Lean Six Sigma (σ) in (Packaging) Industry

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The Flow

- Introduction to quality
- What is Lean Six Sigma?
- Is your company ready for Lean (Six Sigma) Implementation?
- Lean
- Six Sigma – a sample application
- Advanced Tool – Design of Experiments

Quotes to remember

«The bitterness of poor quality remains long after the sweetness of low price is forgotten.» Benjamin Franklin

«A bad system will beat a good person every time.»
W. Edwards Deming

W. Edwards Deming

«It is not enough to do your best; you must know what to do, and then do your best.»
W. Edwards Deming

«In God we trust, all others must bring data.»
W. Edwards Deming

«It is not necessary to change. Survival is NOT mandatory.»
W. Edwards Deming

What is Lean Six Sigma?

- **Lean** - Focusing in waste reduction in all its forms – strong process engineering background.
- **Six Sigma –** Focusing to reduce **process variability** to achieve more predictable and reliable process which leads to increased quality, improved yield and less waste.

They are both essentially **a mindset** and **collection of techniques** deployed to investigate and resolve a given problem or business issue.

Both effectively look at **the cause and effect** around a problem, establishing its magnitude and means of managing or eliminating it altogether.

MINDSET

Waste - Defects
NVA (non-value-added)
Variability
VA (value-added)

Is Your Company Ready for a Success in Lean (Six Sigma) Implementation?

- The management has good understanding of Dr. Deming's System of Profound Knowledge (SoPK) and willing to mentor/coach his/her employees:
  - Appreciation of a system
  - Knowledge of variation
  - Theory of knowledge
  - Knowledge of psychology

SoPK MINDSET
Commitment
Leadership
By TOP MANAGEMENT

- The Management understands and is willing to implement Dr. Deming's 14 Points for the Transformation of Management.

Must for Top Management before Lean Six Sigma Implementation?

- W. Edwards Deming - books
  - The New Economics for Industry, Government, Education (The MIT Press) third edition
  - Out of the Crisis. Reissue (The MIT Press), October 2018
  - The Essential Deming: Leadership Principles from the Father of Quality, December 2012
- W. Edwards Deming – experiments
  - Funnel Experiment – Understanding variation/tampering
  - Red Bead Experiment – System not the person matters/variation
- G.E.P Box - experiment
  - Paper Helicopter Experimet – Design of Experiment (DOE), process improvement

SoPK MINDSET

Essential Lean Tools

ESSENTIAL LEAN TOOLS	
5S	Standardized Works
Overall-Equipment Effectiveness (OEE)	Just-In-Time (JIT)
Takt Time	Poka - Yoke (Error Proofing)
Single-Minute Exchange of Dies (SMED)	Root Cause Analysis
Muda (Waste)	Andon
Continuous Flow	Heijunka (level Scheduling)
Six Big Losses	Kanban (Pull System)
Gemba (The Real Place)	Value Stream Mapping
Bottleneck Analysis	KPIs (Key Performance Indica
Kaizen (Continuous Improvement)	SMART Goals
PDCA (Plan - Do - Check - Act)	Hoshin Kanri (Policy Deploym
Total Productive Maintenance (TPM)	Jidoka (Autonomation)

Underlying TOOLS

1. Control charts
2. Histograms
3. Check sheets
4. Scatter plots
5. Cause and effect diagrams
6. Flowcharts
7. Pareto Charts

Lean Essentials - 1

OEE = Availability x Performance x Quality

$$OEE = \frac{B}{A} x \frac{D}{C} x \frac{F}{E}$$

85%+

$$Availability = \frac{B \ - Run\ Time}{A \ - Total\ Operative\ Time}$$

$$Performance = \frac{D \ - Actual\ Speed}{C \ - Normal\ Speed}$$

$$Quality = \frac{F \ - Actual\ Good\ Product}{E \ - Product\ Output}$$

Lean Essentials - 2

- **5S:** Sort – Set in Order – Shine – Standardize – Sustain
- **Takt Time:** The pace of production that aligns production with customer demand (e.g. one vehicle every 60 secs.)
  TT = Planned Production Time/Customer Demand
- **SMED:** Reducing setup (changeover) time to less than 10 minutes to enable manufacturing in smaller lots, reduce inventory, and improve customer responsiveness.
- **Gemba (The Real Place):** A philosophy that reminds us to get out of our offices and spend time on the plant floor – the place where real action occurs

Lean Essentials - 3

- **Six Big Losses:** Six categories of productivity loss that are almost universally experienced in manufacturing:
  - Breakdowns – Setup/Adjustments – Small Stops
  - Reduced Speed – Startup Rejects – Production Rejects
- **Muda (Waste):** Anything in the manufacturing process that does not add value from the customer’s perspective.
  - Defects – Overproduction – Waiting – Transportation
  - Inventory – Motion – Extra-Processing – Non-utilized Talent

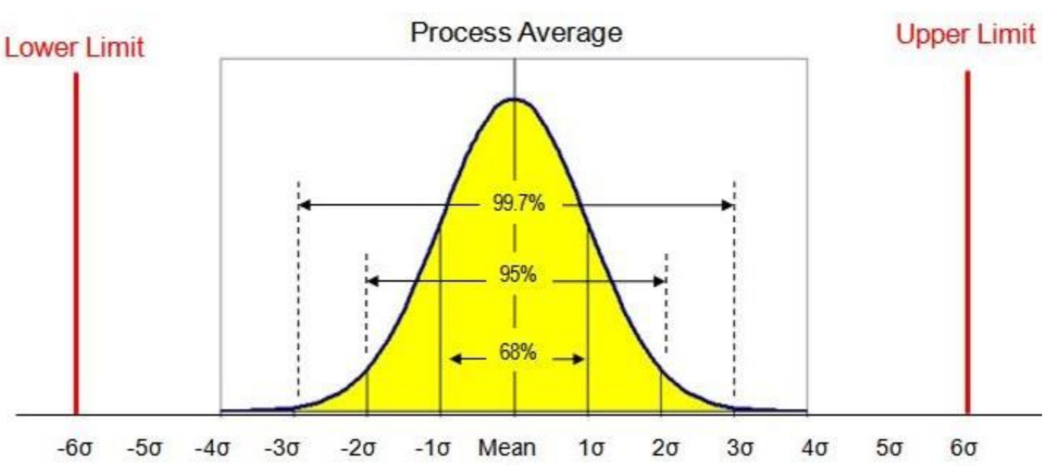
Too technical

	Short Term Process NOT SHIFTED			Long Term Process with 1,5σ shift		
Sigma Level	**Percentage Yield (OK)**	**DPMO**	**Cpk**	**Percentage Yield (OK)**	**DPMO**	**Cpk**
1	68,27%	317.300	0,33	30,23%	697.700	-0,17
2	95,45%	45.500	0,67	69,13%	308.700	0,17
3	99,73%	2.700	1,00	93,32%	66.810	0,50
4	99,9937%	63	1,33	99,3790%	6.210	0,83
5	99,99943%	0,57	1,67	99,97670%	233	1,17
6	99,9999998%	0,002	**2,00**	99,999660%	**3,4**	**1,50**

Waste - Defects: VOP > VOC

Aim is to have a process where:

$$\frac{\boldsymbol{VOC\ (Voice\ of\ the\ Customer\ -Spec\ Limits)}}{\boldsymbol{VOP\ (Voice\ of\ the\ Process\ -Process\ Limits)}} \gg \mathbf{1}$$



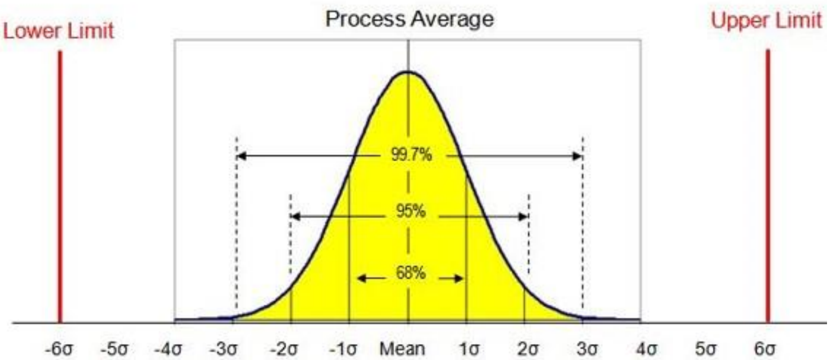
VOC = Mean ± 6σ

VOP = Mean ± Max. 6σ

Sigma Level - Example

If a film must have thickness of between 19 and 21 microns to meet customer requirements (VOC), the the process mean (VOP) should be around **20 microns**, with a standard deviation less than:

- 0,167 [(21-20)/6 = 0,167] - 6σ process
- 0,250 [(21-20)/4 = 0,250] - 4σ process
- 0,333 [(21-20)/3 = 0,330] - 3σ process
- If the process is **NOT** centered at around 20 microns, MUST have even lower standard deviations to meet VOC.



19µ **20µ** **21µ**

σ = 0,250 µ

What is Lean Six Sigma revisited

Lean Six Sigma is known with an acronym **DMAIC** which is **D**efine **M**easure **A**nalyze **I**mprove **C**ontrol.

The DMAIC is a systematic and continuous/sequential methodology for solving problems, improving the quality of products and reducing the defects or waste within an organization. The improvements are through:

- Making process more capable (**reducing variation**), thus reducing defects
- **Modeling the relationship between inputs and outputs** (CTQ-Critical To Quality) to yield improved output. CTQ = f(x1, x2, x3,.....xn)

Each phase of the DMAIC has questions that need to be answered. By answering the questions, deliverables or outcomes are produced. Each deliverable provides a path for completing the DMAIC methodology.

DMAIC

DMAIC for Lean Six Sigma	
DEFINE	Identify and describe the problem to solve or opportunity to attain, the customer and the voice of the customer (VOC)
MEASURE	Quantify the problem. Identify appropriate metrics to generate baseline measurement to compare at the end of DMAIC process to determine if it was a success.
ANALYZE	Analyze the process to identify the root cause of the problem.
IMPROVE	Once root-cause is identified, create solutions for the problem and implement those solutions
CONTROL	Keep the new improvements (compare with earlier benchmark measurements) in place and ensure sustainability

LSS DMAIC Sample Application - Define

Define Phase – Typical Questions:

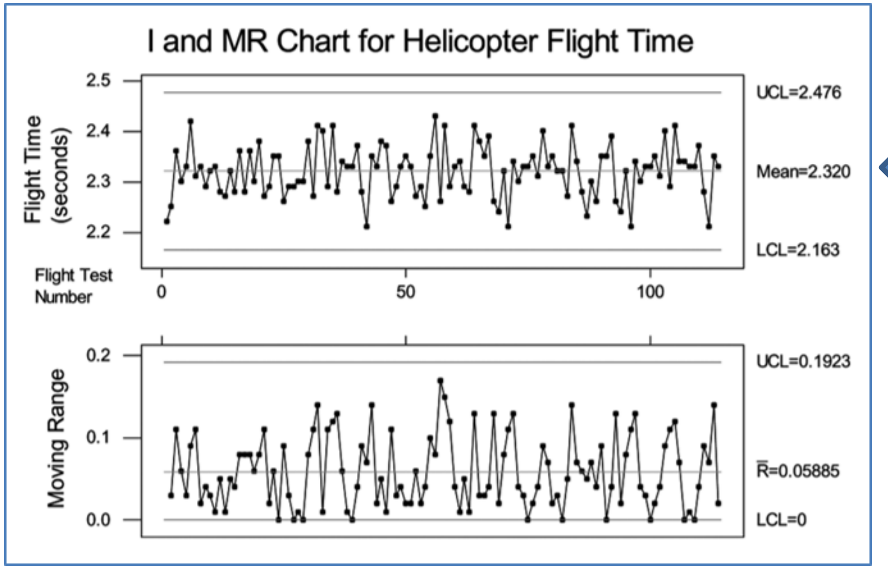
1. What is the name of the product or process?
2. What is the aim of the product or process?
3. What is the economic rationale for doing the project?
4. What is the pain?
5. What is the goal for this project?
6. What is the project scope?
7. What are the benefits of the project?
8. What are the roles and responsibilities of the team members?

Define Phase – Tools

1. **Current State Analysis**
2. **Project Charter**
3. **SIPOC**
4. **Voice of Customer**
5. Brainstorming
6. Surveys
7. Focus Groups
8. Benchmarking

LSS DMAIC Sample Application - Define

Current Level of CTQ



Define Phase – Project Charter:

To develop a xxxx (product) production process for the yyy (customer) that will increase the zzzz (measure - **CTQ**) to at least 2.6s (**goal**) from current state of 2,32. This project is to be completed within agreed budget by ttttt (deadline).

LSS DMAIC Sample Application - Measure

The measurement phase contains three steps:

1. Operationally defining the critical-to-quality variables (CTQs),
   - A criteria for the CTQ
   - A test for CTQ
   - A decision from this test
2. Conducting Measurement System Analysis (MSA or Gage R&R) on each CTQ, and
3. Developing a baseline for each CTQ.

LSS DMAIC Sample Application - Measure

Measure Phase – Typical Questions:

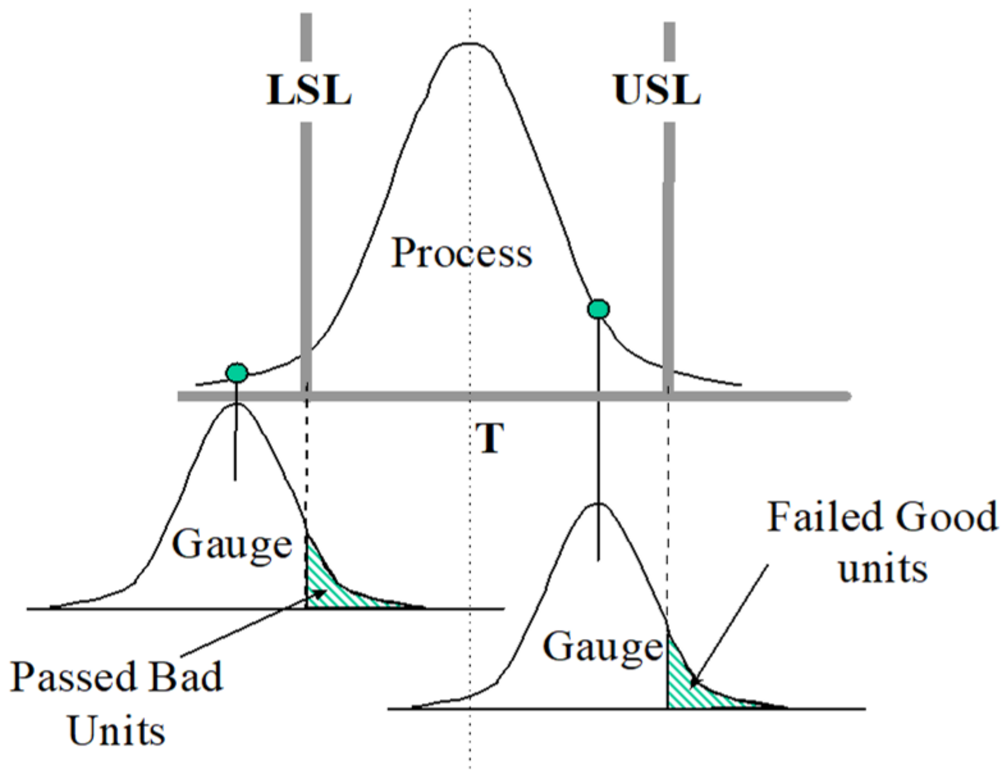
1. What is the current measurement?
2. What are we going to measure?
3. How will we measure it?
4. Where do we find the data?
5. What industry standard do we use as a benchmark?
6. What is the gap between current state and industry standard?
7. What are the team's deliverables?

Define Phase – Tools

1. **Measurement System Analysis (MSA)**
2. Base line sigma level
3. Value Stream Map
4. Process Flow Diagram
5. Plant Layout
6. Check Sheets
7. Process Capability
8. Waste analysis
9. Graphical analysis

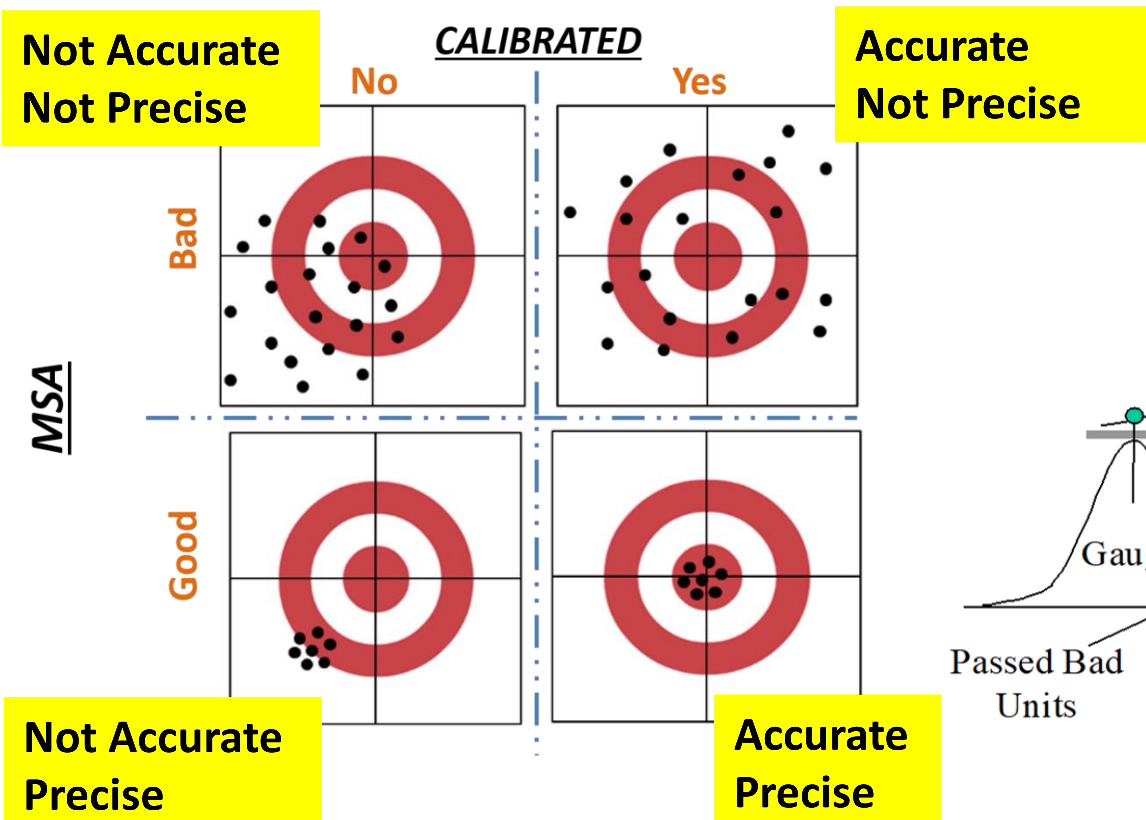
LSS DMAIC Sample Application - Measure

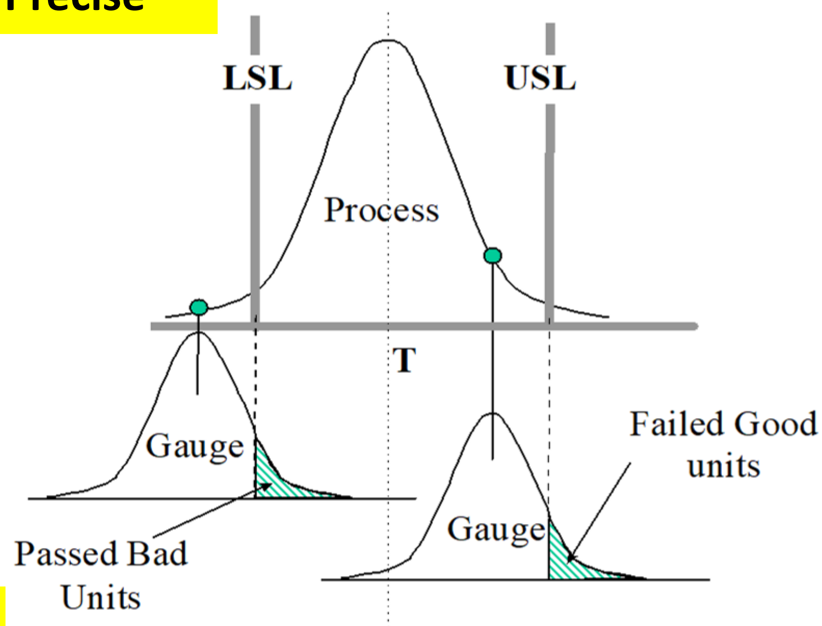
Measurement System Analysis:



LSS DMAIC Sample Application - Measure

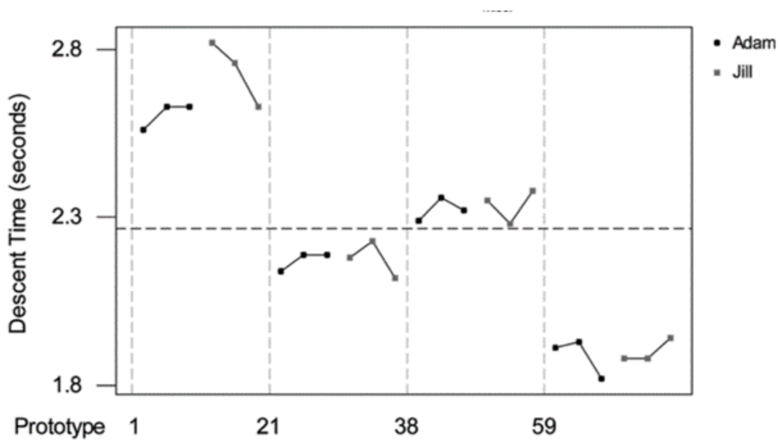
Measurement System Analysis (MSA):





LSS DMAIC Sample Application - Measure

MSA



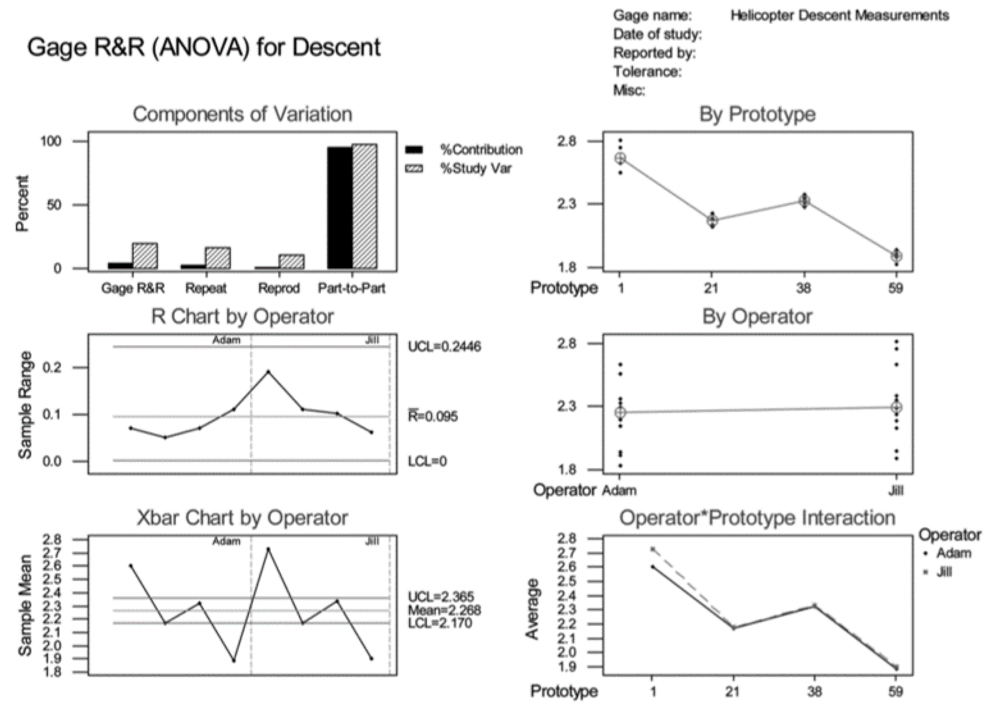


Figure 12. ANOVA output of the gage R&R study.

LSS DMAIC Sample Application - Measure

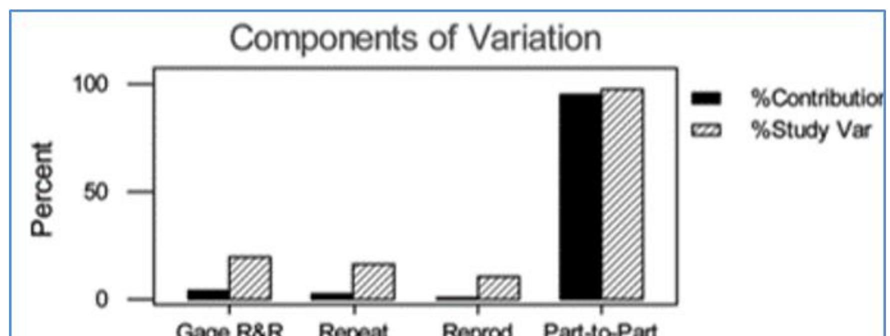
MSA

The 10–30 rule states that a measurement system is:

- **acceptable :** if the variation in the system is less than 10% in the reproducibility and repeatability of the measurements.
- **questionable but could be used:** if they had to be, if the value is between 10 and 30%,
- **Unacceptable:** anything over 30%

Percent contribution table

source	VarComp	%Contribution (of VarComp)
Total gage R&R	0.00411	3.79
Repeatability	0.00293	2.70
Reproducibility	0.00118	1.09
Operator	0.00035	0.32
Operator * prototype	0.00083	0.77
Part-to-part	0.10437	96.21
Total variation	0.10848	100.00



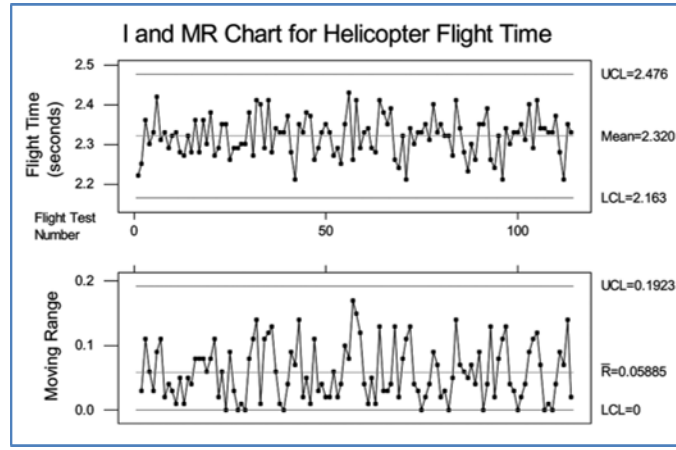
LSS DMAIC Sample Application - Measure

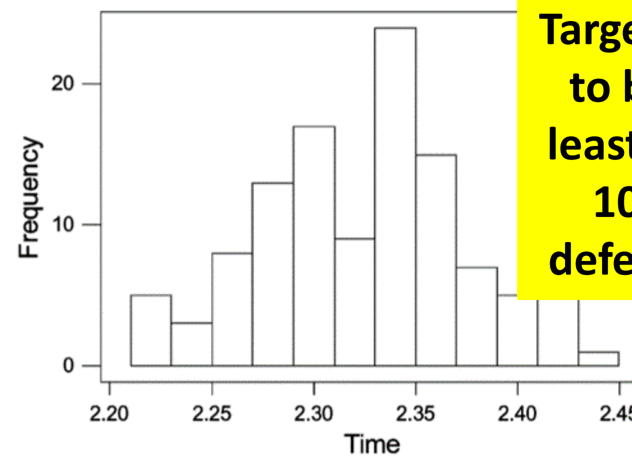
Baseline for CTQ

Once the process is IN CONTROL

- Mean
- Standart deviation
- Shape of distribution
- Test for the distribution
- Determine the current process sigma level
  - 1 defect out of 1000 (or 1.000 DPMO) was the target, that is 4,59 sigma.
  - Current 100% defect, 0 sigma

Current DPMO/Sigma : 1e6/0
Target DPMO/Sigma : 1.000/4,59





Target CTQ to be at least 2,6s, 100% defective.

LSS DMAIC Sample Application - Analyze

During this analyze phase, the data collected during the measure phase is used to analyze the gap between the current and desired performance. Moreover, **performed a root-cause analysis** to define the possible reasons for the performance gap and **quantify the main causes for variation**. The gap between the current and desired state is also calculated in financial terms.

- developing a detailed process map or flowchart, highlighting in input variables (X)
- constructing operational definitions for each process variable (hereafter referred to as an ‘‘X’’),
- running a gage R&R study on each X,
- developing a baseline for each X, and,
- finally, developing hypotheses about the relationships between the CTQ and the Xs.

LSS DMAIC Sample Application - Analyze

Analyze Phase – Typical Questions:

1. What are the six major causes that can create the problem?
2. What are sub causes for each major cause?
3. What is a potential root cause within the problem?
4. What was the consensus vote on the root cause?
5. What evidence supports the root cause?
6. How does the evidence support the root cause?
7. What are the team's deliverables?

Analyze Phase – Tools

1. **Brainstorming**
2. **Cause and Effect Diagram**
3. **FMEA**
4. **Process Maps**
5. **Tree Diagram**
6. **Pareto Chart**
7. **SPC Control Charts**
8. **Hypothesis Testing**
9. **T-testing**

LSS DMAIC Sample Application - Analyze

Developing hypotheses about the relationships between the CTQ and the Xs.

CTQ = f(X1, X2, X3, X4, ...x Potential interaction Effects, Error Effects)

To develop this model, **designed experiments** should be run in IMPROVE phase.

Levels for the individual Xs

Label	Component	Level "low"	Level "high"	Measuring scale	Notes
X1	Paper type				d, and blue is a 24-pound bond paper
X2	Body length				
X3	Body width				
X4	Wing length				
X5	Paper clip				office supply clips
X6	Body tape				dy to hold it closed in flight
X7	Wing joint tape				e joint to hold the wings down in flight

Variables and their levels that may have an effect on CTQ are identified. Their impact levels are to be quantified in IMPROVE Phase.

LSS DMAIC Sample Application - Improve

Improvement Phase: hard work of defining, measuring and analyzing pays off - the point where the ideas for process improvement are formulated and implemented.

This phase of DMAIC mentioned about following results.

1. Confirm the key process inputs that affect the process outputs, causing defects.
2. Identify the acceptable range of each input so the critical to quality output stays within the specified limits.
3. Adjust the process as needed.
4. Plan any special measures that are needed for improvements - for example, implementation of a new or modified software system.
5. Implement the changes.
6. Install and validate a measurement system for the improved process and verify how the new process is working.

LSS DMAIC Sample Application - Improve

Improve Phase – Typical Questions:

1. What ideas did we generate for improving the root cause?
2. How did we select the idea or pilot project to move forward on?
3. What does the pilot visually look like? (Using Process Flow Chart)
4. How do the projected results of the pilot compare to the old way?
5. What can make it fail?
6. How does pilot meet the customer's requirements?
7. What are the team's deliverables?

Improve Phase – Tools

1. **Design of Experiments (DOE)**
2. **Regression Analysis**
3. **Hypothesis Testing**
4. **Control Charts**
5. Future VSM
6. FMEA
7. 5S
8. TPM
9. Poke yoke

LSS DMAIC Sample Application - Improve

Improve Phase

The Improve Phase optimizes the CTQ(s) by manipulated the Xs and their interactions. It has three steps:

1. design and run experiments to isolate the significant Xs and their interactions, - **Design of Experiments (DOE)!!**
2. interpret the results of these experiments to determine the settings of the Xs which optimize the spread, shape, and center of the CTQ(s), and
3. conduct a pilot study to test the settings of the Xs.

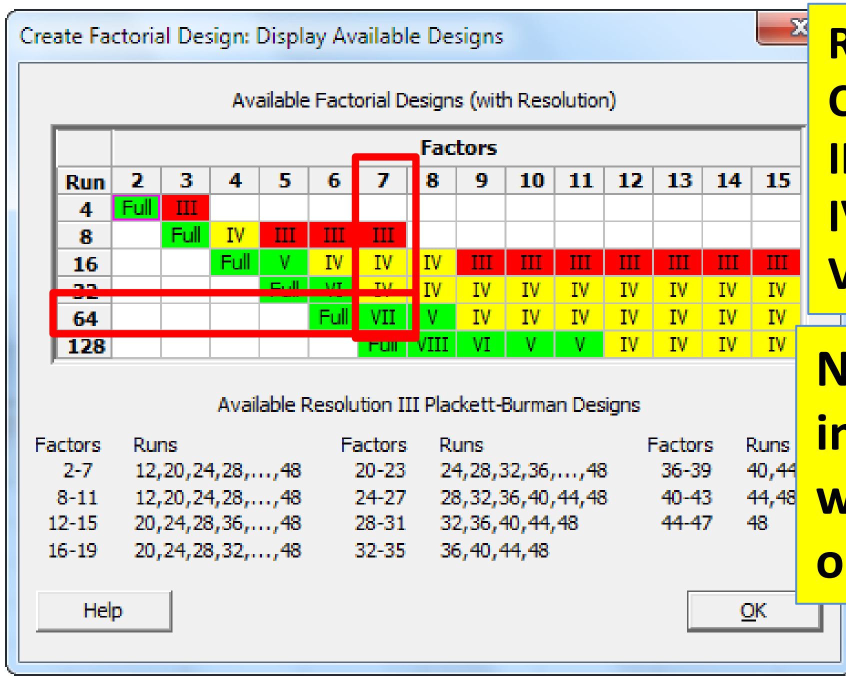
The deliverables of the improve phase are:

1. the levels of the Xs that optimize the CTQ(s)
2. the optimized process map with the optimized settings of the Xs
3. the results of a pilot study of the revised process
4. the estimated capability (sigma level and=or DPMO) of the revised process
5. the statistical gap between the original and the revised system capabilities

LSS DMAIC Sample Application - Improve

Improve Phase – Design and Run Experiments

- **2-level half-fractional factorial designs:**
  $2^7 / 2^1 * 2$ = **128 runs – CONFOUNDING, resolution VII – NOT an ISSUE**



Create Factorial Design: Display Available Designs

Available Factorial Designs (with Resolution)

Run	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

Available Resolution III Plackett-Burman Designs

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

Help OK

Resolution – Confounding Level
III = I + II
IV = I + III, II + II
VII = I + VI, II + V + III + IV

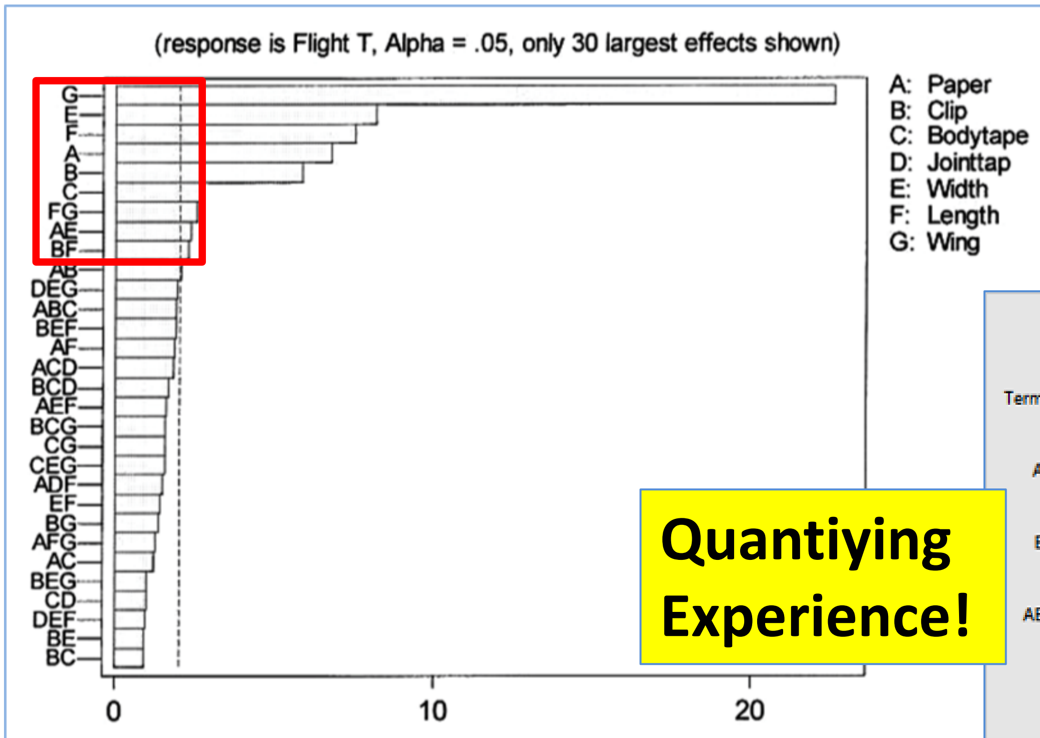
No main effects (I) or 2-factor interactions (II) are aliased with any other main effect (I) or 2-factor interactions (II).

LSS DMAIC Sample Application - Improve

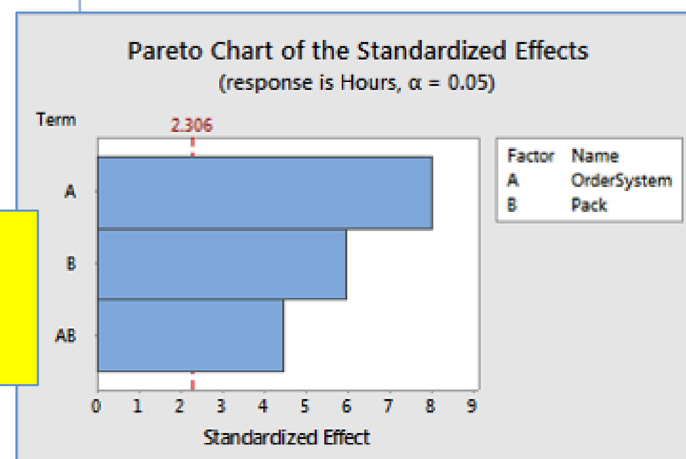
Improve Phase – Interpret the results – Preliminary –

Pareto Chart of Standardized Effects.

Quickly identify which main effects and interactions are significant



Quantiying Experience!



LSS DMAIC Sample Application - Improve

Improve Phase – InDepth- Analysis of Variance (ANOVA)

Original ANOVA output from Minitab

Estimated effects and coefficients for flight (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		2.10523	0.01089	193.39	0.000
Paper	0.14734	0.07367	0.01089	6.77	0.000
Clip	−0.12797	−0.06398	0.01089	−5.88	0.000
Bodytape	−0.05828	−0.02914	0.01089	−2.68	0.009
Jointtape	−0.00516	−0.00258	0.01089	−0.24	0.814
Width	−0.17797	−0.08898	0.01089	−8.17	0.000
Length	−0.16391	−0.08195	0.01089	−7.53	0.000
Wing	0.49297	0.24648	0.01089	22.64	0.000
Paper*Clip	−0.04484	−0.02242	0.01089	−2.06	0.043
Jointtape*Length	0.01672	0.00836	0.01089	0.77	0.445
Jointtape*Wing	−0.00703	−0.00352	0.01089	−0.32	0.748
Width*Length	−0.03047	−0.01523	0.01089	−1.40	0.166
Width*Wing	0.00078	0.00039	0.01089	0.04	0.971

Analysis of variance for flight (coded units)

Source	DF	Seq	Adj MS	F	P
Main effects	7	10.9	1.56830	103.40	0.000
2-Way Interactions	21	0.6	0.02878	1.90	0.026
3-Way Interactions	35	0.5	0.01534	1.01	0.473
Residual Error	64	0.9	0.01517		
Pure Error	64	0.9	0.01517		
Total			13.0900		

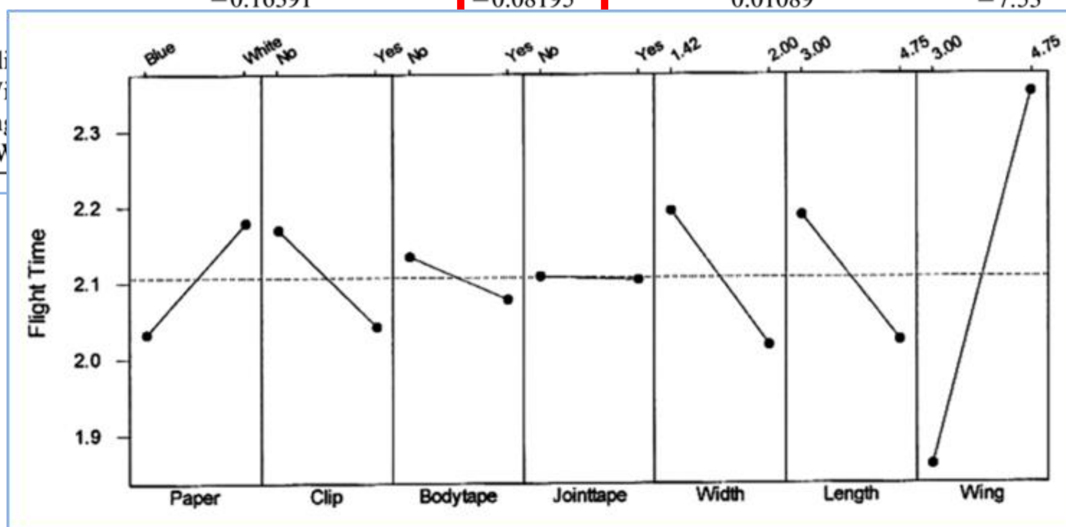
3-way interactions are NOT significant

LSS DMAIC Sample Application - Improve

Improve Phase – InDepth- Analysis of Variance (ANOVA) – MAIN EFFECTS

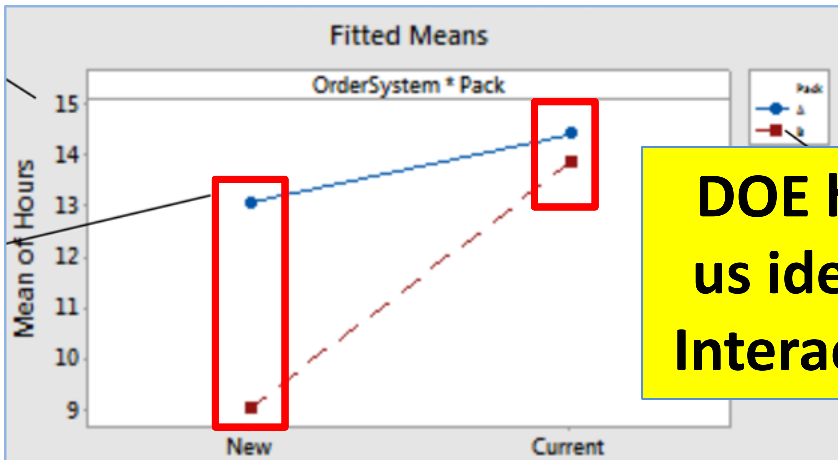
Table 2
Significant effects from Table 1

Term	Effect	Coef	SE Coef	T	P
Constant		2.10523	0.01089	193.39	0.000
Paper	−0.14734	−0.07367	0.01089	−6.77	0.000
Clip	−0.12797	−0.06398	0.01089	−5.88	0.000
Bodytape	−0.05828	−0.02914	0.01089	−2.68	0.009
Width	−0.17797	−0.08898	0.01089	−8.17	0.000
Length	−0.16391	−0.08195	0.01089	−7.53	0.000
Wing					0.000
Paper*Cli					0.043
Paper*Wi					0.021
Clip*Len					0.025
Length*W					0.014

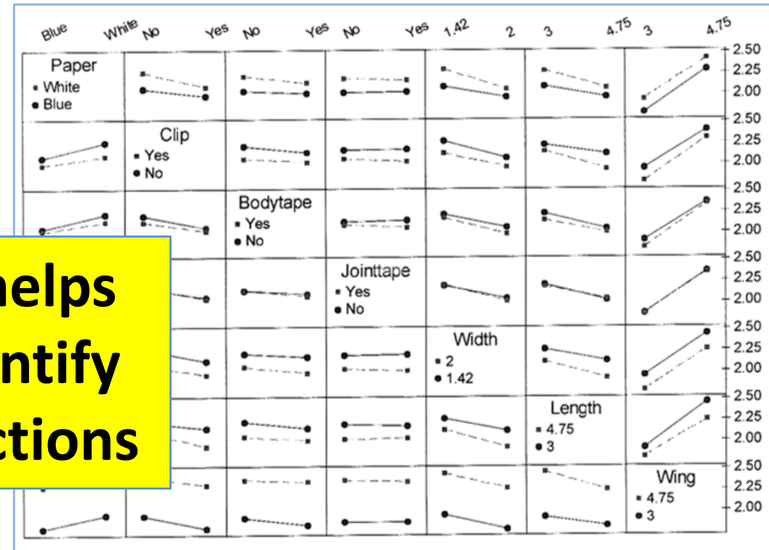


LSS DMAIC Sample Application - Improve

Improve Phase – InDepth- Analysis of Variance (ANOVA) – INTERACTIONS



DOE helps us identify Interactions



Width	−0.17797	−0.08898	0.01089	−8.17	0.000
Length	−0.16391	−0.08195	0.01089	−7.53	0.000
Wing	0.49297	0.24648	0.01089	22.64	0.000
Paper*Clip	−0.04484	−0.02242	0.01089	−2.06	0.043
Paper*Width	−0.05172	−0.02586	0.01089	−2.38	0.021
Clip*Length	−0.04984	−0.02492	0.01089	−2.29	0.025
Length*Wing	−0.05516	−0.02758	0.01089	−2.53	0.014

LSS DMAIC Sample Application - Improve

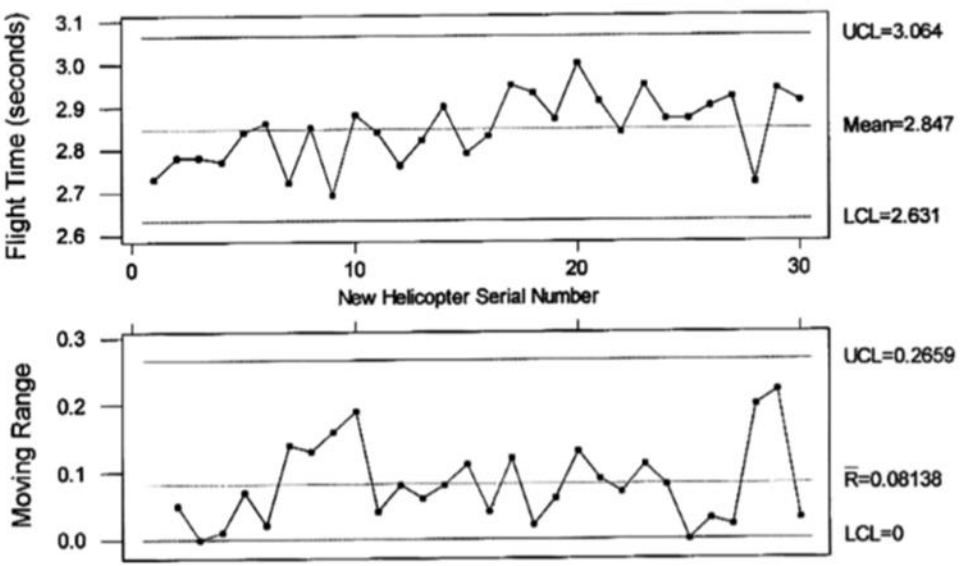
Improve Phase – Interpret the Results - FINAL DESIGN PARAMETERS

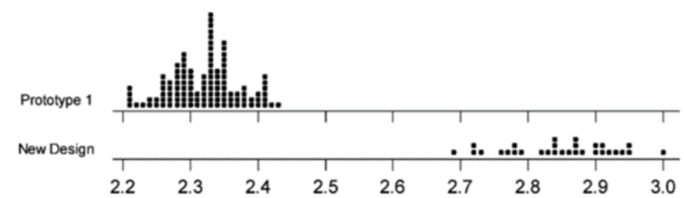
			Low Level	High Level	Unit	Optimizing Value	Level	Coefficient	CTQ (sec)
		FINAL DESIGN PARAMETERS							
		Constant					1	2,10523	2,10523
Variable	X1	Paper Type	**20W**	24B	Pound	20W	-1	-0,07367	0,07367
Variable	X2	Paper Clip	**No**	Yes	NA	No Clip	-1	-0,06398	0,06398
Variable	X3	Body tape	**No**	Yes	NA	No Tape	-1	-0,02914	0,02914
Variable	X4	Joint tape	**No**	Yes	NA	No Tape	-1	-0,00258	0,00258
Variable	X5	Body Width	**1,42**	2,00	Inches	1,42	-1	-0,08898	0,08898
Variable	X6	Body Length	**3,00**	4,75	Inches	3,00	-1	-0,08195	0,08195
Variable	X7	Wing Length	3,00	**4,75**	Inches	4,75	1	0,24648	0,24648
		Paper*Clip					1	-0,02242	-0,02242
		Paper*Width					1	-0,02586	-0,02586
		Clip*Length					1	-0,02492	-0,02492
		Length*Wing					-1	-0,02758	0,02758
									2,6464
								Project Charter	**2,60**
								Current Level	**2,32**

LSS DMAIC Sample Application - Improve

Improve – Pilot Study

The final section of the Improve Phase is taking the optimized design and conducting a pilot study to determine its effectiveness in improving the distribution of the CTQ. As per revised flowchart the new improved prototypes are built and tested.





	DPMO	Sigma Level
Original	1,00E+06	0
Pilot	911	**4,62**
Target	1000	**4,59**

LSS DMAIC Sample Application - Control

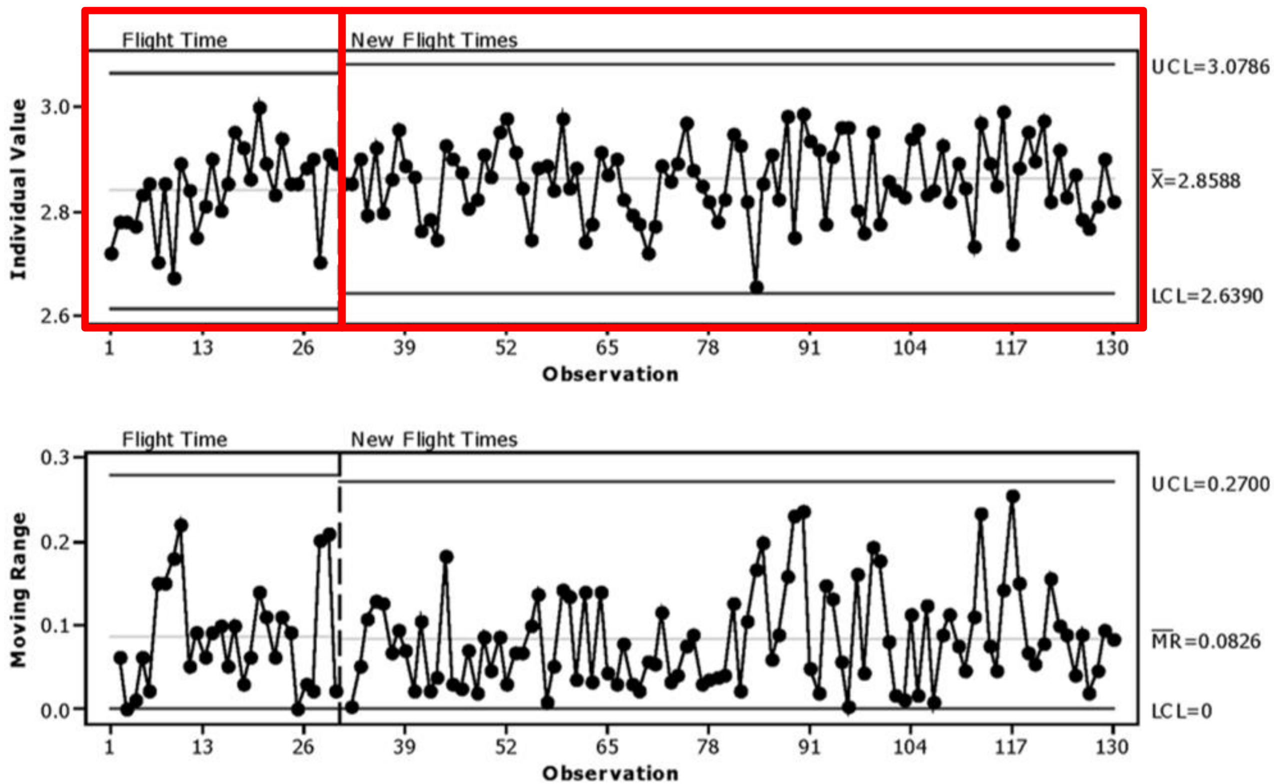
Control Phase – Key Delivarables

The Control Phase establishes the ongoing controls necessary to sustain the benefits from the Six Sigma project.

1. An implemented **standardization** and **mistake proof** control plan
2. **Documentation of the revised process**
3. Demonstration of significant and sustainable improved performance
4. A lesson-learned document
5. A project replication/leverage plan
6. A project financial benefit document
7. **Return of the revised process to the control of the process owner for continuous turns of the PDSA cycle**

LSS DMAIC Sample Application - Control

Control Phase – Demonstration of Significant and Sustainable Improved Performance



Lean Six Sigma (LSS) - SUMMARY

What is it?

- **LEAN – Driving waste out and improving operations in terms of yield, availability, capacity utilization,....increase OEE,...reduce takt time.....**
  - **REQUIRES –** Management KNOWLEDGE and COMMITMENT, excellent communication with shop floor, trust of shop floor and willingness of shop floor, driven by shop-floor
  - **NOT ABOUT – Painting floors, shining/polishing machines and LEAN OFFICES**
- **Six Sigma –**
  - **Optimizing process to reduce variability in CTQs, thus increasing capability and reducing defects (VOC / VOP >>>> 1)**
  - **Modeling cause and effect relationship between CTQs and input variables utilizing advanced statistical methods such as regression and Design of Experiments (DOE)**
  - **REQUIRES:**
    - **Process TO BE IN CONTROL – thus good process knowledge**
    - **Well implemented LEAN**
    - **Decent statistical analysis knowledge (multiple regression, DOE....)**

Lean Six Sigma (LSS) - SUMMARY

- **CHANCE for SUCCESS**

If there is NO WELL IMPLEMENTED LEAN
NO CHANCE for Six Sigma (6σ) SUCCESS

BOTH Lean and Six Sigma are about 10(1) % TOOLS, 90(99)%

- **CULTURE,**
- **COMMITMENT,**
- **TRUST,**
- **COMMUNICATION,**
- **DESIRE and WILLINGNESS for UNCONDITIONAL CHANGE**
- **KNOWLEDGE – comes with these QUALITIES**

THANK YOU.

Design of Experiments (DOE)
A tool to go beyond productivity.

LSS – DMAIC – Improve Phase - DOE

Modelling for Optimization & Prediction

Design of Experiments (DOE) – Designs in MINITAB

- **Secreening - The usual goal of a screening design is to identify the most important factors that affect process quality.**
  - 2-level fractional factorial – **15 factors** – linear terms
  - Plackett-Burman – **47 factors** – linear terms
  - Definitive screening – **48 factors** – quadratic terms and 2-way interactions
- **Factorial Designs**
  - **2-level Full Designs -** 7 factors – 2 levels – 2 replications
    $2^7 * 2 = 256$ runs – **COST and TIME**
  - **2-level fractional designs** - Half-Fractional Factorial –
    $2^7 / 2^1 * 2 = 128$ runs **– CONFOUNDING**
  - **Split Plot Designs – have at least one hard to change, thus randomize factor**
  - **Plackett-Burman designs.**

LSS – DMAIC – Improve Phase - DOE

Design of Experiments (DOE) – Designs in MINITAB

- **Response Surface (3+ levels and curveture involved)**
  - Central Composite and
  - Box-Behnken
- **Mixture**
  - Simplex centroid
  - Simplex lattice
  - Extreme vertices
- **Taguchi**
  - 2-, 3-, 4-, 5-level designs
  - Mixed level designs

LSS – DMAIC – Improve Phase - DOE

- 2-level designs in MINITAB:
  (Fractional) Factorial and Plackett-Burman

Create Factorial Design: Display Available Designs

Available Factorial Designs (with Resolution)

Run	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

Available Resolution III Plackett-Burman Designs

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

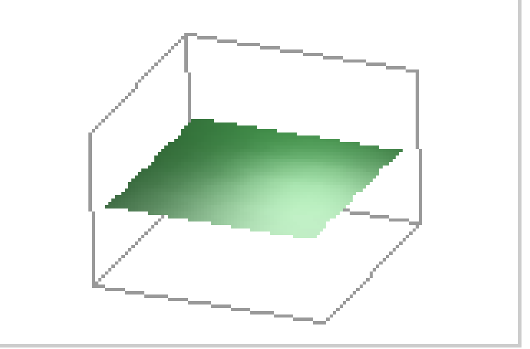
Help OK

Resolution – Confounding Level
III = I + II
IV = I + III, II + II
VII = I + VI, II + V + III + IV

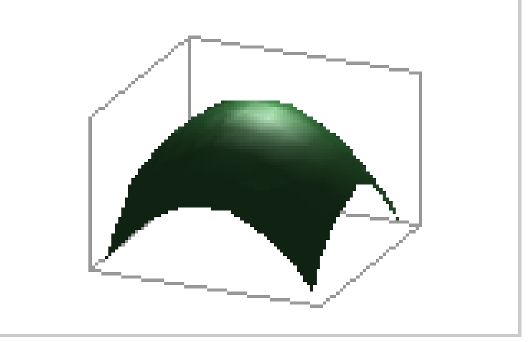
LSS – DMAIC – Improve Phase - DOE

DOE – Central Composite and Box-Behnken

- These designs allow efficient estimation of the first- and second-order coefficients.
- Box-Behnken designs often have fewer design points, thus can be less expensive to do than central composite designs with the same number of factors. However, Box-Behnken designs not having an embedded factorial design, they are not suited for sequential experiments.
- Box-Behnken designs can also prove useful if you know the safe operating zone for your process. Box-Behnken designs do not have axial points, thus, you can be sure that all design points fall within your safe operating zone. **Box-Behnken designs also ensure that all factors are not set at their high levels at the same time.**



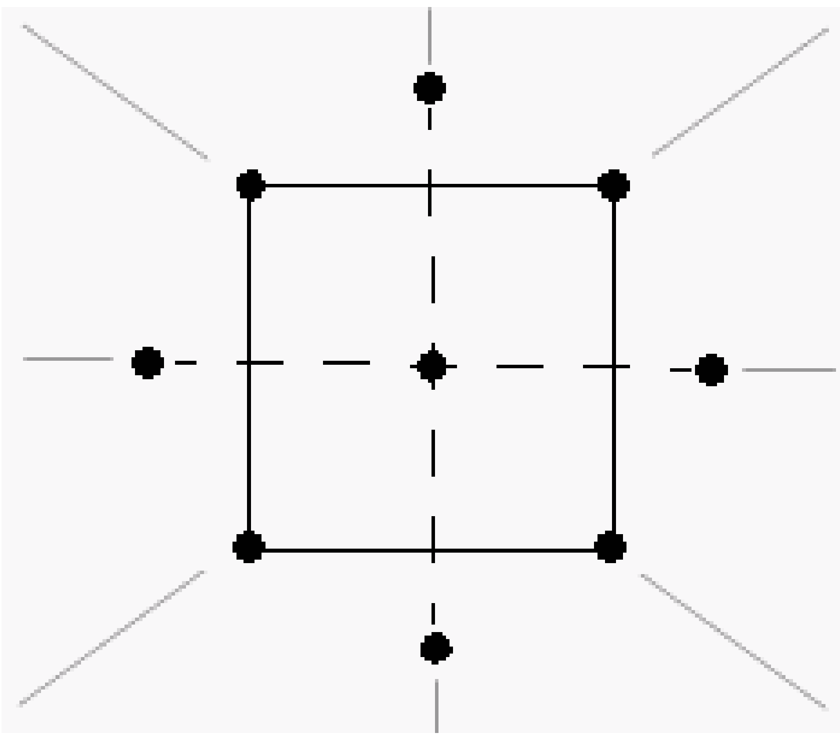
Without Curvature



With Curvature

LSS – DMAIC – Improve Phase - DOE

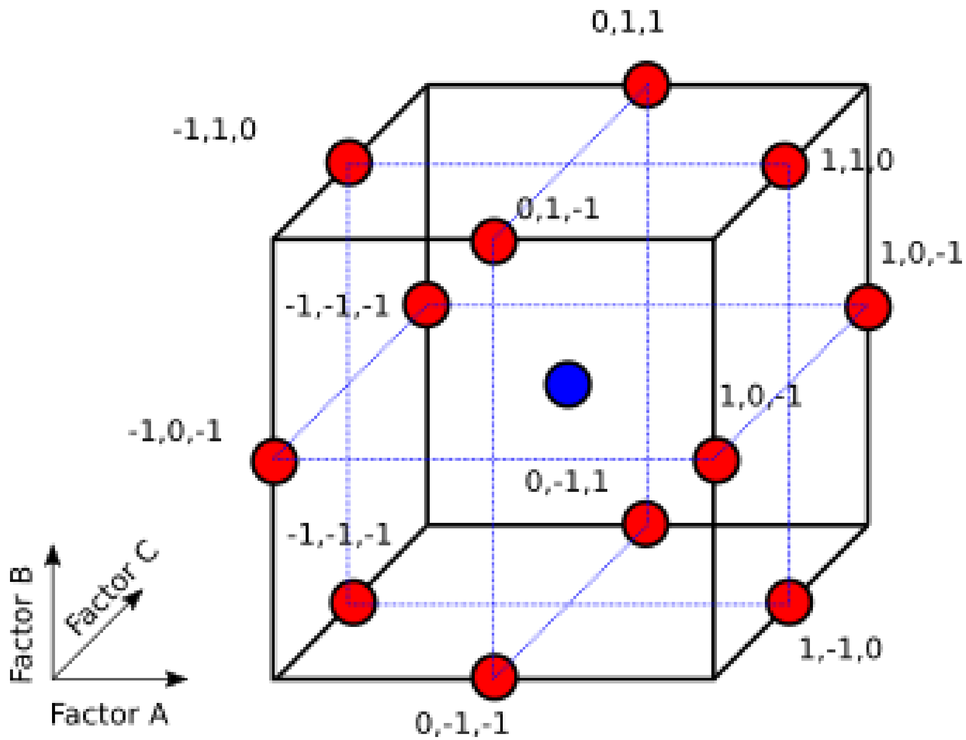
- **Response Surface designs in MINITAB – Central Composite:**



Injection Molding DOE - Central Composite				
Temp	190	210	C	
Press	50	100	Mpa	
	Temp.	Pressure		
1	210,0	100,0	Corner	Embedded factorial design
2	210,0	50,0	Corner	
3	190,0	50,0	Corner	
4	190,0	100,0	Corner	
5	214,1	75,0	Axial	Central Composite design
6	200,0	110,4	Axial	
7	185,9	75,0	Axial	
8	200,0	39,6	Axial	

LSS – DMAIC – Improve Phase - DOE

- **Response Surface designs in MINITAB – Box-Behnken:**

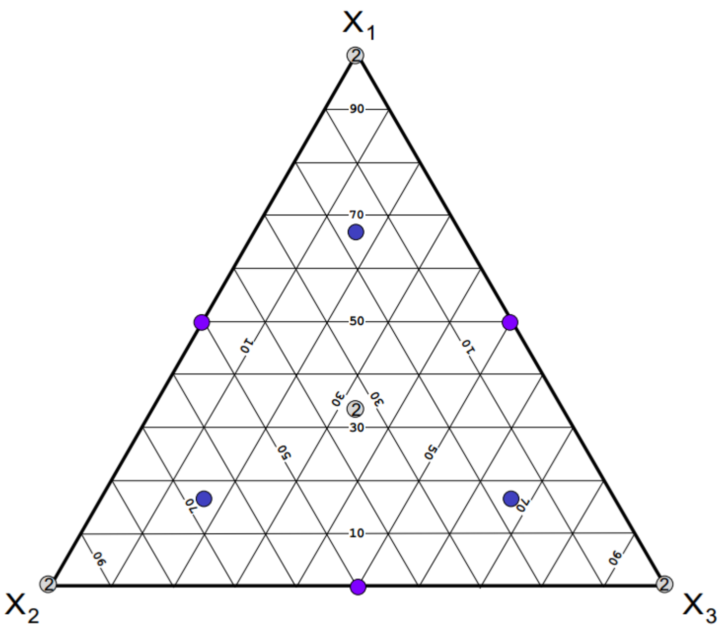


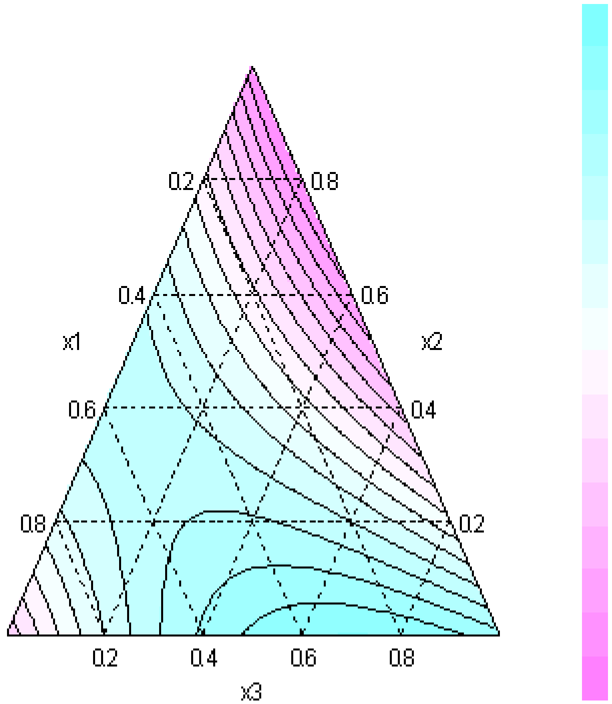
Injection Molding DOE - Box Behnken				
Temp	190	200	210	C
Press	50	75	100	Mpa
Speed	10	30	50	mm/s
	Temp.	**Pressure**	**Speed**	
1	190	50	30	
2	210	50	30	
3	190	100	30	
4	210	100	30	
5	190	75	10	
6	210	75	10	
7	190	75	50	
8	210	75	50	
9	200	50	10	
10	200	100	10	
11	200	50	50	
12	200	100	50	
13	200	75	30	
14	200	75	30	
15	200	75	30	

LSS – DMAIC – Improve Phase - DOE

- **Mixture Design**

Formulation Compounding...





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