DFSS Design for Six Sigma Process Evaluation

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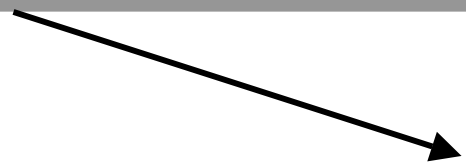
Watch Industry

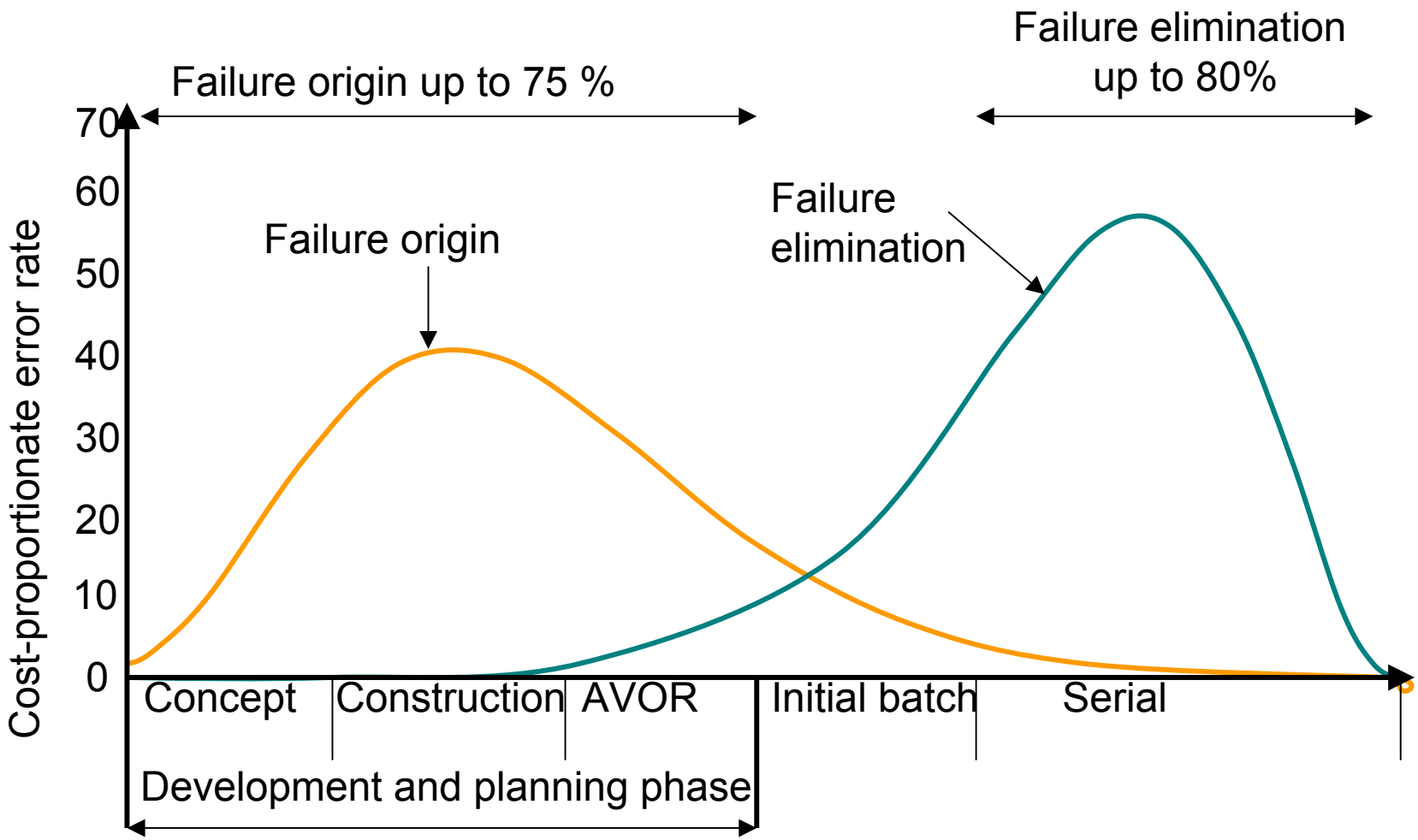
- Traditional industry
- A lot of classic empiric experience
- A lot of variance and individual components



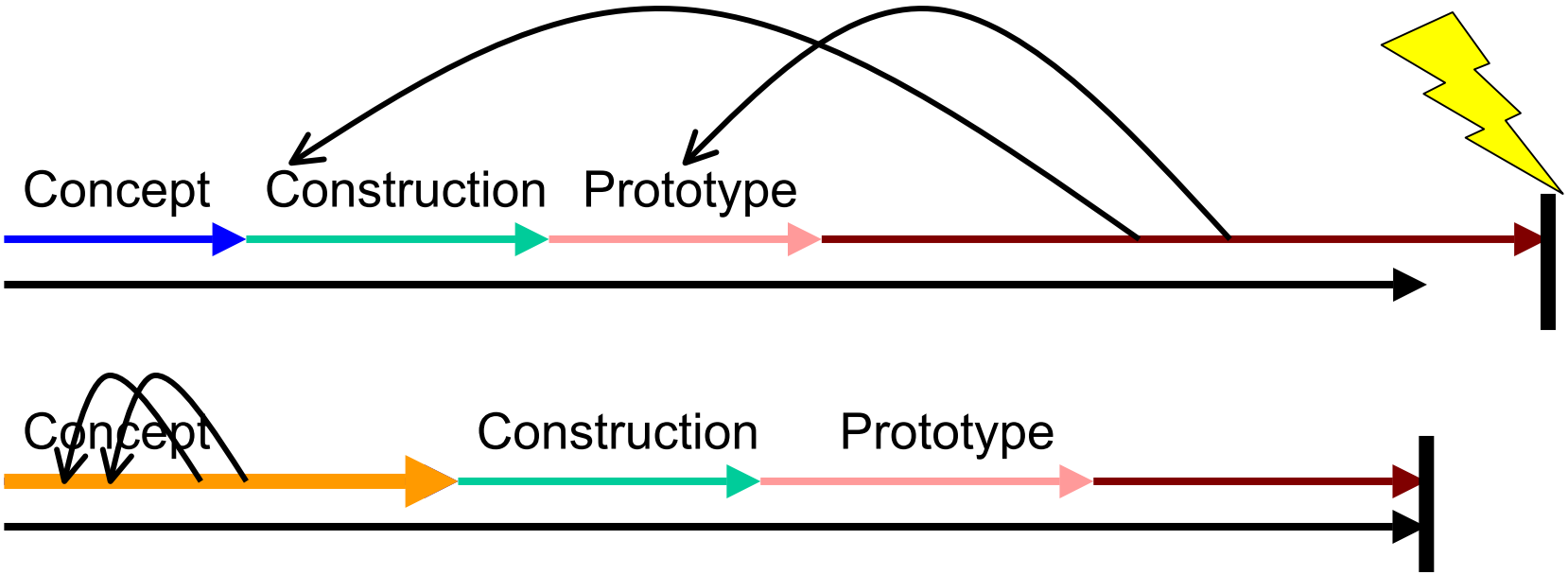
- General industry
- Use of new methods
- Build more standards

A mechanical watch is not better since 1975, compared to a digital camera where we have each year the double number of pixels. If we will make a better mechanical watch and increase the customer satisfaction, we have to use the same state of the art methods.

Why Six Sigma



R&D Consequences



DFSS

Production control
- Maintain capable processes - approach a Six Sigma operation
- Lean Manufacturing

SPC

Understanding and Anticipating Customer's Needs
- Basic Needs (expected needs, yet unspoken)
- Performance Needs (Spoken needs)
- Excitement Needs (Innovations, "WOWs")

VOC CTQ's

QFD

The QFD "House of Quality"
- Create a well documented and prioritised list of requirements to keep them current and visible.
- Develop, metrics and specific goals for customers requirements.

Qualification and Homologation
- Meantime between Failure MTBF
- Stress, shocks, climatic tests

Homologation

$$F(t) = 1 - e^{\left(\frac{-t}{T}\right)^{\beta}}$$

DFSS

Design for Six Sigma

Process evaluation and selection
- Capability of a process
- Evaluate and select production methods

Process evalutation

$$DPMO = \frac{D}{N \cdot O} \cdot 10^6$$

$$Cm = \frac{T}{6s} = \frac{OSG - USG}{6s}$$

Analyse

"Value" Analysis
- Terms of Functions
- Engineering system and its problems

CPM

CPM Critical Parameter Management
- Energy, force, pressure
- Mathematic parameters
- Component Lifecycle
- DOE Design of experiments

$$y = f(x_1, x_2 \ldots x_n)$$

C&E/FMEA

Cause & Effects // Failure Modes & Effects Analysis
- Assure your product and processes perform their inteded functions over their entire life span.

Ishikawa Modell für DMAIC Ref. 5021

$$Cp = \frac{T}{6s}$$

$$f(x) = \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot e^{-0.5\left(\frac{x-\mu}{\sigma}\right)^2} \qquad s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

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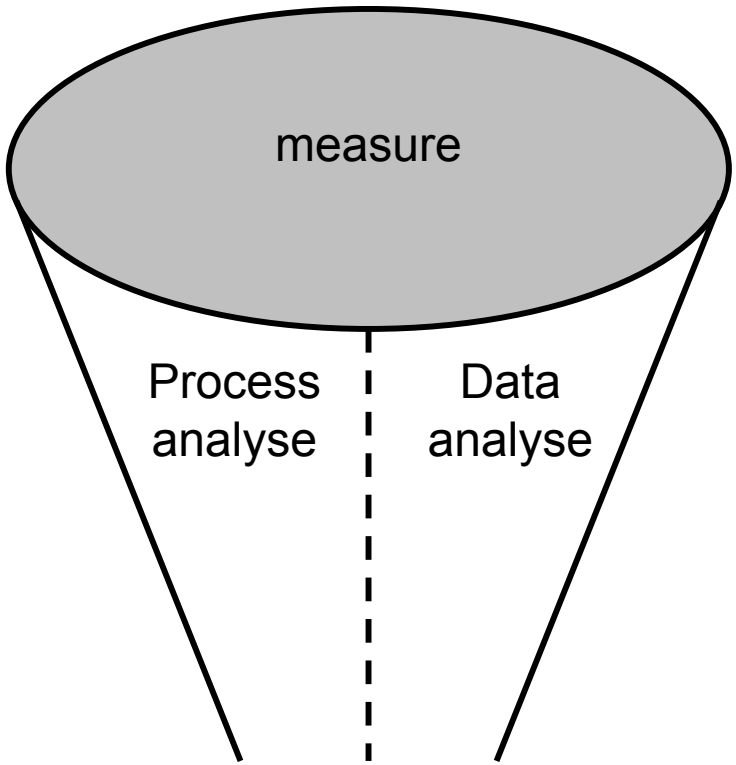
Process and Data Analyse

compress

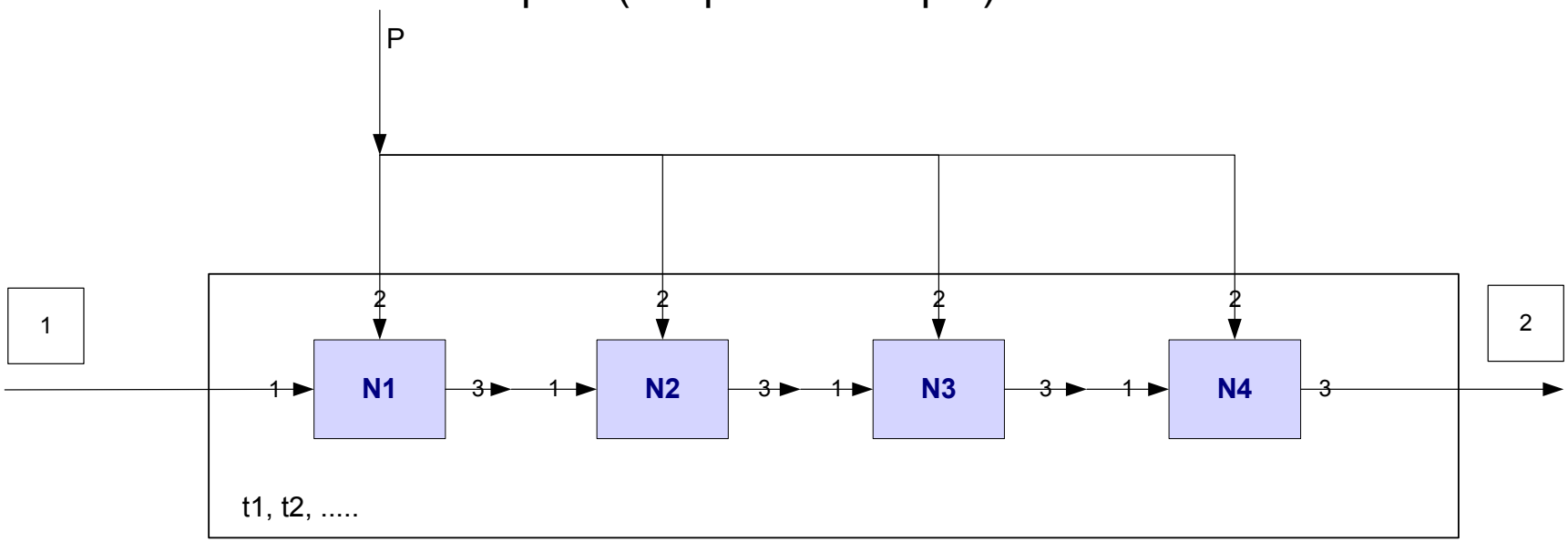


$$Y = f(x_1, x_2 \ldots x_n)$$

OFD Opportunity for Defects

$$OFD = 3N + P + T + C + 2$$

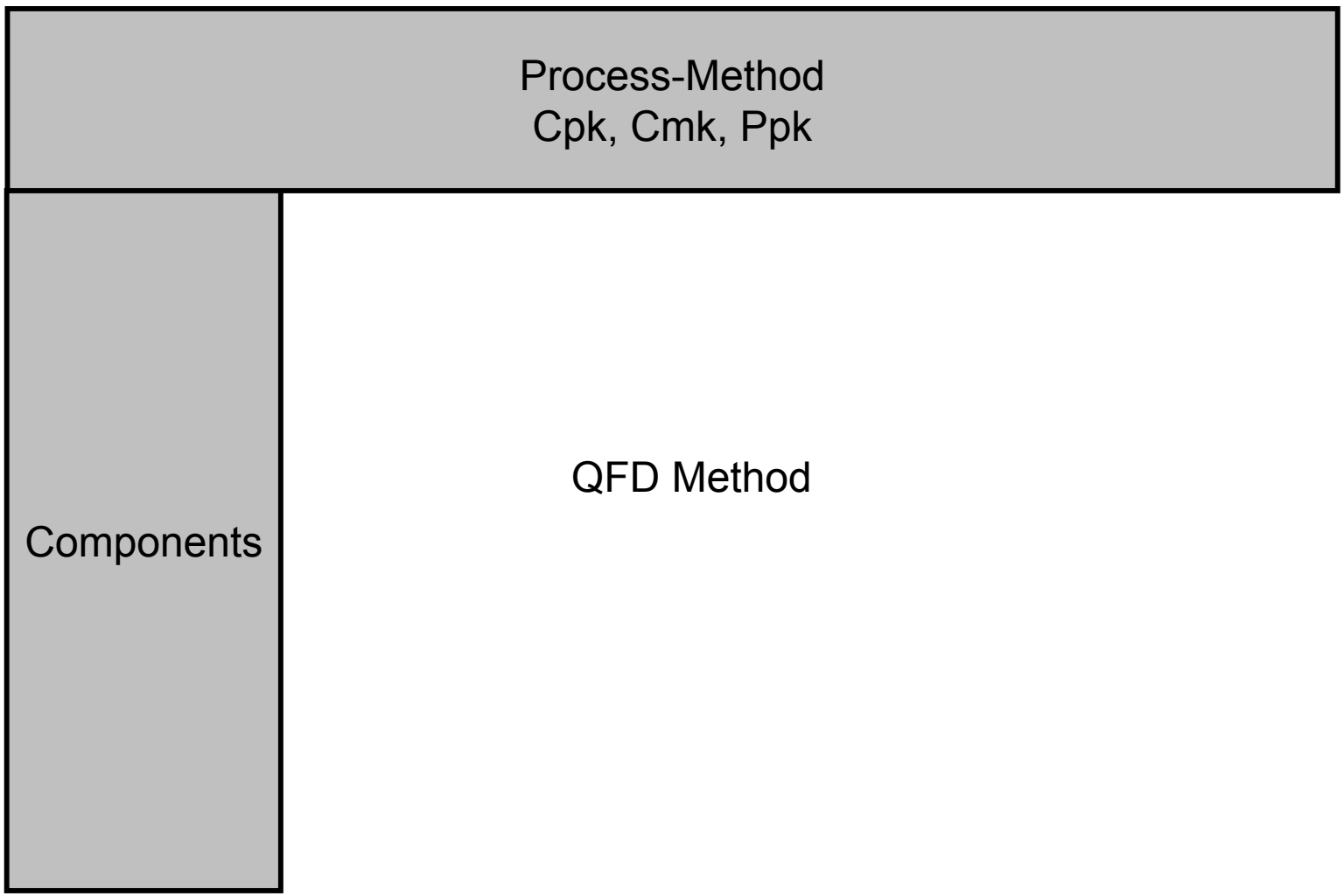
N = Number of **N**eeded process steps/iterations
P = Number of **P**arts
T = Number of **T**ransfers (chemical/surface treatment)
C = Number of **C**onnections
2 = Number of in- and outputs (1 Input + 1 Output)



Complexity of Watches

- Number of new parts
  - Spectrum of parts
    - Springs (steel parts), Bridges Platinum, Gear-train, Regulate organs and escapements
- Number of operations (Process steps) in the manufacturing
  - Exp. Complexity dial
- Number of maximum connections
  - Assembly group
  - Toothings
  - Tolerances
- Quantitative Benchmarking
  - Fault rate per individual part or function => OFD
  - Number of different fault possibilities => FMEA
- Control and testing
  - Checking of the process and not the product

Process Evaluation



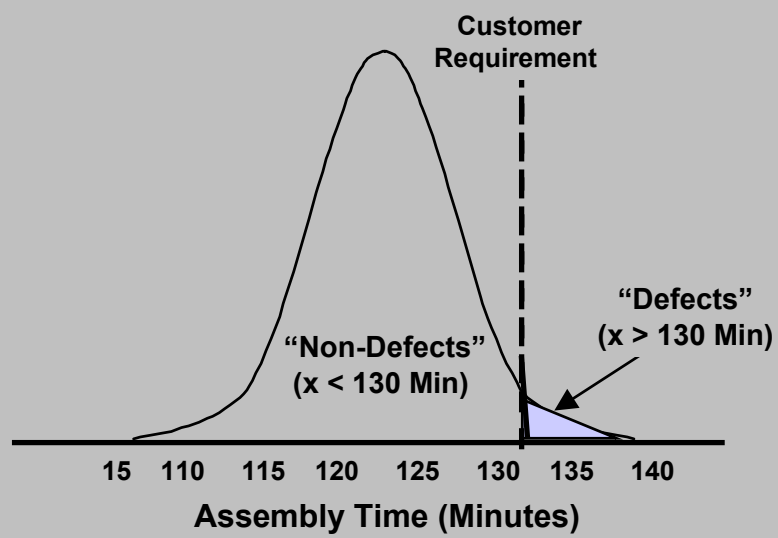
Process Capability

- Verify the process capability on
  - Components, OFD‘s
  - Drawings, tolerances
- Verify the measure capability for the control
- Verify the price evaluation if you have different suppliers for the same process
- Verify the optimisation process => price and quality improvements
- Knowledge of noise factors Z in the production (Taguchi)

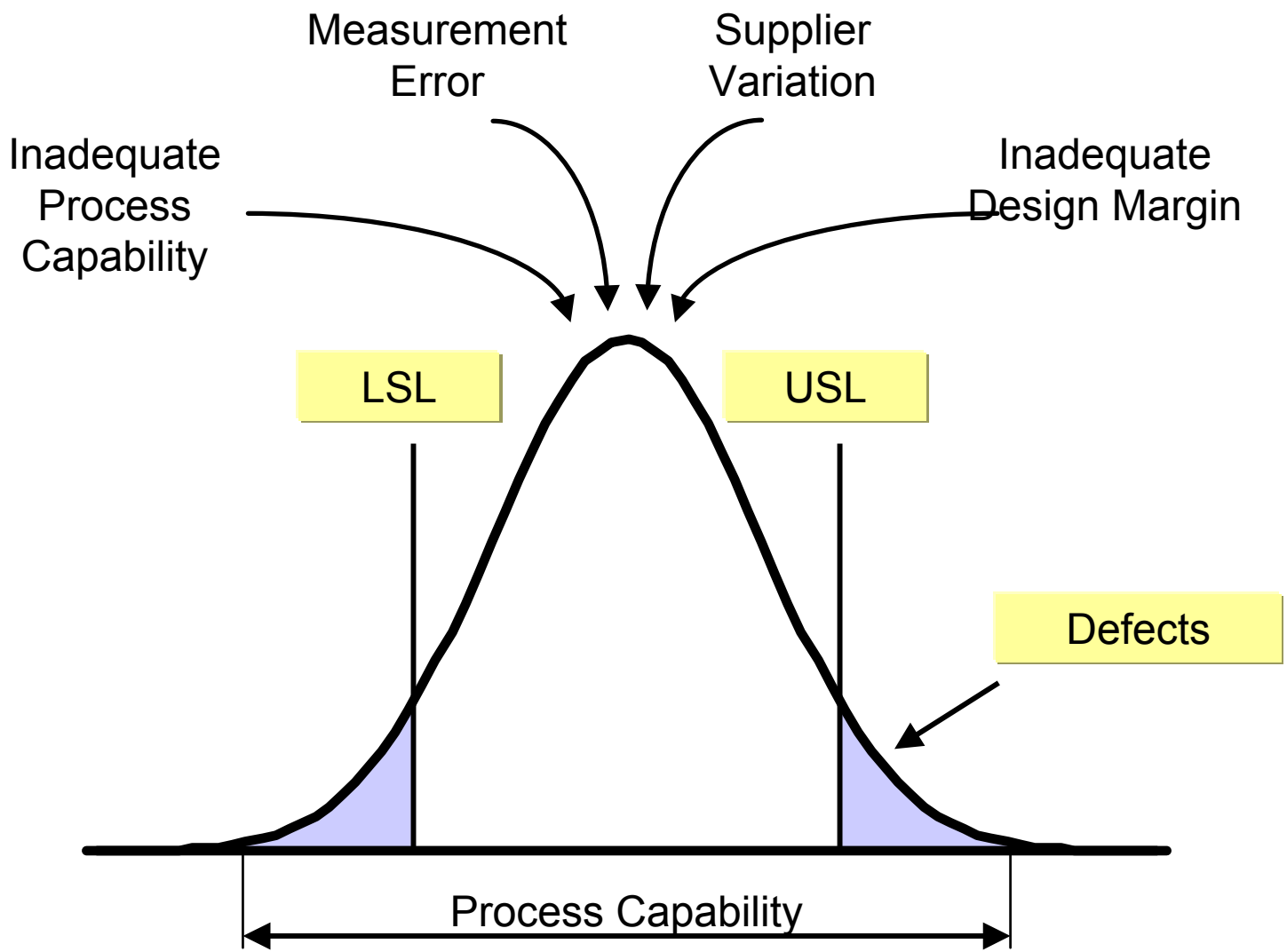
Classify Data

ATTRIBUTES

VARIABLES

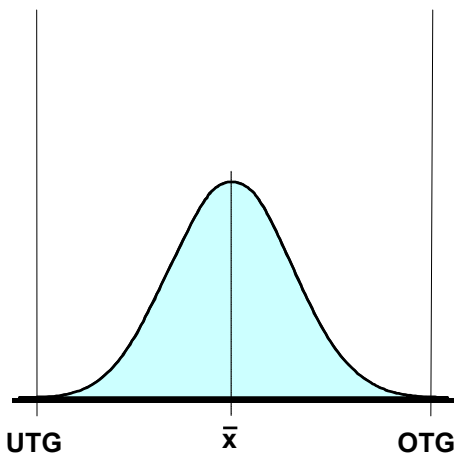


Dissecting Process Capability

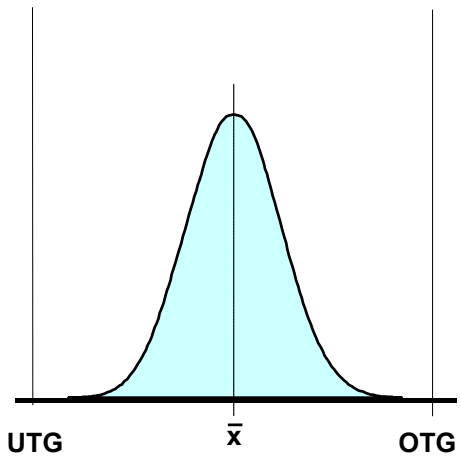


Process Capability – Key Figures

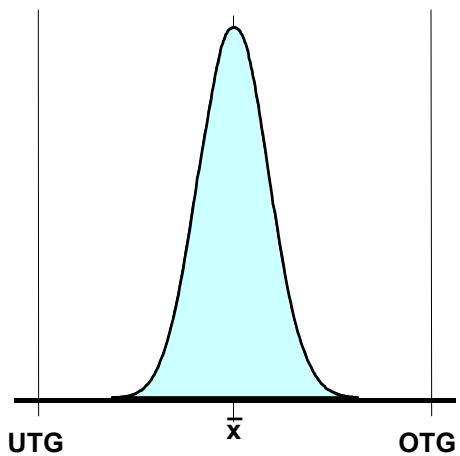
$$Cp = \frac{T}{6s} = \frac{OTG - UTG}{6s}$$



Cp = 1.33
0.27% Off-Spec



Cp = 1.66
0.006% Off-Spec



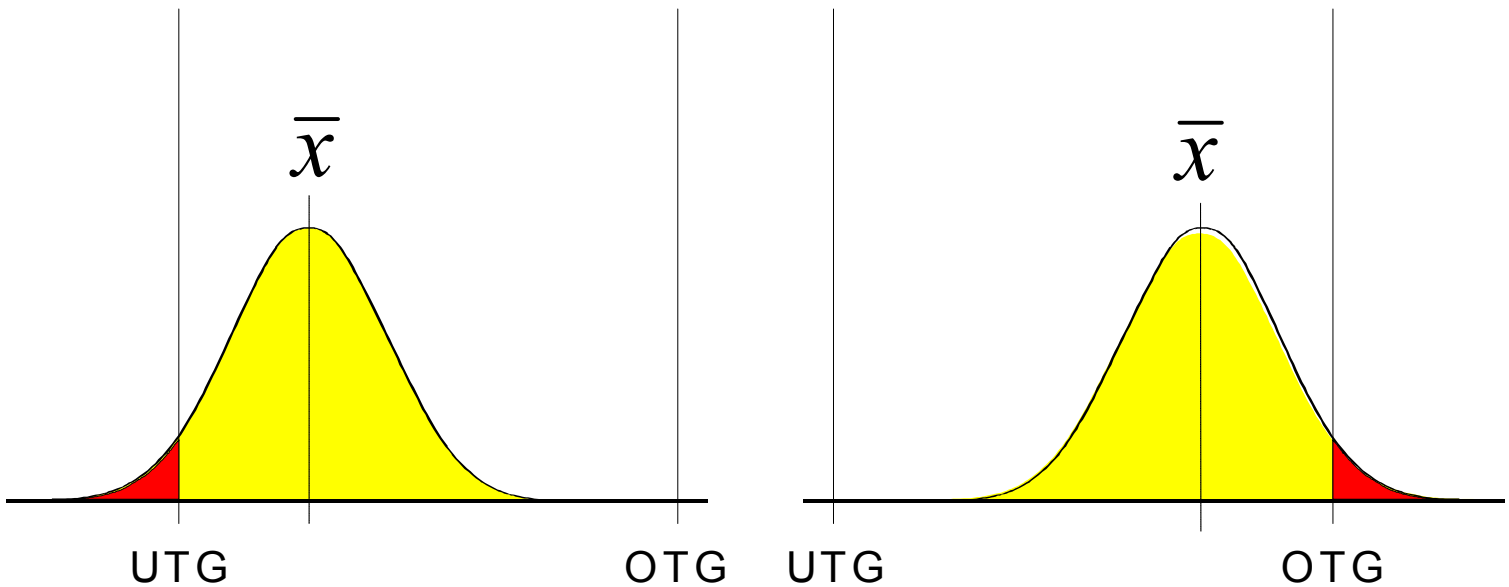
Cp = 2.00
0.00001% Off-Spec

Process Capability – Key Figures

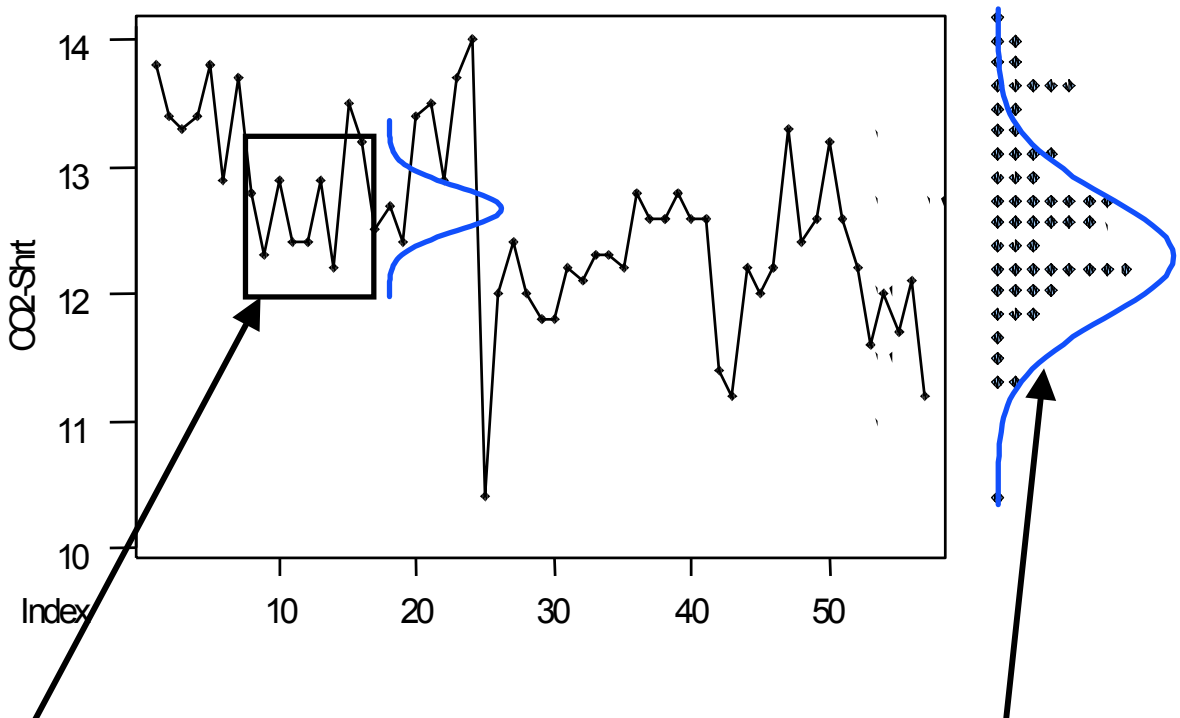
$$Cpk = \min[Cpo; Cpu]$$

$$Cpu = \frac{\bar{x} - UTG}{3s}$$

$$Cpo = \frac{OTG - \bar{x}}{3s}$$



Capability vs. Performance



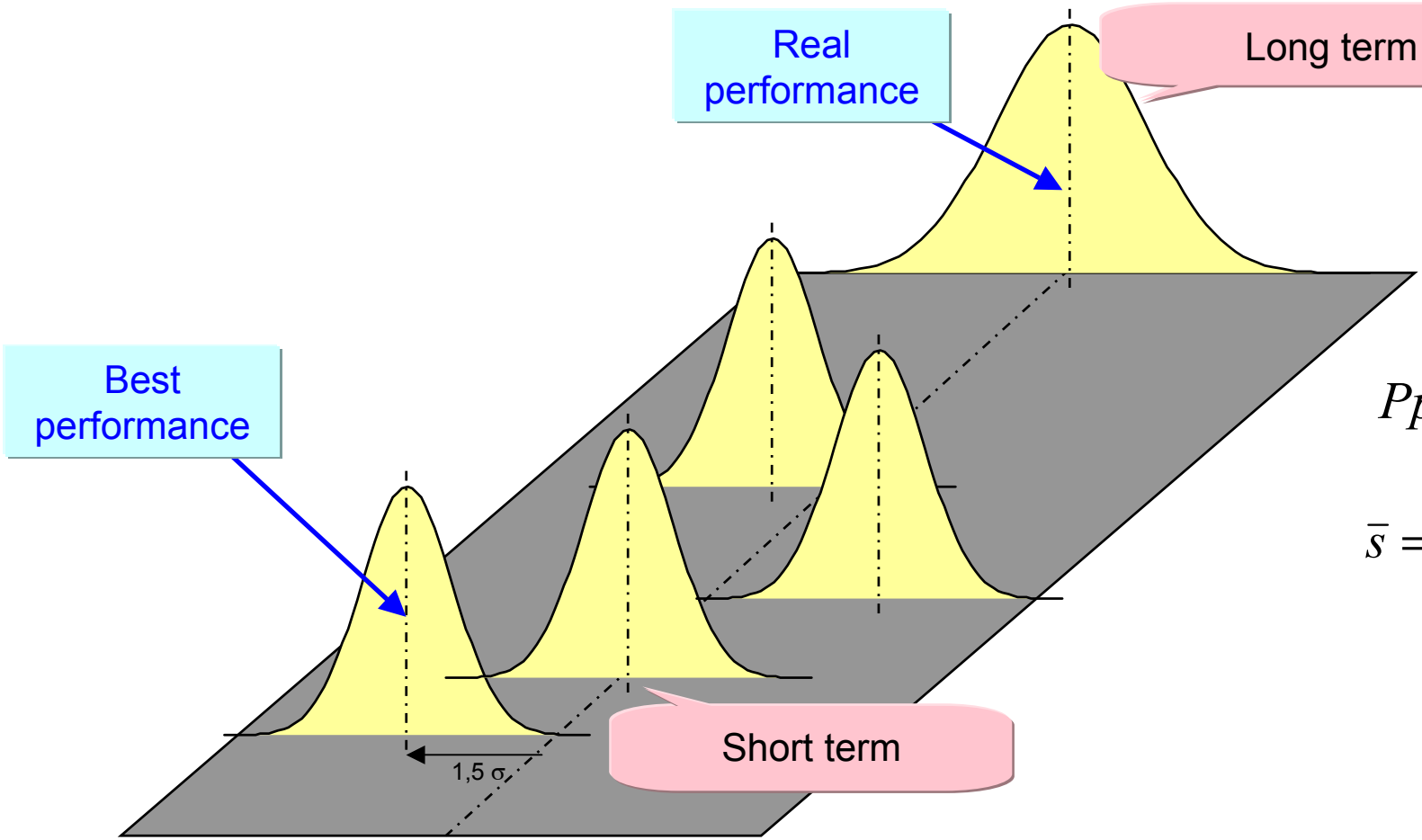
Capability: Only random or short term variability

(Cp & Cpk)

Process Performance: Total Variation including shifts and drifts

(Pp & Ppk)

Variation on the Average Values



$$Pp = \frac{T}{6\bar{s}}$$

$$\bar{s} = \frac{1}{m}\sum_{i=1}^{m} s_i$$

Long term process shift +/-1,5 σ

Evaluation of the Process

For the process capability of single parts we aim for Cp values > = 2.00

With a Cp value of 2.00, the Ppk value is 1.5. The long term capability varies from the average +/- 1.5σ

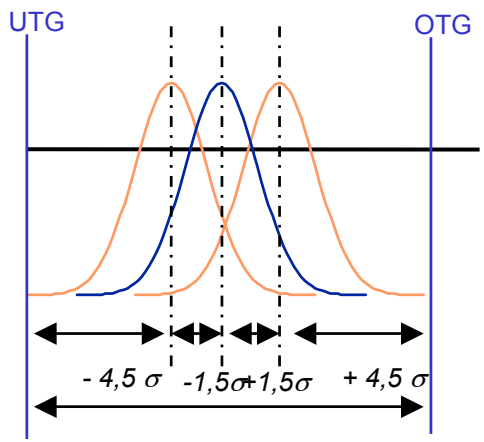
Example: Position tolerance +/-0.006 mm

In order to assure the long term capability of Cp=2.00 and Ppk of 1.5, the machine capability Cm has to be 2.00 with +/-0.004 mm. The Cmk may, with an average fluctuation of 1.5σ, not be under 1.

$$Cp = \frac{T}{6s} = \frac{OTG - UTG}{6s}$$

$$T = Cp \cdot 6s$$

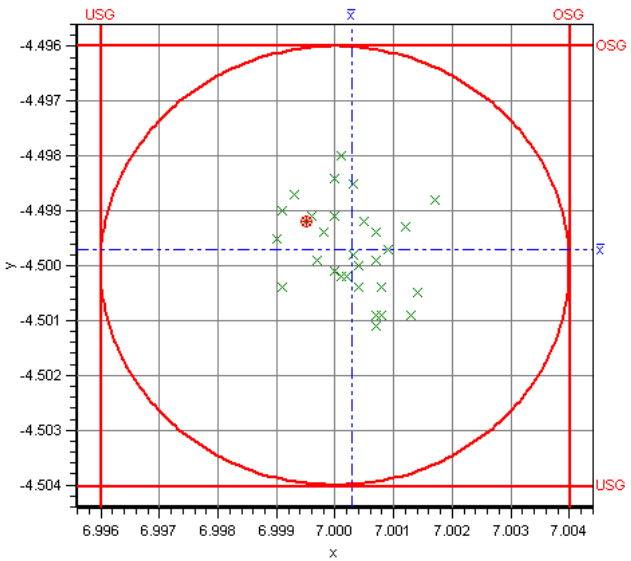
$$Cmk = \frac{(12-3)}{6} = 1.5$$



+/- 6 Sigma

Parameter of Capability

To ascertain the machine capability Cm and Cmk, 30 parts have to be produced consecutively and measured. The tolerance field of the machine, results from a theoretical value of Cm=2 → T=2*6σ. This value has to be 1.5 times better than the plan tolerance. With the measurement capability it has to be considered that it must be 10 times more precise than the tolerance field. In our example 0.008 mm / 10 = 0.0008 mm



Merkm.Nr.	Merkm.Bez.	$\bar{x}$	s	Index		Index		
1	Position 1			P_o		P_{ok}		--- 900
1	x	4.99896	0.00050895	C_m	2.62	C_{mk}	1.94	
1	y	7.49868	0.00062150	C_m	2.15	C_{mk}	1.44	

Complexity of Parts processes

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Process evaluation

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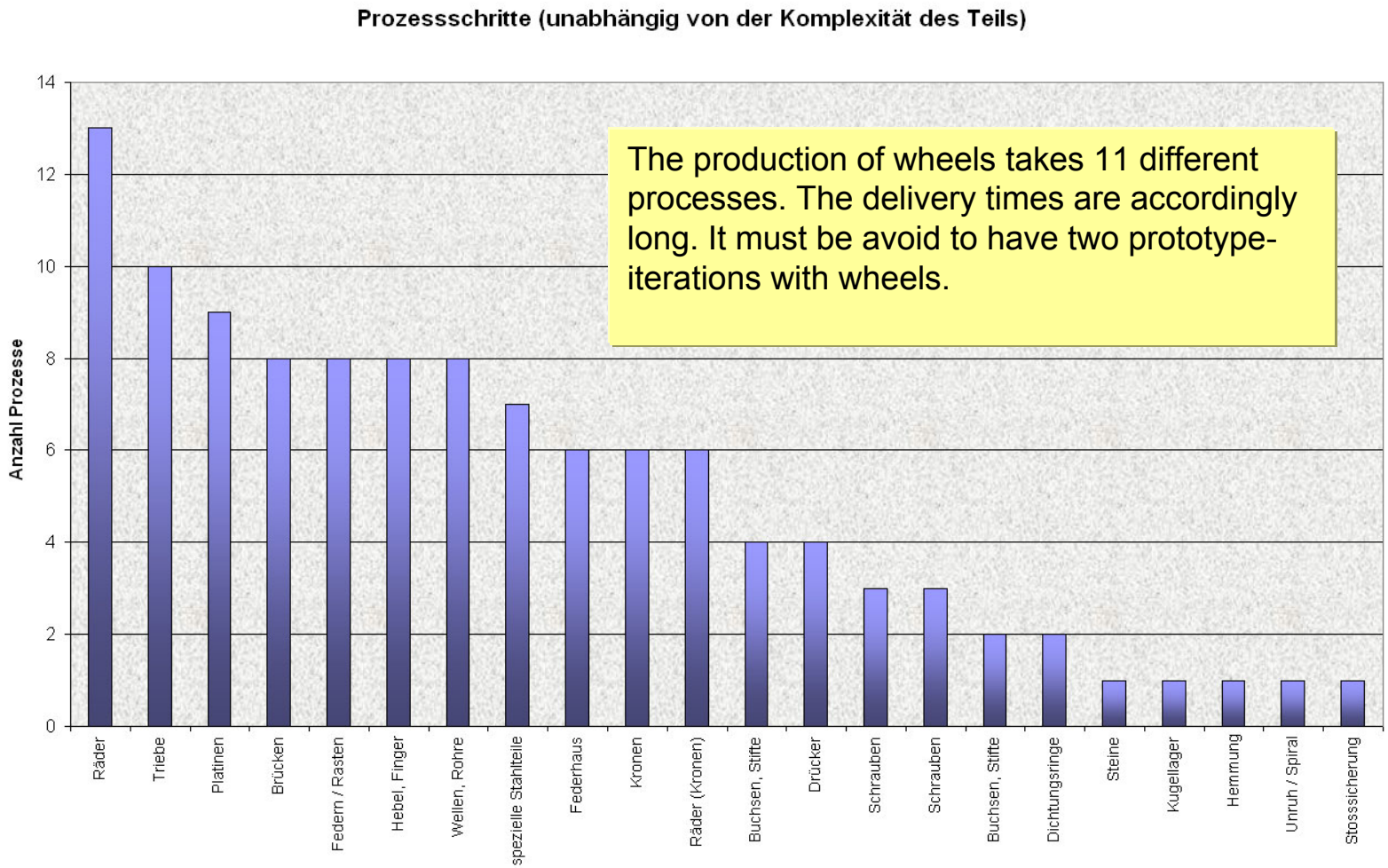
Dok. Nr. 10.855.01

		Treatment Process																				OFD Opportunities for Defects								OFC Opportunities for Complexity						Surface			Procudtion costs
	Cp = 2.0, Ppk=1.5	Milling																	Forming			QS																
	Cmk Machine capability	1.5 +/- 2	1.5 +/-.5	1.5 +/-2	1.5 +/-4	1.5 +/-.5	1.5 +/-.5	1.5 +/-1	1.5 +/- 3	1.5 +/- 2	1.5 +/- 2	1.5 +/- 2	1.5 +/-.5	1.5 +/- 3	1.5 +/- 2	1.5 +/- 2	1.5 +/- 2	+-HV20	1.5 +/-.5	1.5 +/-.4	1.5 +/-.5																		
	Tolerance field T Plan at +/- 1.5s	+/-.3	+/-.7.5	+/-.3	+/-.6	+/-.7.5	+/-.7.5	+/-1.5	+/-.4.5	+/-.3	+/-.3	+/-.3	+/-.7.5	+/-.4.5	+/-.3	+/-.3	+/-.3	+/-.3 0HV	+/-.7.5	+/-.6	+/-.7.5																		
	Cpk Process capability	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5																		
	Cycle time in days		10		1	90		60	1	1	1	1				1	1	1	90	120	40																		
	Internal External																						N	P	T	C	I/O	OFD N=1	OFD										
	Teileklasse	Form Turning	Turning	Cutting	Milling	Machining centre	Engraving	Burnishing	Wire erosion	Polishing	Electrolytic polishing	Grinding	Riveting	Manual work/Deburring	Decoration	Polishing (flat)/ lapping	Electroplating	Heat Treatment	Stamping	Pressing	LIGA-method - electroforming	Quality assurance	Total of processes (Quantity of main process	Number of parts	Number of Transfers	Number of Connections	Number of in- and outputs	OFD N=1 (OFD = N+P+T+C+2)	OFD = 3N+P+T+C+I/O	Complexity 1-6	Average durability in years	elastic	dynamic	*	Total of functional requirements e=9+d=6+s=3	Total of processes N	OFC=[e=9+d=6+s=3]*N	Oil	Fat	eplamisied	Average part-costs [CHF]
Werk	Movement plate		x		x	x	x		x			x		x				x		x		x	10	1	1	0	0	12	32	5	30			x	3	10	30	x	x		30.00
	Bridge				x	x	x		x			x		x				x				x	8	1	1	0	0	10	26	4	30			x	3	8	24	x			8.36
	Barrel	x						x			x						x					x	5	1	1	0	0	7	17	3	10		x	x	9	5	45	x	x		35.00
	Spring					x			x	x		x		x		x		x			x	x	9	1	1	0	0	11	29	4	10	x		x	12	9	108		x		2.69
	Lever					x			x	x		x		x		x		x			x	x	9	1	1	0	0	11	29	4	10		x	x	9	9	81		x		4.56
	Wheels	x		x				x		x	x	x	x		x		x	x		x	x	x	13	2	2	1	0	18	44	6	10		x	x	9	13	117	x		x	6.96
	Pinions	x		x				x		x	x		x				x	x		x		x	10	1	2	1	0	14	34	5	10		x	x	9	10	90	x			1.80
	Arbor, Cane	x						x		x	x						x	x				x	7	1	2	0	0	10	24	4	10		x	x	9	7	63		x		1.44
	special steel parts	x	x						x			x		x				x			x	x	8	1	1	0	0	10	26	4	10		x	x	9	8	72	x	x		6.64
	Pin, Peg	x																x				x	3	1	1	0	0	5	11	2	10			x	3	3	9		x		2.20
	Ruby																					x	1		0	0	0	1	3	1	10			x	3	1	3	x			0.50
	Screw	x								x							x	x				x	5	1	2	0	0	8	18	3	8		x	x	9	5	45				0.30
	Rolling	x										x					x	x				x	5	10	2	0	0	17	27	4	8		x	x	9	5	45	x			15.00
	Escapment	x									x		x				x	x				x	6	2	2	1	0	11	23	3	8		x	x	9	6	54	x			3.60
	Balance / Spiral	x						x					x				x	x				x	6	5	2	1	0	14	26	4	8	x	x	x	18	6	108	x			42.80
	Shock absorber	x															x	x				x	4	4	2	0	0	10	18	3	8	x	x	x	18	4	72	x			2.60
Gehäuse	Button	x						x	x	x	x	x	x				x	x				x	10	8	2	3	0	23	43	6	10	x	x	x	18	10	180		x		
	Joints		x																			x	2	1	0	0	0	3	7	1	3	x		x	12	2	24		x		
	Springs																	x				x	2	1	1	0	0	4	8	2	5	x		x	12	2	24		x		
	Pin	x																x				x	3	1	1	0	0	5	11	2	10			x	3	3	9				
	Movement fixation parts				x													x				x	3	1	1	0	0	5	11	2	30			x	3	3	9				
	Screw s	x								x							x	x				x	5	1	2	0	0	8	18	3	8			x	3	5	15				
	Glas																					x	1	1	0	0	0	2	4	1	10			x	3	1	3				
	Bezel		x		x													x				x	4	1	1	1	0	7	15	2	30			x	3	4	12				
	Casering		x		x									x		x						x	5	1	0	0	0	6	16	3	30			x	3	5	15				
	Crow n	x						x		x	x		x				x	x	x	x		x	10	10	2	3	0	25	45	6	10	x		x	12	10	120		x		
	Movement ring		x		x							x					x	x		x		x	7	1	2	0	0	10	24	4	30			x	3	7	21				
	Inner back		x																				1	1	0	0	0	2	4	1	30			x	3	1	3				
	Back		x		x		x					x										x	5	1	0	0	0	6	16	3	30			x	3	5	15				
	Standard parts / others																						0	1	0	0	0	1	1	1					0	0	0				0.32
	Gesamt / Toutes	15	8	2	7	4	3	7	6	9	7	10	6	6	1	3	13	22	1	5	4	28																	

Complexity of Parts-families



The production of wheels takes 11 different processes. The delivery times are accordingly long. It must be avoid to have two prototype-iterations with wheels.

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