteroscedasticity).

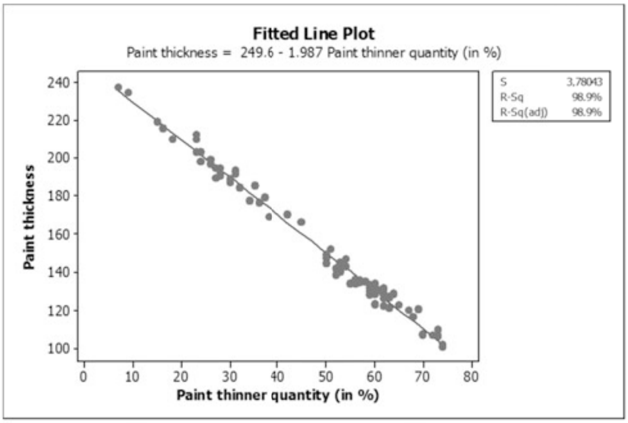
<Normal Plot of Residuals> and <Histogram of Residuals>



If the residuals are normally distributed they are roughly in a line in the Normal Plot and the Histogram has the shape of a bell curve.



If this is not clearly apparent from the graphic display, it is recommended to conduct a Normality Test for the residuals.



The Fitted Line Plot generates the regression function that best fits and explains the underlying data and represents it graphically.

Multiple Linear Regression

Term
Multiple Linear Regression

When
ANALYZE

Goal
- Analyze the effect of more than one independent variable on a dependent variable
- Determine a function that best explains this effect

Procedure
The regression function has the following general form:

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n + \varepsilon$$

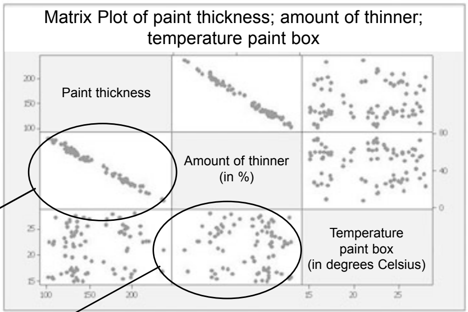
An important prerequisite for multiple linear regression is the independence of the explained variables X_i (regressors), i.e. no multicollinearity.

Independence of the explained variables xi (regressors)

This graphic visualization enables a visual examination of the relationship between the input variables and the output (paint thickness vs. amount of thinner and paint thickness vs. temperature) as well as between the two input variables (amount of thinner vs. temperature).

It is expected that there is a relationship between the input and output (here: paint thickness and amount of thinner).

But between the input variables independence is the prerequisite for the regression (here: amount of thinner vs. temperature).

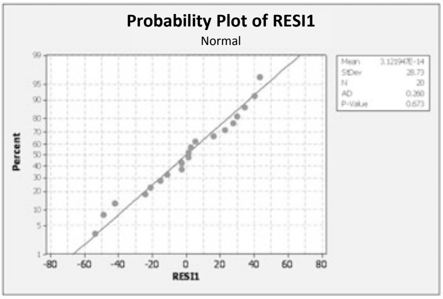


Result: By the high coefficient of determination R^2 and the significant F-test it can be assumed that this model will explain the relationship well. As expected the amount of thinner has an influence on the paint thickness, the temperature, however, is not significant (cf. P-values).

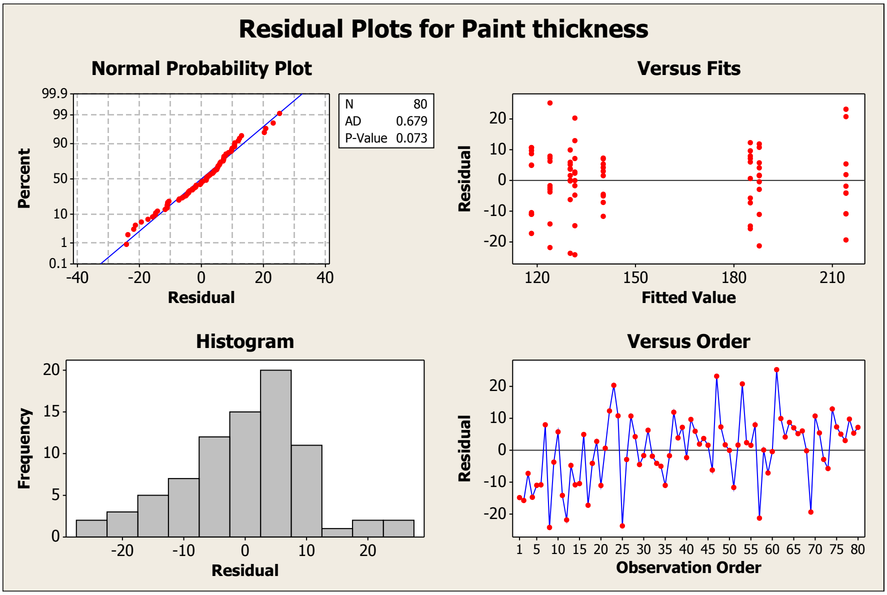
```
Regression Analysis: Paint thickness versus paint thinner (temperature
paint box)

The regression equation is
Paint thickness = 251 - 1.99 paint thinner quantity (in %)
             - 0.067 Temperature paint box (in degrees Cel)

Predictor                                   Coef   SE Coef       T       P   VIF
Constant                                 251.173     2.675   93.91   0.000
Paint thinner quantity (in %)           -1.98909   0.02410  -82.54   0.000   1.0
Temperature paint box (in degrees Cel)  -0.0671    0.1043   -0.64   0.522   1.0

S = 3.79472   R-Sq = 98.9%   R-Sq(adj) = 98.9%

Analysis of Variance

Source            DF      SS       MS         F       P
Regression         2   99315    49658   3448.47   0.000
Residual Error    77    1109       14
Total             79  100424
```

Tip

The VIF (Variance Inflation Factor) hints at the independence of the regressors. A VIF close to 1 means that there is no multicollinearity (i.e. the regressors are independent), a VIF of approx. = >5 indicates strong multicollinearity.



Analysis of residuals:
The graphic analysis of the residuals does not reveal any patterns. A Normality Test can be conducted to be on the safe side (here: The null hypothesis cannot be rejected.)



Residual Plots for Paint thickness
Normal Probability Plot
Percent
Residual
N 80
AD 0.679
P-Value 0.073
Versus Fits
Residual
Fitted Value
Histogram
Frequency
Residual
Versus Order
Residual
Observation Order

Logistic Regression

Term
Logistic Regression

When
ANALYZE

Goal
1. Analyze the relationship between one (or several) continuous, independent influencing variables and a discrete, binary, dependent output variable.
2. Predict the probability for the occurrence of a certain event.

Procedure
1. In (binary) logistic regression the observed event itself ("no defect" ”defect” or 0 /1) is not analyzed, but the probability of the occurrence of such events. P(Y = "no defect“) and P(Y = 0); or P(Y = "defect") and P(Y = 1).
   The question "Which values of the influencing variable(s) X lead to a defect?” is not answered, but the relationship is established between the occurrence probability of a defect and the characteristic of the influencing variable(s) X(s) ("How probable is it that a defect occurs in case of a specific value of X(s)?“)

2. In order to be able to determine the probability of the occurrence, Y = 1 (or probability of a defect), it is assumed that a variable "Z" exists which cannot be observed, but can predict the binary characteristic of Y depending on the characteristics of the independent variable(s) X_i.
   Formal:

   $$y_k = \begin{cases} 1 \text{ if } z_k > 0 \\ 0 \text{ if } z_k \leq 0 \end{cases}$$

   with $z_k = b_0 + b_1x_{1k} + b_2x_{2k} + \dots + b_nx_{nk} + \varepsilon_k$

   "The variable “Z” can be taken as the sum of the individual influences of the independent variables X (s) on the event Y=1 ("defect")."

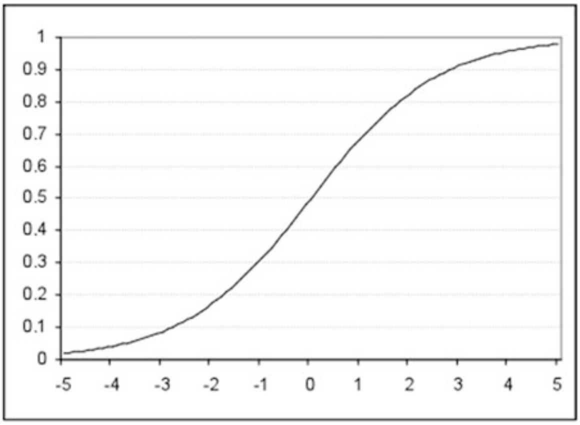
3. A connection between the binary dependent variable and the continuous, independent variables is established. Moreover, it is assumed that the relationship between the variable Xi and the variable Z is linear. The logistic regression equation can be defined as follows:

   $$P_k\,(y = 1) = \frac{1}{1 + e^{-z_k}}$$

   $$z_k = b_0 + b_1x_{1k} + b_2x_{2k} + \ldots + b_nx_{nk} + \varepsilon_k$$

   … whereby the z-values are also referred to as "Logits"

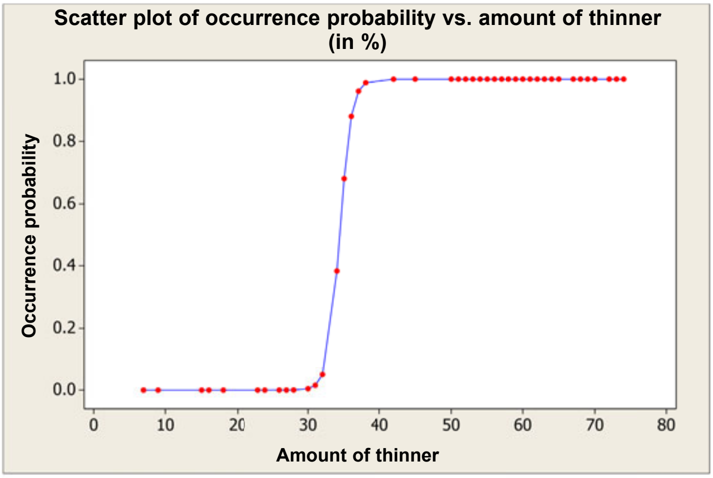
4. The parameters (b_i) of the logistic regression function are predicted with the help of the Maximum Likelihood Method. The goal of this methodology is to determine the parameter b_i in such a way that the Likelihood of obtaining the observed values of the influencing variables X is maximized. The model is supposed to show the values observed in reality in the best possible way



This image clearly shows that the relationship between the occurrence probability of the binary, dependent variables P(Y=1) and the independent variable is non-linear.

Example logistic regression

Does the amount of thinner influence the result of the paint thickness ("paint thickness OK": Y = Yes/No)?



Here, the probability of the event "Paint thickness = OK" (or Y = 1) is plotted against the amount of thinner used (in %). The occurrence probabilities of the observations are calculated by the model and displayed in the scatter plot.
It can clearly be seen that the paint thickness will be OK if the amount of thinner used is greater than 40%. At the same time it is plainly apparent that the probability of satisfactory paint thickness is close to 0 if the proportion of thinner used is less than 30%.

Tip

- The presentation of the statistical results frequently raises more questions than answers for the team and Sponsor due to the complexity of the results. We recommend that Master Black Belts who are experienced in statistics undertake logistic regression. As discussed above in the context of data transformation (cf. Data Transformation) please consider how to present the results to ensure acceptance
- The connection between continuous (influencing) and discrete (output) variables can also be tested with a hypothesis test. The major goal in the ANALYZE phase is not setting up a model but rather identifying the influencing factors and verifying their effect. Thus, the question can be

reversed: In the above example the question could be “is the average amount of thinner in case of "Paint thickness OK" significantly different from "Paint thickness not OK"? This can be a practical alternative to Logistic Regression.

Design Of Experiments (DOE)

Term
Design of Experiments (DOE)

When
ANALYZE, transition to IMPROVE

Goal
- Undertake a systematic investigation of process performance factors
- Quantify the relationship between the influencing factors of a process and the resulting output and process qualities with an optimal number of experiments
- Determine the optimal input and process settings for meeting the customer specifications

Procedure
1. **Define what it is that you want to discover and select an appropriate output response**
2. **Identify influencing variables/factors (Xs)**
3. **Determine relevant factor levels (low/high settings etc)**
4. **Derive the experiment strategy: Select a suitable design and sample size**
5. **Ensure measurement system capability**
6. **Conduct experiments and collect data**
7. **Analyze results and determine measure/actions**

1. **Define the optimization task and set the response**
   – Select the product and/or process to be analyzed
   – Set goals
   – Set the responses for measuring whether the goals are achieved
   – Make sure that the responses display the following characteristics:
     - Completeness: All key process and product qualities have been covered
     - Distinctness Each response describes a different relationship
     - Relevance: Each response is clearly related to the analysis goal

  - Linearity: With several similar responses, the response selected should be the one which has a linear relationship with the influencing factors
  - Quantification: The responses should be as continuous and/or measureable as possible

2. Identify influencing variables

- Identify and document decisive influencing variables with the help of structured brainstorming. Important tools here are:
  - Cause-Effect Diagram
  - Tool 3 – Cause Related Measurement Matrix
  - FMEA
- Results gained during the process and data analysis can be taken into consideration:
  - Analysis of Variance
  - Regression Analysis
- Final evaluation should be based on the following criteria:
  - Importance of factor
  - Accuracy of the possible settings
  - Reproducibility of the settings
  - Effort and expense for changing the settings/levels

3. Determine relevant factor levels

- A maximum and a minimum are set as factor levels. Initially, two factor levels are selected:
  - Continuous variables: The maximum and the minimum should be located in an area which makes sense, so that the response is still quantifiable
  - Discrete variables: If the factor levels are discrete, e.g. there are five producers use the two most important/logical factor levels

4. Decide on the experimental strategy

- Set the sample size (plan the experiment scope)
- Determine the number of blocks
  - Consider the appropriateness of center points for continuous factors
- Decide about randomization and/or take into consideration restrictions in randomization (e.g. due to the expenses of an experimental setup)
- Determine the factor level combinations: Full-factorial or fractional factorial DOE
- Usually a full-factorial DOE is very expensive and time-consuming. If it is possible to conduct the experiments successively, the following procedure is recommended ("Blockwise" procedure):

- *Block 0: Good-Bad Trials*
  - There are two different settings for each factor leading to distinctly different values of the observed response
  - All factors are set in such a way that a "good" result can be expected according to expert opinion, e.g. low error rate, high concentration of agents – all factors are set so that a "bad" result can be expected, e.g. high error rate, low concentration of agents
  - The goal is to ascertain whether effects exist; if no effects are located this can be due to the fact that the selected factors are not relevant or the signal-noise relationship is too weak, i.e. the noise is too "loud"

  At this point, the experiments should be stopped, and if required, further factors should be determined or the noise should be eliminated

- *Block 1: Screening Experiments*
  - It is not unusual that a high number of factors are selected to investigate, possibly as many as 15
  - The purpose then is to see if an effect does exist and this can be checked with a resolution III or IV design
  - The important question is: Are the effects seen of sufficient dimension to be interesting?
  - The goal is to spot the relevant factors in this phase ("separate the wheat from the chaff") – it is often possible to reduce the number of relevant factors significantly and conduct further DOEs based on far fewer experiments
  - When deciding to leave out factors, attention must be given to possible interactions – in practice, the reduction of factors to a resolution III is better avoided as the level of confounding is an issue and a risk

- *Block 2: Fold Over Experiments*

  Fold Over experiments supplement screening DOEs by a complementary plan; this is a reversal of the signs deployed in the original DOE design:
  - The goal is to reduce the number of factors to the really important ones; it is thus possible to estimate the interactions; Fold Over experiments eliminate confounding between the main effects and interactions
  - The statistical analysis can provide initial settings for the optimal settings (Response Optimizer in Minitab®)

- *Block 3: Completion Experiments*
  - If there is reason to assume that the relationships are non-linear, i.e. squared effects exist or effects of a higher order, additional experiments are conducted which, besides the minimum and maximum settings, take into consideration additional mean values
  - This is known as Response-Surface-Methodology (Central Composite Design)

- *Block 4: Optimization Experiments*
  - During the statistical analysis of previous experiments, optimal settings were proposed
  - Now the goal is to test the optimal settings of the factors

  Estimation of costs: Make sure the costs are reasonable in relation to the expected result; if the expenses appear to be too high it should be examined if the costs can be reduced by doing without factors and/or factor levels, block building and/or randomization or by conducting a smaller number of experiments without endangering the goal of the experiment.
  The goal of the experiment might need rethinking in some cases

5. **Ensuring data quality**
   Conduct Measurement System Analysis for all relevant measurements (output (Y), process and input (X)) and improve the measurement system as necessary

6. **Conduct experiments and collect data**
   – Prior to conducting the main experiment it is recommended that you carry out some preliminary tests and/or pilot experiments; the purpose of this is to check whether the estimated effort is realistic and if the results are consistent, i.e. the noise has been eliminated
   – When conducting the experiments it must be ensured that everything goes according to plan; this means that each individual experimental trial should be monitored.

7. **Analyze results and determine measure/actions**
   – The graphical and analytical results should be reviewed after each block in order to determine appropriate next steps; conducting DOE should be seen as an iterative process
   – When analyzing the results and considering the next steps, one or more process experts should be involved in order to avoid false or inappropri-

ate conclusions; e.g. the true relationships can be concealed by measurement errors or noise; the results should be checked for plausibility throughout

Full Factorial Design

Term
Full Factorial Design

When
ANALYZE, transition to IMPROVE

Goal
Identification of, and quantification of, the effects of the main factors and of factor interactions by systematically testing factor combinations

Procedure
Some of the terms and phrases are detailed below:

Factors and factor levels
Factors are influencing variables (Xs). In DOE the factor levels are usually reduced to two extreme values (realistic operating minimum and maximum). This ensures that the largest possible experimental area is covered at justifiable costs and effort.
The mean value of a factor level initially provides less information than the extreme values. Only when a non-linear relationship exists is the mean value of greater significance.
A Full Factorial DOE can be described by the expression 2^k, i.e. k factors each with two factor levels (minimum and maximum).

Trials
A trial is an individual experiment or test. A DOE will consist of multiple trials with each trial testing different combinations of settings. Trials maybe repeated immediately or at a later point in the overall experiment.

Repeats
A Repeat is the immediate repetition of an experimental trial without changing the settings; no other settings are tested between Repeats
- Repeats capture short-term variation
- Repeats don't require a new experimental setup
- Repeats do not generate any additional degrees of freedom in the design

Replicates

A Replicate is the term used to describe the entire series of experimental trials contained in the base design e.g. a 3 factor Full Factorial DOE with each factor having two levels will have a base design of 8 experimental trials – this would be described as one replicate. An additional replicate would therefore add an extra 8 experimental trials.

- Additional replicates increase the number of degrees of freedom in a design
- Each additional replicate will double the sample size
- Additional replicates facilitate the analysis of long-term variation
- Additional replicates increase the required number of experimental setups

Size of the required sample

The following rule of thumb has proven suitable for DOEs:

Standard deviation (based on experience)

$$N = 60 \cdot \left(\frac{\sigma}{\Delta}\right)^2$$

Number of experiments

Granularity

N is the total number of experiments. Moreover, m is the number of single experiments in a design. Accordingly, n – the required number of Replicates – can be calculated as follows:

$$n = \frac{N}{m}$$

Control parameters and noise factors

– Control parameters are the dimensions that can be set and maintained at a desired value; control parameters should be set in such a way that “noise” has as little impact as possible, meaning that the process is robust

– Noise factors can be either known or unknown; known noise factors should be eliminated or included in the experimental design as factors; if this proves impossible the effect they generate can be eliminated by creating blocks*; unknown noise factors cannot be set; they are the background noise, however randomization of experimental trials can significantly reduce their effect

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* Blocks here should not be confused with the previously mentioned blocks which were written about in the context of the iterative nature of DOE activity.

Blocks

Whole experiments can be broken down into logical blocks if conditions might be subject to change during the experiment's duration. If experiments will run across different shifts or production lines for example, then it might make sense to block by shift or by production line. This means is that the entire experiment is split into labeled blocks so that they can be analyzed for differences. It is hoped that there are no significant differences. Blocks are usually used to manage known "noise" factors.

Randomization

– Randomization means that the individual experiments in each block are conducted in a random sequence
– Randomization neutralizes the trends caused by unknown noise factors which could distort the result; the random order is set with the help of a random number generator.

Balanced (Saturated) Design

The same number of positive and negative signs (minimum and maximum settings) is taken into consideration for each factor.

Full Factorial Design

All permutations of factor levels are tested when conducting a Full Factorial Design. Thus, all interactions are covered. For a DOE with three factors the basic pattern of a design would be as follows:

	Factors			Factor interactions			
No.	A	B	C	AB	AC	BC	ABC
1	-	-	-	+	+	+	-
2	+	-	-	-	-	+	+
3	-	+	-	-	+	-	+
4	+	+	-	+	-	-	-
5	-	-	+	+	-	-	+
6	+	-	+	-	+	-	-
7	-	+	+	-	-	+	-
8	+	+	+	+	+	+	+

The advantage of a Full Factorial Design is that it enables the collection and analysis of all information. However, given that the number of experimental trials increases exponentially with each additional factor, the cost and time involved may make it unfeasible or impractical to do a Full Factorial design.

Calculation of effects
The following formula is used to calculate the main effects and the effects generated by interactions:

Effect	=	Mean value of all observations at a high level (+)	–	Mean value of all observations at a low level (-)

NB: The signage of interactions is obtained by multiplying the signage of the factors contained in the interaction

Analyzing the DOE

1. Analyze the collected data with the help of a suitable statistics program such as Minitab®
2. Determine the size of the effects for factors and for factor interactions
3. Remove statistically insignificant effects from the model (usually effects with a p-value bigger than 0.05) and repeat the analysis
4. Analyze residuals to make sure that the model is safe to use (cf. "Analysis of Residuals" from page 230 onwards)
5. Examine and analyze the significant interactions and main effects graphically (Interaction Plot, Main Effects Plot) and set up the mathematical model
6. Translate the model into practical conclusions and determine suitable actions

Example

No.	Temperature	Pressure	Thinner	Result
1	20	15	10	152
2	25	15	10	167
3	20	30	10	180
4	25	30	10	159
5	20	15	20	198
6	25	15	20	201
7	20	30	20	230
8	25	30	20	236

Tip

- Remove non-significant interactions and factors one at a time starting with the smallest
- Do not remove a non-significant factor if a significant interaction contains that factor

Fractional Factorial Designs

Term
Fractional Factorial Design

When
ANALYZE, transition to IMPROVE

Goal
- Identify and quantify relationships between the influencing factors in a process and the resulting product and process characteristics
- Minimize the number of experiments whilst managing risk and retaining statistical validity

Procedure
1. Fractional factorial designs considerably reduce the number of experiments while ensuring that the information lost is minimal.

2. Initially loss of information is accepted; by extending the design (Fold Over) the information lost can be retrieved later

3. Besides wanting to save time and keeping costs low, not all factor interactions are of interest. Further experiment setups can still be deployed afterwards should the initial results demand more precise information

4. A fractional factorial DOE has the form 2k-q, with q being the reduction factor

5. To ensure that the design remains saturated (balanced) the same number of positive and negative signs need to be considered; the signs are selected so that a sensible interpretation is possible; with four factors the following basic pattern applies:

Signs of ABC

No.	A	B	C	D	AB	AC	BC	ABC
1	-	-	-	-	+	+	+	-
2	+	-	-	+	-	-	+	+
3	-	+	-	+	-	+	-	+
4	+	+	-	-	+	-	-	-
5	-	-	+	+	+	-	-	+
6	+	-	+	-	-	+	-	-
7	-	+	+	-	-	-	+	-
8	+	+	+	+	+	+	+	+
9	-	-	-	+	…	…	…	…
…	…	…	…	…	…	…	…	…

The signs of factor D are therefore replaced by the signs of the interaction ABC. This procedure relies on the extremely low probability that these three factors interact with each other simultaneously allowing us to make the assumption that any effect witnessed is as a result of factor D rather than the interaction ABC. However, there is a small possibility that the interaction ABC is significant and that factor D is not. Knowledge of the process would be an important element of determining the risk of this happening.

Confounding and resolution types

Confounding arises in fractional designs only and is caused by the signage of one column being the same as another. This means that when calculating the effect of these factor(s) and/or interaction(s) we will get the same value for the size of the effect.

DEFINE
MEASURE
ANALYZE
IMPROVE
CONTROL

Resolution types:

Number of experiments	Number of factors													
	2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Full	III												
8		Full	IV	III	III	III								
16			Full	V	IV	IV	IV	III	III	III	III	III	III	III
32				Full	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Full	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Full	VIII	VI	V	V	IV	IV	IV	IV

Resolution type	Confounding	Evaluation
III	Main factors are confounded with two factor interactions	Critical
IV	Main factors are confounded with three factor interactions and two factor interactions with two factor interactions	Less critical
V	Main factors with four factor interactions and two factor interactions with three factor interactions	Uncritical

Analysis of Fractional Factorial experiments follows the same steps as for a Full Factorial design.

Example

No.	Temperature	Pressure	Thinner	Paint box	Result
1	20	15	10	1	152
2	25	15	10	2	167
3	20	30	10	2	180
4	25	30	10	1	159
5	20	15	20	2	198
6	25	15	20	1	201
7	20	30	20	1	230
8	25	30	20	2	236
9	-	-	-	-	-
…	-	-	-	-	-

This design is a 4 factor ½ fractional design i.e. a full design would have been $2^4 = 16$ trials which has been reduced to 8 trials. In this example the design is in standard order and is yet to be randomized.

Number of runs can be calculated using the formula 2_R^{k-q} where k is the number of factors and q is the reduction level e.g. 1 would equal a half design, 2 a quarter design etc. The 2 indicates the factor levels will be set at a low & high setting only. R is the level of resolution and is usually shown as a Roman numeral.

Variation Reduction

Term
Variation Reduction

When
ANALYZE, transition to IMPROVE

Goal
Discover at what settings the lowest level of variation is experienced when meeting the process target. This activity is usually combined with optimizing the mean. It is all very well hitting a customer specification but if the variation around that is very high then customer satisfaction is unlikely to be improved.

Procedure

1. At least two data points are required at each setting to estimate variance. In a DOE there are two ways this can be achieved. Firstly, by adding a replication i.e. repeating the whole experiment again, the second way is to repeat (one or more times) each experimental setting immediately. Often both methods are adopted as indicators of long and short term variation.
   Note: it is a good idea to repeat experimental trials even if you are only interested in the location thus avoiding reliance on an exceptionally good or bad individual result. If you do repeats then you would calculate the mean at each setting before doing your analysis.

2. Having obtained the data it is now possible to estimate variance at each setting and use this as a response variable

3. At this point it is a good idea to transform the variance into a Standard Deviation by calculating the square root or perhaps use a natural logarithm.

4. Now that there is an estimate of Standard Deviation for each setting, the data can be analyzed as for a full/fractional factorial DOE

Example o

Factors and factor level settings				Results of Repeats					Mean value and standard deviation	
A	B	C	D	M 1	M 2	M 3	M 4	M 5	$\bar{x}$	s
+	-	+	+	y_{11}	y_{21}	y_{31}	y_{41}	y_{51}	$\bar{x}_1$	s_1
-	-	+	+	y_{12}	y_{22}	y_{32}	y_{42}	y_{52}	$\bar{x}_2$	s_2

Response Surface Methods

Term
Response Surface Methods (RSM)

When
ANALYZE, transition to IMPROVE as an optimization experiment

Goal
- Check for non-linear relationships around the specification range
- Improved optimization of response by more precise setting of factors

Procedure
Reduce the number of factors as far as possible by full/fractional factorial designs and continue to observe only the really critical factors further; this procedure requires repeated experiments because mean performance is the key focus

The following model takes into account non-linear relationships and describes the curvature of the surface in the response area

$$y = b_0 + b_1\, x_1 + b_2\, x_2 + b_{11}\, (x_1)^2 + b_{22}\, (x_2)^2 + b_{12}\, x_1\, x_2$$

Response

y-axis

Coefficients of factors

Mean values between the extreme values of the factors are required in order to determine the additional coefficients. Here for example the Central Composite Design (CCD) has been applied.

The analysis largely follows the procedure previously explained. However, it is expected that at least one non-linear relationship is significant.

Further Experimental Designs

Term
Further Experimental Designs

When
ANALYZE, transition to IMPROVE

Goal
- Undertake a systematic procedure in the sense of an efficient process analysis
- Develop the relationship between the influencing factors in a process and the resulting product and process characteristics with a minimal number of experiments
- Determine the optimal settings for establishing the responses within the customer specifications
- Take into consideration the restrictions of factorial designs

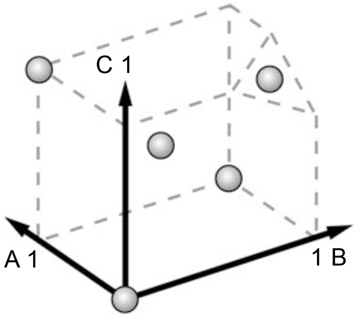
Procedure
Two further designs are particularly noteworthy:

1. D-Optimal Designs …

… are special designs which allow the clear identification of all main effects and interactions with the lowest possible number of experiments, i.e. main effects and interactions are not confounded

They are especially recommended if …
… the number of levels for each factor is different
… the distances between the levels (equidistant or non-equidistant) can be freely selected
… the model can be extended step by step by further factors
… certain combinations of factor settings must be excluded as unfeasible e.g. for safety reasons

Mapping Experiment space D-Optimal Plan (schematic)



2. Taguchi's Experimental Designs:

Taguchi's Experimental Designs focus on the robustness of processes. These look for settings where the response(s) react with minimum sensitivity to random variations in factors.

Taguchi makes a distinction between two types of factors:

- *Control Factors*
  In the production process they can be set to a specific value, e.g. temperature of a drying cabin, pressure of spray guns
- *Noise Factors*
  These are not control factors and will not be adjusted in normal production circumstances but knowledge about them is seen as useful so they are tested during the experiment. It is hoped that their impact on the response variable is independent and small e.g. position of a part in a kiln, the surrounding temperature of electronic circuits

The goal of Taguchi's Experimental Designs is to select the setting of individual control factors in such a way that the result (response) varies as little as possible due to the influence of noise factors.

Example of Taguchi's Experimental Design

Outer array – Noise factors

No.	1	2	3	4
N_1	-	+	-	+
N_2	-	-	+	+
N_3	+	-	-	+

Inner array – Control factors

No.	A	B	C	D	E	F	G	Result field 1	2	3	4
1	-	-	-	+	+	+	-				
2	+	-	-	-	-	+	+				
3	-	+	-	-	+	-	+				
4	+	+	-	+	-	-	-				
5	-	-	+	+	-	-	+				
6	+	-	+	-	+	-	-				
7	-	+	+	-	-	+	-				
8	+	+	+	+	+	+	+				

3. Evolutionary Operations (EVOP):

EVOP is a technique for experimental designs dating back to the 1950's, which was developed by George Box.

The factor levels of EVOP designs deviate only minimally from the standard settings. This means that production doesn't have to be interrupted. The change of the settings is not large enough for the product/output to become useless but on the other hand, they are meaningful enough to generate a significant improvement. The disadvantage of EVOP designs is that because there is a very low Signal-to-Noise ratio many experiments are necessary in order to recognize any difference. Thus, this technique is only rarely applied in improvement projects, being more frequently used to gain incremental improvements in the context of a continuous improvement process, i.e. in process management. EVOP is rather an investigating "Modus Operandi" in production.

Derive Main Causes

Term
Main causes, root causes, derive Vital Few causes

When
ANALYZE, during and at the end of the phase

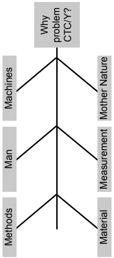
Goal
- Identify the main causes for the non-fulfillment of customer and/or business requirements
- Ensure that the project goal is achievable through the elimination of the identified main causes i.e. the Vital Few

Procedure
1. Complete Tool 3

2. Make sure that the improvement potential has been quantified for each verified cause

3. Check if the project goal can be reached after the elimination of the identified main causes; verify further potential causes if required to achieve the goal

Example



Hypotheses to be verified	The training of the spray-painters is not sufficient	The spray-painting result depends on the spray-painter	The spray-painting result depends on the paint box	The spray-painting result depends on the amount of thinner	POTENTIAL FOR THE TARGET ACHIEVEMENT
Formation of sags and runs	3	9	3	3	90%
Coloration	3	9	3	0	80%
Paint thickness	1	3	9	9	100%
Prioritization for verification	7	21	15	12	
Constant or variable?	X	X	X	X	
Input/process measurement	I	I	I	P	
Data type	Discrete	Discrete	Discrete	Continuous	
Method	Process analysis	Data analysis	Data analysis	Data analysis	
	Check SOP comprehensibility and availability with the help of testers	Comparison mean value and spread of spray-painters	Comparison mean value and spread of paint boxes	Correlation & Regression Analysis	
Result of analysis	• 3 out of 3 SOPs not clear • Only 3 SOPs available	The spray-painting result depends on the spray-painter ($p = 0$)	The spray-painting result depends on the spray-painter ($p = 0$)	Very good model $R^2 = 99\%$	
% influence (after verification) – optional	20%	20%	40%	5%	
Cause description	SOPs partly not available, not comprehensible and employees insufficiently trained	Spray-painters have different experience and training levels	Spray-painters have different experience and training levels	Paint thinner is not in the SOP. Experiments show there is significant influence of paint thinner on color quality	
Main Cause (Y/N)	Y	Y	Y	Y	

Tip

- Find out the potential not only in a mathematical way, but also conduct discussions with the team and make an estimation based on common sense
- Make sure that any estimation of the potential is realistic; the focus is on the impact on the CTC/CTB fulfillment!
- Consolidate the main causes in order to simplify the communication in the company; the following types of causes frequently become apparent:
  1. Defective process inputs and/or process steps
  2. Constraints, i.e. insufficient amount of existing capacity
  3. Inventory and/or Work in Process are too high
  4. Waste in the process and/or high complexity and over fulfilling customer requirements
  5. Insufficient qualification and/or information and communication
  6. Imprecise or no articulation of responsibilities

Gate Review ANALYZE

- **Collect potential causes**
  - How were potential causes identified for the non-fulfillment of the CTCs and CTBs?
  - Have the causes of the causes been discovered by further questioning, in particular by use of the “5 Why?” technique?
  - Which causes are constants – i.e. can’t be dealt within the scope of the project? What might be done to address these, if anything, in the longer term?
  - Which potential root causes were taken forward for further analysis? How were they prioritized?
  - Has a connection been verified between the causes (Xs) and the output measurements (Y) representing the CTCs and CTBs

- **Analyze process**
  - Has the process been analyzed in sufficient detail to reveal important weak points in the process?
  - Which visualization technique was selected for this purpose?
  - Has a sufficient amount of potential been identified using Value Analysis to maximize the proportion of value adding activities?
  - Which of the potential root causes could be validated as real causes using process analysis?

- **Analyze data**
  - Have the right statistical hypotheses been formulated for identified statistical problems?
  - Which statistical tools were applied in order to verify the hypotheses?
  - Do the selected cause-related measurements really show a significant relationship to the output measurements?
  - Which potential root causes could be confirmed using data analysis?

- **Derive main causes**
  - Have main causes been identified for non-fulfillment of all customer and/or business requirements being addressed by the project?
  - Are the arguments put forward in support of the identified causes rational and logical?
  - Is there confidence that the project goals will be satisfied by eliminating the cause validated so far?
  - How much financial impact will the resolution of the individual identified causes have in relation to the project goal?

SIX SIGMA^{+LEAN} TOOLSET

IMPROVE

What are the Solutions for Eliminating the Causes?

R. Meran et al., *Six Sigma^{+Lean} Toolset: Mindset for Successful Implementation of Improvement Projects*, Management for Professionals, DOI 10.1007/978-3-642-35882-1_5,

Summary IMPROVE Phase

D M A I C

Objective and Scope of Phase

- The IMPROVE phase answers the question: "What are the top solutions for eliminating the root causes?" i.e. how can the cause(s) be eliminated so that the project goal can be reached
- This requires solution ideas to be created, evaluated and selected, all based on the root causes with a detailed implementation plan then being developed.

The Meaning of the IMPROVE Phase

- Using a combination of tried and tested tools from Lean Management and appropriate creativity techniques effective solutions for eliminating the verified causes are identified
- The goal of the project is to be achieved by checking the effect of these solutions with pilots etc. and searching for further solutions if the goal is not reached
- The sustainability of the improvement is already taken into consideration during the implementation of the new process: The actions for process monitoring and control are integral components of the new process

Procedure in the IMPROVE Phase

- Identify as many potential solutions as possible
- Check potential solutions for corporate acceptability, impact level, effort, and feasibility and select the best; combining solutions and/or sub solutions may be beneficial. Consolidate the selected solutions into a new lean process and ensure the project goal is achieved
- Prepare process monitoring and control mechanisms and conduct the implementation utilizing the new process

Road Map IMPROVE Phase

D M A I C

A.4 Identify All Causes

What are the main causes of the problem – the "Vital Few"?

ANALYZE

IMPROVE

I.1 Generate Solutions

What are the possible solutions for eliminating the root causes and thus the problem?

I.2 Refine and Filter Solutions

Which of the solutions can be pursued further based on corporate specific expectations e.g. company values as well as their effort-benefit-relationship?

I.3 Finalize Solutions

How can the solutions be combined and integrated?
Has each root cause an appropriate (sub) solution which addresses/eliminates it?
Are the solutions conflict-free?

I.4 Implement Solutions

In what form and over what time period will a sustainable solution be implemented?

I Gate Review/Phase Closure

Tool Overview IMPROVE Phase

I.1 Generate Solutions

Conceive Solutions	5 S	Poka Yoke	Workplace Layout	Theory of Constraints	Setup Time Reduction (SMED)
Total Productive Maintenance (TPM)		Generic Pull System (GPS)	Replenishment Pull System (RPS)		Complexity Reduction
Brainstorming	Anti Solution Brainstorming	Brainwriting	SCAMPER	Analogy Brainstorming	

I.2 Refine and Filter Solutions

Affinity Diagram	Must Criteria	Effort Benefit Matrix	N/3 Method	Nominal Group Technique	Pugh Matrix

I.3 Finalize Solutions

Tool 4 Solution Cause Matrix		Should Be Process Map	Cost Benefit Analysis

I.4 Implement Solutions

Process Control	Reaction Plan	Pilot	Implementation Plan	Risk Analysis	Rollout

I Gate Review

Conceive Solutions

Term
Conceive Solutions, Derive solutions, Generate Solutions, Solution Design

When
IMPROVE, first step of IMPROVE

Goal
Identify the best solutions for eliminating the identified root causes

Procedure
1. List obvious solutions for the verified root causes e.g. the optimization of process and input parameters, selection of a new supplier, material etc., alignment of equipment temperature

2. Consideration of best practice approaches

3. Adopt Lean best practices:
   a. Avoid defects
   b. Remove constraints
   c. Reduce inventories
   d. Reduce complexity

4. Use creativity techniques applicable to the specific situation

Tip
- Note that some solutions are often obvious based on earlier project work
- Experience shows that classic solution approaches work for certain types of cause and can be adapted to the given situation to eliminate the cause. Elimination of constraints by increasing of equipment utilization e.g. through better preventive maintenance (TPM) and/or the reduction of setup times

5 S

Term
5 S, (Sort – Seiri, Set in Order – Seiton, Shine – Seiso, Standardize – Seiketsu, Sustain – Shitsuke)

When
IMPROVE, generate solutions, any time during the project to create order, or indeed as a stand alone activity

Goal
- Create and maintain an organized, safe, clean and efficient working environment which is the basis for other process optimization approaches
- Avoid defects and/or recognize defects quickly, minimize search times and prevent work accidents
- Evaluate your working environment to see whether normal conditions prevail
- Get all involved employees to participate to generate a sense of responsibility to enhance the probability of long term sustainability

Procedure
1. **Sort – Seiri**
   – The purpose of this element is to separate what is needed and what is not needed to do the job.
     - Sort and mark all materials and objects in the working environment discarding things which are clearly not required
   – Attach red adhesive stickers or tags to items which are not immediately required ("Red Tagging"); keep these items in a marked zone for a specified period of time in case they are actually required in the future
   – After the specified time period has lapsed the tagged objects should be:
     ... disposed of if they have been tagged as "unnecessary", i.e. they are to be sold or thrown away
     ... kept/stored if they have been tagged as "required"
     ... if you are not sure, follow the rule: "When in doubt, throw it out!"

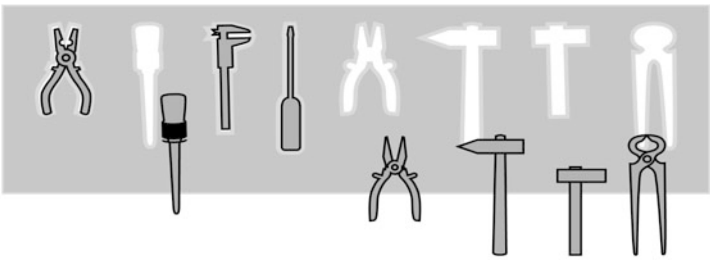
Example: "Red Tagging"

RED TAG			
No.			
Date			
Department			
Category	1	Inventory	
	2	Machines/other equipment	
	3	Devices	
	4	Tools and provisions	
	5	Other (description)	
Description			
Quantity			
Total value			
Availability/ evaluation			Date
	a	Taken to "red storage"	
	b	Thrown away	
	c	Taken to more suitable environment	
	d	Left at its previous storage place	

2. Set in Order – Seiton

- The purpose of this element is to arrange and mark required objects in such a way that anyone can find them quickly and once used return them to the correct place. Any missing items can be identified as such by a quick visual check.
- Sorted objects are allocated "their permanent place" which has been labeled/marked appropriately
- Various techniques are available to assist e.g. colored markings for defined areas
  - "Home addresses" in order to assign objects to particular areas
  - Labels and color or shadow markings designating the object and its storage place

Example: "Shadow Board"



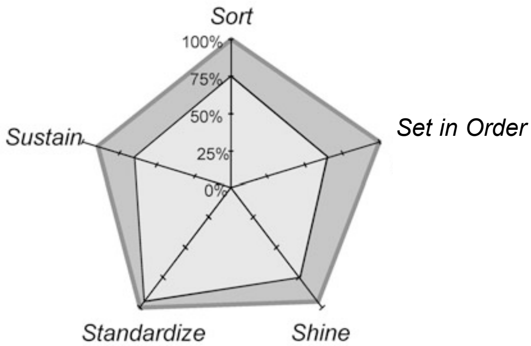
- Use the Principles of Motion Economy i.e. ”Use of Body movement”, ”Arrangement of the work area”, ”Design of relevant tools and machines”

3. **Shine – Seiso**
   - The purpose of this element is to establish and maintain a clean working environment so that problems can be quickly identified e.g. breakages, wear etc. and accidents caused by dirt/spills etc eliminated. Remove dirt, other impurities, scrap and waste materials in the immediate working area
   - Define cleaning objectives and the areas or items to be cleaned
   - Draw up and distribute a schedule defining ownership and responsibilities
   - Define procedures for regular cleaning activities
   - Establish regular audits and audit objectives

4. **Standardize – Seiketsu**
   Purpose of this element is to …
   … create a consistent procedure for things that have to be carried out on a daily basis within the scope of Sort, Set in Order and Shine
   … follow the motto: “Do things correctly, at all times!”

5. **Sustain – Shitsuke**
   The purpose of this element is to ensure longevity of the activity and work on improving the level of its’ adoption and success
   - Integrate 5 S culture into daily routines and all processes; 5S is not, and should not become, a one off event ("Flavor of the Day")
   - Create 5 S audit forms for collecting and presenting results. A Radar Chart is ideal for this purpose
   - Establish a regular audit cycle to ensure sustainability

The current status can be mapped with the help of a Spider Web diagram or Radar chart.



Tip

- Take photos of the area before and after the 5S action; this is a simple means for visualizing the results and creating acceptance
- Use 5 S above all if a work place and/or a work area is to be optimized
- Engage all employees in a 5S action
- Use the strength of the 5S methodology to significantly reduce search times as well as potential sources of accident in the working environment
- Make sure that “Sustain” is lived, otherwise the majority of earlier efforts will have been in vain
- Do not forget that 5S can be applied both in production and in administrative environments

Poka Yoke

Term
Poka Yoke, Error Proofing

When
IMPROVE, generate solutions

Goal
- Produce 100% quality by not making, ignoring or passing on defects
- Recognize defects as early in the process as possible in order to minimize the cost of rectification or avoidance

Procedure

1. **Identify and describe defects**
   Information on the yield rates or efforts for rework e.g. from a Value Stream Map can be used in order to target the relevant areas and describe the defect type

2. **Check suitability for Poka Yoke**
   Is it feasible to eliminate this defect by Poka Yoke?

3. **Analyze defects**
   Causes of defects should be confirmed; for instance: insufficient preparation of tool, use of wrong material, setting error, skipping of a processing step, disregard of process instruction

4. **Develop and select a solution idea**
   Based on the analysis potential solution ideas can be collected, refined and a suitable one selected. The preventive Poka Yoke approach is preferred; the reactive approach should only be selected if no acceptable preventive solution can be found i.e. because of cost and practicality

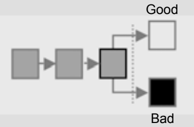
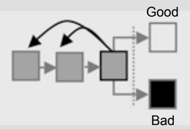
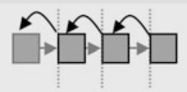
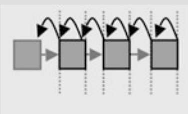
   Preventive approach to avoiding defects:
   - Implement methods that do not allow the production of a defect
   - Strive for 100% elimination of defects i.e. mechanically, systematically or automatically

Reactive approach to avoiding defects i.e. by use of control/warning mechanisms:

- Stop the process or give employee a signal if a defect occurs
- Fix the defective part if a process step is incomplete
- The process stops if irregularities occur (makes sense if preventing the defect is too cost intensive)
- High probability of achieving the goal of zero defects

Examination methods

- Traditional test: Distinction between good part and scrap and/or rework

Examination Methods		
Traditional Examination		• Distinction between good part and scrap and/or rework • Reduces the defective parts delivered to the customer • Doesn't prevent error production • Slow feedback on scrap and rework
Statistical Examination		• System for reduction of examination costs • Doesn't prevent error production, does not ensure non-defective parts • Errors can be passed through due to examination of samples • Slow feedback on scrap and rework
Continuous Examination		• Each process step controls the quality of the previous process • 100% of the parts are examined • Doesn't prevent error production • High effort/expenses of examination – efficient only for small amounts
Self-examination		• Each process step controls its own quality • Immediate feedback and corrective actions • The further processing of the defective part is stopped • High effort/expenses for examination – 100% of the parts are examined
Complete Examination		• Each process step controls its own quality and that of its supplier • Problem detection before finishing the process step • Immediate feedback and corrective action • The further processing of the defective part is stopped • High effort/expenses for examination – 100% of the parts are examined

5. **Implement solution idea and ensure sustainability of effect**
   The implementation should be accompanied on site in order to check its feasibility; after a suitable period of time its effect can be tested

All in all, Poka Yoke should be seen as a design principle. Examination functions mirror the preventive approach (e.g. examination of defect source, i.e. prevent the cause (input) leading to a defect). Trigger functions make deviations in the process visible (e.g. in case of contact method via geometric key figures). The regulation mechanism intervenes in the defective output (e.g. as an alarm when a defect occurs).

Examination function (input)	+	Trigger function (process)	+	Regulation mechanism (output)	=	Poka-Yoke-system

➾ **Tip**
- Please bear in mind that the earlier the defect is detected in the process the lower the costs will be for its elimination

Detection in development	**Detection in production**	**Detection during final control**	**Rejection by customer**	Customer
Change of design/ construction	Material costs, rework	Repair, delay of delivery, additional actions for quality assurance	Default costs, compensation, loss of turnover and loss of reputation	

- Take into account the idea of Poka Yoke when developing solutions and changing the process
- Prefer mechanical solutions to electronic ones, since the latter generally have a greater tendency to fail

- During the implementation you should take into consideration the following criteria for a good Poka Yoke mechanism:
  - It can be delivered quickly and easily requiring little investment
  - It is part of the process and no additional working steps are necessary for it
  - Its' effect is immediately recognizable at the potential defect source and it enables immediate correction by the employee
  - It integrates the employee directly rather than controlling the employee and provides support with respect to generating quality
  - Holistically it can make the need for further control at the end of the process redundant

Workplace Layout

Term
Work Cell Optimization, Workplace Layout, Workplace Design

When
IMPROVE, generate solutions

Goal
- Design the workplace in such a way that the work can be carried out efficiently and without defects
- Protect employees from accidents and long term harm due to nature of tasks
- Reduce the required time effort for completing a task or series of tasks
- Eliminate causes of defects in the working environment

Procedure
Phase 1: Preparation
- Stabilize process lead times in the entire process
- Eliminate shortages of parts
- Make sure that the process as a whole is aligned to customer requirements

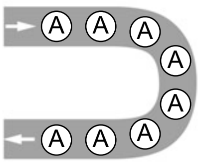
Phase 2: Design workplace layout
- Draw up a workplace for several machines or several steps per machine operator
- Decide about where raw materials and the WIP storage should be located
- Select workplace layout and implement (cf. opportunities listed below)
- Reduce batch sizes if possible
- Use process balancing to adjust time periods for tasks
- The ultimate goal is a batch size of one and single piece continuous flow.

Guidelines for the workplace layout
- Locate similar work operations in close proximity, if required in groups
- Adjust arrangement of resources (machines/employees) in the process sequence
- Use simple cost effective equipment

- Align speed of production in all workplaces to TAKT rate
- Plan work operations if possible with employees standing up with few movements
- Define standard operations
- Train employees for several activities so that flexibility of staff is guaranteed

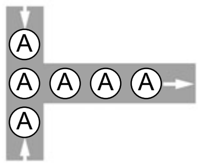
Tip

- Go to the "place of action" (Gemba), in order to define a suitable layout and to organize the environment
- Take into consideration that the design will not be perfect initially, further optimization will be required with the support of the people involved



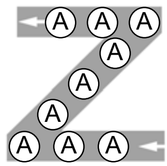
U-Shape

- Total working area visible
- Multiple machine work simple



T-Shape

- Suitable for two or more input sources
- Additionally suitable for workplaces processing several products and/or sharing individual work operations



Z-Shape

- Suitable e.g. in case of low amount of available space
- Multiple machine work and/or processing of several operations by one person possible

Theory of Constraints

Term
Theory of Constraints (ToC) (according to Eliyahu M. Goldratt)

When
IMPROVE, generate solutions

Goal
Increase the exit rate of a process with the minimum use of resources in order to meet market demand

Procedure

1. **Identify constraint**
   - Analyze material flow
   - Find bottlenecks and compare capacity with TAKT rate

2. **Improve constraint**
   - Plan to maximize output from the constraint
   - Reduce setup times and minimize setup procedures
   - Avoid unplanned downtimes
   - Minimize planned downtimes by flexible use of staff

3. **Subordinate everything else (non-constraints) to the constraint**
   - Improve quality and reliability of non-constraints in order to have potential effect on the constraint
   - Keep capacities
   - Adjust the utilization rate to the capacity of the constraint

4. **Increase the theoretical capacity of the constraint**
   - Increase the technical capacity of the constraint by investments

5. **Identify further constraints**
   - Identify "new" bottleneck and potential constraints that might emerge
   - If a steps’ capacity is below the demand apply steps 2-4
   - Address any "external constraint" by marketing and sales

Background

The Israeli-American physicist and consultant Eliyahu M. Goldratt developed the basics of his constraint theory during the 1970's which he published under the title "What is this Thing Called Theory of Constraints" (North River Press 1990).

Constraint Theory is based on a specific logic for prioritizing production. According to Goldratt production should be organized as follows:

- Top priority is to increase capacity since it is compared directly to additional turnover (assuming corresponding market potential)
- Second priority is the reduction of inventories, without, as far as possible, getting into conflict with the first objective
- Once the first two priorities have been addressed the third priority is the reduction of operating expenses.

Setup Time Reduction

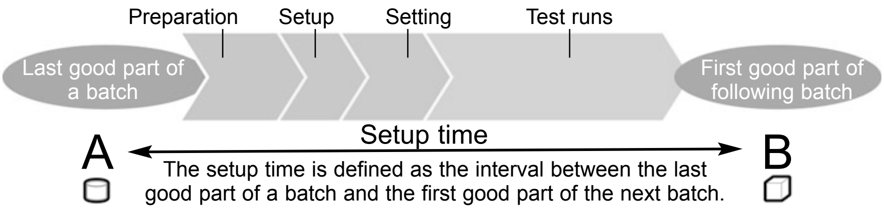
Term
SMED (Single Minute Exchange of Die), Setup Time Reduction, 4 Step Methodology

When
IMPROVE, generate solutions

Goal
- Reduce setup times in order to maintain exit rate when there are frequent setup procedures and to be able to realize lower batch sizes and thus become more flexible
- Reduce setup times at points of constraint and by doing this increase actual capacity
- Increase the proportion of the theoretical capacity of a constraint point so that more actual production time is available
- Reduce working capital, increase the flexibility of production and reduce scrap/rework by shortening the learning cycle
- Increase the efficiency and (in particular administrative and service processes) maximize the time with the customer

Procedure

1. Document setup processes and divide individual activities into internal and external activities



- Internal setup activities: Activities which can only be conducted when the machine is shut down (e.g. exchange of molds and tools) and/or when no service is rendered

- External setup activities: Activities which can be conducted while the machine is operating (e.g. preparing materials, booting tool programs) and/or while a service is rendered (e.g. provision of information for the next counseling interview)

2. Convert internal into external activities

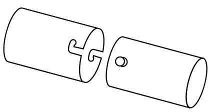
- Focus primarily on activities which delay or disrupt the process flow since much setup time is lost by searching for material and information
- Conduct a detailed analysis of reasons for disruption
- Brainstorm to identify opportunities for converting internal into external activities.

No.	Setup process spray-painting [Description]	Time needed [Minutes]	Activity	
			Internal	External
1	Fix spoiler	2	2	
2	Mix paint	1	1	
3	Clean spray-gun	7	7	
4	Prepare nozzle	5		5
5	Fill spray-gun	…	…	…
6	Switch on ventilation	…	…	…
7	Put on breathing protection	…	…	…
8	Set spray-gun	…	…	…
	Total time required	…	…	…

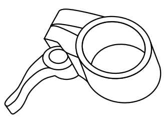
3. Streamline remaining internal activities

- Streamline remaining internal activities through simplification, elimination and reduction
- Reduce and/or eliminate the necessity for hand tools, nuts, bolts and screws
- Use materials that help to prevent defects occurring at the point of source
- Enable quick change of systems and/or systems access when services are being rendered, e.g. when an order is processed; reduce disruptive factors

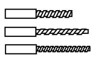
Bayonet fittings

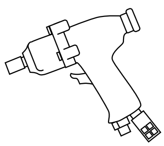


Quick Release



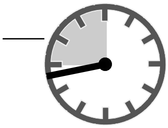
Pneumatic screwdriver

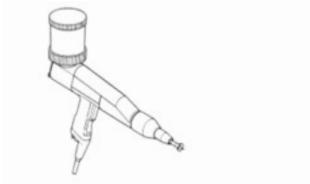




4. Eliminate adjustments and test runs

- Eliminate intuition and estimates from adjustments and replace them with facts and fixed settings
- Use visual control mechanisms to reduce adjustment times caused by inaccurate alignments, settings and/or measurements





Application of SMED in administrative areas:

The described methodology for setup time reduction can be applied in the administrative environment if

- information must be traced back in order to complete reports
- necessary information is not available upon demand
- a change of some type is required before moving onto the next step

All of these points contain waste and lead to sub optimal performance of value adding work. Thus, setup time reduction in the administrative environment places should focus on all activities which stop the optimal execution of value adding work.

In this context, reasons for disruption are systematically questioned and solutions are developed. Unavoidable disrupting activities are simplified e.g. electronic notes and reminders are used in order to accelerate complex working steps.

Procedure of setup time reduction in the administrative environment

1. Document process and divide individual activities into internal and external activities	2. Convert internal into external activities	3. Streamline remaining activities	4. Eliminate adjustments and test runs
Value Analysis of process tasks and divide into disrupting and/or preventing activities	Exclusion of disrupting and/or preventing activities	Streamlining of remaining disrupting and/or preventing activities	Check Operational procedure of process steps and draw up checklists

Tip

- Bear in mind that when planning and conducting activities for setup time reduction the effort involved should justify the reward
- Record the setup process on video: When you watch the film (not just once) with the team you may discover surprising instances of waste
- Ensure that all employees have been informed and that the Works Council approves of this action
- A Spaghetti Diagram is particularly suitable for visualizing the process and the instances of waste
- During the preparation phase of an action for setup time reduction you should use a Value Stream Map in order to identify constraints by mapping the material and information flows

Opportunities for applying SMED in service processes are for instance:

- cleaning an aircraft between flights,
- resetting the table once a diner has left a restaurant,
- tidying up the desk between two customer interviews or between two shifts in a Call Center.

Total Productive Maintenance (TPM)

Term
Total Productive Maintenance, Concept of Preventive Maintenance

When
IMPROVE, generate solutions

Goal
- Increase productivity by improving the work efficiency, the restoration of high plant performance and early detection and reduction of disturbances and failures
- Increase quality by reducing scrap rate, rework and customer complaints
- Cut costs by reducing the expenses for maintenance, the reduction of the energy consumed by equipment and reduction of production losses due to equipment failures
- Reduce inventories and the process lead time by increasing the inventory turnover, reducing the inventory level, reducing variation in process lead time and mid-term reduction of the total process lead time
- Improve the working environment and working safety by involving workers in maintenance and encouraging the acceptance of the need for planned maintenance in improving safety and reducing accidents

Procedure

1. **Analyze current situation:**
   - Document the costs for maintenance and repairs (replacement parts and work)
   - Determine the Overall Equipment Effectiveness or O.E.E. to find out the proportion of time a machine produces at the desired quality

Overall Equipment Effectiveness or O.E.E.

Availability level	Performance level	Quality level
Equipment downtimes Mechanic, pneumatic, hydraulic or electric defects leading to production loss. **Losses due to setup and settings** Equipment is adjusted for the production of a new part.	**Idle time and short downtimes** Time during which equipment runs without producing anything, as well as short interruptions (e.g. employee comfort breaks, search for material, etc.) or short disruptions to equipment which can be repaired quickly (e.g. confirmation of error report). **Reduced speed/ exit rate** The equipment is not operated at the scheduled speed/exit rate.	**Quality losses** Activities with are connected with the quality assurance of a product (scrap and rework). Rework frequently means that the complete production step must be run through once again. On the other hand, scrap means that the machine time used for producing the scrap part hasn't been used in a value adding way.

Calculation of O.E.E. as a product of availability, performance and quality:

Scheduled busy time		T = Total no. of hours for plant operation [h]					
Availability level (AL)	$AL = \frac{A}{T} \cdot 100\%$	A = Availability [h]			Plant breakdown	Setup and setting	Idle time, standstill
Performance level (PL)	$PL = \frac{S}{A} \cdot 100\%$	S = max. takt speed [h]		Speed loss			
Quality level (QL)	$QL = \frac{Q}{S} \cdot 100\%$	Q = Good Quality [h]	Rework, scrap				

OEE	$OEE = AL \cdot PL \cdot QL$

Availability level (AL)	$AL = \frac{T_{Run}}{T_B} \cdot 100\%$
Performance level (PL)	$PL = \frac{T_{Cons} \cdot N_{Produced}}{T_{Run}} \cdot 100\%$
Quality level (QL)	$QL = \frac{N_{Good}}{N_{Produced}} \cdot 100\%$
Example	$OEE = 73\% \cdot 91\% \cdot 80\%$ $= 53\%$

T_B = Scheduled busy time [h]

T_{Run} = Machine running time [h]

T_{Cons} = Constraint takt time [h/unit]

N_{Good} = Number of finished goods [unit]

$= N_{Produced} - N_{Scrap} - N_{Rework}$

85% World Class

2. Quick checks to maintain equipment in a reliable state:
- Inspect and clean machine, identify necessary repairs and mark defects which need to be repaired
- The team or operator thoroughly clean the machine
- Check and mark any areas requiring service or repair
- Document all necessary repairs and draw up Time Plan for conducting the work
- Conduct repairs
  – Improve access opportunities to the area and/or the respective equipment so actions such as cleaning, lubricating, setting and inspection can be conducted regularly and easily always bearing in mind health and safety regulations.

3. Implement concept for "planned maintenance":
Structure maintenance process in order to ensure a stable production environment and monitor equipment with planned ("preventive") actions in a way that no unscheduled downtimes occur:

1. Define maintenance priorities:
Identify the areas (equipment and/or production areas) occupying the maintenance department most in terms of breakdown frequency, need for replacement parts, etc. Introduce logbooks to record all incidents affecting the equipment.

2. Assess current status and create baseline position:
Undertake a detailed analysis of weak points for parts and components susceptible to breakdown, using the logbooks and other relevant documents.

3. Introduce information, planning and steering system (IPS):
Document and analyze information about individual equipment and required maintenance activities. Use dynamic computer driven schedules so that maintenance actions can be easily planned, controlled and coordinated.

4. Introduce process related maintenance:
Undertake regular inspection and maintenance of the equipment. Maintenance plans and lists the tasks to be undertaken annually, monthly or weekly help to coordinate these inspection and servicing actions.

5. Optimize internal operations:
Optimize existing internal maintenance procedures when carrying out maintenance actions. Potential optimization approaches:

- Reduce the time required for the diagnosis of defects – analysis of breakdowns is often very time-consuming
- Optimize the storage of replacement parts – nature and location of storage directly influences the repair time
- Optimize the exchange of replacement parts – aim to reduce the time needed to exchange parts

6. Ensure sustainability – continuously improve planned maintenance programs:

- Guarantee the early detection of problems by training employees in preventive and predictive maintenance methods
- Install visual controls
- Implement 5 S
- Regularly control and improve the machine performance
  - Has the equipment causing most problems been identified?
  - Have all weak points been effectively eliminated?
  - Can the IPS system be further improved?
  - Can maintenance plans and standards be further improved?
  - How effective are the maintenance department's actions and workflows?
  - Can the repair and service times be reduced further?
  - What do the key TPM indicators show?
    - Overall Equipment Effectiveness (O.E.E.)
    - Mean Time Between Failure (MTBF) and
    - Mean Time To Repair (MTTR)

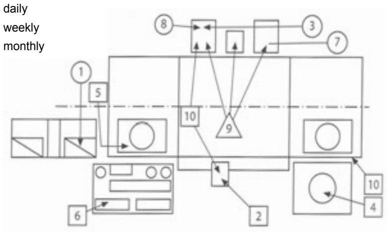
Tip

- Machine operators must be instructed in the basic maintenance activities such as cleaning, lubricating, identifying causes for damage etc.
- Basic familiarity with, and know-how of, equipment contributes to raising productivity and reducing downtimes
- TPM is only successful if all employees have been actively involved

Example Maintenance Plan

Machine No.				Machine Name		
Chart No.				Manufacturer		
No.	Machine parts to be lubricated		Lubricant	Quantity	Method	by
1	Pneumatic control panel	□	ESSO ZD5	50 ml	Orange oil can	PRD
2	Stock 1 and 2	△	SHELL T32	2 l	Blue tank	RS
3	Shaft	○	ESSO ZD5	0.5 l	Control oil level	PRD
4	Spindle	△	SHELL T16	1 l	Violet jerry can	RS
5	Gear unit	□	ESSO ZD5	10 ml	Control oil level	PRD
6	Tracks	△	SHELL T3	/	Green container	RS
7	Hinge joints	△	SHELL T11	/	Blue oil can	RS
8	Power unit 3	△	ESSO ZD5	0.5 l	Red jerry can	PRD
9	Power unit 4	△	SHELL T11	1.5 l	Blue oil can	PRD
10	Power unit 5	△	ESSO ZD5	1 l	Red jerry can	PRD

□ daily
○ weekly
△ monthly



RS = repairs & servicing	PRD = production	Creation date

Generic Pull System (GPS)

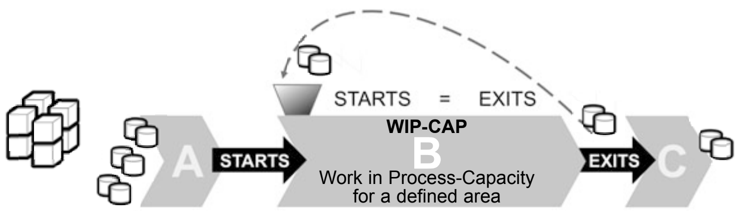
Term
Flow Pull System, Generic Pull System (GPS)

When
IMPROVE, generate solutions

Goal
- Orient and control production towards meeting actual demand and avoiding overproduction as well as delivery constraints
- Reduce inventory in the process (Work in Process) and reduce/ stabilize the process lead time (PLT)
- Increase the process speed and flexibility

Procedure
1. Implement a strict "First-in-First-Out System"

2. Introduce signals: A signal at the end of production informs the beginning about when a part (batch) leaves production; only then should the production of a new part (batch) begin; the rest of the material and information flow remains unchanged



The quantity to be maintained in the process

- The product reaches the customer at a predictable point in time
- By the reduction of variation in process lead time inventories can be reduced – and by doing this the process lead time itself
- Lower variation in the process lead time is a prerequisite for implementing a Replenishment Pull System

3. The inventories in the process can be gradually reduced; a target level can be set in two ways:
   - Using process lead time, e.g. on the basis of a customer request
   - Using process efficiency, e.g. on the basis of a benchmark

   Target level via process lead time:
   $$\mathbf{WIP_{TARGET} = WIP_{AS\ IS} \cdot (PLT_{TARGET} \div PLT_{AS\ IS})}$$

   Target level via process efficiency:
   $$\mathbf{WIP_{TARGET} = WIP_{AS\ IS} \cdot (PE_{AS\ IS} \div PE_{TARGET})}$$

4. The inventories are gradually pulled from the process to the target level and process control is instigated

Tip
- Check if the physical process must be changed
- In case of a strict First-in-First-out system the so-called "rush job" must be clear before production starts
- In the event that disruptions occur a reduction of inventories poses the risk of a halt to the complete process, since no replenishment is available. Causes of process disruptions must be identified and addressed (e.g. machine failures, material constraints, quality problems, search times, loss of employees, setup times etc.). Value Stream maps are a good basis for this. Only if counter measures have been introduced and been shown to work can inventories be reduced on a step by step basis until the target level is reached.

Generic Pull Systems in the administrative environment
In the administrative environment the control of the WIP level (units such as documents, forms, mails etc.) is the primary lever for increasing process speed as well securing Service Level Agreements (SLAs). The determination of the WIP's upper limit restricts the number of units entering the respective working process to this level. It is very important that the input into the process is controlled with the help of a priority system. This does not apply for processes with direct customer contact, e.g. at the Point of Sale (PoS). According to Little's Law it is more likely that reliance will be placed on the flexible use of (additional) resources in order to process varying input quantities by increasing or reducing exit rate than might be the case in an industrial situation given the slightly more predictable demand levels and probable process lead times.

Example of the successive reduction of inventories

Pattern: WIP Reduction Action Plan

	Time Frame	Value Add (hours)	Output (unit/day)	WIP (item)	PLT (days)	PE
Today	Month 0	3	30/day	300	10	1.25%
Step 1	Month 1	3	30/day	200	7	1.79%
Step 2	Month 2	3	30/day	100	3	4.17%
Step 3	Month 3	3	30/day	37.5	1.25	10.0%

Replenishment Pull System (RPS)

Term

Replenishment Pull System (RPS), Pull production in connection with the creation of strategic buffer stocks.

When

IMPROVE, generate solutions

Goal

- Avoid high capital utilization, delivery constraints and over production using demand oriented control of production.
- Control inventories by triggering an order with a supplier and/or production when a stipulated reorder level is breached. This reorder level being calculated based on consumption data; the same principle is used for procurement (Purchase Pull) as well as for production (Manufacturing Pull)
- Enable short-term orders by reduced process lead times

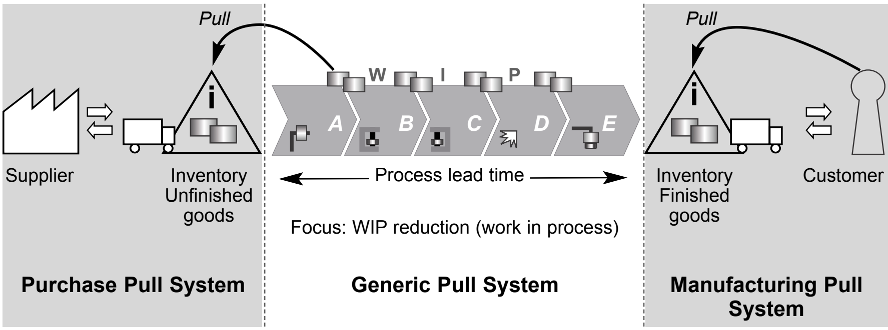
Procedure

1. Prerequisites for Purchase Pull and Manufacturing Pull

- Replenishment time (delivery time and/or production time) is higher than the delivery time requested by the customer (otherwise production after order receipt is preferred)
- Demand (of production and/or of final customer) varies only to a limited extent and is not due to seasonal factors
- Variation of the Replenishment Time (delivery time and/or production time) is low; that's why a system for regulating the process lead time in the process and thus the inventories in the process is strongly recommended

2. Test the Pull System capability

Pull capability is assumed if the coefficient of variation ($s/\bar{x}$) is smaller than 1



3. **Calculate inventory of finished products and/or unfinished material – the following are usually taken into consideration**
   - Replenishment Time
     – For Purchase Pull: Delivery time from time of order until receipt into inbound stock
     – For Manufacturing Pull: Production lead time from order receipt until arrival in finished goods warehouse, taking into account the production cycle, i.e. the frequency of production

   - Demand:
     Regularly recurring need (e.g. daily, weekly)

   - Safety factor:
     The safety stock or buffer stock can initially be fixed and adjusted later. More complex calculations take into consideration, Service Level (probability of being able to immediately serve the demand when an order is made) and fluctuations in production and demand quantities (cf. e.g. Anupindi, R. et al (2004)

4. **Set (re)ordering logic**
   - When should a new order be triggered?
     Inventory + non-delivered orders < reorder level

   - Order quantity:
     Takes into account reorder level and stock of inventory as well as undelivered orders

Opportunities for post-production triggers when the inventory limits have been reached

Visual Kanban
- Empty or free containers in the buffer zone (Two Bin Replenishment Pull)
- Production team recognize when the sales team remove buffer material and/or empty containers are standing in the Kanban supermarket

Kanban Disposition Boards
- Triggered by using cards stuck to displays
- Production and sales unit are in the same company unit but are some distance from each other

Electronic Kanban
- Transmission of Kanban information via internet and/or company networks within the framework of a Supply Chain Management system

Two Bin Replenishment Pull System

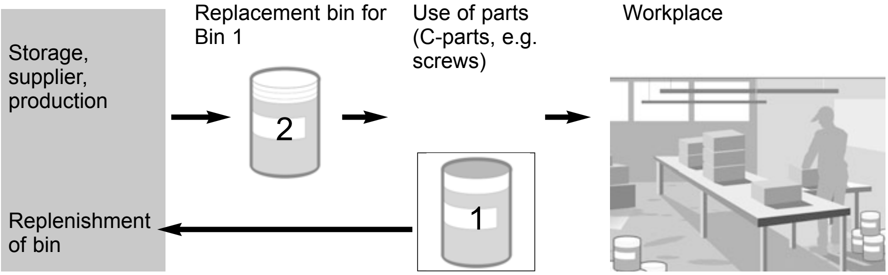
A Two Bin Replenishment Pull System is a simplified variant of the standardized Replenishment Pull System. Two bins containing the relevant product are used for this:

- Bin 1 contains a sufficient amount of the product for a specified period of time; it is located directly at the workplace
- When Bin 1 is emptied Bin 2 is already available, meaning Bin 1 can now be refilled in readiness for replacing Bin 2 when that too is emptied and so the cycle continues

The size of the bins and the quantity of product held relies on a similar calculations used for the standardized Replenishment Pull System

Tip

- As storage requirements vary by industry reference must be made to appropriate specialist literature in order to determine the required inventory quantity
- All areas involved in a Kanban system should be subject to ongoing performance control
- A person responsible for Kanban should check the system continually for optimization potential
- You should focus on the system components e.g. employees (is Kanban understood and accepted?), inventories (inventory quantity and safety), products (coping with parts capable of Kanban), setup times (does need for setup time reductions exist?), safety (stability of Kanban System), quality (scrap and rework) and customers (customer satisfaction, flexibility and speed)
- You should record the status of individual components in the course of regular audits and visualize it (e.g. in Radar Charts)



Determination of Batch Size

Term

Batch sizing, determination of batch sizes, smallest safe batch size

When

IMPROVE, generate solutions

Goal

- Determine the optimal batch size (which corresponds largely to market demand)
  – Be able to react as quickly as possible to customer needs: Projects for setup time reduction enable significant improvements of process lead times by up to more than 50% in combination with reasonable batch sizes
- Make maximum use of the capacity of constraints in the process
- Compensate for the process's yield loss
- Achieve high quality and lowest total costs; the production runs with the minimal amount of WIP and inventories (which can be reduced by up to 50%) in order to enable quick learning cycles with respect to quality increase

Procedure

1. Determine the optimal batch size with the help of the formulas which are commonly used in the company; the following aspects must be taken into consideration at least:
   - Production time for the quantity demanded by the customer
   - Process yield (meaning % good product produced)
   - Setup times
   - Need of an item for a defined period of time

2. Batch size is to be continuously evaluated and adjusted based on practical experience until such times as the optimal settings have been reached.

Tip

Make use of the calculation formula as starting point for the batch size and optimize the batch size gradually in order to enable an On-Time and/or Just-in-Time delivery

Process Flow and Process Logic

Term
Process flow and process logic

When
IMPROVE, generate solutions and finalize solutions, in the course of developing the SHOULD BE process

Goal
- Eliminate defect opportunities
- Maximize degree of value addition (eliminate non-value adding activities)
- Minimize process lead time
- Minimize necessary resources

Procedure
1. Determine the essential tasks of a process:
   What must happen by all means so the output corresponds to the specifications?

2. Determine individual process steps and evaluate them critically:
   Major activity, important additional activity or necessary supporting activity for a different process step – eliminate all other activities

3. Ensure process logic by the sequence and parallelization of tasks; avoid process and feedback loops

4. Use further process elements in an optimal way, e.g. information, IT, material resources, skills of employees

Brainstorming

Term
Brainstorming

When
Project selection, ANALYZE, IMPROVE, generate solutions

Goal
- Find ideas in general
- Generate and prepare ideas for eliminating the main causes
- Transfer derived potential solution for the elimination of a problem to a specific situation

Procedure
1. Define rules for conducting Brainstorming in the team
2. Define and write down the key topic and/or the question formulation
3. Develop ideas
4. Collect ideas
5. Explain ideas and structure and/or cluster them (cf. Affinity Diagram)
6. Elaborate on individual ideas by renewed Brainstorming

Facilitate Brainstorming
The facilitation of the Brainstorming is decisive for the session's success. Generally, one facilitator leads the session. Different variants for collecting ideas exist:
- Flip chart: The facilitator collects the ideas and writes them down
- Metaplan Board (1): The facilitator collects the ideas, writes them down and pins them randomly on the board; clustering takes place later together with the group
- Metaplan Board (2): Everyone writes down his ideas and clusters them around existing topics

Which variant of facilitation is used frequently depends on the facilitator's experience and the team's openness.

Brainstorming Rules

- Listen to the contributions of others and don't interrupt
- Every proposal counts
- All participants are integrated
- No "killer" phrases
- Quantity is more important than quality
- No content-related discussions and explanations
- Everything is written down
- Define a suitable time frame (5 to 10 minutes)

Tip

- Use the Brainstorming variant which best matches the respective team, topic and situation
- Hang up the rules for the Brainstorming in the meeting room so that they are visible for everyone
- Separate the phase during which ideas are collected from the evaluation of ideas afterwards during which the ideas are summarized and prioritized
- Consolidate the ideas by crossing out double ideas, find (cluster) connected ideas/thoughts, formulate cluster headlines and combine ideas
- Generally use Post-its® or facilitation cards in order to simplify clustering
- When the clustering is conducted there are frequently different reasonable connections and consequently there is no right or wrong
- Afterwards, you should prioritize the ideas with suitable methods; however, you should adjust the method selection to the time available
- When selecting and applying creativity techniques you should bear in mind that during the daily routine one brain hemisphere is preferred and thus trained in a better way; the left brain hemisphere is all about figures, data, facts, rational logic and analytical thinking whereas the right brain hemisphere supports imagination and intuition; it is especially the latter which must be addressed in a targeted way
- Those who are used to forming analogies and thinking laterally may feel restricted when suddenly having to solve a problem in a structured way; conversely, a person acting rather rationally and logically cannot produce new ideas at the touch of a button; this concerns not only the team but also the facilitator; both must feel at ease with the technique
- Not every technique is suitable for each cause; the selection of creativity techniques must ensure a balance between cause, team and facilitator

Anti-Solution Brainstorming

Term
Anti-Solution Brainstorming

When
IMPROVE, generate solution

Goal
- Collect ideas for finding solutions by thinking about the question: What could make the situation even worse?
- Resolve blockages preventing the identification of solutions

Procedure
1. Set up rules
2. Identify and write down topic: What could make the situation even worse?
3. Develop ideas
4. Collect ideas
5. Explain ideas and structure and/or cluster them
6. Transform ideas into improvement proposals
7. Go further into individual ideas by renewed Brainstorming

The Brainstorming rules apply.

Tip
- Use red cards for collecting anti solutions and green cards for positive solutions
- After having generated anti solutions a further Brainstorming should be conducted in order to derive positive solutions in the team

Example Anti-Solution Brainstorming

What can make our process even worse?	→	**Improvement proposal**
Longer transport routes		Shorter routes, more efficient means of transport
No cleaning of machine(s)		Regular planned cleaning
Each operator sets the machine differently		Standardized settings for every-one

■ Red ■ Green

Brainwriting

Term
Brainwriting

When
Project selection, ANALYZE and IMPROVE

Goal
- Develop ideas in a group session in a quiet atmosphere.
- Develop unusual combinations and links between ideas. Often used when concepts being explored or potential solutions are more complex.

Procedure

Classic Brainwriting
1. Determine the topic with the group
2. Everyone gets sheet of (A4) paper
3. Everyone writes down an idea for solving the problem
4. The sheet is passed on to the neighbor in a clockwise direction (everyone at the same time) after a specified period of time e.g. 3 minutes
5. The neighbor now considers the predecessor's idea and elaborates on it or develops a completely new one.
6. After the specified time period has lapsed pass on the sheet once more
7. Collect the sheets at the end of a set time or once the whole group has seen each sheet
8. Attach the sheets to a board and explain the contents
9. Summarize the proposals on a flip chart or on cards

Brainwriting 6-3-5
Brainwriting 6-3-5 follows the classic model. The term indicates the nature of the procedure i.e. 6 people write down 3 ideas and pass on after 5 minutes.

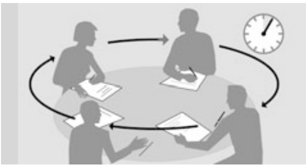
Idea Card Method
This method is another alternative to classic Brainwriting. The ideas are collected on cards or Post-its®. The advantage is that there is no need to copy the ideas later.

Brainwriting Pool
Brainwriting Pool is another variant where the ideas are not passed on systematically in a clockwise direction but are collected in the middle of the table. Each team member can draw one or several ideas from those in the pool and develop it/them further.

Notebook Method
Instead of collecting the ideas during a session, each team member can write down his own ideas irrespective of time and place. The ideas are passed on to other team members via email. After some time they are collected and discussed at a team meeting. A typical time frame for this kind of Brainwriting is 2 to 4 weeks.

Tip
- Display the evolving solutions so they are visible for everyone
- Start with one topic and collect all of the formulated ideas – then continue with the next topic on the agenda before grading all formulated ideas
- It is best to develop ideas with the team to leverage everybody’s input and build more comprehensive solutions.

Brainwriting Examples
Example 1: Classic Brainwriting



Example 2: Notebook Method

SCAMPER

Term
SCAMPER

When
Application of creativity techniques, ANALYZE and IMPROVE, generate solutions

Goal
- Provide additional options and triggers for creativity when identifying solutions
- Provide some structure for furthering development of solution ideas

Procedure
1. Compare the process steps from the AS IS process and/or generated solution ideas to the SCAMPER checklist

2 Start answering the following questions:

Substitute	What can be substituted by what? Can the process be designed differently? Are there elements from other countries or times that might be brought in?
Combine	What could be combined with something else? Could this be connected with other ideas, subdivided into components and transformed into a winning idea?
Adapt	How can ... be adapted? Can parallels with other industries, processes etc. be identified? Can we empathize with this?
Modify	How can ... be changed (maximized, minimized)? – Meaning, color, movement, size, form, etc., – Enlarge something, add something, increase the frequency, – Reduce something, remove something, reduce the frequency.

Put to other uses	How can ... be put to another use? Does it have other possible uses? Can it be deployed elsewhere?
Eliminate/ erase	How can ... be eliminated and/or deleted? Is this really necessary?
Reverse/ rearrange	What happens if ... is reversed or rearranged? Can the sequence be changed? Can the idea be flipped around? Can the items be interchanged?

Documenting SCAMPER

	S	C	A	M	P	E	R
Process step 1 and/or idea 1							
Process step 2 and/or idea 2							
Process step 3 and/or idea 3							
etc.							

Analogy Brainstorming

Term
Best Practice Sharing, Analogy Brainstorming

When
Application of creativity techniques, ANALYZE and IMPROVE, generate solutions

Goal
- Enhance creativity when identifying solutions
- Look for solutions in other processes or situations or industries that could be adapted to this situation

Procedure
1. Select the feature of the original system or product, or find a feature with the help of the 8-P-feature checklist

2. Find another system or product which has this feature

3. Formulate question: How did that system or product solve the problem and how could it help us solve the problem?

4. Transfer the solution to the original system or product

Analogy Brainstorming goes beyond Best Practice Sharing in so far as the latter focuses on the adaptation of an especially high-performance solution found elsewhere.

Feature category	Question
People	Who is involved?
Processes	What procedures exist?
Places	Where does something happen?
Purposes	What goals/purposes are pursued?
Parameters	What features does the system have?
Policies	What rules/traditions exist?
Problems	What problems exist?
Parts	What components exist?

Tip

- Involve all Stakeholders early on and create room for your own variants and adjustments; the implementation of insights gained elsewhere frequently meets resistance even if the solution is sophisticated; this is known as the "not invented here" syndrome
- Take into consideration that the effort to transfer back to the original problem is not easy; this can cause frustration

Affinity Diagram

Term
Affinity Diagram, Clustering, Affinity Diagram

When
Generally when ideas are collected, IMPROVE, refine and filter solutions

Goal
Bundle ideas (cluster) and summarize in order to identify and understand the core themes

Procedure

1. Sort and structure solution ideas according to topic

2. Give each group of ideas a concise heading

Tip

- Always look for logical connections when sorting ideas; if the idea is moved from one group to another, write it down again so that it can be assigned to both groups
- Some ideas/stickies can justifiably, stand on their own. They might be just as important as any of the groups of ideas.

TOPIC		
Heading 1	Heading 2	Heading 3
Idea	Idea	Idea
Idea	Idea	Idea
Idea	Idea	Idea

Must Criteria

Term
Must Criteria

When
IMPROVE, refine and filter solutions, should use before other filtering methods

Goal
Review generated solutions and make sure that they satisfy essential criteria (so called Must Criteria).

Procedure

1. Check every potential (sub) solution for Must Criteria; Must Criteria are the requirements which must be fulfilled regardless of what else is delivered. Among these are:
   - Legal regulations
   - Safety regulations
   - Project related customer requirements
   - Corporate strategy and philosophy
   - Company agreements
   - Norms/Standards
   - Environmental regulations

	Fulfillment of criteria by solution idea …				
List of criteria	A	B	C	D	…
Regulation 1	✓	✓	✓	X	
Condition 1	✓	X	✓	✓	
…					

2. If a solution idea which has been proposed violates a Must criterion it is rejected and not considered for further development

Tip
Make the solutions to be filtered out clearly visible for everyone in the meeting room and document them afterwards

DEFINE
MEASURE
ANALYZE
IMPROVE
CONTROL

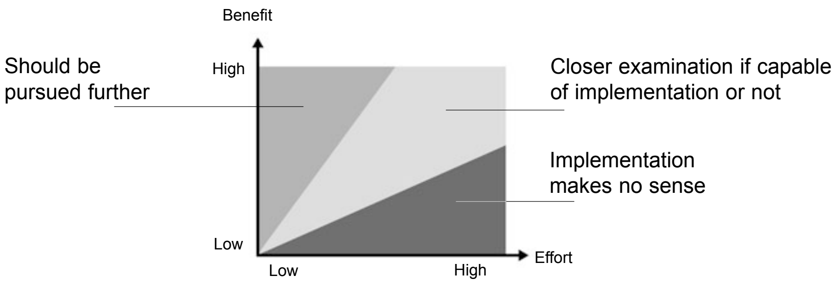
Effort Benefit Matrix

Term
Effort Benefit Matrix

When
IMPROVE, refine and filter solutions after having checked the Must Criteria

Goal
- Evaluate potential solutions according to effort and benefit
- Select the solutions with the most favorable effort-benefit ratio

Procedure
1. Develop an agreed operational definition of effort and benefit within the team
2. Check each solution against the operational definition of effort and benefit: evaluation is done by the team
3. Place the solutions into/on the matrix according to the evaluation
4. Reject solutions with high effort and low benefit
5. Prioritize solutions with low effort and high benefit for further consideration



Tip
Put up definitions of effort and benefit to assist further sorting of solution proposals in the meeting room so everyone can see them.
It can be energizing for the team to place the ideas on the matrix themselves and can sponsor constructive debate about relative merits of ideas

N/3 Method

Term
N/3 Method, ("N over 3", "N divided by 3")

When
ANALYZE, collecting potential causes, IMPROVE, refining and filtering solutions

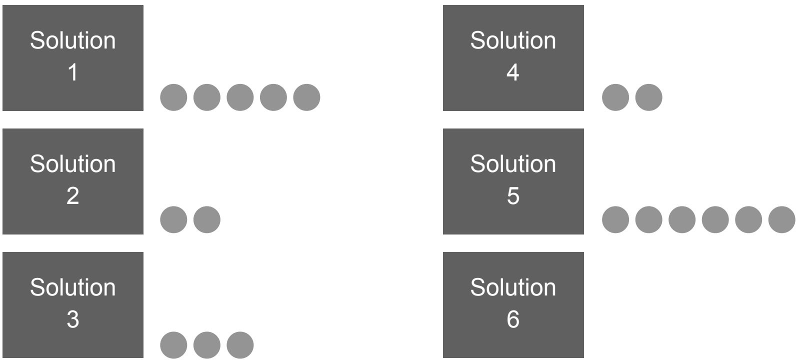
Goal
Reduce a high number of alternatives by sorting out the least preferred ones

Procedure

1. **Each group member gets a certain number of votes based on the following:**

$$\text{Number of votes per team member/workshop participant} = \frac{N}{3} = \frac{\text{Number of alternative solutions/ideas}}{3}$$

2. **Team members distribute their votes according to their personal preferences:**



3. **The alternatives with the majority of points are pursued further**

4. **Ideas that are filtered out should be checked to ensure that something valuable has not been accidently overlooked**

Tip

- It may be necessary to repeat the procedure until the target reduction has been reached
- This method should only be applied if reasonable alternatives exist; do not apply this methodology if solutions can only be implemented after having been combined

Nominal Group Technique

Term
Nominal Group Technique

When
Project selection, IMPROVE, refine and filter solutions, selection of alternatives

Goal
- Prioritize alternatives (topics, problems and solution approaches)
- Let a team of experts evaluate a manageable number of alternatives

Procedure
1. Gather the remaining alternatives and list in a table

2. Each team member ranks the alternatives; the highest-ranked alternative receives the highest number of points

3. Add up the values and rank again based on these; the alternative with the highest ranking is the one selected by the group

Tip
- Only realistic alternatives should be compared using this method
- Avoid ambiguity and build to common understanding in the team
- This methodology works best with 10 to 12 proposals – it is difficult to compare a ranking for a larger number of alternatives; if there really are many realistic proposals you should use the N/3 methodology (once again)
- If two or more solutions receive the same total score you should discuss in the team how the evaluations differ; the understanding of the solution may not be the same
- If this situation can't be resolved then perhaps a Criteria Based Matrix or Cost Benefit Analysis should be considered

Example Nominal Group Technique on the following page.

Example Nominal Group Technique

Topic/solutions		Person A	Person B	Person C	Sum
A	New paint supplier	3	5	4	12
B	Training	7	3	3	13
C	New mixing scales	4	2	2	8
D	New undercoat	5	6	6	17
E	New employees	2	4	1	7
F	New spray nozzle	6	7	7	20
G	Remodel paint box	1	1	5	7

Pugh Matrix

Term
Pugh Analysis, selection procedure according to Pugh, Pugh Matrix

When
IMPROVE, refine and filter solutions

Goal
- Find the best alternative (e.g. a complete solution) by direct comparison against a number of evaluation criterion
- Potentially find a new solution by adapting features of one proposal to another in such a way that an even better proposal is obtained

Procedure

1. **Identify the evaluation criteria**
   Apart from CTCs (effectiveness) the evaluation criteria could also comprise efficiency (Voice of Business/CTBs), cost, implementation time, market potential etc.

2. **Prioritize the evaluation criteria**
   The criteria are ranked from 1 (lowest rating) to n (number of criteria and highest rating)

3. **Select a benchmark solution to use as a standard**
   The Benchmark might be the existing solution or one of the new ones that people consider “satisfactory”. This will be the standard against which all solutions compete

4. **Draw up the evaluation matrix**
   - Enter solutions
   - Enter criteria
   - Enter prioritization

5. **Evaluate the alternatives in pairs**
   Compare the alternative concept ideas with respect to their fulfillment of

the individual criteria with the standard: A better evaluation than the standard is evaluated with a plus (+), a worse evaluation with a minus (-); for each concept the number of the same evaluations is added and weighed according to the prioritization of the evaluated criteria (e.g. concept 1: prioritization of criterion 1 (=3) + prioritization of criterion 2 (=4) corresponds to the weighed sum + (=7))

Alternative / Criteria	Concept 1	Concept 2 (Standard)	Concept 3	Prioritiz-ation/ weighing
Criterion 1	+	0	-	3
Criterion 2	+	0		4
Criterion 3	0	0	+	2
Criterion 4	-	0	0	1
Sum +				
Sum -				
Sum 0				
Weighed sum +				
Weighed sum -				

Alternative / Criteria	Concept 1	Concept 2 (Standard)	Concept 3	Prioritiz-ation
Criterion 1	+	0	-	3
Criterion 2	+	0		4
Criterion 3	0	0	+	2
Criterion 4	-	0	0	1
Sum +	2	0	1	
Sum -	1	0	2	
Sum 0	1	4	1	
Weighed sum +	7	0	2	
Weighed sum -	1	0	7	

Alternative / Criteria	Concept 1	Concept 2 (Standard)	Concept 3	Prioritiz-ation
Criterion 1	+	0	-	3
Criterion 2	+	0		4
Criterion 3	0	0	+	2
Criterion 4	-	0	0	1
Sum +	2	0	1	
Sum -	1	0	2	
Sum 0	1	4	1	
Weighed sum +	7	0	2	
Weighed sum -	1	0	7	

6. **Analyze the solutions' strengths and weaknesses:**
   - Is there a solution which dominates the others?
   - Why does it dominate?
   - What are its weaknesses?
   - Can these weaknesses be balanced by the characteristics of others?

Tip
When the columns of the dominant concept within the Pugh Matrix are observed, potential conflicts/contradictions with respect to the degree of fulfillment of individual criteria can be seen; these contradictions can be addressed, especially in a technical environment, with the help of the TRIZ methodology (Theory of Inventive Problem Solving)

Tool 4

Term
Solution Cause Matrix, Tool 4

When
IMPROVE, finalize solutions

Goal
- Ensure that each main cause is eliminated by one or several (sub) solutions and that the project goal can be attained
- Check and visualize the direct influence of selected solutions on the fulfillment of the CTCs/CTBs by connecting and visualizing Tools 1 to 4
- Support the prioritization of selected solutions with respect to the project goals
- Recognize positive (synergy) and negative correlations (conflicts) between the solutions

Procedure
1. Copy the verified root causes from Tool 3 into the table

2. Enter all selected solutions i.e. after having used the appropriate selection tools (Must Criteria, Effort Benefit Matrix)

3. Confirm that one or more solutions have been found for each root cause: No main causes should remain without a solution (each row must have at least one "9" or sufficient, complementary "3"s)

4. Check the correlations between individual solutions:

Main causes	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6	Solution 7	Solution 8	Solution 9	Solution 10
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
Sum	0	0	0	0	0	0	0	0	0	0

Do they reinforce each other's effect (positive effect, +/++), or prevent each other's effect (negative effect, -/--). Then there is a conflict! Alternatively, there is no effect (neutral 0)

Main causes	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6	Solution 7	Solution 8	Solution 9	Solution 10
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
From Tool 3										
Sum	0	0	0	0	0	0	0	0	0	0

Note: The correlation between the solutions can also be mapped in a table (cf. example on the following page)

Example Tool 4

Main causes \ Possible Solutions	Exchange spray-gun	Calibrate spray-painting device	Optimize setup pro-cedure (color change)	Train spray-painters	Introduce regular audit for spray-painting procedure	Revise SOPs
SOP not available	0	0	0	0	0	0
Spray-painters have different training and experience	0	3	0	3	3	0
SOPs are partly not available and partly incomprehensible	1	1	3	3	3	3
Sum	1	4	3	6	6	3

Correlation	Exchange spray-gun	Calibrate spray-painting device	Optimize setup procedure (color change)	Train spray-painters	Introduce regular audit for spray-painting procedure	Revise SOPs
Exchange spray-gun		0	0	0	0	0
Calibrate spray-painting device	0		0	0	0	0
Optimize setup procedure (color change)	0	0		-	++	0
Train spray-painters	0	0	-		++	+
Introduce regular audit for spray-painting procedure	0	0	++	++		+
Revise SOPs	0	0	0	+	+	

Should be Process Map

Term
Should be Process Map, Future State Map

When
IMPROVE, finalize solutions

Goal
- Draft SHOULD BE process and map it for implementation
- Visualize the selected process improvements
- Everyone understands the impact of the improvements on the work flow
- Create a foundation for other tools e.g. workplace layout, documentation and work instructions as well as visual process control

Procedure

1. **Define and visualize the Should Be process:**
   a) Define SHOULD BE process in line with the solutions. Take into consideration
      - the elimination and avoidance of waste (TIMWOOD)
      - Poka Yoke mechanisms
      - Constraint Theory and alignment of new process to the takt rate and/or takt time as well as process balancing
      - complexity reduction and setup of a lean process (cf. also process flow and process logic)

   b) Define responsibilities

   c) Visualize SHOULD BE process with a suitable visualization technique. The same mapping techniques as in ANALYZE can be used.

2. **Check Should-Be process with respect to R = $(Q \times A)^M$**
   a) **Result:** Is the result strived for been achieved? Is the expected improvement in the output measurement in line with the project goal?

DEFINE
MEASURE
ANALYZE
IMPROVE
CONTROL

b) **Quality**: Is the process complexity as low as possible? (cf. I.1.3.4 Reduce Complexity). What risks will exist if all actions are implemented as planned? (cf. FMEA, simplified FMEA)

c) **Acceptance**: Are suitable resources available (number, skills etc) for the new process? How can the buy-in of staff be ensured? Have all roles in the new process been filled according to their requirements?

d) **Management**: Have people responsible for the new process been defined using RACI? How will process control be facilitated? (KPIs, control instruments, response plans etc.)

Tip

1. Focus on the parts of the SHOULD BE process which will change when the solutions are implemented.
2. Use an FMEA in order to test the process for potential risks and weak points.

Cost Benefit Analysis

Term
Cost Benefit Analysis, Benefit Calculation, CBA

When
IMPROVE, finalize solutions

Goal
- Compare the expected financial benefits of a solution with the budgeted costs in order to confirm the business benefit of proceeding
- Compare the final few alternatives from a financial perspective in order to make a final choice

Procedure
The Cost Benefit Analysis and/or the Benefit Calculation differ from company to company, but usually there is an established method. If no basis for calculation exists the following aspects should be taken into consideration:

1. Determine the baseline for calculation – generally this is the time period of 12 months before the project start (AS IS situation); for comparison the SHOULD BE situation, generally 12 months after the implementation of solutions is observed; the difference is the project gross benefit

+[1)] **Situation before Implementierung** (one-year basis) # of KPI units **x** base units/KPI **x** costs of base unit e.g. rework: 1,500 parts x 2 hours x 200 €/h	**-**[1)] **Situation after Implementierung** (one-year basis) # of KPI units **x** base units/KPI **x** costs of base unit e.g. rework: 200 parts x 2 hours x 200 €/h

- **Operating costs by project implementation** (one-year basis)
e.g. rental of equipment: 6,000 €

- **Required investments for the implementation** (one-year depreciation)
e.g. annual depreciation of equipment: 3,000 €

- **Direct project cost**
e.g. project team: 300 hours x 60 €/hour

Net Benefit of project (one-year basis)

2. All expenses of the implementation including operating expenses, investment, training costs and direct project costs if considered appropriate.

3. Subtract the expenses mentioned above from the calculated gross benefit; the result is the net benefit

Tip

- Always use accepted methods and practices for your company when doing calculations for Cost Benefit Analysis; discuss specific calculations with an expert, e.g. from Finance and get a confirmation of the result; this avoids disruptive challenges which may undermine any argument you are putting forward later.
- The definition of the benefit should not be formulated too tightly: Apart from the result effectiveness, productivity increases and other benefits which are not easily quantifiable can also be used as positive reasons for proceeding

Prepare Process Control

Term
Process Management, Statistical Process Control, Process Management, Process Control

When
IMPROVE, implement solutions, before the rollout

Goal
Create a process which identifies deviations of important input and process variables, driving appropriate responses with the intention of protecting the satisfactory fulfillment of customer requirements permanently.

Procedure

1. Select and define suitable measurements and/or key figures for process control; these are usually the output, process and input measurements which have already been collected within the course of the project, particularly data on the “vital few”.

2. Prepare the data collection (cf. 4 steps of data collection), especially when it comes to determining the appropriate sample sizes and frequencies. Ensure the quality of the measurement system(s)

3. Ensure the reporting structure is clear and that the methods for recording key figures are properly documented. (KPI profile)

4. Define the target values of key figures (e.g. "traffic light status")

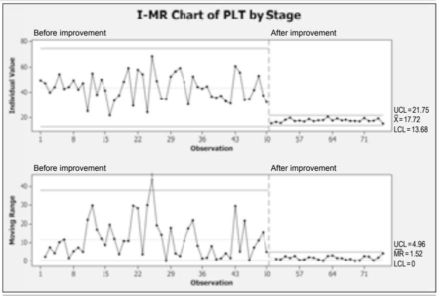
5. Develop a RACI Chart for the collection and reporting of key figures and coordinate it with those involved

6. Instigate ongoing monitoring of this process and of the defined key figures/reports

Tip

- When setting the key figures you should pay attention to the fact that you focus on controllable variables i.e. variables which can be influenced – always make a distinction between pure information factors and control variables when prioritizing measures
- Bear in mind that the monitoring will take place continuously; the effort of data collection and data preparation as well as the interpretation of results (reports, dashboards etc) must be proportionate to the expected benefit

Example:

<table>
<tr><th>Measurement</th><th colspan="2">Process Cycle Time</th></tr>
<tr><td>Operational Definition</td><td colspan="2">Process cycle time of order processing (from mail in-tray to filing) in minutes</td></tr>
<tr><td>Specifications</td><td>20 min. (± 5)</td><td rowspan="3">
</td></tr>
<tr><td>Sample</td><td>Daily 5th and 10th order per employee</td></tr>
<tr><td>Person responsible for data collection</td><td>Carl Collector</td></tr>
<tr><td>Person responsible for data analysis and reporting</td><td>Anna Cruncher</td><td>Immediate action(s) – in case of violation of specification:
• Deploy additional employees from department X at short notice</td></tr>
<tr><td>Process Owner</td><td>Otto Owner</td><td>Immediate action(s) – in case of repeated violation of control limits:
• Training of employees
• Adjustment of sample intervals</td></tr>
</table>

Reaction Plan

Term
Reaction Plan, Response Plan

When
IMPROVE, implement solutions, when preparing for process control.

Goal
Describe specific, pre agreed, actions to be undertaken when certain specified process conditions have been violated e.g. specification limits, control limits

Procedure

1. Set and/or identify limits for each key figure; three opportunities are available for this:
   - Target values according to the critical business requirements (CTB)
   - Specifications according to the critical customer requirements (CTC)
   - Statistical i.e. control limits and other special cause signals

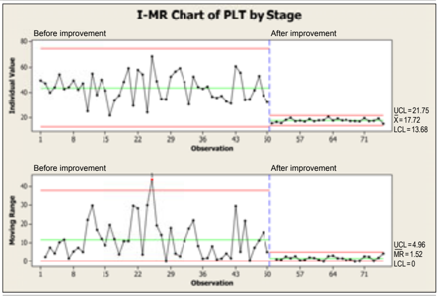
2. Define necessary actions for each measurement/key figure in the event that the limits are violated:
   - Immediate actions usually refer to an error correction i.e. elimination of the output's deficiency symptom; examples of this are:
     – rework of the output
     – stop production
   - Corrective actions are aimed at eliminating the cause of the defect and avoiding it reoccurring; before it is decided which corrective action is implemented, a short cause analysis should take place; it can be accelerated by an existing FMEA; examples of this include:
     – (repeated) training of people involved in the process
     – improvement of work instructions (e.g. by visualization of working steps)
     – review of material features and machine settings
     – adjustment of machine settings to match changed input features
     – adjustment of sample intervals etc.

3. Identify who is responsible for implanting actions in order to track the effectiveness of them once concluded.

Tip

- Review your sampling strategy to confirm its statistical validity; it is common to find an increase in sample size necessary as one of the immediate actions
- Formulate the actions in a SMART way – avoid general and less helpful actions such as "meet the Six Sigma team"
- During the structuring of the reaction plan you should consider implementing a “blame free” defect learning culture.
- Take your time drawing up a reaction plan since it is the most important document for the Process Owner going forward

Example Reaction Plan

Measurement	Process Cycle Time	
Operational Definition	Process cycle time of order processing (from mail in-tray to filing) in minutes	
Specifications	20 min. (± 5)	
Sample	Daily 5th and 10th order per employee	
Person responsible for data collection	Carl Collector	
Person responsible for data analysis and reporting	Anna Cruncher	**Immediate action(s)** – in case of violation of specification: • Deploy additional employees from department X at short notice
Process Owner	Otto Owner	**Immediate action(s)** – in case of repeated violation of control limits: • Training of employees • Adjustment of sample intervals

Pilot

Term
Pilot program, piloting

When
IMPROVE, implement solutions

Goal
- To improve understanding of the solution implementation and impact
- Test acceptance by the users and the organization
- Quicker implementation of part solutions
- Demonstrate that selected solutions provide the expected outcomes i.e.
  – Decision to select this particular solution was correct saving potential/ degree of usability match target
  – Improve understanding about the selected solution so that:
    • the "big" implementation will be smoother
    • previously unidentified weaknesses can be dealt with
    • solutions can be enhanced
    • risks can be better or further mitigated
- During the implementation the focus is on understanding the consequences/impact; this includes reviewing acceptance. A successful pilot can contribute significantly to wider acceptance of the project solutions.

Procedure

1. **Check prerequisites for pilots**
   It is not always necessary to conduct a pilot. A pilot makes sense especially if:
   - extensive changes are planned
   - the solution could trigger far-reaching, unpredictable consequences
   - the implementation of the solution is very cost intensive
   - planned changes cannot be reversed easily

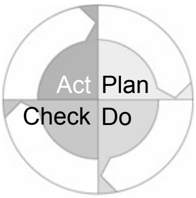
2. **Preparing pilots**
   - Identify potential pilot areas and select an area for piloting

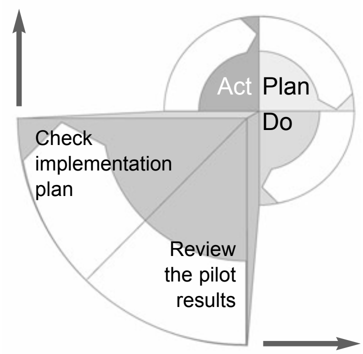
- Reach an agreement with the management of the respective area, obtain approval and determine who should be on the steering committee
- Plan the pilot project in a holistic way (make use of all project management tools from the DEFINE phase)
- Inform everybody involved – gain the confidence of and integrate employees

3. Conducting the pilot

- Train the employees involved and ensure that everyone understands their new task and the importance of the pilot program
- Implement action plans
- Be on hand to address issues
- Conduct regular briefings and reviews and undertake any required adjustments
- Document the results
- Report results to involved employees, the steering committee, the project team and to management. Don't forget to obtain feedback!

Illustration Deming Wheel
The Deming Wheel, also known as the PDCA methodology, is especially suitable for conducting pilots.





After reviewing the pilot results and the Implementation Plan, adjustments can be made.

Tip

- Conduct a pilot program only after having tested a small-scale implementation successfully or at least carried out a dry run.
- It is probably better that the area selected for the pilot is a true test of the solution i.e. not one where success could be considered guaranteed nor one where many additional hurdles might need to be overcome
- Your own participation is important in order to ensure success
- Always document the results in writing
- After a successful pilot you should extend the implementation to an additional, more difficult area.
- In the event the pilot doesn't go as expected don't panic. Explore the reasons and consider whether something was missed. Revisit previous work and look to address the issue. Sometimes at the beginning of a pilot things do not go as expected and a small adjustment to the plan can soon rectify the issue.

Implementation Plan

Term
Implementation Plan, Action Plan, Activities Plan

When
IMPROVE, implement solutions

Goal
- Determine and map all activities, responsibilities and dates which are relevant for implementing the solution
- Ensure acceptance of the implementation by Change Management focus

Procedure

1. Set the scope for the implementation; above all use the Project Charter, the consolidated solutions and the Cost-Benefit estimate of the improvement project and once again take into consideration the interests of important Stakeholders; answering the following questions is helpful:
   - What must be available at the end of implementation?
   - What deadlines exist for the implementation?
   - What are the planned costs for implementation?

2. Create work packages from the consolidated solution blocks e.g. Define "communication" by listing the main elements, allocating an owner i.e. person bearing overall responsibility and allocating an overall completion date/ milestone

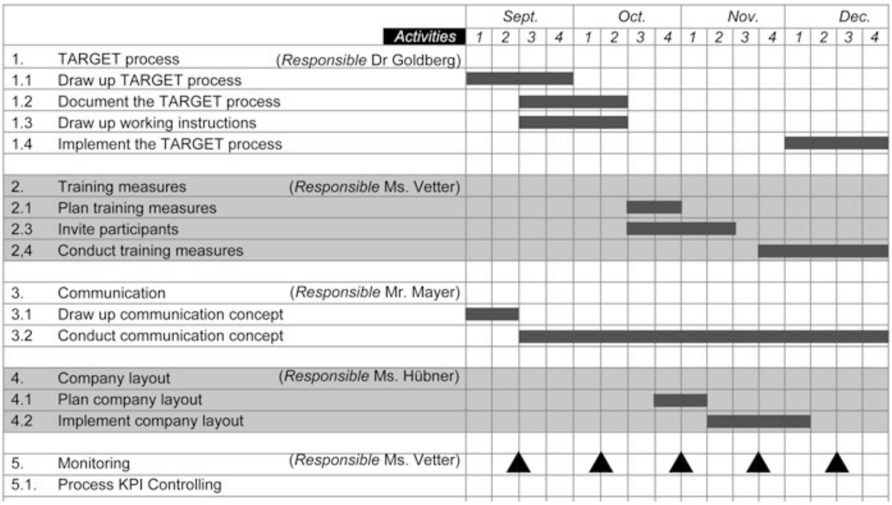
3. Break down these work packages into detailed actions; assign people responsible for this as well as dates (start-end)

4. If required further information must be integrated e.g. effort/benefit, implementation status, dependencies

5. Develop a Change Management strategy which is designed to guarantee that acceptance of implementation is supported and that resistance is minimized – especially draw up a communication plan which contains details

of each target audience and the information that they should receive including method of delivery

6. For large and or complex implementations formal project management should be established which should support an efficient implementation. This has the effect of almost creating an independent project but doing this should avoid rework and assist in removing obstacles. Nevertheless, you should also consider the following:
   - Resource Planning: The implementation of solutions requires that clear roles and responsibilities have been set e.g. with respect to reporting, decisions to be made and follow-up actions
   - Change of team composition – the team organization should be reviewed and adjusted depending on the project needs; on occasion a greater improvement effort might be required in which case a steering committee might need to be formed. A RACI chart is also a helpful tool at this stage.
   - Ensure budget and required resources are available so unexpected delays are avoided e.g. IT resources are often scarce and fiercely fought over
   - Integrate existing infrastructure e.g. for describing and implementing the new process or new systems



Tips on the following page.

Tip

- Describe the activities in as much detail as possible otherwise there is a risk of not being able to implement the solutions as planned
- Ideally the project leader should take over a more active and supporting function in the implementation since this requires not only project management know-how but also dedication

Risk Analysis

Term
Risk Analysis

When
IMPROVE, implement solutions

Goal
- Anticipate potential risks
- Understand the level of current mitigations and the necessity for additional preventative actions/detection processes

Procedure
1. Identify and describe all risks
2. Evaluate these risks in terms of their impact
3. As necessary, extend action plans to deal with a highly rated risk so as to limit the likelihood and impact – or better still – find a way to eliminate the risk
4. In the event of a weakly rated risk you will need to decide if it is worth the effort in creating an additional action plan.

Remaining risks	Impact on process (H-M-L)	Impact on Net Benefit (H-M-L)	Occurrence Probability (H-M-L)	Action: preven-tive (Implemen-tation Plan)	Action: reactive (Reaction Plan)

Tip
- For DMAIC projects a simplified "FMEA" has proven worthwhile: H = high, M = medium, L = low
- Use the tool for risk identification which is best suited to your project. Which tools might aid acceptance of your findings based on the communi-cation skills within your organization?

Rollout

Term
Rollout

When
IMPROVE, implement solutions

Goal
Implement the selected solutions, as confirmed and improved by the pilot, across the whole area as defined by the project scope.

Procedure

1. Draw up an Implementation Plan for all areas defined in the project scope (Rollout Plan); use a Gantt chart to evaluate the impact of any time delays in delivering work packages on the implementation deadlines; use common reporting tools such as progress reports, RAG system and Milestone Trend Analysis

2. Implement Rollout Plan and use for managing problems that occur e.g. system change doesn't work as expected, key worker is sick etc. follow the PDCA methodology (cf. Pilot) previously described

3. In case of additional requirements being identified, assess the impact on deadlines and the project goal. Determine what is required to fix the issues and seek the necessary decisions from people responsible in order to make the fixes happen.

Phase	Department	Duration	Start	Closed	Delays	Action
1	Dept. 1	4 weeks	CW 5	CW 9		
	Dept. 2	3 weeks	CW 5	CW 8		
2	Dept. 3	4 weeks	CW 10	CW 14		
3	Dept. 4-8	4 weeks	CW 15	CW 19		

Gate Review IMPROVE

- **Generate Solutions**
  - Have solution ideas been derived from the root causes?
  - Which methods were used for creating the solution ideas?
  - Have obvious/quick win solutions already been implemented?
  - Have the actions plans used to implement the obvious/quick win solutions been monitored consistently?
  - Have best practice approaches been considered for identifying solutions?
  - Have suitable Lean techniques been applied to the situation?

- **Refine and Filter Solutions**
  - What Must Criteria were defined?
  - Do the potential solutions take into consideration the Must Criteria?
  - What other criteria were used for selecting potential solutions?
  - Have technical, entrepreneurial, cultural and time aspects been taken into consideration when considering benefit and effort?

- **Finalize Solutions**
  - Have the solution ideas been developed for the implementation in sufficient detail?
  - By what criteria have the solutions been prioritized and selected?
  - Have process changes been defined precisely in the SHOULD BE process?
  - How does the SHOULD BE process differ from the AS IS process?
  - Have people responsible been set for the individual process steps?
  - How has it be ensured that the new process has as little waste as possible and contains the lowest possible complexity?
  - What assumptions were made for the Cost Benefit Analysis?
  - How much are the costs for the implementation of the solutions and how much is the monetary benefit of the project?
  - Has it been ensured that the consolidated solutions can solve the problem?
  - Can the expected project benefit be achieved?
  - Have the Cost Benefit Calculations been agreed to with Finance?

- **Implement Solutions**
  - Have solutions been developed in sufficient detail such that the implementation can be conducted?
  - Which key figures are to be used for process control and how will collection of them be monitored?

- Has a Reaction Plan been drawn up explaining how deviations to any target values (in case of selected input, process and output measurements) should be dealt with?
- Have specific actions been defined in case the planned goals are not reached and/or the process is not capable and/or stable?
- Have the solutions been tested in practice? If yes, how representative was the test?
- What problems did the pilot reveal that could occur in the implementation?
- Was the Process Owner actively involved in the pilot?
- Have actions for implementation been clearly assigned to individuals and are those actions planned realistically?
- What residual risks have been defined?
- What proactive actions for risk mitigation and impact reduction have been identified?
- Are the actions planned adequate and their level of adoption acceptable in the event that the risk does arise?
- Has the move from pilot to full rollout been documented and a plan produced?
- Has the communication about the planned changes been correctly developed? What else must be taken into consideration?
- Which other corporate divisions can the solution be useful?
- Will the implementation of the proposed solution ensure that the root causes will be eliminated and that the problem targeted by the project can be solved?

SIX SIGMA^{+LEAN} TOOLSET

CONTROL

How can the Improvement's Sustainability be Ensured?

R. Meran et al., *Six Sigma^{+Lean} Toolset: Mindset for Successful Implementation of Improvement Projects*, Management for Professionals, DOI 10.1007/978-3-642-35882-1_6,

Summary CONTROL Phase

Objective and Scope of Phase
- Above all, the CONTROL phase answers the question: "How will sustainability be ensured?" i.e. how is the improvement to be measured, verified and sustainability sustained?
- All the knowledge gained about the process and how it performs will be utilized in building a suitable process control system
- Capturing and documenting the organization's increase of knowledge as a result of the project must be done in a transparent and comprehensible fashion so that others may leverage this learning and experience.

The Meaning of Sustainability
- In the context of an improvement project sustainability means that an improvement is "maintained over the long term"
- Sustainability is not only achieved by the successful implementation of solutions and actions in the process but also by behavioral changes of people involved in the process

Procedure in the CONTROL Phase
- The process documentation is completed and ensures transparency and understanding of the altered process
- Monitoring the performance capability of the upgraded process with suitable tools must be implemented
- Process Control, including response plans should be introduced and securely integrated into the organization. Designated ownership and responsibility should be assigned.
- The size of improvement is measured and the degree of goal achievement is reviewed

Road Map CONTROL Phase

D M A I C

I.4 Implement Solutions

What will the sustainable solution look like and how long will it take to implement?

IMPROVE

CONTROL

C.1 Finalize Process Documentation

Has the improved process been documented with all its details in a transparent and comprehensible way for everyone?

C.2 Monitor Process

How is the new process performing, is this displayed graphically and how capable is it?

C.3 Control Process

Is the team for the process management known and have the responsibilities been defined?
Is the team capable of controlling the process in a sustainable way?

C.4 Ensure Success

How is the success of the improved process measured and reviewed?
Has the improvement, i.e. the project been documented in a transparent and comprehensible way for other teams?

C Gate Review/Phase Closure

Tool Overview CONTROL Phase

C.1 Finalize Process Documentation

- Process Documentation
- Visual Management

C.2 Monitor Process

- Control Charts
- Dashboards

C.3 Control Process

- Process Control Team
- Glass Wall Management

C.4 Ensure Success

- Audits
- Project Documentation
- Project Closure

C Gate Review

Process Documentation

Term
Process Documentation

When
CONTROL, at the beginning of the phase

Goal
- Create a structured, transparent and (intuitively) comprehensible map of the changed process for the people involved in it
- Clearly and simply describe changed tasks and work tools
- Clearly define process responsibilities and interfaces
- Enable autonomous decision making by the people involved in the process and avoid hierarchical loops and delays
- Enable fulfillment of the defined process standards
- Simplify introductory training of new employees
- Ensure documentation for the new process remains up to date

Procedure
1. Prepare process documentation
   - Go through the changed process step by step
   - Question or survey employees about the changes implemented (who received what information, how and when?)
   - Find out the status of the adjustments which were made to work instructions and standard operating procedures and/or process documentation

2. Set level of detail
   Determine the necessary level of detail for the documentation with the people involved in the process; make sure that what is provided is suitable for everyday use

3. Visualize the process
   - Map the sequence of process steps, responsibilities and interfaces
   - Take into consideration inputs and outputs, their sources and customers (internal/external).
   - Document and visualize working steps

4. Create Standard Operating Procedures (SOPs) for each working step (who does what, when, with which tools?)
   - Formulate instructions clearly and precisely in a suitable form of text, pictures and schematics etc.

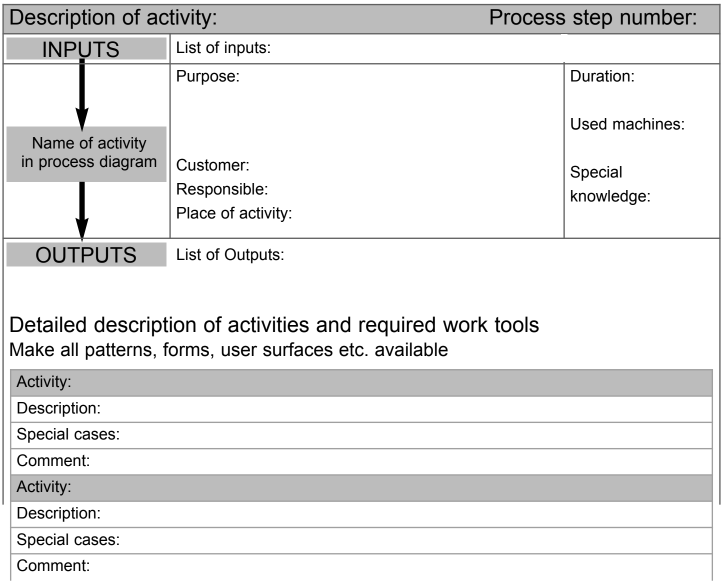
5. Set up workplaces according to the Standard Operating Procedures

6. Train and/or instruct employees

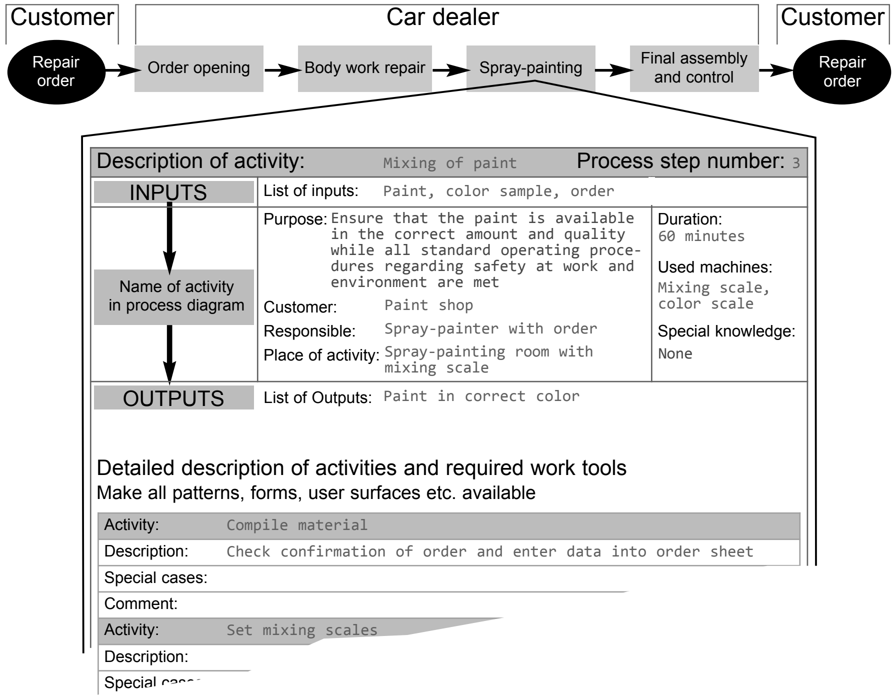
7. File process documentation
   - Reflect corporate standards (EDP, formats) in anything that you prepare

8. Ensure this remains updated
   - Implement an updating process: contents, dates and responsibilities

Example: Standard Operating Procedure Template



Example: Process Diagram and Standard Operation Procedure

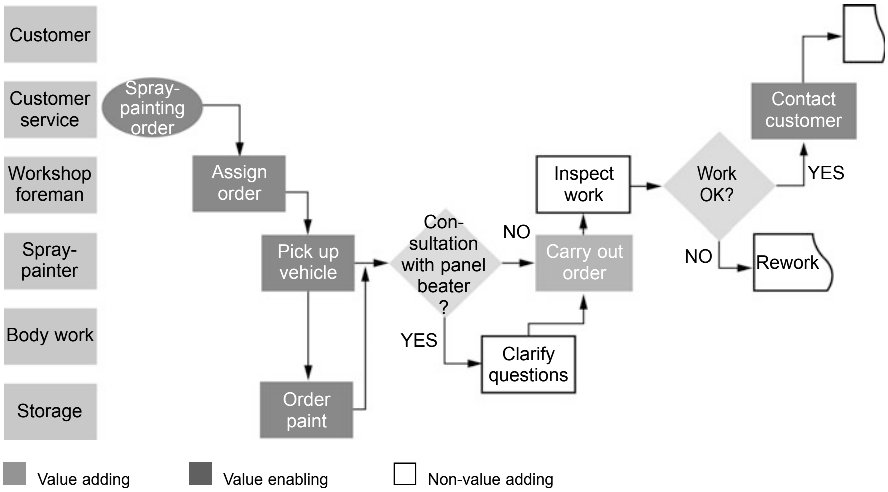


Tip

- Bear in mind who is the “customer” of process documentation: Not the IT department, not an auditor but the employee engaged in the process
- Survey the employees in a structured way about the procedure; potential questions are: “What difficulties do you have when following the standard operating procedures?”, “Are there opportunities for improving the work and achieving the desired business outcomes?”
- Act according to the guiding principle: "Less is more!"; the development, reading and above all the cultivation of process documentation means a lot of effort; that’s why you should only document as much as absolutely necessary
- Keep documentation readily available along the work flow, the best way is the visualization of working steps (Visual Management): It must be available when it is needed; this is always better than picking up a file or opening a data file in a system that you don't know well

- Beware of Over Engineering: Teams can spend many man years documenting processes in IT platforms which are never actively used by employees and/or are already obsolete when they are released

Example: Swim Lane Diagram



DEFINE
MEASURE
ANALYZE
IMPROVE
CONTROL

Visual Management

Term
Visual Management

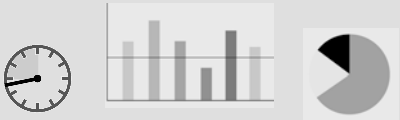
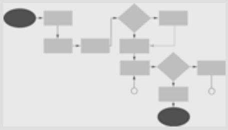
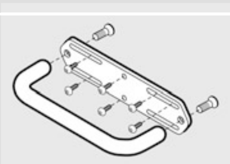
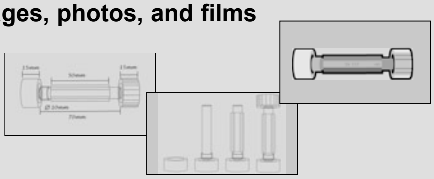
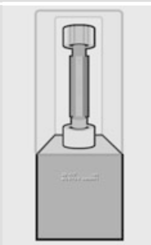
When
CONTROL, visualize process documentation

Goal
- Make information about process performance transparent and available for all employees and executives at any time
- Display work instructions and standard operating procedures prominently for everyone involved to see
- Mark routes and storage space and determined SHOULD BE settings on equipment etc. clearly
- Set work priorities and make them known
- Quickly recognize any deviations from the standard expected
- Recognize and eliminate defects early (Poka Yoke approach)

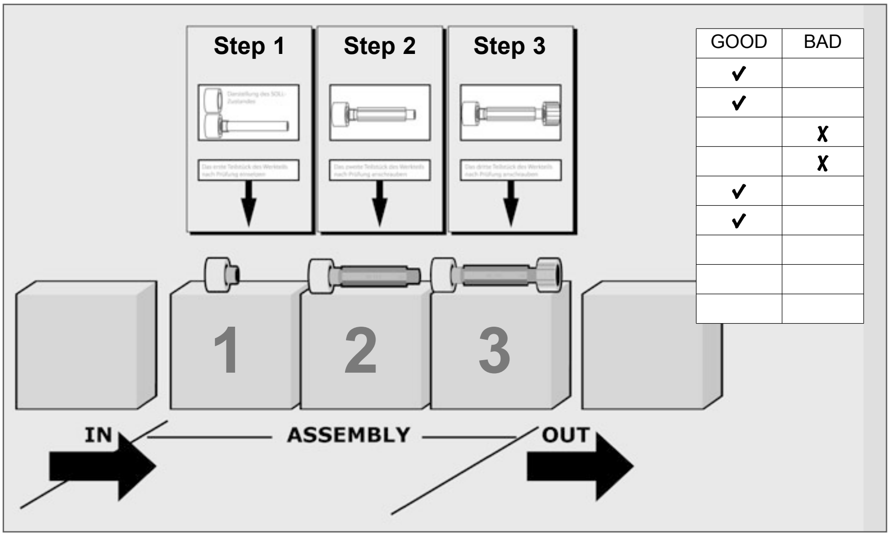
Procedure
Depending on the goal different tools can be used:
Examples of Visual Management tools on pages 356/357

Tip
- How could you use Visual Management techniques so everyone involved in the process can identify with the company (by transparency of information), with the task (work instructions and standard operating procedures) and with the product (SHOULD BE state); this promotes comprehension and motivation
- Visual Management is equally applicable in administrative processes

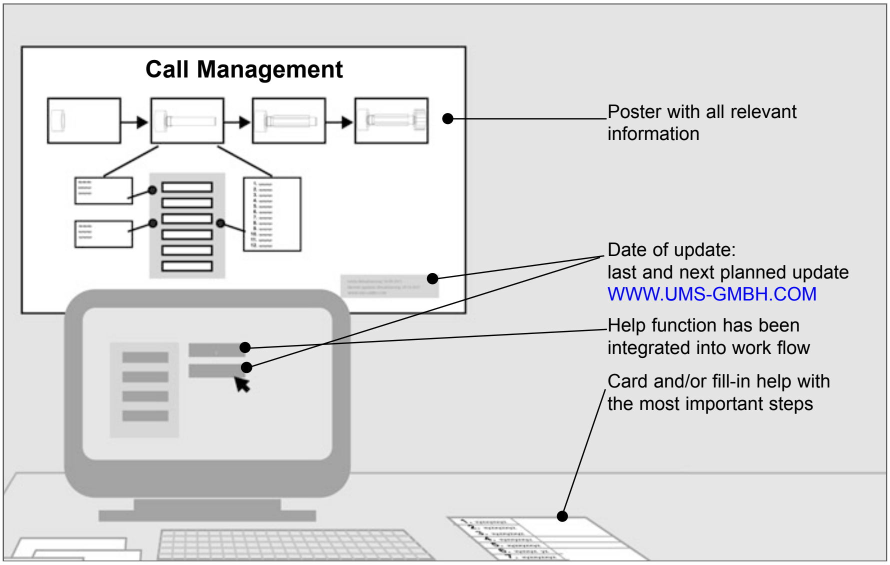
Examples of Visual Management tools

Tool	Application
Graphics and diagrams 	Visualization of figures and data, as required in connection with summaries of figures and tables
Flow Charts 	Visualization of processes i.e. of process steps and their sequence
Exploded Drawings 	Graphic perspective of complex objects and their individual parts
Pictograms 	For information signs and reinforcement of regulations
Images, photos, and films 	Examples of SHOULD BE state or defects for comparison
Reference parts 	Three dimensional representation of SHOULD BE state or defect for comparison

Visual Management in production



Visual Management in a service process



Control Charts

Term
Control Charts, Shewart Charts

When
MEASURE, ANALYZE and CONTROL, Process Monitoring

Goal
- Gain significant understanding of process performance:
  – Recognize and track process variation
  – Establish if the process is statistically stable
  – Differentiate between common and special cause variation in order to determine the nature of improvement action to be taken
- Display "before" and "after" performance
- Everyday tools for ongoing process control

Procedure

1. Determine the sampling strategy and sample size
- Samples must be taken for Control Charts. The right sampling strategy is critical to producing reliable control charts.
- A sampling strategy contains not only the sample size but also sampling frequency. This means that a sample with a specific size is taken at a specific moment in time or after a specific number of parts.
- The samples should always be selected in such a way that they provide the best possible statement of process performance. If the wrong point in time is selected, e.g. when raw materials are being changed, it is quite possible that an inappropriate signal manifests itself.

Formation of subgroups

- To be able to rely on a Control Chart depends on both the quality of the sample as well as of the quality of the subgroups.

- When forming subgroups it must be ensured that:
  - they provide the best possible information on the process
  - depict the variation of the variable under review in its entirety, since the total variation (both within a subgroup and also between subgroups) determines the limits for the Control Chart.

- The subgroups must be formed rationally. Generally there are two approaches for forming rational subgroups:
  - The units from the sample have been produced at the same time (or in very close proximity to each other) (cf. comment on sample size and frequency).
  - The sample size is representative of all units which have been produced since the last sample was taken. This approach (representative sampling) is strongly recommended when there is reason to assume that the process has had periods of instability but is now believed to be stable. In such cases the first method would not be adequate to detect the temporary instability.
  - However, caution is required when Control Charts are interpreted: if the process has shifted several times within the monitored time interval this can lead to a considerable increase in the variation of the sample. This in turn causes wider control limits. In principle, every process can be interpreted as stable if the intervals between the samples are big enough.

Rational Subgroups

The idea behind rational subgroups can be illustrated with an Xbar-R Chart.If we are trying to detect a shift in the mean value: the formation of rational subgroups means that they are selected in such a way that, given the existence of special causes, the probability of differences between the subgroups is maximized, whilst at the same time, the probability that a special cause causes a difference within the subgroup is minimized.

Tip

- The factors of time and costs are to be taken into consideration when the sample strategy and the determination of the sample size is made.
- If possible, the samples should be taken under the same conditions (e.g. same work station, machine).
- When forming rational subgroups it may make sense to formulate separate Control Charts for different stratification factors (e.g. work station/machine, operator, shift).

2. Select a suitable Control Chart depending on data type and sample size

Continuous and discrete data

- **Continuous data**
  - Two graphs are drawn up for Control Charts formed with continuous data: in the first, the mean value or the single values of each group are entered, into the second, the range or standard deviation of each subgroup
  - The sample size for continuous data is usually between four to six measurements
  - Usually control limits of ±3s* are used. (*Estimation methods of s vary)
  - 99.73% of data is expected within these limits (for data with a normal distribution)
- **Discrete data**
  - One graph is drawn up for a discrete data variable depending on the situation e.g. the proportion or the number of defective parts, the number of defects or the defects per unit, of each subgroup are entered

Data type		Sample size (subgroup)	Control Chart
Continuous data		1	IMR Chart
		< 10 (usually 3 to 5); constant	Xbar-R Chart
		> 10 and/or variable	Xbar-S Chart
Discrete data	Defect per part	Constant (usually > 50); number of defects > 5	c-Chart
		Variable (usually > 50); number of defects > 5	u-Chart
	Defective parts	Constant (usually > 50)	np-Chart
		Variable (usually > 50)	p-Chart

3. Collect data paying attention to:
- Data Collection Plan
- Operational Definition
- Measurement System Analysis if required

4. Calculate the statistics and control limits:
- Many statistics programs support the automatic generation of Control Charts.
- **For continuous data:**
  Control charts comprise two graphs:
  – The individual values (I-Chart) and/or mean values of the subgroups (Xbar Charts) are entered in the first graph. It shows the variation between the subgroups in the Xbar Charts
  – The second graph displays the changes of the values (MR Chart) and/or the ranges or the standard deviations of the subgroups and shows the variation within the subgroups (R/S Chart). The following formulas for calculation apply for continuous data:

"Manual" calculation of Control Charts – (k is the number of subgroups)

Type of Control Charts	Subgroup samples	Center line	Control limits	
Average and Range	Constant and <10, but usually 3 to 5	$\bar{\bar{x}} = \frac{(\bar{x}_1 + \bar{x}_2 + \ldots \bar{x}_k)}{k}$	$UCL_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R}$	$LCL_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R}$
Xbar-R		$\bar{R} = \frac{(R_1 + R_2 + \ldots R_k)}{k}$	$UCL_R = D_4\bar{R}$	$LCL_R = D_3\bar{R}$
Average and Standard Deviation	Variable or ≥10	$\bar{\bar{x}} = \frac{(\bar{x}_1 + \bar{x}_2 + \ldots \bar{x}_k)}{k}$	$UCL_{\bar{x}} = \bar{\bar{x}} + A_3\bar{s}$	$LCL_{\bar{x}} = \bar{\bar{x}} - A_3\bar{s}$
Xbar-S		$\bar{s} = \frac{(s_1 + s_2 + \ldots s_k)}{k}$	$UCL_s = B_4\bar{s}$	$LCL_s = B_3\bar{s}$
Individual values and Moving Ranges	1	$\bar{x} = \frac{(x_1 + x_2 + \ldots x_k)}{k}$	$UCL_x = \bar{x} + \frac{3}{d_2}\bar{R}_m$	$LCL_x = \bar{x} - \frac{3}{d_2}\bar{R}_m$
IMR		$\bar{R}_m = \frac{(R_1 + R_2 + \ldots R_{k-1})}{k-1}$ $\bar{R}_m = \lvert(x_{j+1} - x_j)\rvert$	$UCL_{Rm} = D_4\bar{R}_m$	$LCL_{Rm} = D_3\bar{R}_m$

Note on the IMR Chart:
The constants (D_2, D_3 and D_4) for calculating the control limits are selected for n = 2 (number of observations used to calculate the Moving Ranges).

– **Control Charts for discrete data:**
They comprise one graph and show variation between the subgroups.
The following formulas for calculation apply for discrete data:

"Manual" calculation of Control Charts – (k is the number of subgroups)

Type of Control Charts	Sample size	Center line	Control limits	
Proportion defective parts p-chart	Variable usually n > 50	$\bar{p}=\frac{\sum\hat{p}_i}{k}$ whereby $\hat{p}_i=\frac{\#\text{ defective parts}}{n_i}$	$UCL_p=\bar{p}+3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}$	$LCL_p=\bar{p}-3\sqrt{\frac{\bar{p}(1-\bar{p})}{n_i}}$
Proportion defective parts np-chart	Constant usually n > 50	$\bar{p}=\frac{\sum\hat{p}_i}{k}$ whereby $\hat{p}_i=\frac{\#\text{ defective parts}}{n}$	$UCL_{np}=n\bar{p}+3\sqrt{n\bar{p}(1-\bar{p})}$	$LCL_{np}=n\bar{p}-3\sqrt{n\bar{p}(1-\bar{p})}$
No. of defects per unit u-chart	Variable	$\bar{u}=\frac{\sum u_i}{k}$ where $u_i=\frac{\#\text{ defects}}{n_i}$	$UCL_u=\bar{u}+3\sqrt{\frac{\bar{u}}{n_i}}$	$LCL_u=\bar{u}-3\sqrt{\frac{\bar{u}}{n_i}}$
No. of defects per unit c-chart	Constant	$\bar{c}=\frac{\#\text{ defects}}{\#\text{ units}}$	$UCL_c=\bar{c}+3\sqrt{\bar{c}}$	$LCL_c=\bar{c}-3\sqrt{\bar{c}}$

Note: The value zero limits the lower control limits (LCL) for discrete data. A negative value makes no sense.

Creating Control Charts "by hand" – Table of Constants

Sample size n	Xbar-R Chart			Xbar-S Chart			
	A_2	D_3	D_4	A_3	B_3	B_4	c_4
2	1.880	0	3.267	2.659	0	3.267	0.7979
3	1.023	0	2.575	1.954	0	2.568	0.8862
4	0.729	0	2.282	1.628	0	2.266	0.9213
5	0.577	0	2.115	1.427	0	2.089	0.9400
6	0.483	0	2.004	1.287	0.030	1.970	0.9515
7	0.419	0.076	1.924	1.182	0.118	1.882	0.9594
8	0.373	0.136	1.864	1.099	0.185	1.815	0.9650
9	0.337	0.184	1.816	1.032	0.239	1.761	0.9693
10	0.308	0.223	1.777	0.975	0.284	1.716	0.9727

Sample size n	IMR Chart		
	D_3	D_4	d_2
2	0	3.267	1.128
3	0	2.574	1.693
4	0	2.282	2.059
5	0	2.114	2.326
6	0	2.004	2.534
7	0.076	1.924	2.704
8	0.136	1.864	2.847
9	0.184	1.816	2.970
10	0.223	1.777	3.078

Source: Montgomery, Douglas C. (2001), Introduction to Statistical Quality Control, 4th Edition, John Wiley & Sons

5. Draw up Control Charts

- The time interval monitored is on the x-axis.
- The data points are entered for each graph (analogous to the Run Chart i.e. in time order).
- The center lines are drawn and the control limits calculated and entered. The control limits are calculated using the formulas mentioned previously.
- If using software to create the charts switch on the appropriate tests.

6. Interpret Control Charts:

- *Observation of center line*
  Is the process centered in the correct position with respect to customer requirements or the target value? Was the process centered before? Has the process changed? Have customer requirements or the target value changed?

- *Analysis of data with respect to the control limits*
  Is the variation special or common cause?
  - The variance within the control limits is due to random deviations in the process itself. This is known as common cause variation which can only be reduced by introducing a change to the system or process e.g. running a DMAIC project
  - Data points outside the control limits or patterns within the control limits (systematic deviations) hint at special cause variation. They need to be examined individually, and as soon as possible, then eliminated before the Control Chart can be relied on for process monitoring.

Is the process under control/stable? A process is under control/stable if all points are within the control limits and no patterns are recognizable i.e. there are no special causes evident

Computer programs such as Minitab® have a variety of tests that can be used to identify special cause variation. These can be set to work automatically or manually depending on personal preference The most commonly used tests are listed below:

1	One point is outside the control limits (3 Sigma from the center line).
2	9 consecutive points are on the same side of the center line.
3	6 consecutive points, in ascending or descending order.
4	14 consecutive points, alternating above and below the center line.
5	2 out of 3 consecutive points are more than 2 Sigma away from the center line (on the same side).
6	4 out of 5 consecutive points are more than 1 Sigma away from the center line (on the same side).
7	15 points in a row are located within the 1 Sigma limits.
8	8 points in a row are more than 1 Sigma away from the center line.

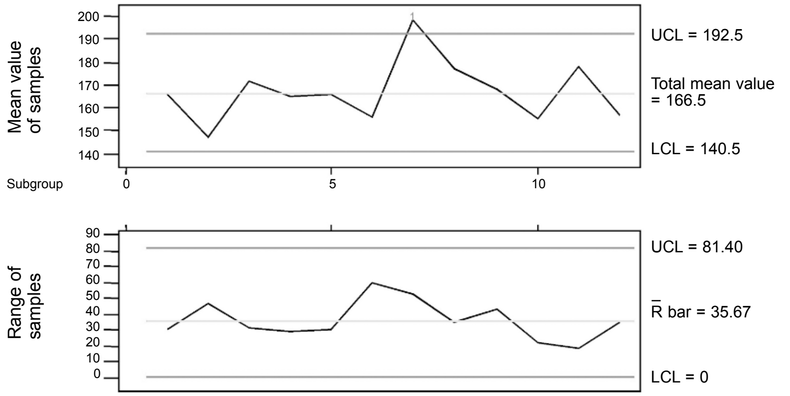
Example: Draw up the Control Chart (Xbar-R) paint shop – "manually"

	Week	Paint thickness	$\bar{x}$	R
February	1	167 / 155 / 184 / 154	165.00	30
	2	134 / 165 / 166 / 120	146.25	46
	3	188 / 174 / 157 / 166	171.25	31
	4	166 / 148 / 167 / 177	164.50	29
March	1	179 / 162 / 149 / 170	165.00	30
	2	178 / 182 / 140 / 123	155.75	59
	3	230 / 199 / 178 / 186	198.25	52
	4	175 / 158 / 181 / 192	176.50	34
April	1	193 / 168 / 159 / 150	167.50	43
	2	150 / 158 / 155 / 144	154.25	21
	3	187 / 181 / 172 / 169	177.25	18
	4	157 / 146 / 144 / 179	156.50	35
			$\bar{\bar{x}} = 166.50$	$\bar{R} = 35.67$

Example: Control limits for the Control Chart (Xbar R) paint shop – "manually"

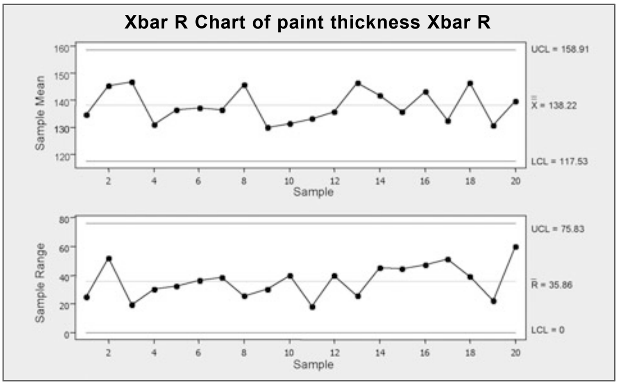
Control limits for Xbar Chart	Control limits for R Chart
$UCL_x = \bar{\bar{x}} + A_2 \cdot \bar{R}$	$UCL_R = D_4 \cdot \bar{R}$
$UCL_x = 166.50 + 0.729 \cdot 35.67 = 192.50$	$UCL_R = 2.282 \cdot 35.67 = 81.40$
$LCL_x = \bar{\bar{x}} - A_2 \cdot \bar{R}$	$LCL_R = D_3 \cdot \bar{R}$
$LCL_x = 166.50 - 0.729 \cdot 35.67 = 140.50$	$LCL_R = 0 \cdot 35.67 = 0$

Example: Control Chart (Xbar R) paint shop – created "manually"



Example: Control Charts for continuous data: Xbar R with Minitab®

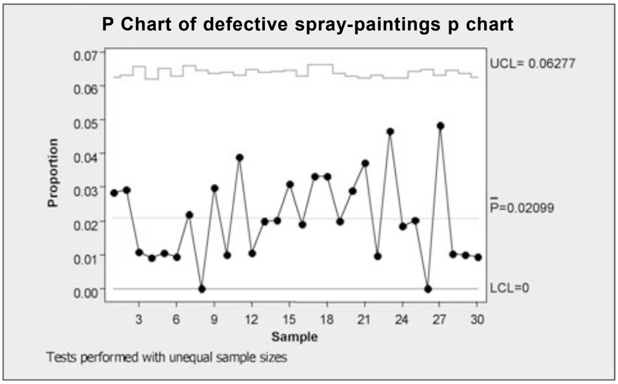
The results show only common causes for variation. The values are within the control limits.



Example: Control Charts for discrete data: P Chart Minitab®

The results display no special causes.

.



Dashboard

Term
Dashboard, Instrument Panel, Cockpit Chart

When
CONTROL, monitor process

Goal
- Convey the current degree of fulfillment of customer and business requirements at a glance, in a comprehensible way
- Recognize deviations by observing input and process measurements
- Review success of actions
- Timely triggering of follow up actions for process control

Procedure
1. Check metrics for suitability, adequacy and completeness. Select the key figures ("less is more") – consider predicted and target values
   - Completeness: Have all CTCs/CTBs been covered comprehensively?
   - Validity: Will changes over time be recorded? Are the key figures easily understood?
   - Suitability: Can the key figures be collected at regular intervals?

2. Select graph (be economical with colors, graphic elements – focus on essentials)
   - Mark Run Chart, if required, with specification limits (are key figures moving in the correct direction?); it might make sense to chart the Confidence Intervals in order to demonstrate that changes are statistically significant
   - Use Control Charts in order to recognize the cause of variation: Has the change been triggered by a common or a special cause? If required, suitable actions can be identified.

3. Plan dashboard and "build" prototype

4. Present to interested employees and executives. Obtain feedback

5. Make any necessary final adjustments

6. Train process control team and employees involved as well as executives in the aspects relevant to them

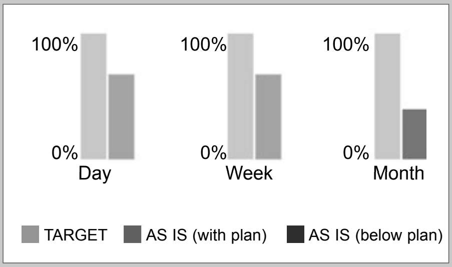
7. Commence production of the new dashboards in their final version and work to continuously improve them

Tip

- When drawing up Dashboards you should bear in mind that: "beauty sells", i.e. optics and/or the comprehensibility play an important role when the biggest concern is to maximize the utilization rate
- A Dashboard can be compared with special components and instruments in a car; the car driver receives all necessary information for driving the car from them:
  - Looking ahead through the windscreen equals forecasts, i.e. information on the future
  - The car dashboard provides information on the current process (speed, temperature) as well as input parameters (water,oil & fuel levels)
  - The rear view mirror provides information on the past; steering processes only with the help of the 'rear view mirror' is probably a rather dangerous way of behaving
- Make sure that the people involved in the process and decision makers understand which information (and not only which figures) they can take from the Dashboards and what benefit they provide; this is a mandatory prerequisite for the sustainable use of Dashboards

Example: Dashboard

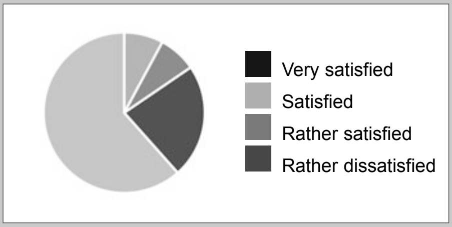
QUANTITY

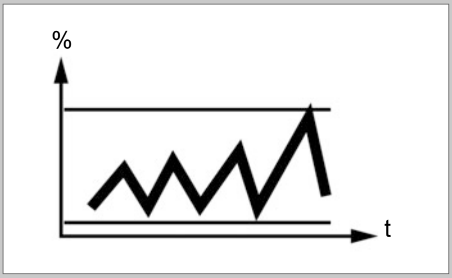


DEFECTIVE UNITS (ppm)

	Day	Week	Month
Current	0	500	300
USL	1,000	1,000	1,000

CUSTOMER SATISFACTION





Process Control Team

Term
Process Management Team, Process Control Team

When
CONTROL, control process

Goal
- Active control of process
- Integrate dedicated employees in order to distribute process control responsibility across several shoulders and to improve the chances for success

Procedure
1. Designate the team and set responsibilities, e.g.
   - Manager: Solves problems with process inputs so that employees can act in a value adding way
   - Team Leader: Solves problems and supports team members so that they can act in a value adding way
   - Employees: Act in a value adding way

2. Set frequency for meetings and dates

3. Conduct meetings regularly, discuss Dashboard status and derive actions if required; the people involved in the process should meet on a regular basis in order to discuss the current status of the process.”Stand up“ meetings or “huddles” lasting 5 to 10 minutes at the beginning of each shift are especially suitable; typically the following topics are might be discussed:
   a. How did the process perform yesterday, what problems occurred?
   b. What improvement ideas/opportunities exist?
   c. What backlogs are there and what are the goals for today?
   d. What are the priorities, what tasks need doing and how should the work be divided?
   e. What is happening in the wider organization and/or the product which might influence the daily routine?

4. Implement actions and monitor results

Tip

- It is best to conduct all matters related to process control close to the action i.e. in the vicinity of the process itself
- Acceptance of process control leads to its sustainability: To engage people and win them over is very important in this context. Ensure a positive culture for dealing with mistakes and create an environment in which one can learn from them with the help of the Sponsor. Finger pointing and reproach are unacceptable!
- Ensure that the process owners, process managers and other people involved in the process have been trained, they know what data is charted, in which way, and can interpret and draw conclusions from it on this basis
- For the rollout in the company it is moreover important that the management understands the Dashboards, advocates their use and visibly controls processes with them.

Glass Wall Management

Term
Glass Wall Management*

When
CONTROL, control process

Goal
Control processes better by transparency

Procedure

1. Define work units (groups, teams, departments, etc.), which can be considered as 'microenterprises', and can be controlled consistently with the help of key figures. These units live a pronounced customer-supplier-customer relationship regarding internal and external interfaces which is supposed to lead to a waste-free value chain over the long term?

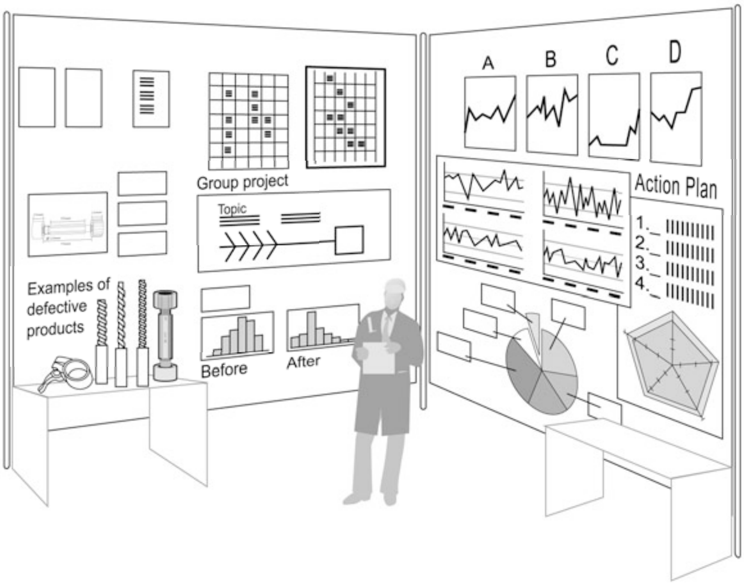
2. The most important key figures are displayed continuously for everyone to see, irrespective of the results

3. The units use figures in order to control their processes and work to improve them continuously

4. Progress and success are communicated and visualized; by doing this competitive thinking is promoted

* The concept of Glass Wall Management was developed and presented by Kiyoshi Suzaki in his book "Results from the Heart: How Mini-Company Management Captures Everyone's Talents and Helps Them Find Meaning and Purpose at Work" (Free Press, 2002)..

Example



Tip

Check in advance if a suitable working environment and a respective culture (openness and defect culture) is available for the implementation of Glass Wall Management

Audits

Term
Auditing, Audits, benefit collection

When
CONTROL, measure success, regularly after project closure

Goal
Measure quality of improvement and/or the actual realized project result

Procedure

1. Prepare audit
   - Set goal and scope of audit
   - Get an overview of process documentation
   - Draw up and/or adjust audit checklist
   - Inform employees: remember $R = (Q \times A)^M$

2. Conduct audit
   - Survey employees and inspect solution implementation on site (is the planned TARGET process alive? Have adjustments been made?)
   - Document results and coordinate with employees on site

3. Follow up audit
   - Discuss audit results with Process Owner
   - Define corrective actions if required and name people responsible
   - Communicate results to the project team and employees in the process

4. Conduct follow-up actions if required
   - Conduct actions
   - Check effect
   - Plan follow-up audit if required

5. Identify benefit
   - Check change of KPIs with Process Owner (ensure data quality)

- Calculate benefit (hard and soft benefit) and confirm with Finance as required
- Communicate results

Tip

- Following the motto "Do good and talk about it“, you should communicate success openly and often
- Let your team and the Sponsor look good
- Think of an important principle of the learning organization: A bad result is also a learning opportunity
- In the sense of Glass Wall Management: Transparency supports autonomous actions
- Take along the Cost Benefit chart: It will enable you to provide information and you can identify the benefit on site

Example on the following page.

Example

Process step/solution	Status/ Effect	Action/ Corrective action	Date	Person responsible
1. Exchange nozzle	Taken place; improvement clearly evident	None	n/a	n/a
1. Train employees	Taken place; improvement not yet realized	Visualize working steps (introduce Visual Management)	Dec. 2010	A. H.
…				
Performance key figures	KPI improvement, however, the target value has not been reached yet	Wait for actions and measure again	Jan. 2011	A. H.
Non-monetary benefit	Processing time for spray-painting reduced by 20%	Verified by: Date: Signature:		
Monetary benefit	Planned Benefit already realized by 50% (45 KEUR)	Verified by: Date: Signature:		
Lessons learned				

Project Documentation

Term
Project Documentation

When
In the course of the entire project duration, closure at the end of the CONTROL phase

Goal
- Provide a basis for the exchange of experience between project leaders (Black Belts)
- Map the Cause-Effect Relationships (Y = f(xi, xn)) in the process as a summary so it can function as an important component of the continuous improvement process
- Serve as a reference for all other projects or for the rollout of solutions in other areas
- Provide experience and knowledge to be used as a Best Practice for other projects going forward.

Procedure
1. Update project documentation continuously; the project documentation is supposed to map the history of the project; the minimum requirements are:
   - A Project Charter
   - A Goal, method followed in, (tools if required) and results of, each phase
   - Project result, i.e. improvement proven by figures
   - Monetary and non-monetary benefit (agreed to by Finance)
   - Management Summary ("One Pager")
   - Lessons Learned (What made the project successful, what impaired it?)

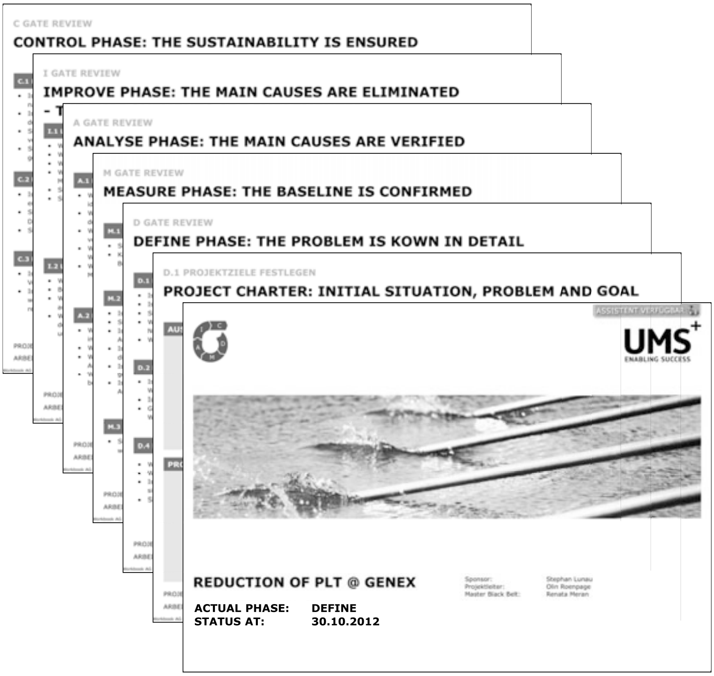
2. File the project documentation in a suitable directory with clear access rights defined in advance

3. Communicate project success

Tip

- Strive to update project documentation as quickly as possible; a Project Workbook which has been updated continuously and is well kept can be transferred into the final documentation very quickly and with little effort; bad project documentation ...
  - … is no added value for the company
  - … is no fun
  - … is WASTE (time mostly but also mistakes)
- A good Project Workbook is the prerequisite for the Six Sigma^{+Lean} certification for the Green and/or Black Belt
- Use the Management Summary on one to two pages in order to successfully communicate and market the results and success of the project

Example



Project Closure

Term
Project Closure

When
CONTROL, at the end of the phase when the project has been completed, i.e. when ...
- … the audit has shown a statistically significant KPI improvement and Finance has confirmed the calculated Net Benefit
- … the audit has shown that the Process Owner/the line manager has reassumed responsibility for the process and is actively in control of it.

Goal
Return total responsibility to the Process Owner and thus release the Black Belt

Procedure
1. Check the prerequisites for the formal project closure:
   a. The project is only closed officially if a significant improvement has taken place and been proven by data (KPI change)
   b. The improvement is identified by audits (after 3, 6 and 12 months) and is confirmed by Finance
   c. Finance confirms the monetary benefit of the project (monetary benefit collection)

2. Have the project results been handed over to the Process Owner and has the responsibility been transferred back completely?

3. Plan and conduct last project meeting:
   a. Invite all employees and Stakeholders involved in the project; room, facilitation etc. are organized
   b. Reminder of the project goal, most important insights and results are presented
   c. Collect lessons learned in the group for future project work
   d. Project Leader and the Sponsor express appreciation for the work and results achieved by the team

Example

<table>
<tr><td>Project title</td><td>[Title]</td><td>Documents handed over</td></tr>
<tr><td>Sponsor and Process Controller</td><td>[Name Sponsor]

[Name Process Controller]</td><td rowspan="3">List of root causes

List of improvements

Process documentation

Control Charts and actions

RACI Matrix

Audit dates:
[DD.MM.YY] (+3 months)
[DD.MM.YY] (+6 months)

Other (attached)</td></tr>
<tr><td>Process documentation</td><td>A common understanding of the TARGET process was reached.</td></tr>
<tr><td>Process improvements</td><td>The process manager has a comprehensive understanding of the identified root causes, the implemented solutions as well as of auditing procedure and contents.</td></tr>
<tr><td>Project Benefit (monetary and non-monetary)</td><td colspan="2">The project benefit was reviewed by the Black Belt, Sponsor and process manager.
Dates for the 3 and 6 months Sustainability Audits have been set.</td></tr>
<tr><td>Process key figures</td><td colspan="2">The process manager will continue to measure the defined KPIs and will report regularly to the Sponsor.</td></tr>
<tr><td>Training</td><td colspan="2">The process manager is responsible for the training of persons involved in the process, the KPI data collection as well as the further development of measurements.</td></tr>
<tr><td>Open points</td><td colspan="2">All open points from the Handover Meeting have been completed.</td></tr>
</table>

Confirmation

Date
(Signature Process Owner/Manager)

Tip

- Make sure the team members receive official appreciation for their performance in the form of a certificate, an expression of thanks or a dinner; other tokens of appreciation for the team might be little presents (t-shirts, baseball caps, key holders, USB sticks etc.); this helps make team members proud and enhances the team spirit
- The project closure meeting usually conveys to the team a feeling of success and/or the feeling of completed work; do not leave it too late for this meeting; if the implementation or the benefit collection is expected to take some time you should still make an appointment for the meeting after the closure of the CONTROL phase (of course after consultation with the Sponsor as potential sponsor of the event)

Gate Review CONTROL

- **Finalize Process Documentation**
  - Is the improved process with all its details transparent and comprehensible for everyone involved?
  - Is the status of the process documentation current and does it satisfy corporate standards?
  - Are the work instructions and standard operating procedures comprehensive and easily understood?
  - Have interfaces and responsibilities been clearly defined?

- **Monitor Process**
  - Is the performance capability of the improved process known and/or quickly recognizable?
  - Have measurements/key figures been summarized in well visualized Dashboards?
  - Are Dashboards suitable for controlling the process?

- **Control process**
  - Has a team been defined for the process control and are the tasks and responsibilities known?
  - Has process control been established, i.e. do regular meetings take place, are actions established and conducted and do regular follow ups take place?

- **Ensure success**
  - Is the quality of the improvement reviewed and the project's success measured?
  - Has the improvement of key figures and the monetary benefit connected to this been recognized by Finance?
  - Has the project been well documented, and in a comprehensible way?
  - Have the project results been handed over to the Process Owner and has the responsibility been transferred back to him/her completely?

Continuous Improvement Process

Term
Continous Improvement Process (CIP)

When
After the project's closure

Goal
- Continue to enhance process performance over time
- Implement a culture of employee ownership for improvements in the process

Procedure
1. Identify improvement opportunities and potential:
   - Within the frame of process control
   - Best Practices and exchange of experience
   - Idea platform of employees
   - …

2. Define procedure for improvement:
   - Simple improvement opportunities can be dealt with using simple action plans in the course of day to day business and adopting the PDCA methodology. (Plan, Do, Check, Act)
   - More complex improvement opportunities can utilize the DMAIC methodology, either, by Lean Workouts, i.e. Workshops with a duration of 2 to 5 days, or using a standard Six Sigma^{+Lean} DMAIC project

3. Realize improvement and communicate success

Tip
Connect the procedure Plan, Do, Check, Act in a process control meeting with an Action Plan and map the respective status graphically, e.g. with the help of Harvey Balls (see below)

Example Action Plan on the following page.

Example Action Plan

What	Who	With whom	By when	Status (PDCA)
Improvement of Online form	Hr. Ericson	Hr. Petersen	12/31/2010	
Clarification of complaint process	Hr. Nocia	Hr. Soni	11/30/2010	
Install customer information	Hr. John	Hr. Lunau	10/31/2010	
…				

 Not started yet

 Plan

 Do

 Check

 Act

Lean Workout

Term
Lean Workout, Kaizen Workshop, Kaizen Flash, Rapid DMAIC, Lean DMAIC

When
During the project in IMPROVE, within the frame of continuous improvement

Goal
Address a serious problem in an existing process using an accelerated version of the DMAIC methodology either in a production or service environment. Rapidly identify causes and solutions with immediate implementation.

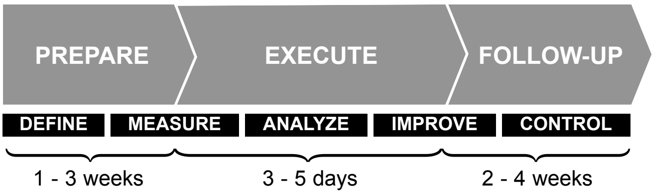
Procedure

1. Check prerequisites for a Lean Workout, usually by talking with the Sponsor:
   - The scope of the problem has already been recognized beforehand, defined and can be limited to a particular area, e.g. long setup times for a machine, 5S action due to long search times in a clearly scoped area, reduction of waste and defect prevention at an assembly line, long processing times in a specific area

2. A Kaizen DMAIC includes preparation and follow-up work for which a time period of a maximum of 30 days is provided for; it usually takes place in three phases:
   a. Preparation (includes DEFINE and MEASURE; 5 to 10 days)
      - Define the problem in a Project Charter
      - Collect any necessary measurements and material
      - Select the team members
      - Get information through research and survey
      - Organize Workshop

   b. Delivery (includes ANALYZE and IMPROVE; 3 to 5 days)
      - Analyze the problem
      - Work with involved employees to verify the causes of the problem on site or very close nearby
      - Derive solution approaches and actions
      - Implement the solution approaches – as required – and if possible start this during the Workshop

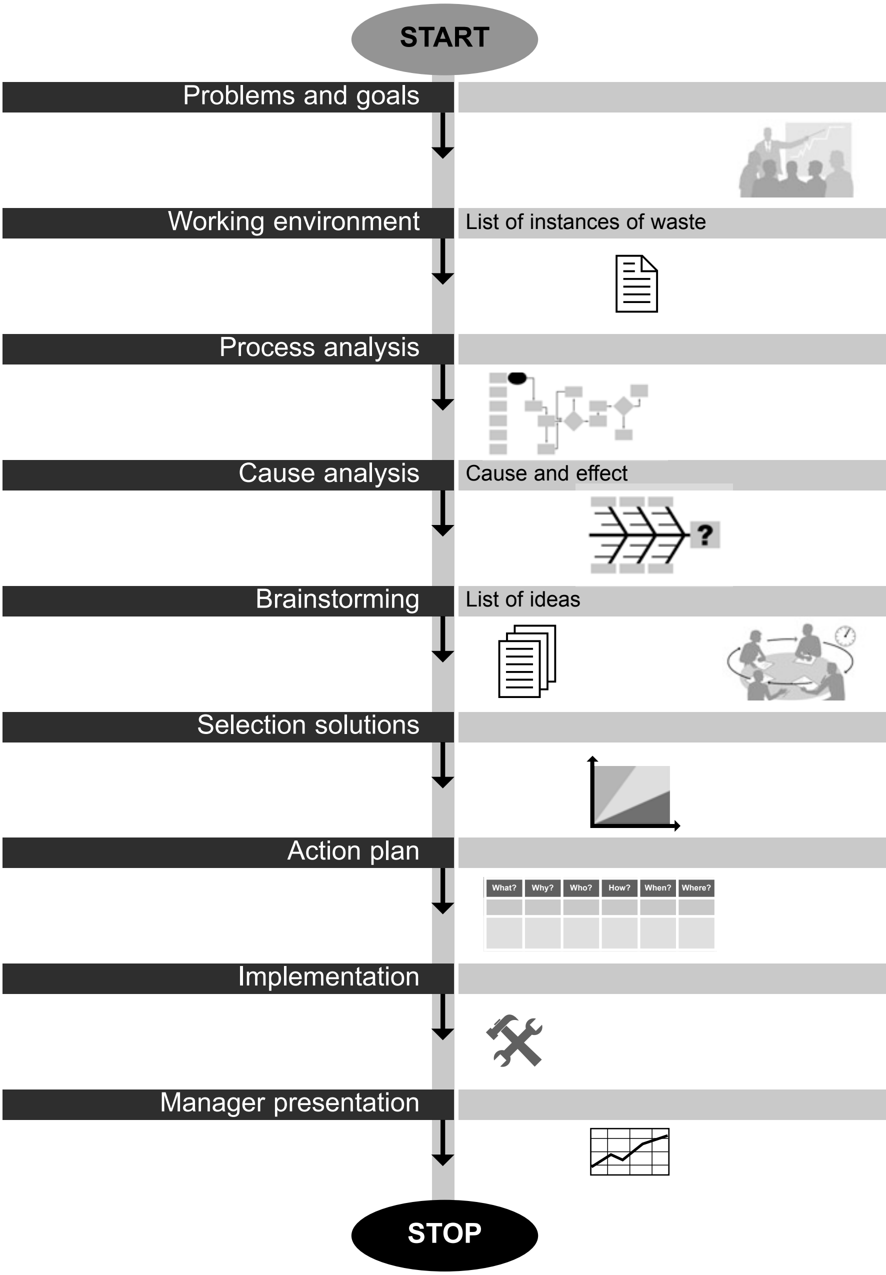
c. Follow up (includes the phases IMPROVE and CONTROL; 15 to 20 days)
   - Those remaining actions which haven't been concluded during the Workshop are to be carried out now
   - Ensure sustainability, e.g. by new standard operating procedures, visual process monitoring and regular trainings etc



Tip

- Deploy only an experienced Workshop Leader/Facilitator who can react flexibly to changes in the direction of the Workshop and who can improvise if required
- Prepare the Workshop thoroughly, so that everything is available and the Workshop can be successful
- Select the people involved carefully and ensure their participation so that acceptance of the results in the company is increased
- Symbolize team membership with t-shirts, caps etc.
- Make sure that the Sponsor and other relevant managers attend the beginning and the end of the Workshop. Allocate time at the end of each day to share insights, findings and recommended actions with those people responsible.
- Always check the hypothesized causes with small samples and with the help of the employees involved to make sure that they are real.

Overview of A One Week Kaizen DMAIC Workshop



5S	Sort, Set in Order, Shine, Standardize, Sustain
AL	Availability Level
ANOVA	Analysis of Variance
approx.	approximately
BB	Black Belt
BPM	Business Process Management
Cap	Capacity
CCD	Central Composite Design
CED	Cause-Effect Diagram
CEO	Chief Executive Officer
cf.	confer, see
CI	Confidence Interval
CIP	Continuous Improvement Process
CNX	Constant, Noise, Variable
CSI	Customer Satisfaction Index
CTB	Critical To Business
CTC	Critical To Customer
Cum.	cumulative
Dept.	Department
DFSS	Design For Six Sigma
DMADV	DEFINE, MEASURE, ANALYZE, DESIGN, VERIFY
DMAIC	DEFINE, MEASURE, ANALYZE, IMPROVE, CONTROL
DOE	Design Of Experiments
DPMO	Defects Per Million Opportunities
DPO	Defects Per Opportunity
DPU	Defects per Unit
e.g.	for example
ed.	editor/edition
etc.	et cetera
EVA	Economic Value Added
FMEA	Failure Mode and Effect Analysis
GB	Green Belt
GPS	Generic Pull System

R. Meran et al., *Six Sigma+Lean Toolset: Mindset for Successful Implementation of Improvement Projects*, Management for Professionals, DOI 10.1007/978-3-642-35882-1,

GR	Gate Review
H	hours
H0	Null hypothesis
HA	Alternative hypothesis
i.e.	that is
ICR	Internal Cost Rate
incl.	including
IPS	Information, Planning and Steering system
IT	Information Technology
KPI	Key Performance Indicator
LCL	Lower Control Limit
Log	Logarithm
LSL	Lower Specification Limit
m.	million
max.	maximum
MBB	Master Black Belt
MD	Man days
MGP	Multi Generation Plan
min.	minimum
min.	minute
Mm	millimeter
MSA	Measurement System Analysis
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
n/a	not available
OEE	Overall Equipment Efficiency
OTOBOS	on time, on budget, on specification
p.	page
PCI	Process Capability Index
PDCA	Plan, Do, Check, Act
PE	Process Efficiency
PL	Performance Level
PLT	Process Lead Time

Ppm	Parts Per Million
QL	Quality level
R & D	Research and Development
R&R	Repeatability & Reproducibility
RACI	Responsible - Accountable - Consulted - Informed
RPN	Risk Priority Number
RPS	Replenishment Pull System
RSM	Response Surface Method
RTP	Rolled Throughput (yield)
SCAMPER	Substitute, Combine, Adapt, Modify, Put to other uses, Eliminate, (Erase), Reverse (Rearrange)
SIPOC	Supplier, Input, Process, Output, Customer
SLD	Swim Lane Diagram
SMART	Specific, Measurable, Agreed to, Realistic, Time Bound
SMED	Single Minute Exchange of Die
StDev	Standard Deviation
SV	Study Variation
TIMWOOD	Transport, Inventory, Motion, Waiting, Overproduction, Overprocessing, Defects
TOC	Theory Of Constraints
TP	Throughput
TPC	technical - political - cultural
TPM	Total Productive Maintenance, Preventive Maintenance
TQM	Total Quality Management
UCL	Upper Control Limit
USL	Upper Specification Limit
VOB	Voice Of Business
VOC	Voice Of Customer
vs.	versus
VSM	Value Stream Map
WIP	Work in Process
VSM	Value Stream Map
WIP	Work in Process

INDEX

5 S	272 et seq.
Accuracy	95, 97 et seq., 241
Affinity Diagram	313
Alternative hypothesis	211 et seq.
Analogy Brainstorming	311 et. seq.
Analyze data	204 et seq.
Analyze process	178 et seq.
ANOVA	205, 214, 217-225
Anti Solution Brainstorming	305 et seq.
Audits	374 et seq.
Bar Chart	116
Bartlett's Test	214
Batch size	301
Benefit calculation	28 et seq.
Black Belt	24
Block building	243 et seq.
Bottleneck	200 et seq., 282 et seq.
Box Plot	123 et seq.
Brainstorming	165 et seq., 303-304 et seq.
Brainwriting	307 et seq.
Budget planning	50 et seq.
Buffer stocks	297
Calculation of effects	248
Capacity	200 et seq., 282 et seq.
Capacity Analysis	200 et seq.
Cause-Effect Diagram	165
Central Composite Design	256
CNX	166
Coefficient of determination	219, 229, 234
Collect Data	82, 100, 158, 240, 361
Complexity reduction	327
Confidence Interval	94 et seq., 208 et seq.
Confounding	251 et seq.
Constraint	180, 200-202
Constraint Theory	282 et seq.

R. Meran et al., *Six Sigma+Lean Toolset: Mindset for Successful Implementation of Improvement Projects*, Management for Professionals, DOI 10.1007/978-3-642-35882-1,

Continuous Improvement Process	383 et seq.
Control Charts	128 et seq., 358 et seq.
Control limits	105 et seq., 358 et seq.
Control parameters	246
Correlation	226 et seq.
Correlation coefficient	226 et seq.
Cost Benefit Analysis	329 et seq.
Cross Functional Diagram (CFD)	186 et seq.
CTC/CTB Matrix	66 et seq.
Customer Needs Table	61 et seq.
Dashboard	367 et seq.
Data CollectionForms	89 et seq.
Data Collection Plan	112 et seq.
Data Sources	86
Data Stratification	206
Data Transformation	151 et seq.
Data Type	87 et seq.
Defects per Million Opportunities (DPMO)	143 et seq.
Defects per Unit (DPU)	146
Dependency Assessment	37
Derive Main Causes	260 et seq.
Design of Experiments (DOE)	240 et seq.
Dot Plot	119
Effort Benefit Matrix	316
Exit Rate	197-199, 200 et seq., 282, 295
Experimental strategy	241 et seq.
F-Test	214
Factor levels	217 et seq., 241 et seq.
Failure Mode and Effect Analysis (FMEA)	168 et seq.
Fishbone Diagram	165 et seq.
Fold Over	242 et seq., 250
Fractional Factorial Design	250 et seq.
Full Factorial Design	245 et seq.
Further Experimental Designs	257 et seq.
Future State Map	327 et seq.

Gage R&R	99, 102 et seq., 106 et seq.
Gage R&R - continuous data	106 et seq.
Gage R&R - discrete data	99 et seq.
Gantt Chart	44
Generate Solutions	271
Generic Pull System	294 et seq.
Glass Wall Management	372 et seq.
Granularity	94, 246
Graphical display	87, 103
Histogram	120 et seq.
Hypothesis Tests	211 et seq.
Idle time	188, 195, 289
Implementation Plan	338 et seq.
Input-Process-Output-Measurement Matrix	175 et seq.
Interaction	219, 223, 242 et seq., 248 et seq.
Inventory	189 et seq., 262 et seq., 288, 294-300
Ishikawa Diagram	165 et seq.
KANBAN	299 et seq.
Kano Model	63 et seq.
Kick-off Meeting	57
Lean Workout	385 et seq.
Levene's Test	214
Linear regression	228 et seq.
Linearity	98, 108 et seq., 241
Little's Law	197 et seq.
Mean	133
Mean Time Between Failure (MTBF)	292
Mean Time to Repair (MTTR)	292
Measurement Matrix	79 et seq.
Measurement System Analysis	97 et seq.
Median	135 et seq.
Multi Generation Plan	33 et seq.
Multiple Linear Regression	233 et seq.
Must Criteria	314 et seq.
N/3 Method	317

Net Benefit	29, 329
Network plan	42
Noise factors	246 et seq.
Nominal Group Technique	319 et seq.
Normal Probability Plot	131
Normalized Yield	142
Notebook Method	308
Null hypothesis	212 et seq.
One Proportion Test	214
One sample t-Test	214
One-factorial variance analysis	217
Operating costs	30, 329
Operational Definition	83 et seq.
Optimization experiment	243
Overall Equipment Effectiveness (OEE)	142, 288 et seq.
Pareto Chart	117
Parts per Million (PPM)	145
Percentile Distance	149
Pie Chart	115
Pilot	335 et seq.
Poka Yoke	276 et seq., 327, 355
Prepare Process Control	331 et seq.
Procedural instruction	352
Process capability	153 et seq.
Process documentation	351 et seq.
Process Efficiency	199 et seq.
Process Flow Analysis	202 et seq.
Process Flow Chart	179, 184 et seq.
Process Lead Time	180, 188, 195-199, 280, 288-294
Process Management Team	370 et seq.
Process Owner	332, 334, 371, 374, 379
Process Performance	142
Process Sigma	144, 157
Process Stability	153 et seq.
Process visualization	178

Project Charter	23 et seq.
Project Closure	379 et seq.
Project communication	59 et seq.
Project Documentation	377 et seq.
Project Frame	31 et seq.
Project goal	19, 23 et seq., 33, 38, 71, 176, 267, 324
Project Management	38 et seq.
Pugh Matrix	321 et seq.
Pull System	294 et seq., 300
Quality key figures	142
R square	219, 229, 234
RACI Chart	48 et seq.
Radar Chart	274
Randomization	241, 246 et seq.
Range	140
Rational subgroups	359
Reaction Plan	333 et seq.
Regression	228 et seq.
Regression Analysis	228 et seq.
Reorder level	297
Repeat	245 et seq.
Repeatability	97
Replenishment Pull System	297 et seq.
Replicate	243 et seq.
Reproducibility	98
Residuals	220 et seq, 230 et seq., 248
Resolution type	251 et seq.
Resource Planning	46, 339
Response Surface Methods	243, 256 et seq.
Risk Analysis	341
Risk Management	52 et seq.
Rolled Throughput Yield (RTY)	142, 147
Rollout	342
Run Chart	125 et seq.
Sample	91 et seq., 208 et seq.

Sample size	92 et seq., 246, 358
Sampling Strategy	91 et seq.
SCAMPER	309 et seq.
Scatter Plot	130
Screening Experiment	242
Setup Time Reduction	284 et seq.
Should be Process Map	327 et seq.
Simple linear regression	228 et seq.
SIPOC	35 et seq.
SMED	284 et seq.
Solution Cause Matrix	324 et seq.
Spaghetti Diagram	179, 182 et seq.
Span	141
Stability	98, 153
Stakeholder Management	54 et seq.
Standard Deviation	138
Subgroups	359
Superfluous information	194
Swim Lane Diagram	179, 186 et seq.
Takt rate	200 et seq.
Takt time	200 et seq.
Theory of Constraints	282 et seq.
Time Analysis	195 et seq.
Time Plan	44
Tool 1	66 et seq.
Tool 2	79 et seq.
Tool 3	175 et seq.
Tool 4	324 et seq.
Total Productive Maintenance	288 et seq.
Two Proportion Test	214
Two Sample F-Test	214
Two Sample t-Test	214
Two Way ANOVA	222 et seq.
Types of error	212 et seq.
Types of waste	191, 193 et seq.

Understanding Variation	114
Value Analysis	191 et seq.
Value Stream Analysis	188 et seq.
Value Stream Map	179, 188 et seq.
Variance	137
Variation Reduction	254 et seq.
Visual Management	355 et seq.
Voice of Business (VoB)	61 et seq.
Voice of Customer (VoC)	61 et seq.
Work Breakdown Structure	40 et seq.
Work packages	38, 40-42, 44, 338, 342
Workplace Layout	280 et seq.
Yield	142, 147 et seq.
α (alpha) error	212
β (beta) error	212
χ^2 (Chi-square) - homogeneity test	214

PROCESS SIGMA TABLE INCLUDING 1.5 SIGMA SHIFT

Yield	Process Sigma	Defects per 1,000,000	Defects per 100,000	Defects per 10,000	Defects per 1,000	Defects per 100
99.99966%	6	3.4	0.34	0.034	0.0034	0.00034
99.99946%	5.9	5	0.54	0.054	0.0054	0.00054
99.99915%	5.8	9	0.85	0.085	0.0085	0.00085
99.99867%	5.7	13	1	0.1	0.01	0.001
99.99793%	5.6	21	2	0.2	0.02	0.002
99.99683%	5.5	32	3	0.3	0.03	0.003
99.99519%	5.4	48	5	0.5	0.05	0.005
99.99277%	5.3	72	7	0.7	0.07	0.007
99.98922%	5.2	108	11	1.1	0.11	0.011
99.98409%	5.1	159	16	1.6	0.16	0.016
99.97674%	5	233	23	2.3	0.23	0.023
99.96631%	4.9	337	34	3.4	0.34	0.034
99.95166%	4.8	483	48	4.8	0.48	0.048
99.93129%	4.7	687	69	6.9	0.69	0.069
99.90324%	4.6	968	97	9.7	0.97	0.097
99.86501%	4.5	1350	135	13.5	1.35	0.135
99.81342%	4.4	1866	187	18.7	1.87	0.187
99.74449%	4.3	2555	256	25.6	2.56	0.256
99.65330%	4.2	3467	347	34.7	3.47	0.347
99.53388%	4.1	4661	466	46.6	4.66	0.466
99.37903%	4	6210	621	62.1	6.21	0.621
99.18025%	3.9	8198	820	82.0	8.20	0.820
98.92759%	3.8	10724	1072	107.2	10.72	1.072
98.60966%	3.7	13903	1390	139.0	13.90	1.390
98.21356%	3.6	17864	1786	178.6	17.86	1.786
97.72499%	3.5	22750	2275	227.5	22.75	2.275
97.12834%	3.4	28717	2872	287.2	28.72	2.872
96.40697%	3.3	35930	3593	359.3	35.93	3.593
95.54345%	3.2	44565	4457	445.7	44.57	4.457
94.52007%	3.1	54799	5480	548.0	54.80	5.480
93.31928%	3	66807	6681	668.1	66.81	6.681
91.92433%	2.9	80757	8076	807.6	80.76	8.076
90.31995%	2.8	96800	9680	968.0	96.80	9.680
88.49303%	2.7	115070	11507	1150.7	115.07	11.507
86.43339%	2.6	135666	13567	1356.7	135.67	13.567
84.13447%	2.5	158655	15866	1586.6	158.66	15.866
81.59399%	2.4	184060	18406	1840.6	184.06	18.406
78.81446%	2.3	211855	21186	2118.6	211.86	21.186
75.80363%	2.2	241964	24196	2419.6	241.96	24.196
72.57469%	2.1	274253	27425	2742.5	274.25	27.425
69.14625%	2	308538	30854	3085.4	308.54	30.854
65.54217%	1.9	344578	34458	3445.8	344.58	34.458
61.79114%	1.8	382089	38209	3820.9	382.09	38.209
57.92597%	1.7	420740	42074	4207.4	420.74	42.074
53.98278%	1.6	460172	46017	4601.7	460.17	46.017
50.00000%	1.5	500000	50000	5000.0	500.00	50.000
46.01722%	1.4	539828	53983	5398.3	539.83	53.983
42.07403%	1.3	579260	57926	5792.6	579.26	57.926
38.20886%	1.2	617911	61791	6179.1	617.91	61.791
34.45783%	1.1	655422	65542	6554.2	655.42	65.542
30.85375%	1	691462	69146	6914.6	691.46	69.146
27.42531%	0.9	725747	72575	7257.5	725.75	72.575
24.19637%	0.8	758036	75804	7580.4	758.04	75.804
21.18554%	0.7	788145	78814	7881.4	788.14	78.814
18.40601%	0.6	815940	81594	8159.4	815.94	81.594
15.86553%	0.5	841345	84134	8413.4	841.34	84.134
13.56661%	0.4	864334	86433	8643.3	864.33	86.433
11.50697%	0.3	884930	88493	8849.3	884.93	88.493
9.68005%	0.2	903200	90320	9032.0	903.20	90.320
8.07567%	0.1	919243	91924	9192.4	919.24	91.924

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