Lean and Six Sigma Fundamentals

Lean and Six Sigma Workshop

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Smart Manufacturing Research Group

Lawrence Technological University

Lean vs. Six Sigma

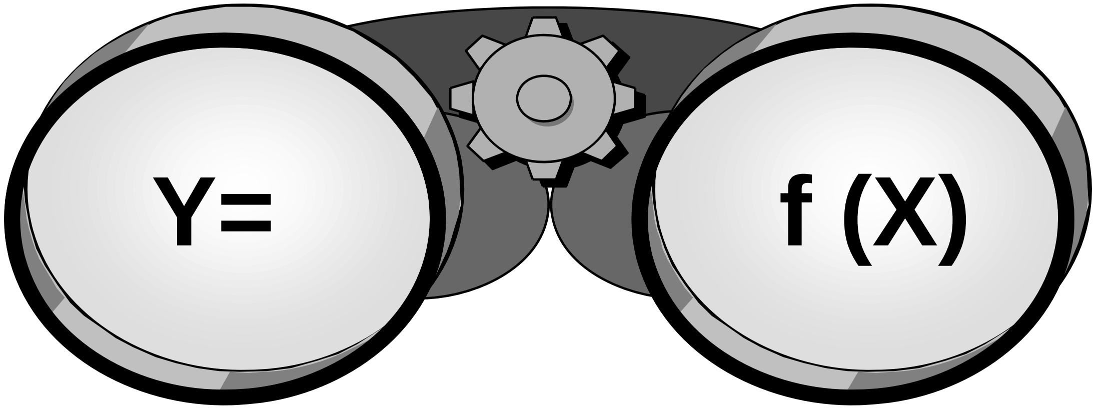
Values of Six Sigma

Six Sigma is a process that enables companies to increase profits dramatically by streamlining operations, improving quality, and eliminating defects or mistakes in everything a company does, from raw materials to finish goods. A Six Sigma process generates a defect probability of 3.4 parts per million (PPM).

- **Key activities in Six Sigma are:**
  1. **Understanding customer needs (in quantifiable terms)**
  2. **Translating the needs into the measurable outcomes**

- **Key objectives in Six Sigma are:**
  1. **Understanding & measuring the process inputs**
  2. **Looking at the root causes of variation**

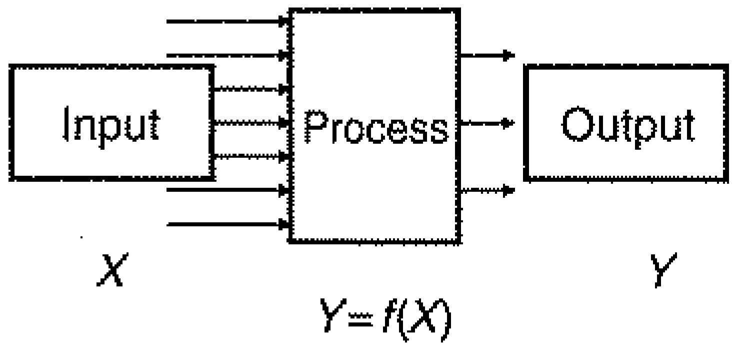
The Focus of Six Sigma



- **Y**
- **Dependent**
- **Output**
- **Effect**
- **Symptom**
- **Monitor**

- $X_1 \ldots X_N$
- Independent
- Input-Process
- Cause
- Problem
- Control

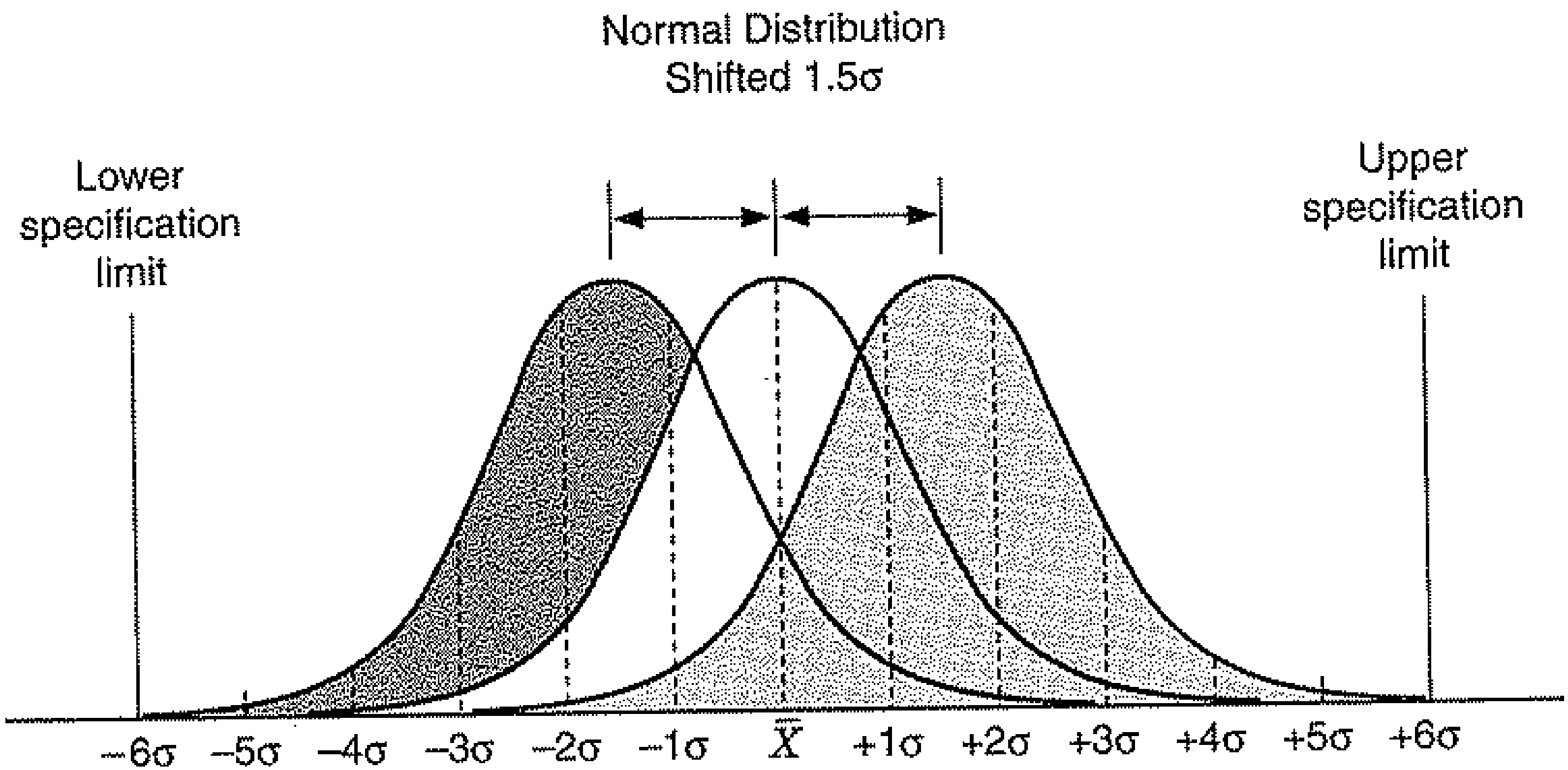
Key Process Input Variable (KPVI)



	Ys or KPOVs	Xs or KPIVs
1	Profits	Actions taken to improve profits
2	Customer satisfaction	Out of stock items
3	Strategic goal	Actions taken to achieve goal
4	Expense	Amount of WIP
5	Production cycle time	Amount of internal rework
6	Defect rate	Inspection procedures
7	Critical dimension on a part	Process temperature

key process input variable (KPIV)

PPM in Six Sigma



Spec. limit	Percent	Defective ppm
±1 σ	30.23	697700
±2 σ	69.13	308700
±3 σ	93.32	66810
±4 σ	99.3790	6210
±5 σ	99.97670	233
±6 σ	99.999660	3.4

Sigma Quality Level

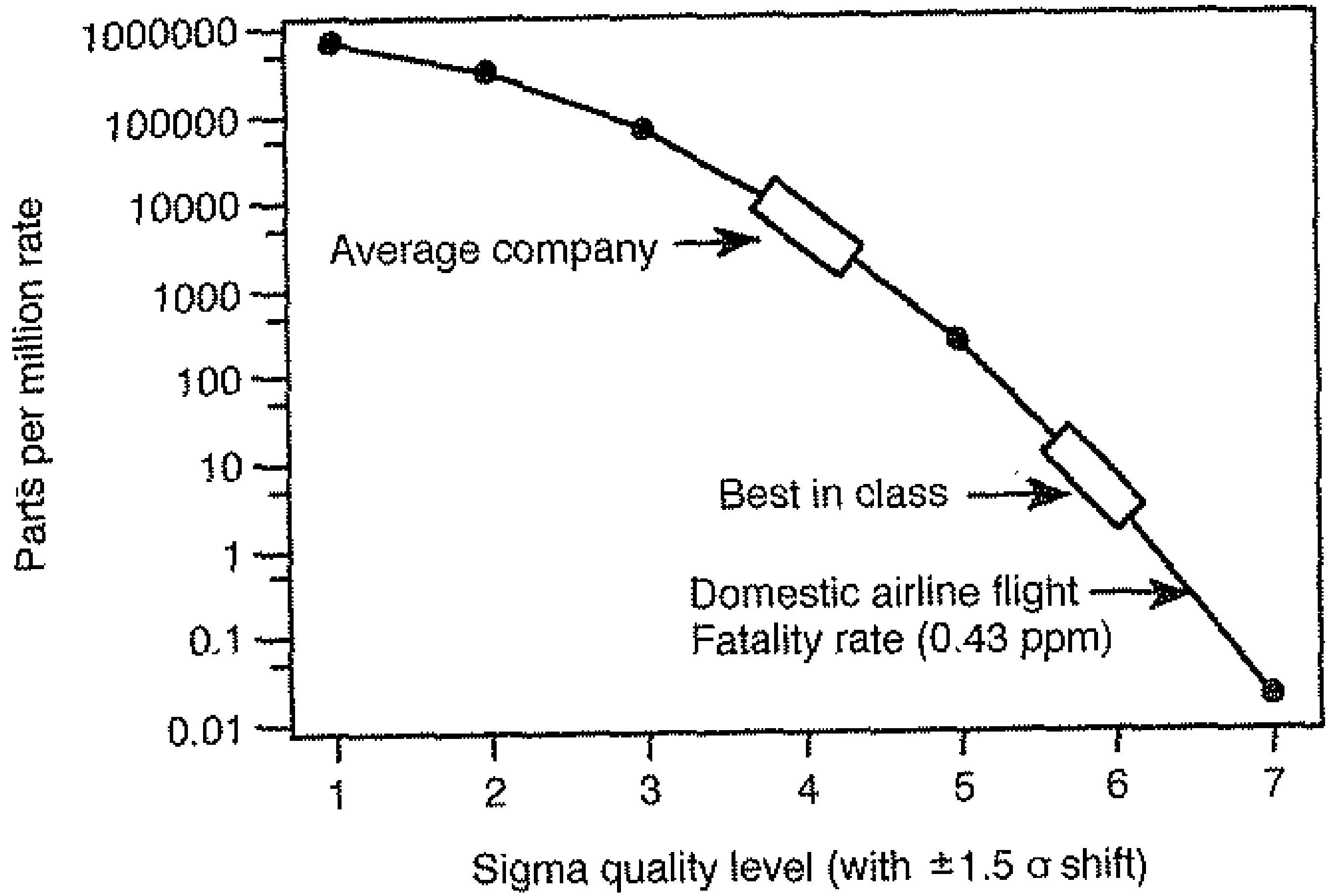
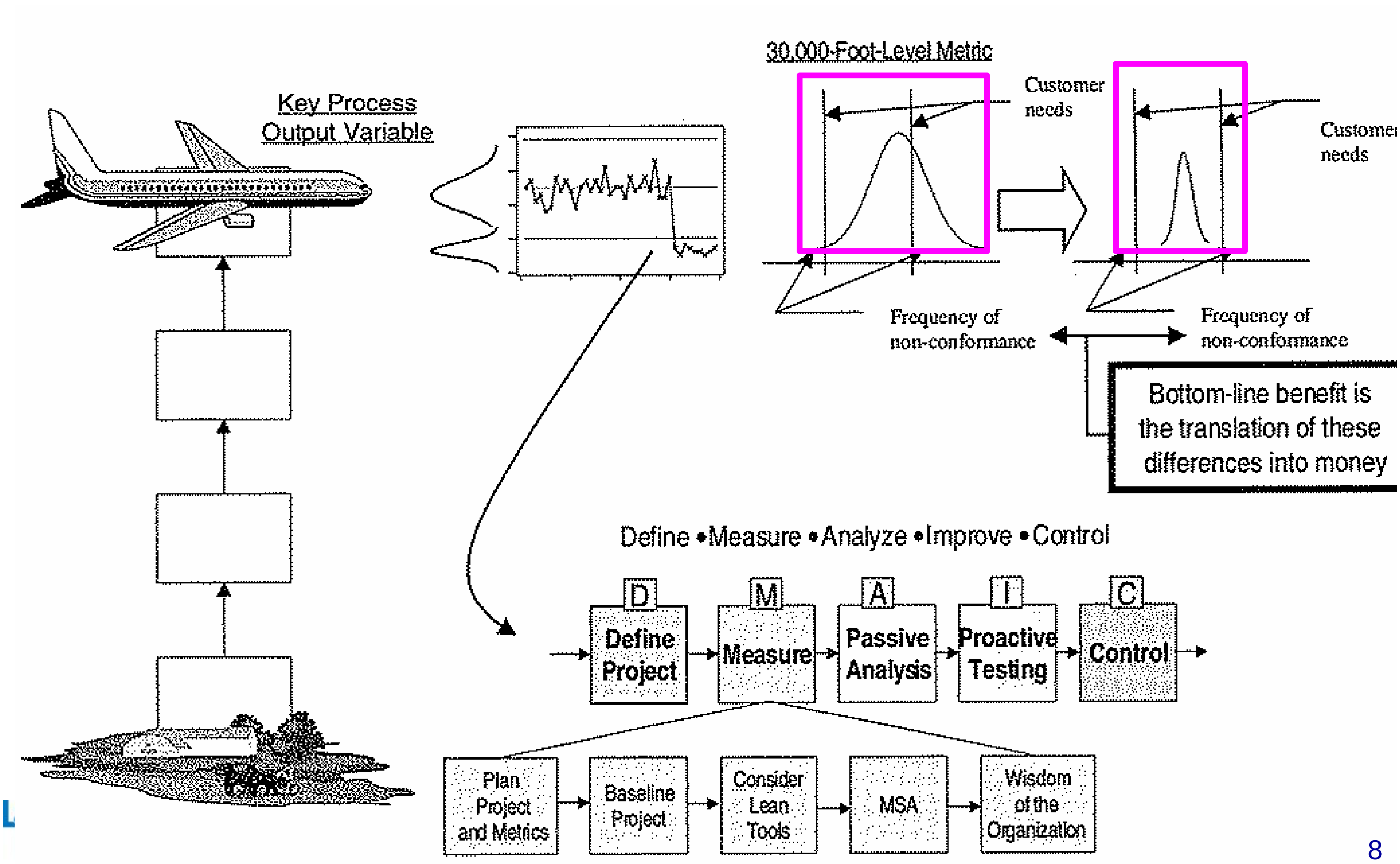
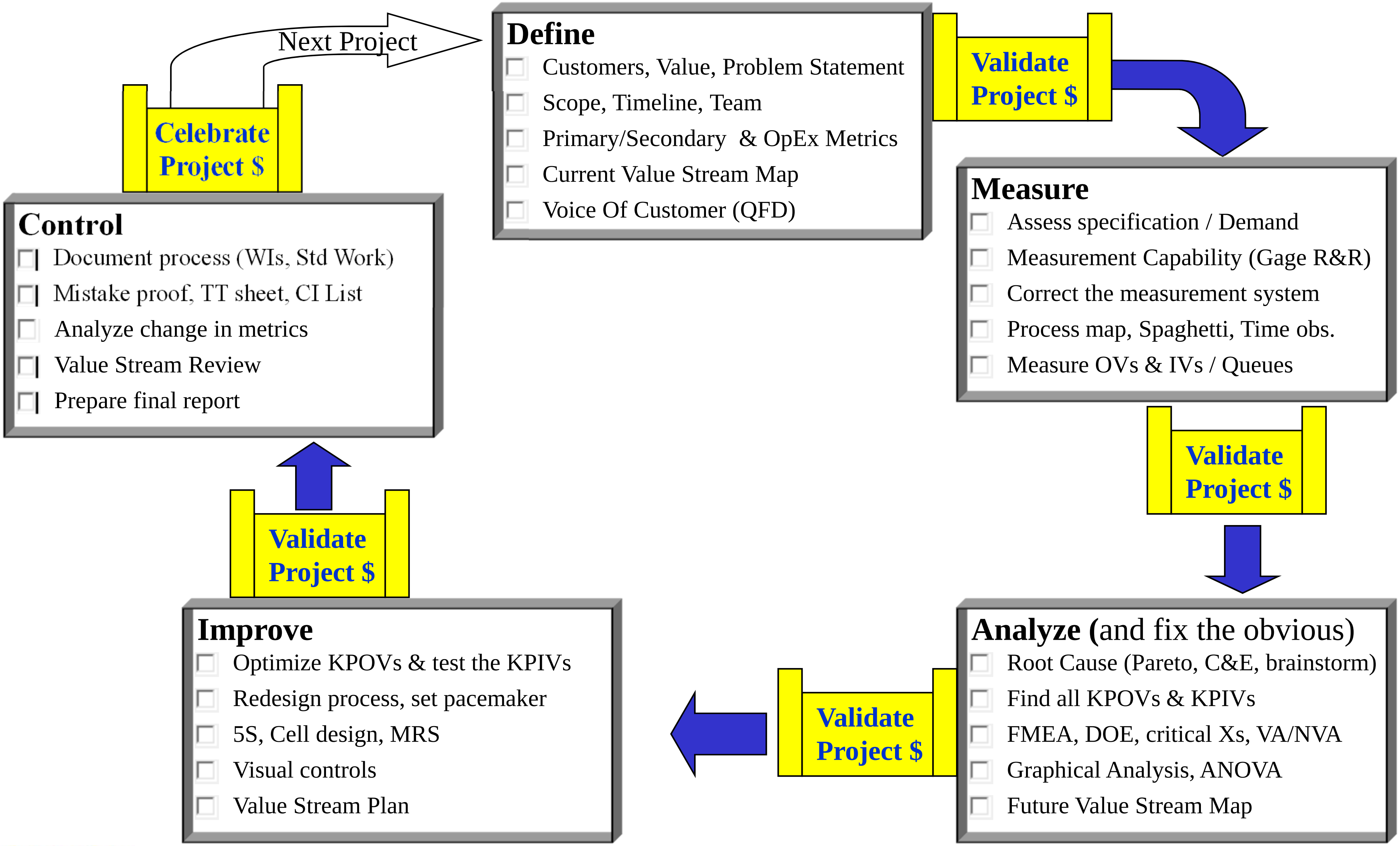


FIGURE 1.3 Implication of the sigma quality level. Parts per million (ppm) rate for part or process step.

30,000-Foot-Level Metric



Six Sigma Roadmap: DMAIC



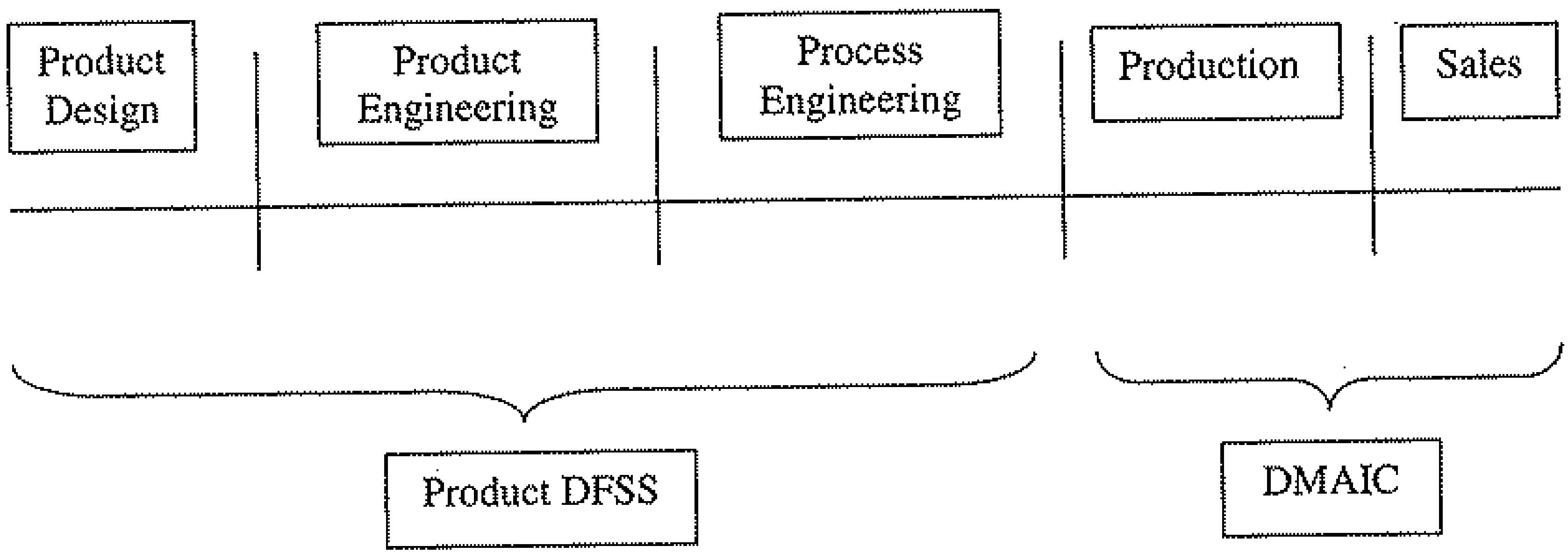
Six Sigma Methodology (DMAIC)

Project Name:				
DMAIC PROCESS AND PHASE GATE		Estimated completion date	Actual completion date	Status
Define				
Met Define Phase Criteria				**No**
• Define Customers and Requirements (CTQs)				
• Develop Problem Statement, Goals and Benefits				
• Identify Champion, Process Owner and Team				
• Define Resources				
• Evaluate Key Organizational Support				
• Develop Project Plan and Milestones				
• Develop High Level Process Map				
Measure				
Met Measure Phase Criteria				**No**
• Define Defect, Opportunity, Unit and Metrics				
• Detailed Process Map of Appropriate Areas				
• Develop Data Collection Plan				
• Validate the Measurement System				
• Collect the Data				
• Begin Developing Y=f(x) Relationship				
• Determine Process Capability and Sigma Baseline				

Six Sigma Methodology (DMAIC)

Analyze				
Met Analyze Phase Criteria				**No**
• Define Performance Objectives				
• Identify Value/Non-Value Added Process Steps				
• Identify Sources of Variation				
• Determine Root Cause(s)				
• Determine Vital Few x's, Y=f(x) Relationship				
Improve				
Met Improve Phase Criteria				**No**
• Perform Design of Experiments				
• Develop Potential Solutions				
• Define Operating Tolerances of Potential System				
• Assess Failure Modes of Potential Solutions				
• Validate Potential Improvement by Pilot Studies				
• Correct/Re-Evaluate Potential Solution				
Control				
Met Control Phase Criteria				**No**
• Define and Validate Monitoring and Control System				
• Develop Standards and Procedures				
• Implement Statistical Process Control				
• Determine Process Capability				
• Develop Transfer Plan, Handoff to Process Owner				
• Verify Benefits, Cost Savings/Avoidance, Profit Growth				
• Close Project, Finalize Documentation				
• Communicate to Business, Celebrate				

DFSS vs. DMAIC

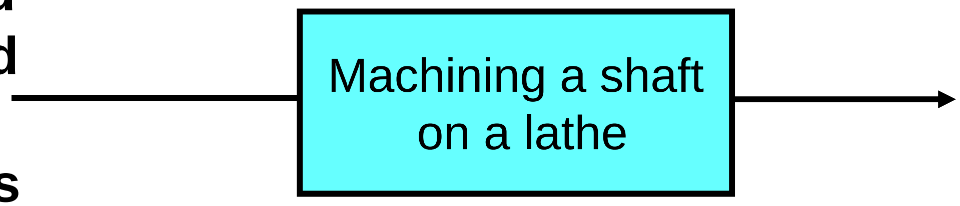


Product DFSS with DMAIC.

Measure

Inputs (x's)

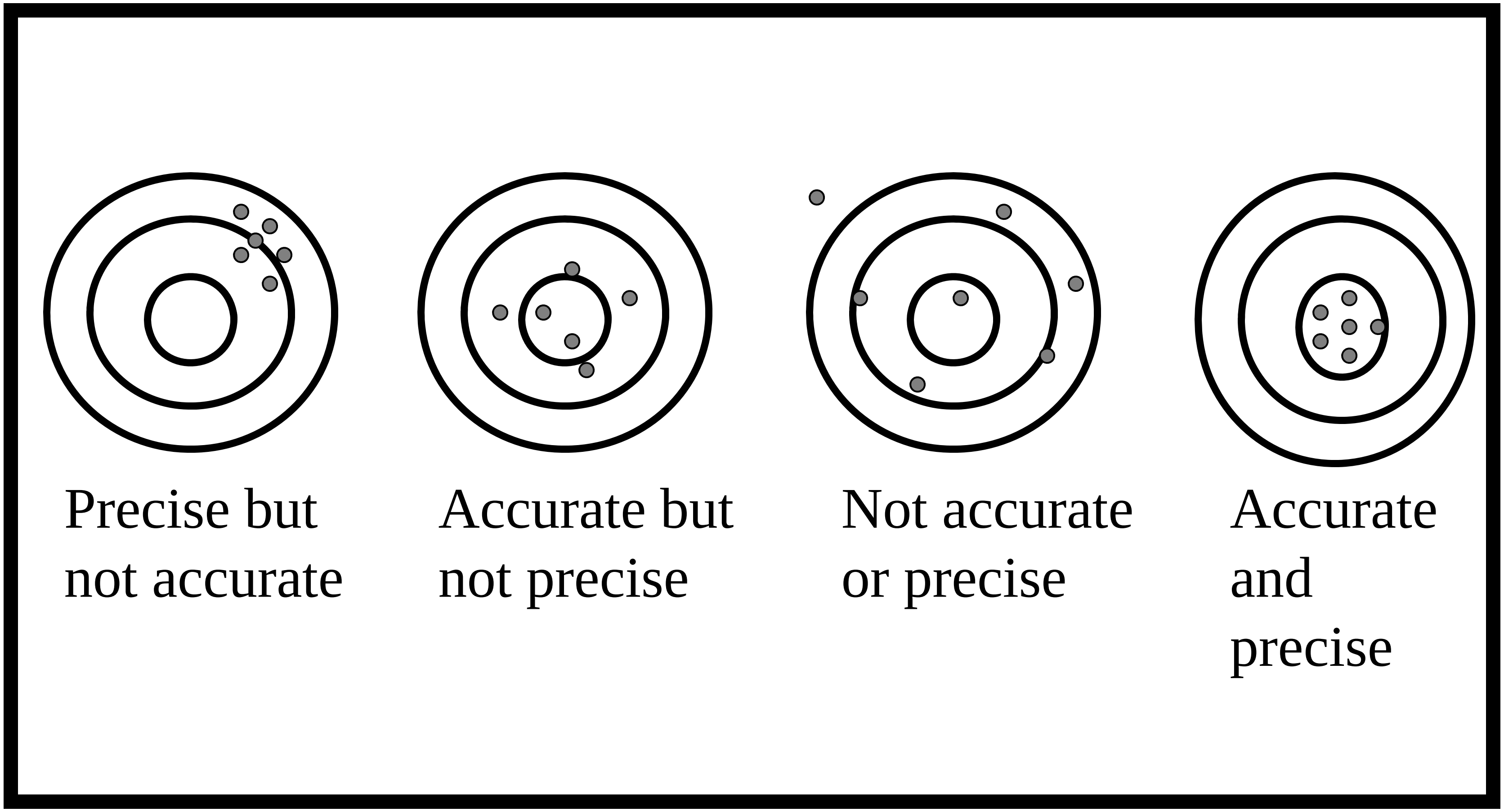
Rotation speed
Traverse speed
Tool type
Tool sharpness
Shaft material
Shaft length
Material removal per cut
Part cleanliness
Coolant flow
Operator
Material variation
Ambient temperature
Coolant age



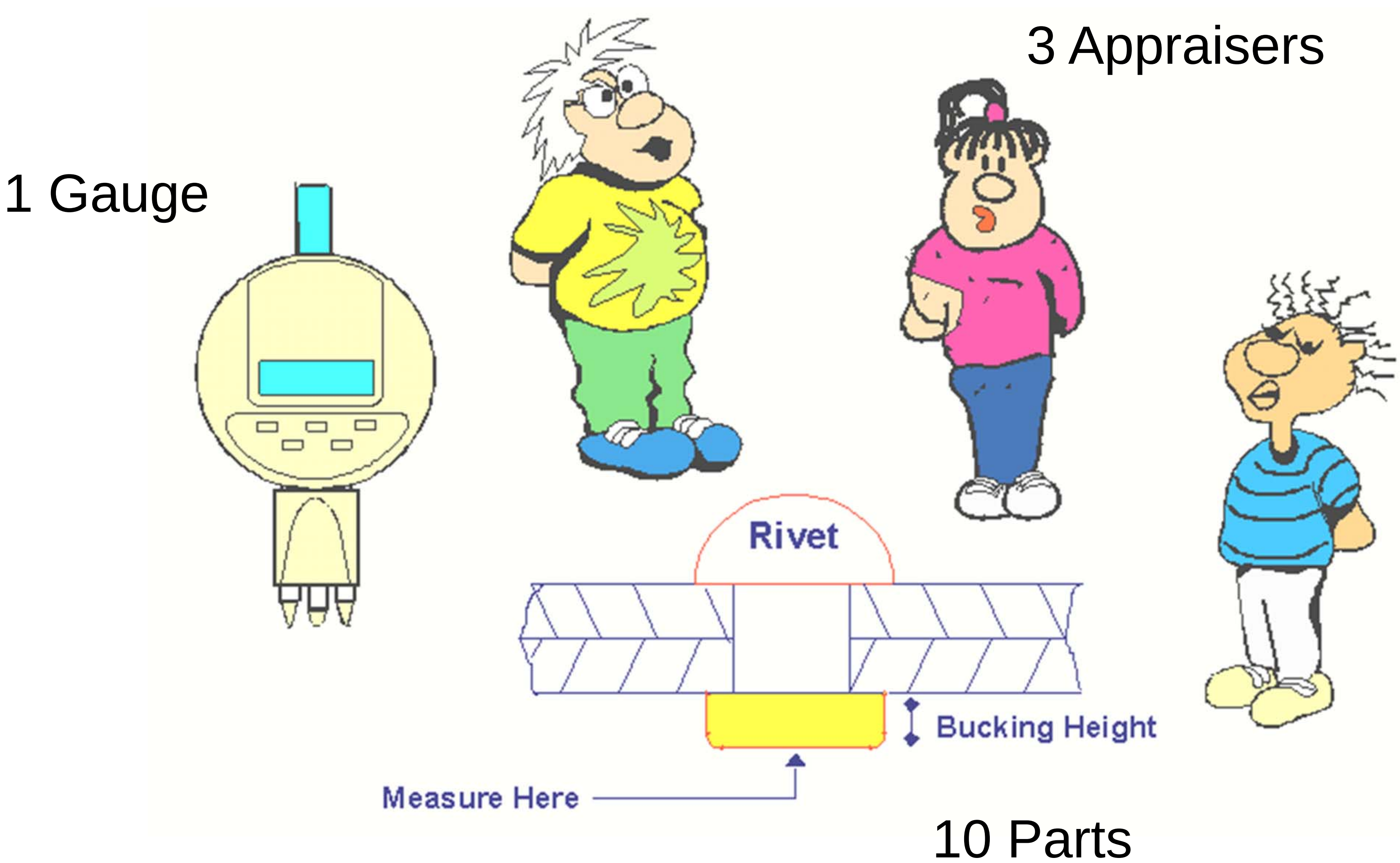
Outputs (Y's)

Diameter
Taper
Surface finish

Measurement System Error

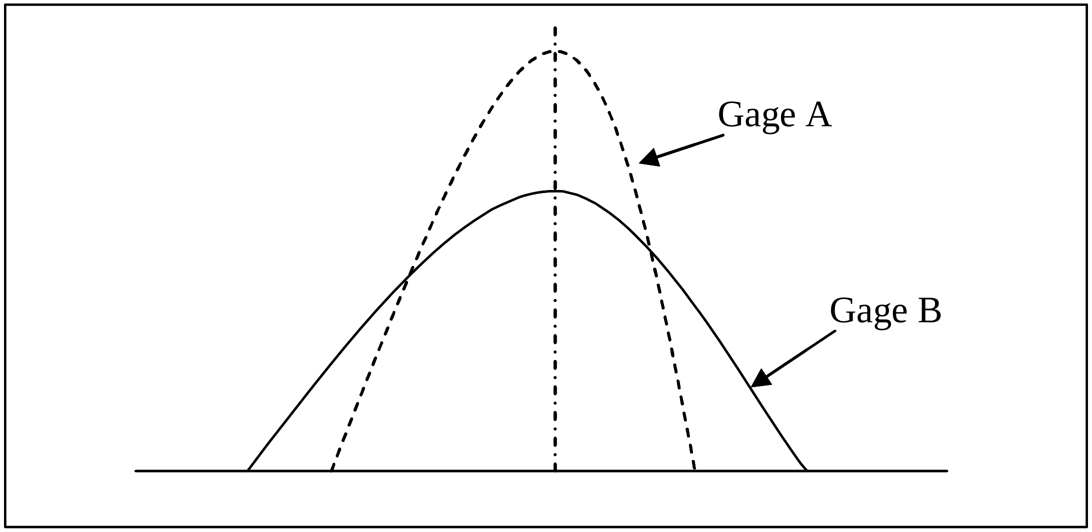


Variable Gauge R&R - What's Involved?



Repeatability

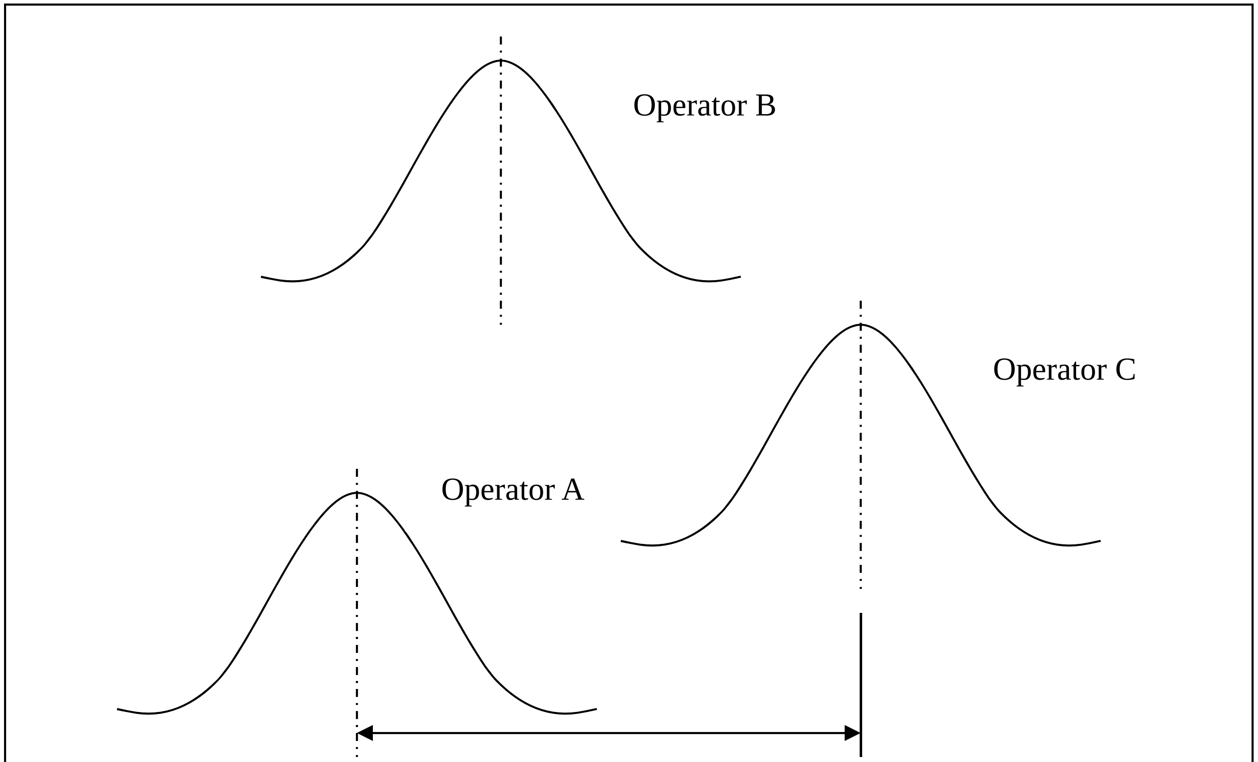
Repeatability is the variation in measurements obtained with one measurement instrument when used several times by an appraiser while measuring the identical characteristic on the same part. It is also commonly known as equipment variation.



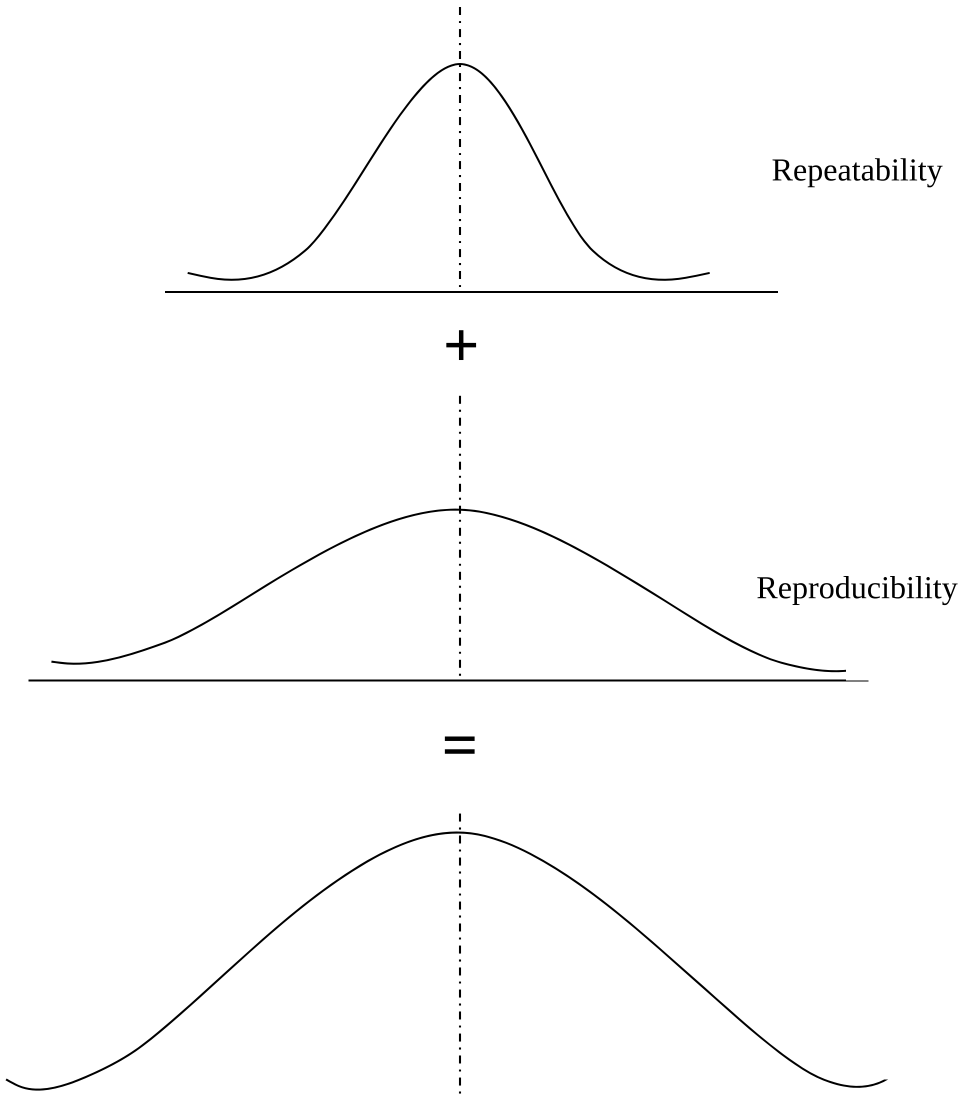
In the above figure, the repeatability of Gage A is more than that of Gage B as shown by their probability density functions.

Reproducibility

Reproducibility is the variation in the average of measurements made by different appraisers using the same instrument when measuring the identical characteristic on the same part. It is commonly known as appraiser variation.



Repeatability and Reproducibility



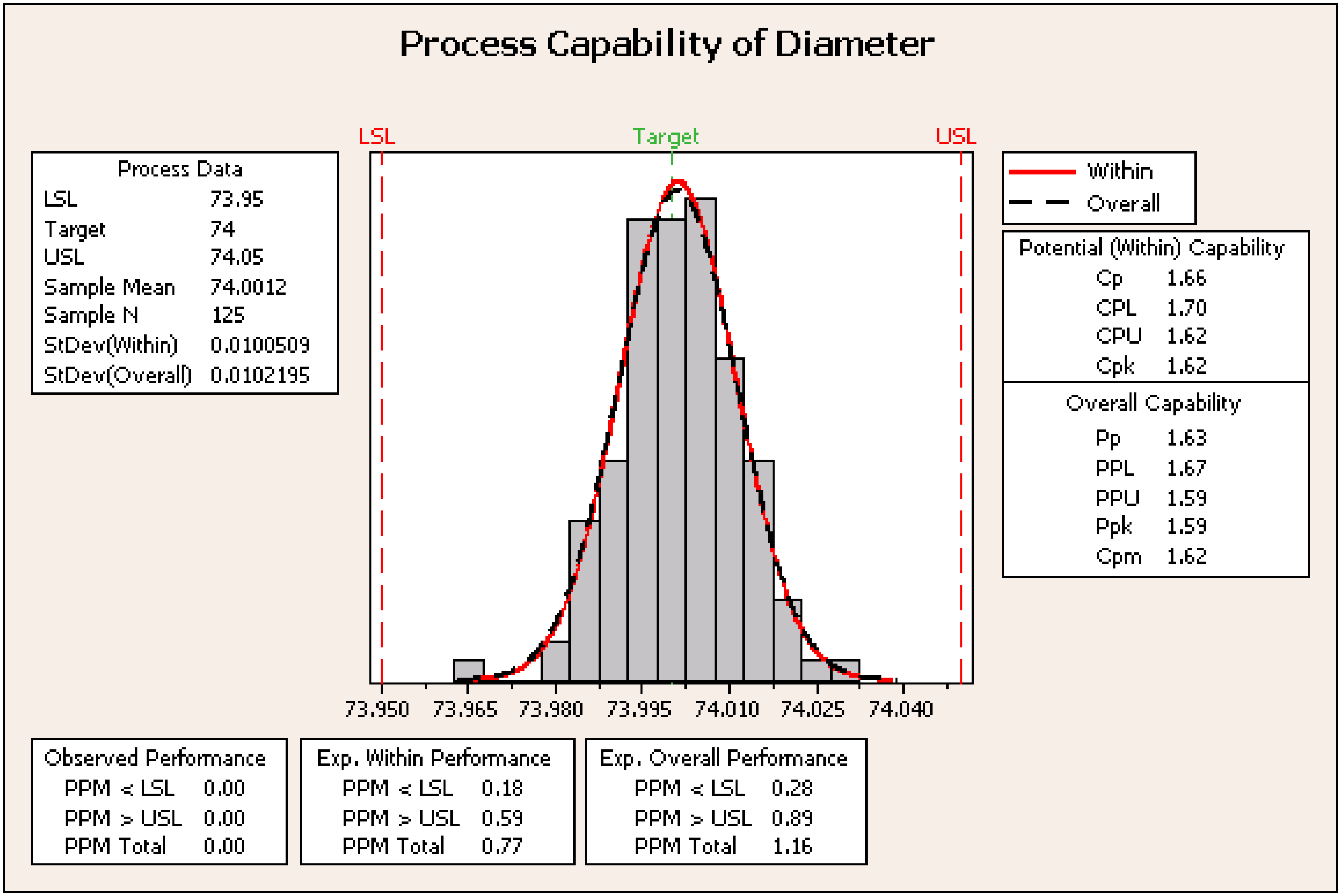
Average and Range Method (Example)

Consider the following example: (Taken from Measurement System Analysis Reference Manual)

No. of Appraisers	= 2
No. of Trials	= 3
No. of parts	= 5

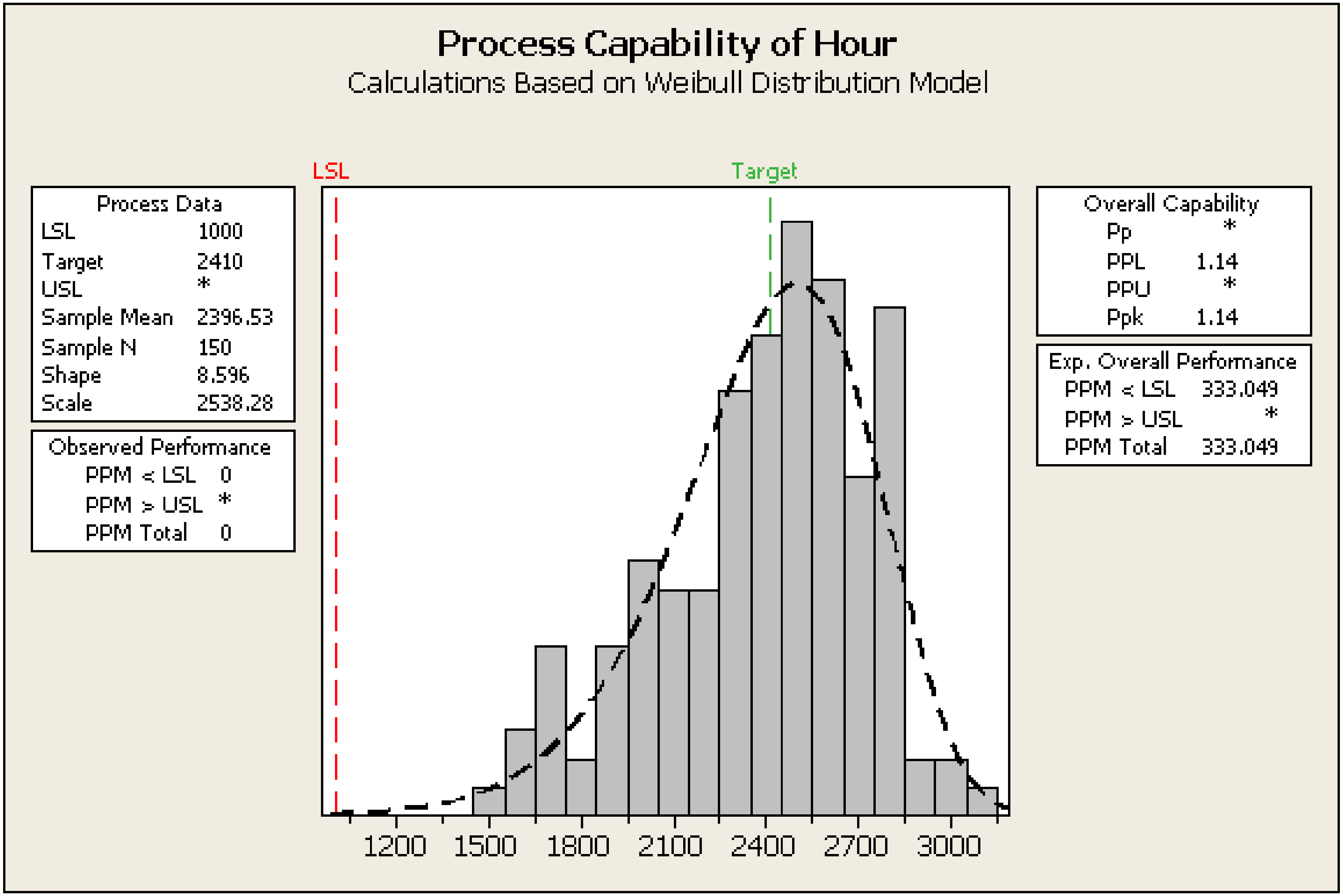
Appraiser/ Trial #	Part 1	2	3	4	5	6	7	8	9	10	Average
A 1	217	220	217	214	216						216.8
2	216	216	216	212	219						215.8
3	216	218	216	212	220						216.4
Average	216.3	218	216.3	212.7	218.3						216.3
Range	1.0	4.0	1.0	2.0	4.0						2.4
B 1	216	216	216	216	220						216.8
2	219	216	215	212	220						216.4
3	220	220	216	212	220						217.6
Average	218.3	217.3	215.7	213.3	220						216.9
Range	4.0	4.0	1.0	4.0	0.0						2.6
C 1											
2											
3											
Average											
Range											
Part Average ($\bar{X}_p$)	217.3	217.7	216	213	219.15						$\bar{\bar{X}} = 216.6$ $R_p = 6.15$
$\bar{\bar{R}} = (\bar{R}_a + \bar{R}_b) / No. of Appraisers = 2$											2.5
$\bar{X}_{DIFF} = Max\bar{X} - Min\bar{X}$											0.6
$UCL_R = \bar{\bar{R}} * D_4$											6.4
$LCL_R = \bar{\bar{R}} * D_3$											0.00

Process Capability



Lower Specification Limit, Upper Specification Limit

Process Capability



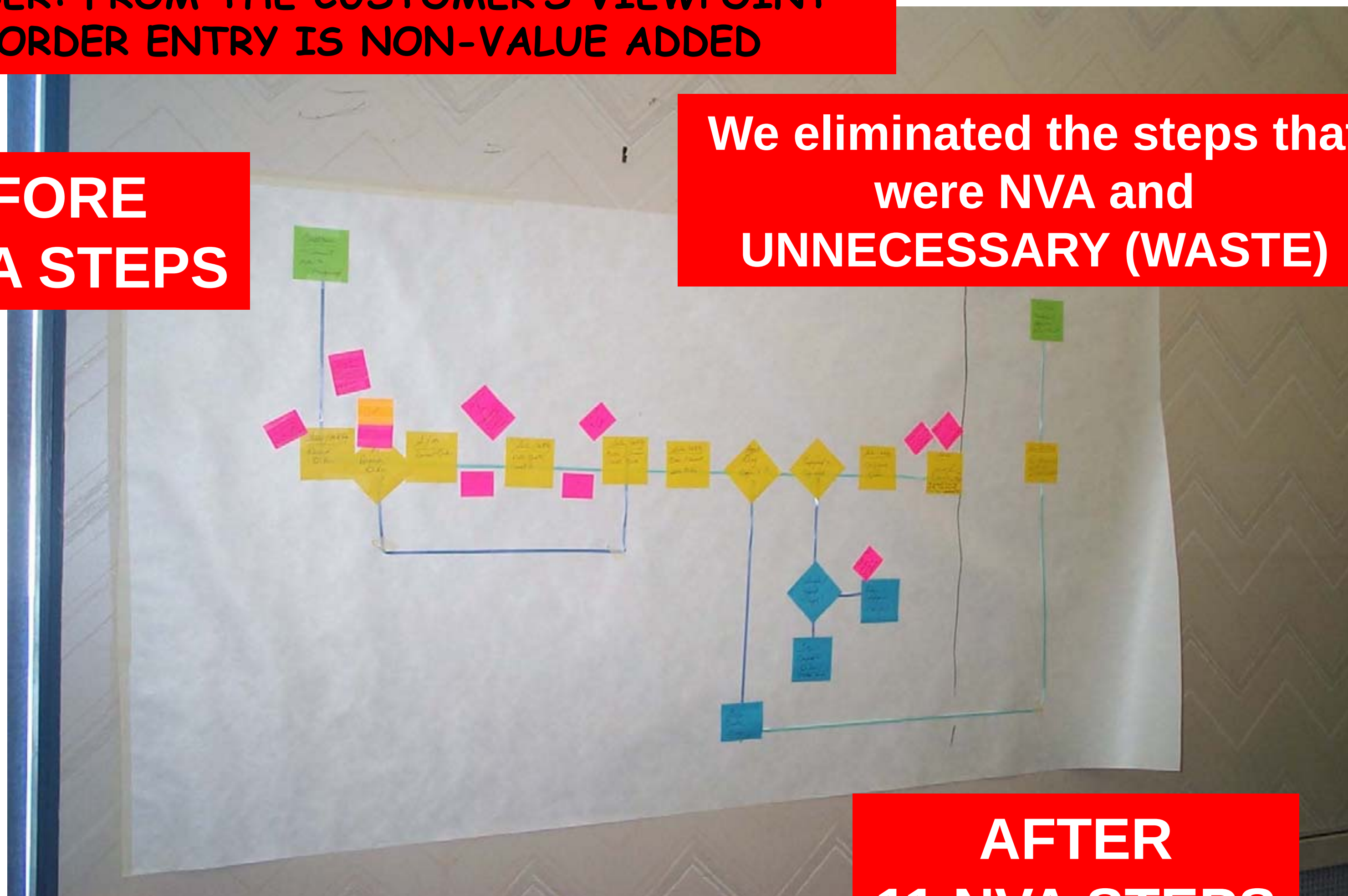
Order Entry Process Map (As-Is)

BEFORE
40 NVA STEPS

NOTE: FROM THE CUSTOMER'S VIEWPOINT ALL OF ORDER ENTRY IS NON-VALUE ADDED

Order Entry Process Map (New)

REMEMBER: FROM THE CUSTOMER'S VIEWPOINT ALL OF ORDER ENTRY IS NON-VALUE ADDED

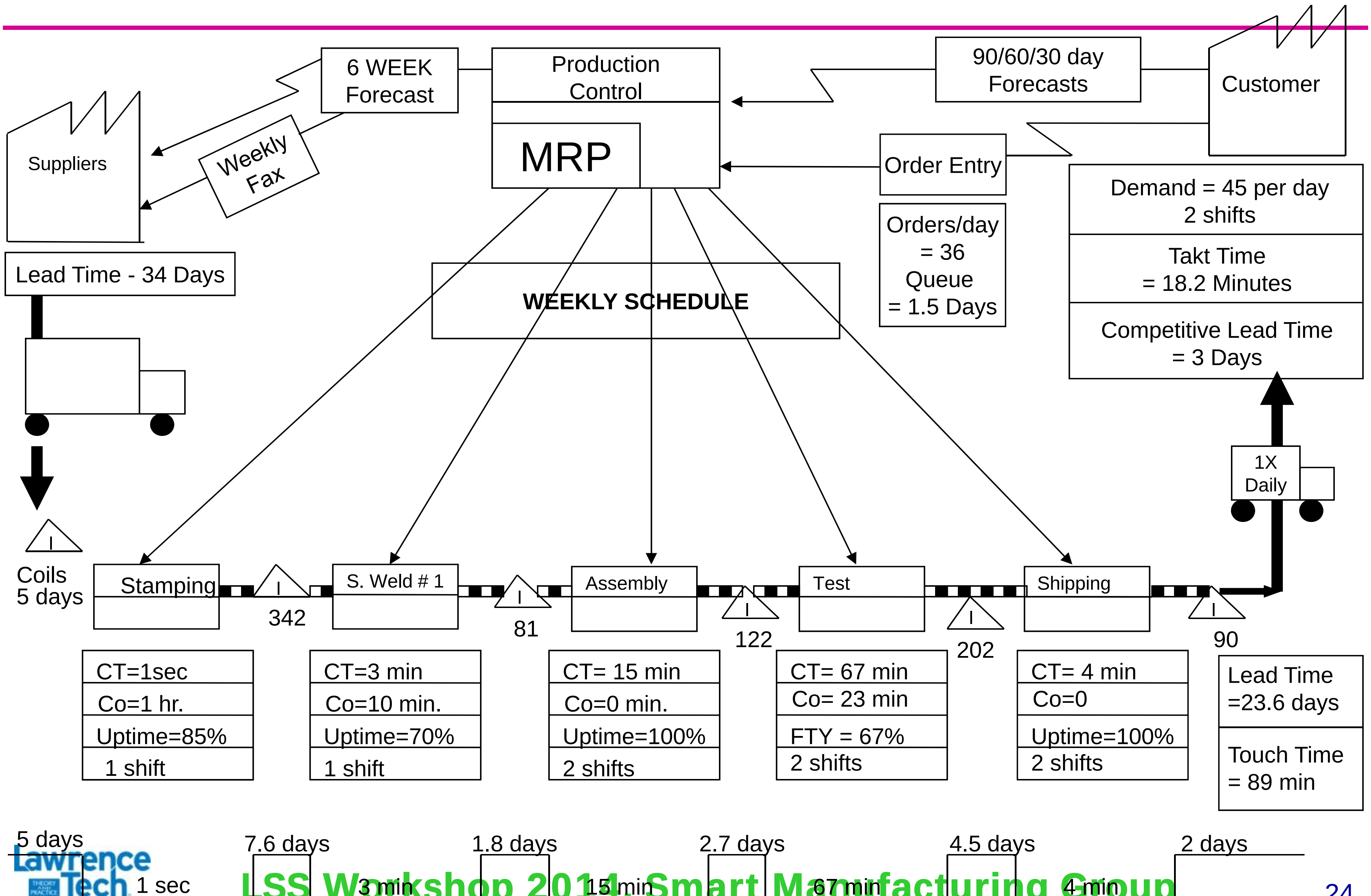


BEFORE
40 NVA STEPS

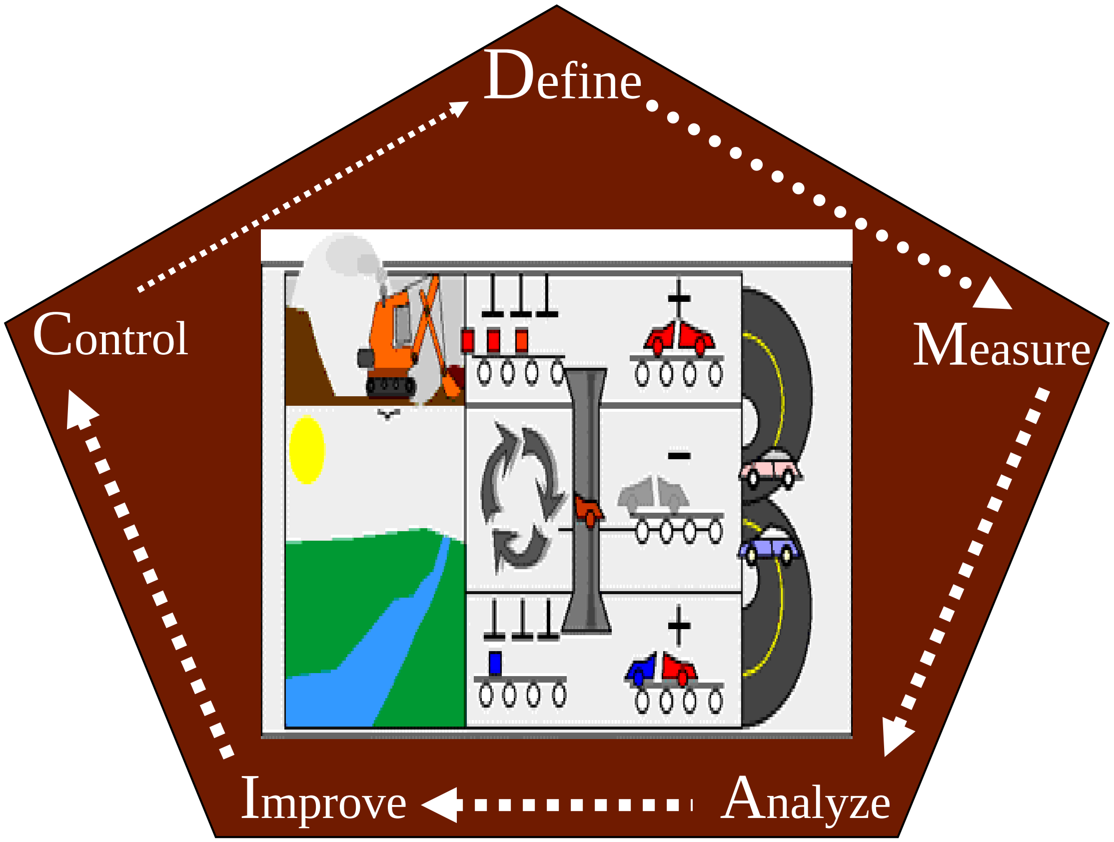
We eliminated the steps that were NVA and UNNECESSARY (WASTE)

AFTER
11 NVA STEPS

Value Stream Map - Current State



Analyze Phase



Define the problem and customer requirements.

Measure defect rates and document the process in its current incarnation.

Analyze process data and determine the capability of the process.

Improve the process and remove defect causes.

Control process performance and ensure that defects do not recur.

Ref: www.ccse.kfupm.edu.sa%2F~duffuaa%2Fdownload%2FCourses%2FSE534%

DMAIC: Analyze

Analysis
- Complete FMEA
- Perform Multi-vari Analysis
- Identity Potential Critical Inputs
- Develop Plan for Next Phase

Analyze

What is wrong?

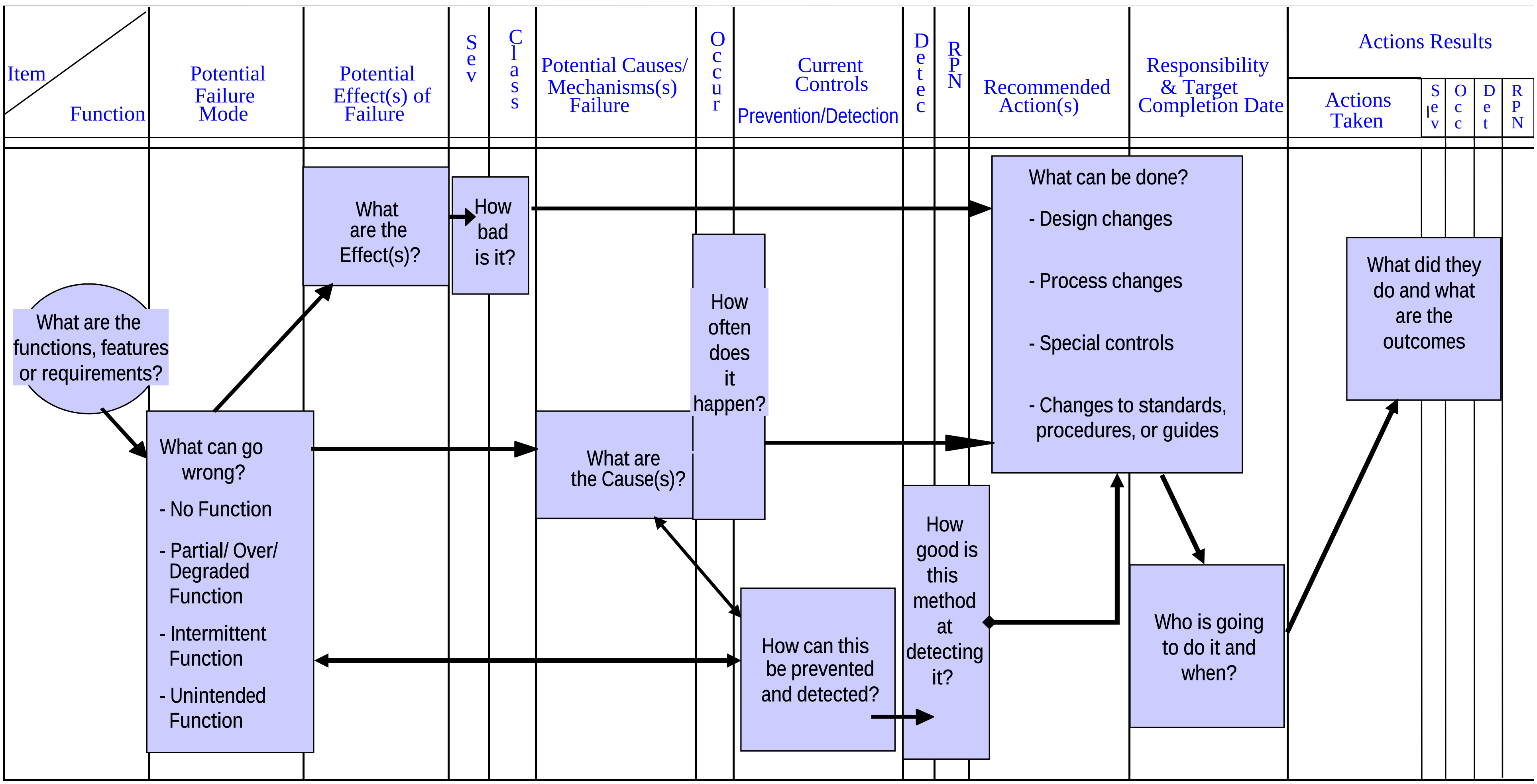
Objectives

- To identify and validate the root causes that assure the elimination of "real" root causes and thus the problem the team is focused on.
- To determine true sources of variation and potential failure modes that lead to customer dissatisfaction.

Main Activities

- Stratify Process
- Stratify Data & Identify Specific Problem
- Develop Problem Statement
- Identify Root Causes
- Design Root Cause Verification Analysis
- Validate Root Causes
- Comparative Analysis
- Sources of Variation Studies
- Regression Analysis
- Process Control
- Process Capability
- Design of Experiments

Potential
Failure Mode and Effects Analysis



Summary of DFMEA/PFMEA

(D,F,GM. FMEA, 2001)

System FMEA Product

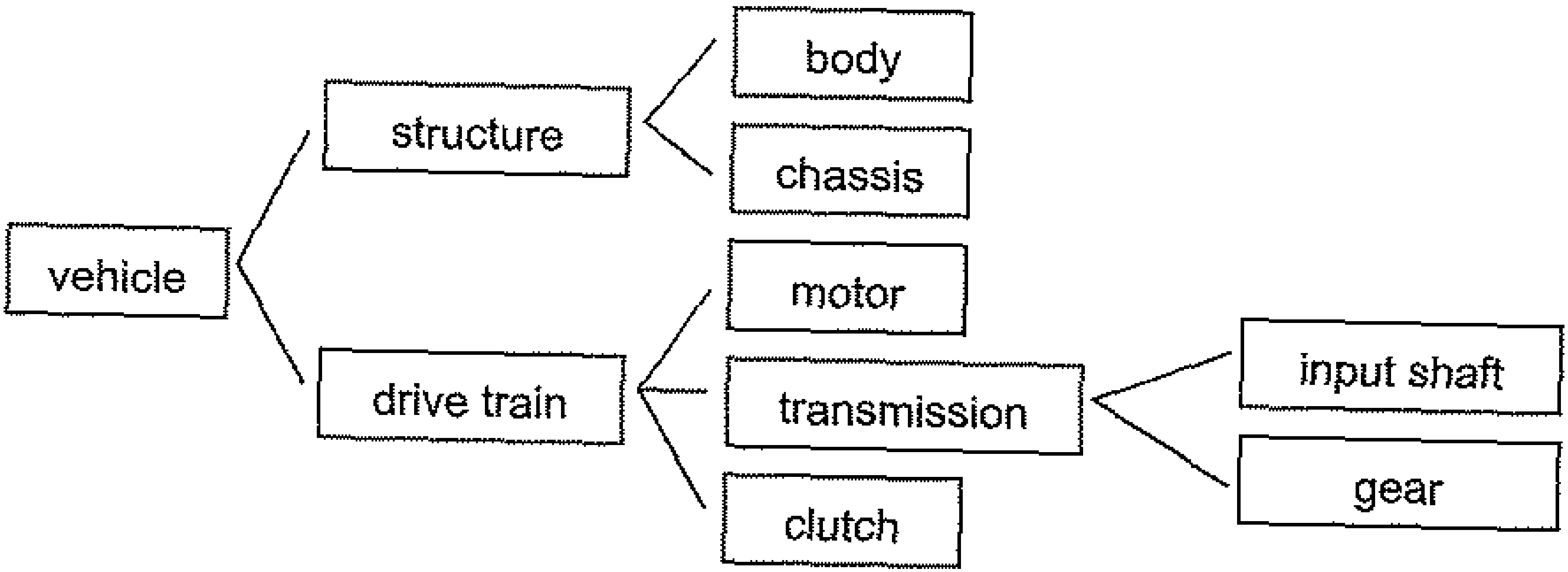


Figure 4.24. System structure of a "Complete Vehicle System" [4.7]

Ref: Bertsche, B., Reliability in Automotive and Mechanical Engineering, Springer, 2008.

Table 4.1. Typical potential failure modes

- fracture
- crack
- abrasion
- rejected
- chips away
- wear (also bedding-in, pittings,...)
- insufficient time characteristics
- rotted, decomposed (prematurely)
- damaged, prematurely worn out
- vibrates
- swings
- resonances
- unpleasant sound
- too loud
- congested
- contaminated
- leaky
- busted
- depressurized
- false pressure
- corroded
- overheated
- burnt
- charred
- blocked
- overstretched
- bent, sagging
- distorted, deformed, dented
- relaxed, loose, wobbles
- clamps, sluggish
- friction is too high of too low
- too much expanded
- part is missing
- wrong part (not a safely usab constr.)
- wrong position (no constr. mea urement)
- constr. inverted assembly possible
- interchanged (no constr. measur ment)
- location to reverse side is false
- false configuration
- entry of dirt and water
- false speed
- false acceleration
- false spring characteristics
- false weight
- poor degree of efficiency
- too maintenance intensive
- poorly replaceable
- not further useable

Lawrence Tech

Risk Priority Number (RPN)

1.4, 2.4	radial shaft seal, no or false flow effect	540
1.7, 2.6	sleeve, breakage	420
1.3, 2.3	radial shaft seal, worn	180

Occurrence (O)

1.4, 2.4	radial shaft seal, no or false flow effect	9
1.7	sleeve, breakage	7

Severity (O)

1.1, 2.1	input shaft / output shaft overload breakage / fatigue breakage	9

Detection (O)

false layout	10
unforeseen, unallowable stress	10

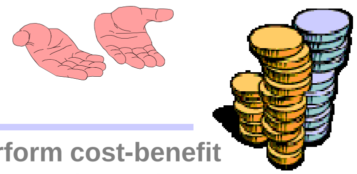
Figure 4.57. Extract from the "highlights" for the adapting transmission

Web-based FMEA

Web-based Collaborative Methods to Facilitate FMEA Process for Beamformer

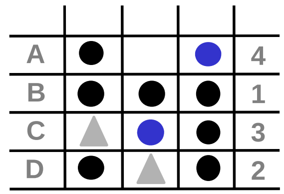
Improve Phase

Cost-Benefit Analysis



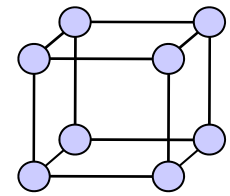
Perform cost-benefit analysis for the preferred solution

Generating Solutions



Generate solutions including Benchmarking and select best approach based on screening criteria

Design of Experiments

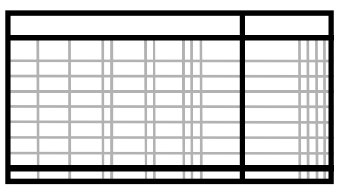


Use DOE and response surface optimization to quantify relationships.

Selecting the Solution

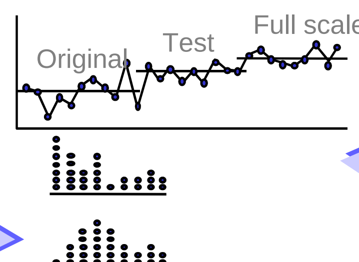
Recommend a solution involving key stakeholders.

Assessing Risks



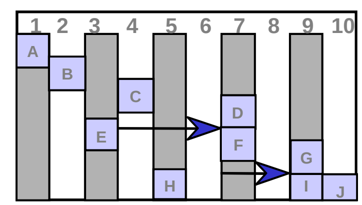
Use FMEA to identify risks associated with the solution and take preventive actions

Piloting



Pilot the solution on a small scale and evaluate the results

Implementation

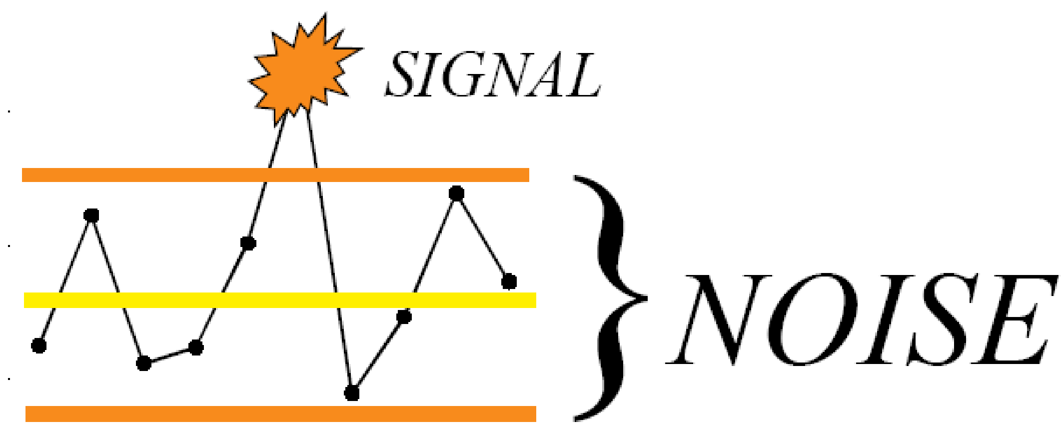


Develop & Execute a full plan for implementation and change management

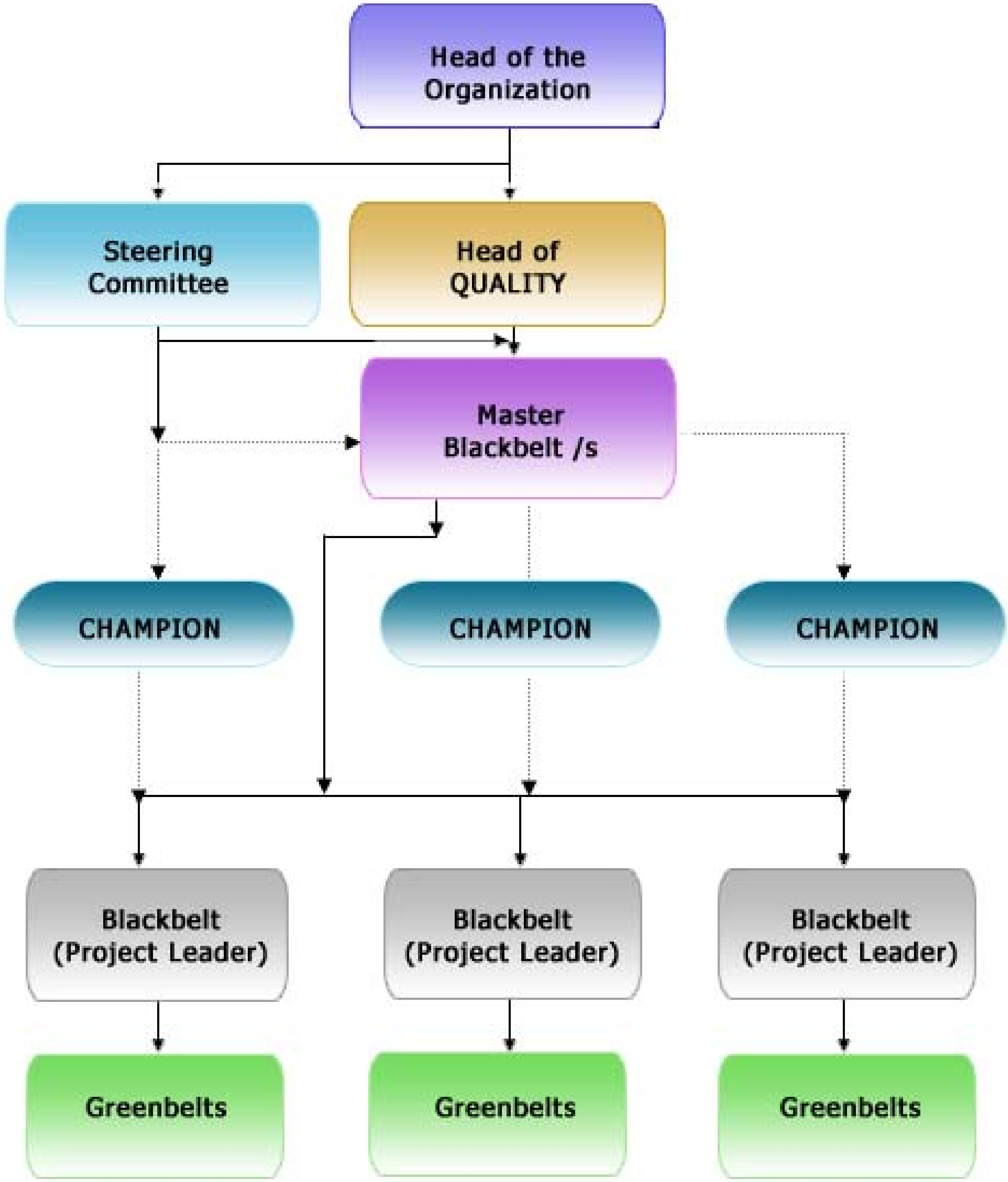
Control Phase

Noise and Signal

- Process Control Limits are a filter to differentiate Special Cause Variation from Common Cause Variation.
  - Common Cause Variation is NOISE
  - Special Cause Variation is SIGNAL.



- The Minitab Rules to detect Special Cause Variation maximize the chance of detecting SIGNAL while minimizing the risk of reacting to NOISE.


Head of the Organization
Steering Committee
Head of QUALITY
Master Blackbelt /s
CHAMPION
CHAMPION
CHAMPION
Blackbelt (Project Leader)
Blackbelt (Project Leader)
Blackbelt (Project Leader)
Greenbelts
Greenbelts
Greenbelts

Comprehensiveness of Problem Solving Approaches

- **Problem Solving Approach**
  - **Statistical Approach**
    - **7 Statistical Tools**
      1. Pareto Analysis
      2. Cause-and-Effect Analysis (Ishikawa or Fishbone diagram)
      3. Histograms
      4. Scatter Diagrams
      5. Graphs
      6. Check Sheets
      7. Control Charts
    - **Advanced Statistical Tools**
      1. Simple Regression
      2. Multiple Regression
      3. Analysis of Variance (ANOVA) & Hypothesis testing
      4. Design of Experiments (including Taguchi methods)
  - **Systems Design Approach**
    - **Industrial Engineering Tools**
      1. The "5 W's and 1 H" Analysis
      2. Flow Diagram
      3. Flow Process Chart
      4. Operation Process Chart
      5. Work Distribution Chart
      6. Gantt Chart
      7. Multiple Activity Chart
      8. Left-Hand–Right-Hand Chart
      9. Work Sampling
      10. Direct & Pre-Determined Time Studies
      11. Ergonomics
      12. Operations Research (OR) Tools
      13. Simulation
      14. Surveys
      15. Activity Relationship Chart
      16. Relationship Diagram
      17. Space Relationship Diagram
      18. Content Analysis
    - **New Seven QC Tools**
      1. Relations Diagram
      2. Affinity Diagram
      3. Tree Diagram
      4. Matrix Diagram
      5. Matrix Data Analysis Diagram
      6. PDPC (Process Decision Program Chart)
      7. Arrow Diagram (CPM/PERT Diagram)

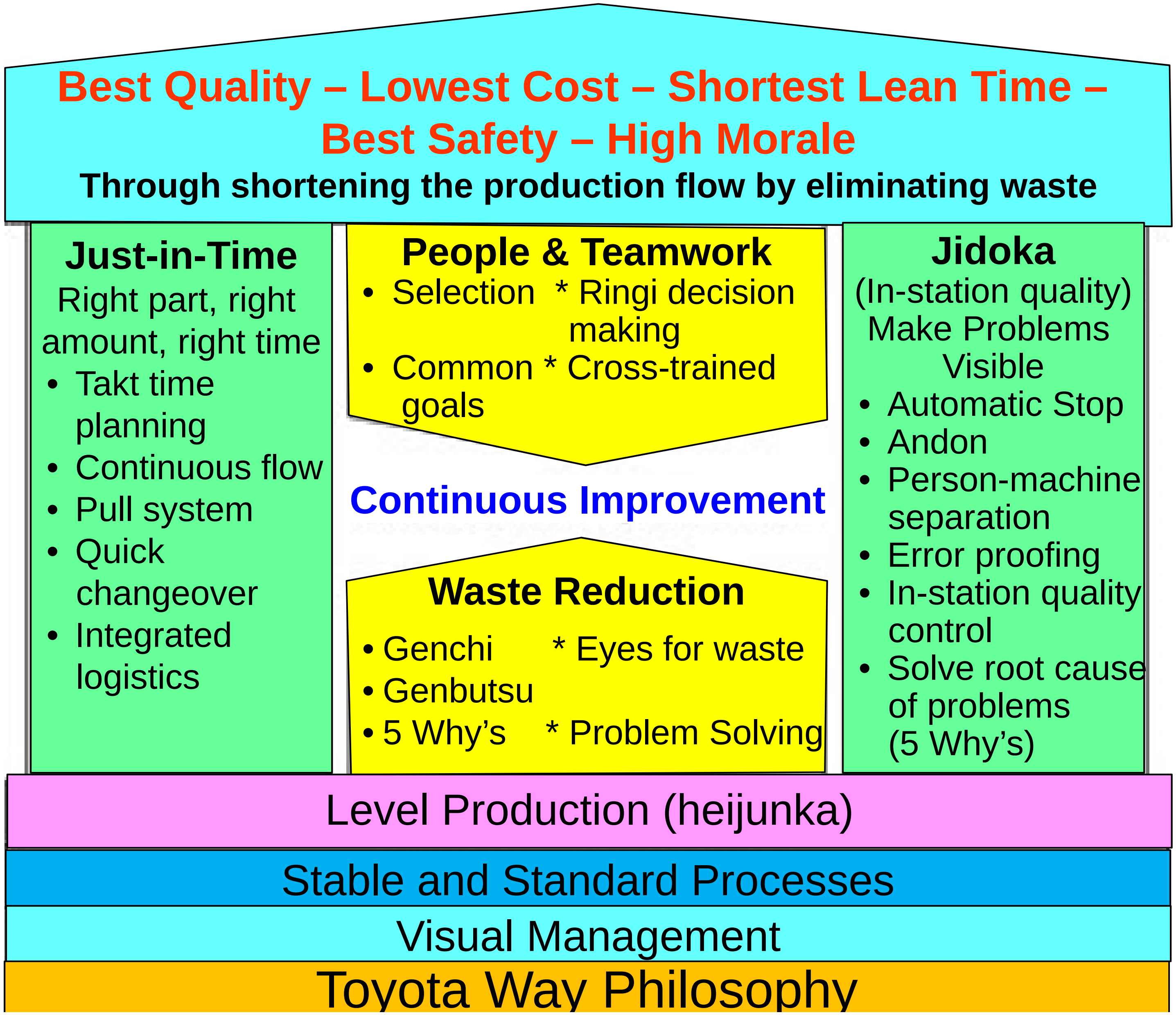
FIGURE 6.15 A wide variety of problem-solving tools available in TPmgt. (©1991, D.J. Sumanth.)

LEAN

A moving assembly line is continuously flowing, like a river, and the ideal is to keep all material continuously flowing.

Anything that prevents the flow of material is waste.

Toyota Production Systems House Diagram

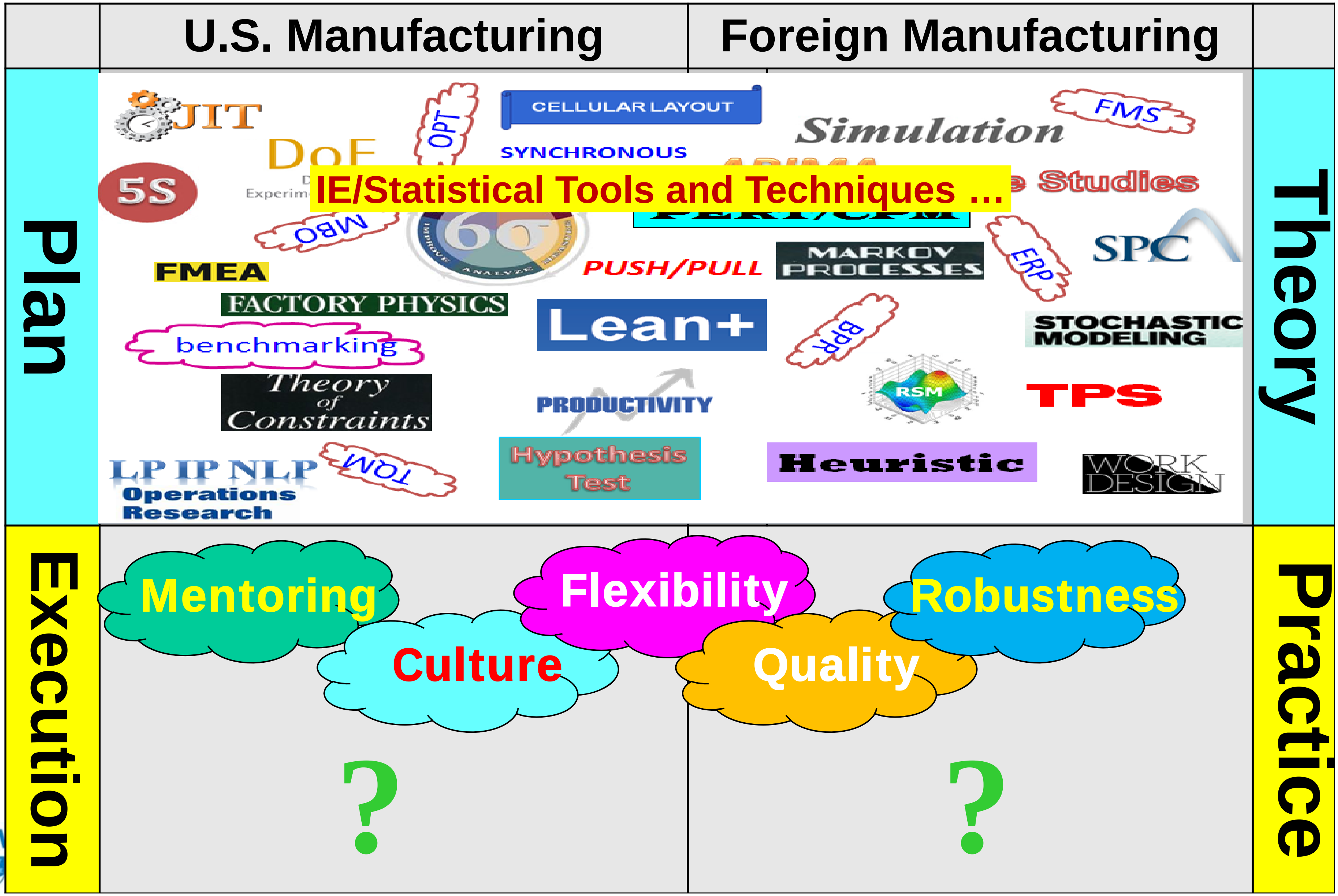


(Liker, 2004)

IE/Statistical Tools and Techniques …

- JIT
- DoE Design of Experiments
- 5S
- OPT
- CELLULAR LAYOUT
- SYNCHRONOUS
- Simulation
- FMS
- ARIMA
- Time Studies
- MBO
- 6σ (CONTROL, DEFINE, MEASURE, ANALYZE, IMPROVE)
- PERT/CPM
- SPC
- FMEA
- PUSH/PULL
- MARKOV PROCESSES
- ERP
- FACTORY PHYSICS
- Lean+
- BPR
- STOCHASTIC MODELING
- benchmarking
- Theory of Constraints
- PRODUCTIVITY
- RSM
- TPS
- LP IP NLP
- Operations Research
- TQM
- Hypothesis Test
- Heuristic
- WORK DESIGN

Challenges in U.S. Manufacturing Systems



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- Cavanagh, R. R., Neuman, R. P. and Pande, P. S., The Six Sigma Way: How GE, Motorola and Other Top Companies are Honing Their Performance.
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- Munro, R. A., Maio, M. J. and Nawaz, M. B., Govindarajan Ramu, and Daniel J. Zrymiak, The Certified Six Sigma Green Belt Handbook.
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- Pyzdek, T. and Keller, P., The Six Sigma Handbook, Third Edition: A Complete Guide for Green Belts, Black Belts, and Managers at all levels.

Six Sigma Related Resources

- Annual Lean Six Sigma & Process Improvement Summit
- Lean and Six Sigma Conference – ASQ,, AZ http://www.asq.org/conferences/six-sigma/
- American Society for Quality, http://www.asq.org/index.html
- ASQ Reliability Division, http://www.asq.org/reliability/index.html
- IEEE Reliability Society http://www.ieee.org/portal/site/relsoc
- IIE Quality Control/Reliability Division, http://www.iienet2.org/Landing.aspx?id=898
- Institute of Industrial Engineers, Six Sigma, Quality and Reliability, http://www.iienet.org/
- IIE Engineering Lean Six Sigma Conference

Six Sigma Related Resources

- International Journal of Lean Six Sigma
- International Journal of Quality & Reliability Management, Emerald
- International Journal of Quality, Statistics, and Reliability
- International Journal of Reliability, Quality & Safety Engineering, World Scientific Pub.
- International Journal of Six Sigma and Competitive Advantage
- International Society of Six Sigma Professionals (ISSSP), http://www.isssp.com/

Six Sigma Related Resources

- **National Science Foundation (NSF) Industry University Cooperative Research Center for Quality and Reliability Engineering, Rutgers University and Arizona State University, http://coewww.rutgers.edu/~ie/qre/about.html**

- **Quality & Productivity Journal**

- **Six Sigma References from ASQ Store: http://www.asq.org/quality-press/search-results/index.html?search_mode=keyword&search_query=six+sigma**

- **Some real-world applications http://www.amazon.com/World-Class-Applications-Six-Sigma/dp/0750664592**

- **www.isixsigma.com**

Thank You