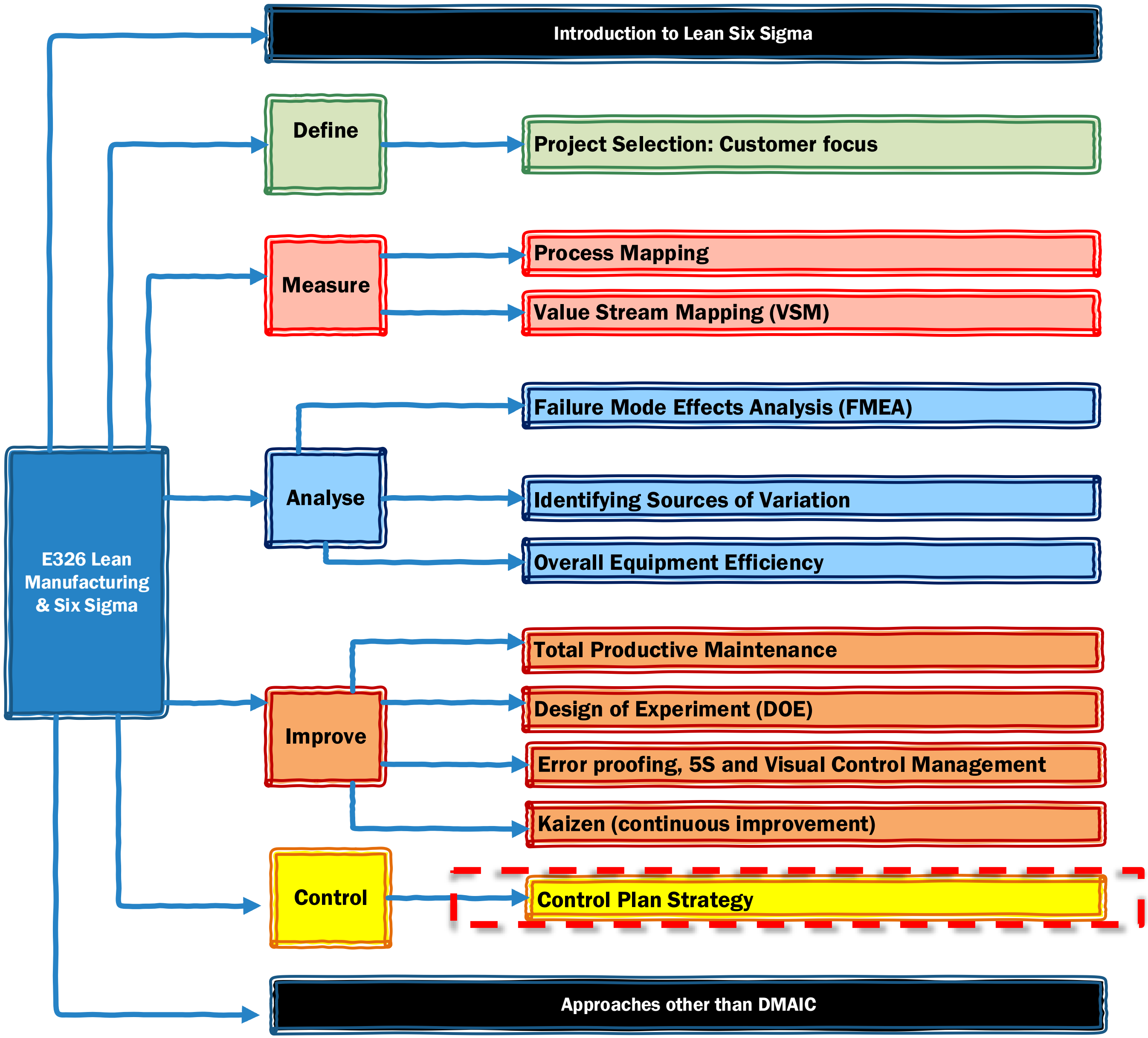
Problem 12
Maintaining Control

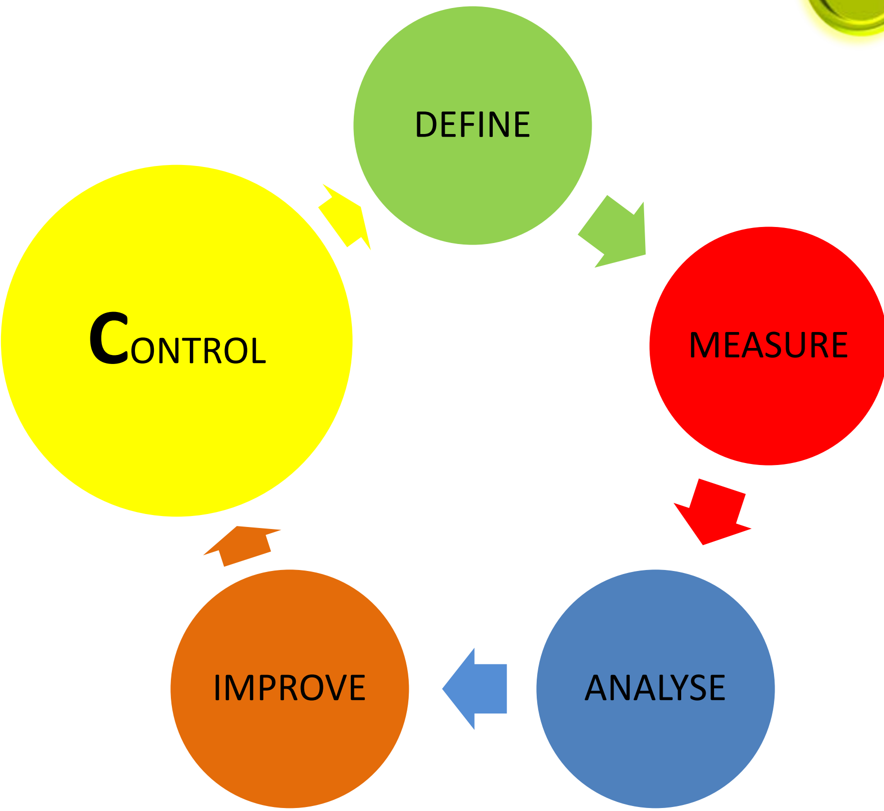
E326 – Lean Manufacturing & Six Sigma

SCHOOL OF ENGINEERING

E326 Lean Manufacturing and Six Sigma Topic Tree



DMAIC



- Pre-Control
- Control Plan

Objectives of Control phase:

- Ensure that the gains of the Improve phase are maintained.

Control Phase - Purposes

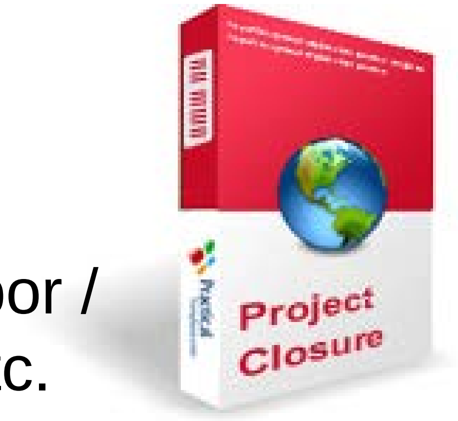
Control Phase is one of the important activities when closing a Six Sigma project. It aims to ensure that the solutions that have been implemented become ‘embedded’ into the process, so that the improvements will be sustained after the project has been closed.

– Provide consistent level of service to the customer (e.g. CTQ)
– Provide direction for improvement activities (further improvement)
– Hold the gains created by improvement activities
– Transfer ownership and knowledge to process owner

Overview of Control Phase

1. Implement ongoing measurement
   – How will the process be measured after the project?
   – Tools: Statistical Process Control, Control plans etc.
2. Standardize the solutions
   – Have the changes become ‘business as usual’?
3. Quantify the improvement
   – Has the project goal been achieved?
   – Tools: Hypothesis testing, Statistical Process Control, etc.
4. Close the Project
   – Ensure the project has a clear closure process
   – Tools: Project report, Closure action log, etc.

Six Sigma Project Closure



- Project objective is met
  - For example, production yield target, labor / machine efficiency and cost reduction etc.
- Critical process parameters are identified and verified.
- Improvement is confirmed (consistent in a period of time).
- Further improvement requires new Six Sigma initiative due to project timeline and resources.

Improvement & Changes in Organization

- Policy changes
- New Standards
- Modify procedures
- Modify quality appraisal and audit criteria
- Update prices and contract bid models
- Change engineering drawings
- Change manufacturing planning
- Revise accounting systems
- Revise budgets
- Revise manpower forecasts
- Modify training
- Change information systems

Control Techniques

- Monitoring
  - To ensure that the process is in control
  - To provide opportunities for future improvement
- Standardizing
  - To ensure that “best practices” are adopted as the standard and utilized at each step
- Documenting
  - To ensure that the recommended actions developed in the Improvement phase are shared and officially implemented

Control Phase Steps

- Plan
  - Update FMEA
  - Develop a Process Control Plan
  - Prepare for transition
    - Project Transition Action Plan

- Execute
  - Mistake proofing
  - Control and monitor the process - SPC
  - Monitor the product yield, defect per unit, DPPM (defect per million opportunity)

Pre-Control

Pre-control is an active process control tool used to quickly check the status of a process.

Pre-control allows one to know:

1) when the process can be run (after five consecutive pieces pass).

2) when to adjust the process.

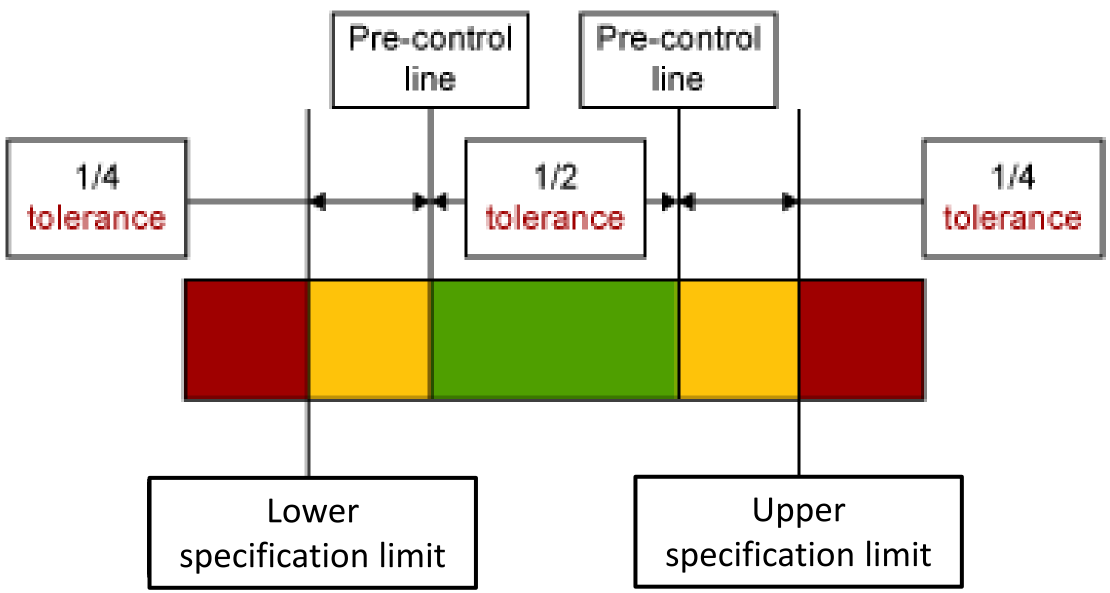
3) when sampling is safe to use.

4) when the process needs attention.

5) when to leave the process alone.

Pre-Control Technique

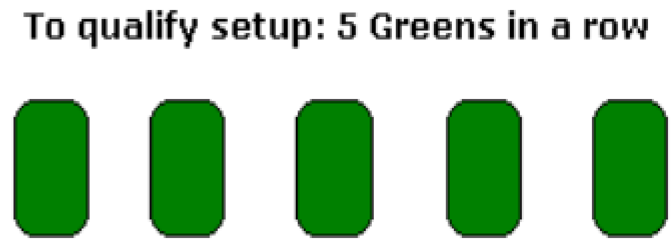
The idea behind pre-control is to divide the total tolerance into zones. The two boundaries within the tolerances are called “Pre-Control lines” as shown below. The location of these lines is halfway between the center of the specification and specification limits. It can be shown that 86% of parts will be inside the P-C lines with 7% in each of the “yellow zones, if the process capability Cpk = 1.



PRE-Control Rules

To qualify parts during setup:

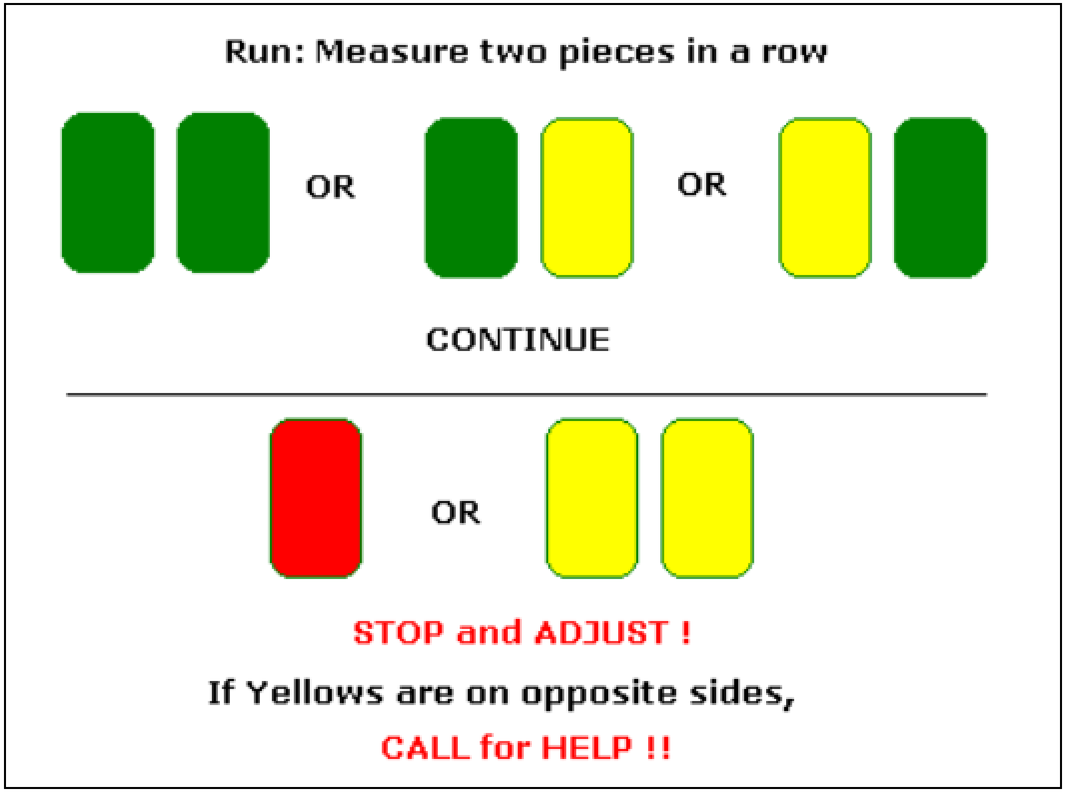
- If five consecutive pieces are in Green zone, set-up is ok to run
- If one yellow, restart counting
- If two consecutive yellows, adjust the process
- If one reading is red, adjust the process



PRE-Control Rules

After qualification, sample two consecutive pieces A and B.

- If both are green or one is yellow and the other is green, continue.
- If both A and B are yellow on the same side, adjust the process. If yellows are on the opposite sides, call for help as this may require review of the process.
- If any of the pieces is red, adjust the process. In such a case, parts produced from the last sampling must be inspected.



What is a Process Control Plan ?

A Control Plan lists all product and process inspection points required to deliver a defect-free outcome, and is essential for maintaining process control over the long run.

- The intent of *process control* is:
  - Run the process on target
  - Minimize variation about the target
  - Minimize required adjustments and over-control
- The purpose of *a process control plan* is:
  - Initiate process improvements
  - Highlight areas requiring extra education
  - Provide one-stop document for control information

Develop a Process Control Plan

- Possible Inputs to the Process Control Plan:
  - Final process map
  - Failure Mode and Effect Analysis (FMEA)
  - Process Documentation
  - Measurement System
  - Capability studies (Cp, Cpk etc..)
  - Maintenance schedules and procedures
  - Training materials
  - Troubleshooting guides
  - Calibration schedules
  - Standard Operation Procedure
  - Out-of-control action plans

Comparing Control Plan with FMEA

- Recall P05 FMEA
- The components of a typical control plan can be seen to summarize many of the essential Six Sigma tools;
- A Control Plan has similar elements to a FMEA, but both documents have a distinct role to play as process management tools.
- FMEA are used to identify and assess risks, and to document existing controls in a process. Control plans provide increased detail on the measurement controls that will remain in place as ‘business as usual’ after a Six Sigma project is closed.

Components of A Process Control Plan

- Process Step
  - From Process map, FMEA, C&E and etc..
- What is to be controlled
  - Input or output
- Specification Limits/ Requirements
  - Target and specification for each critical input or output (customers' requirement, process improvement activities)
- Measurement Method
  - Process or machine for measurement. E.g., GO/ NO Gauge, Caliper, Sensor, Weighing scale and etc
- Control Method
  - Statistical Process Control, Mistake-proofing

Components of A Process Control Plan

- Sample Size and Frequency
  - Statistical consideration: how well the sample can represent the population, what is the acceptable percentage error – it can be calculated.
  - Operational consideration: cost and resources (operators and measurement system, natural of measurement – destructive?), customer requirement, “Online” or “Offline” Measurement system etc..

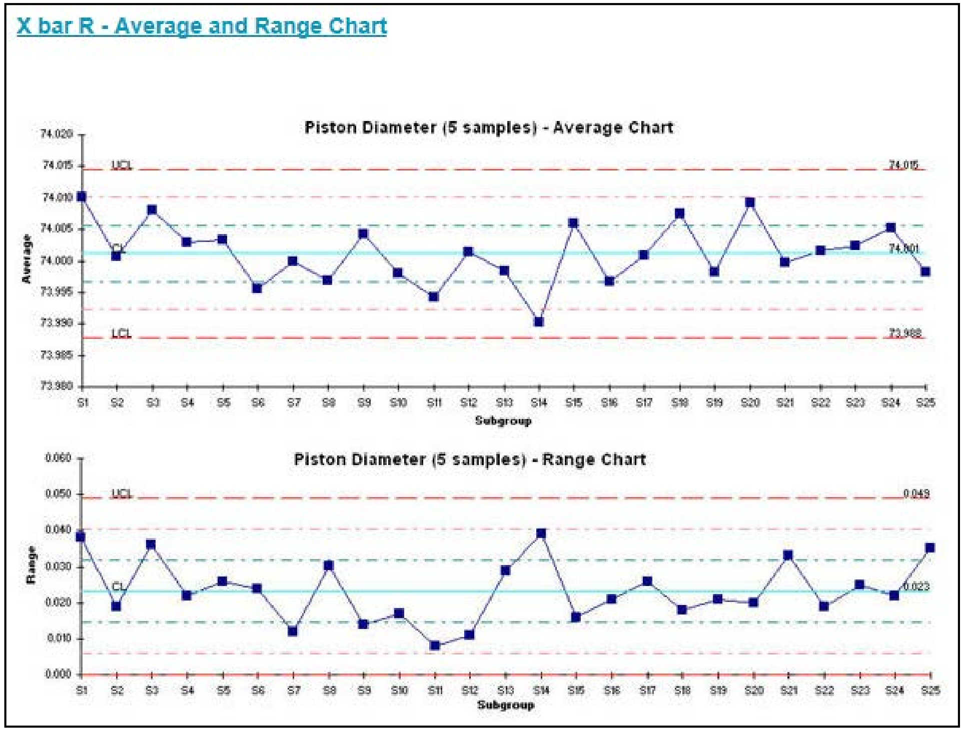
- Who/ What does the Measuring
  - Who or what is responsible to ensure the data is taken and is correct?

Components of A Process Control Plan

- Where to record?
  - Where does the data reside? Computer Database, charts, both?
- Decision Rule/ Corrective Action
  - What happens when the process is out of control?
  - Who takes the action
- Standard Operation Procedure (SOP's)
  - What documentation governs this control process?

Control Charts in Control Phase

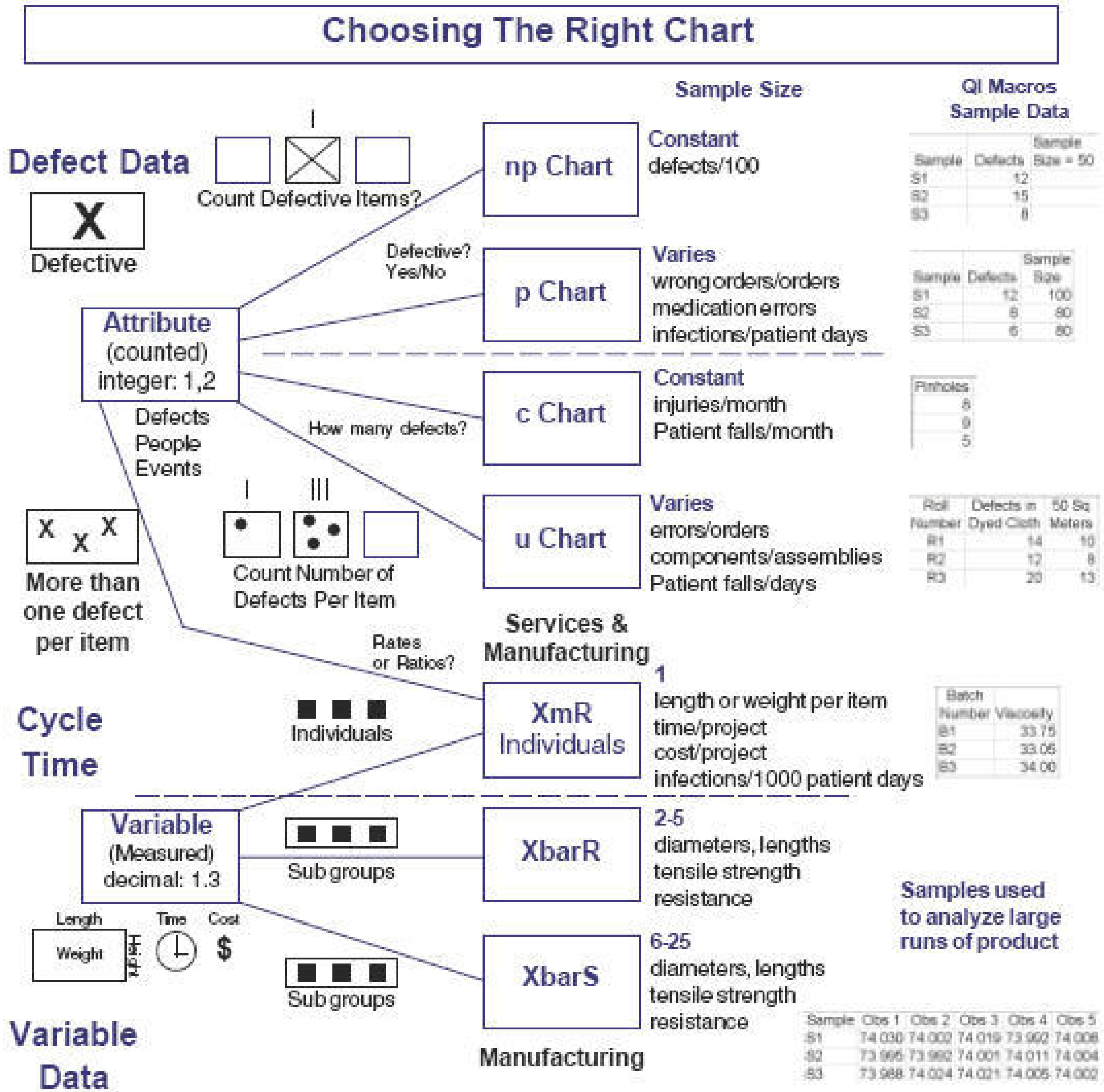
The control chart is a graph used to study how a process changes over time. Data are plotted in time order. A control chart always has a central line for the average, an upper line for the upper control limit and a lower line for the lower control limit.



Use of Control Charts in Control Phase

- When controlling ongoing processes by finding and correcting problems as they occur.
- When predicting the expected range of outcomes from a process.
- When determining whether a process is stable (in statistical control).
- When analyzing patterns of process variation from special causes (non-routine events) or common causes (built into the process).
- When determining whether your quality improvement project should aim to prevent specific problems or to make fundamental changes to the process

Use of Control Charts in Control Phase



Monitoring & Supervision of Improved Processes

- Monitoring of improved process
  - To ensure that the improved process is in control after changes have been made

- Supervision of improved process
  - To ensure that the improved process is performing as it is intended

- Documentation
  - To ensure that all necessary documents (control charts, operating instructions) have been updated for the improved process.
  - Control plan is a living document and designed to be maintained and updated, e.g. in the event of a key personnel change / turnover, etc.

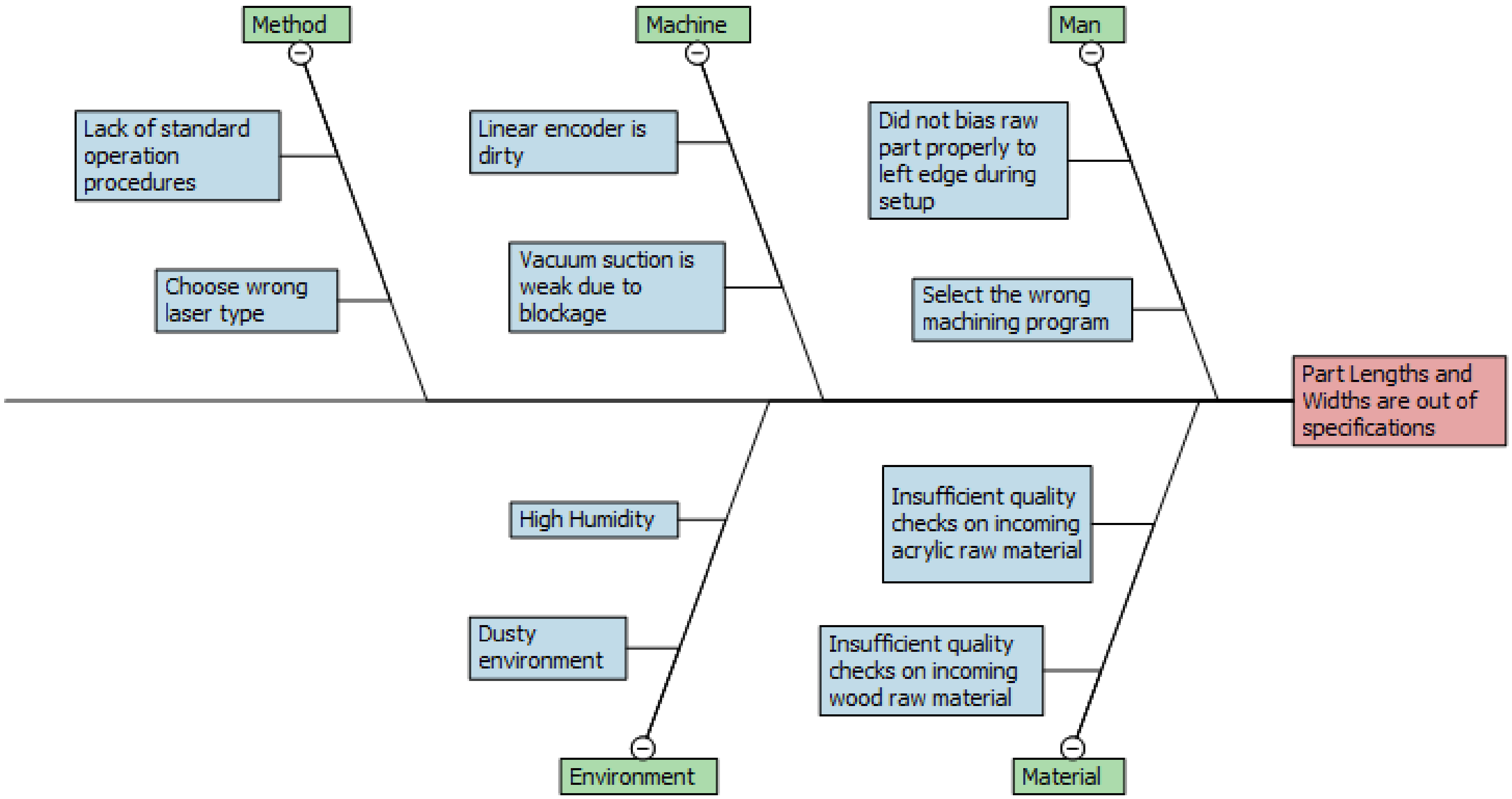
Quality System Audit
- Another Function of Process Control Plan

- Process audits are a requirement of most quality system standards, such as ISO 9001:2015. As such, Process Control Plan will be used as a checklist during audit.

- In manufacturing where companies has attained the ISO 9001:2015 requirements, work instructions and visual aids are normally referenced from the Control Plan, along with "everything" associated with the production process.

Problem 12
Suggested Solution

Fishbone Diagram



Cause-Effect Action Plan

Potential Failure Mode(s)	Problem Areas			Suggested Action Items / Any Design Controls to be put in place?
	Potential Effect(s) of Failure	Affinity	Causes	
Cut-out is of wrong shape	Dimensions X and / or Y are out of specifications	Man	Did not bias raw part properly to left edge during setup	- Supervisor to make sure operators follow all procedures properly
First columns of parts have Xmm of missing material		Man	Select the wrong machining program	- Trainer to provide detailed trainings to make sure all operators are well trained to carry out the operations correctly.
Laser cut edges appeared jagged		Machine	Linear encoder is dirty	- Perform regular cleaning of linear encoder especially after having perform multiple material cutting
Part appeared to not sit firmly during cutting		Machine	Vacuum suction is weak due to blockage	- Implement Total Productive Maintenance (TPM) programme, ensure all functional parts are working
Laser cut edges appeared blunt		Machine	Lens blurred due to coating of dust over time	- Replacement of lens
Part is too thick / hard to be cut through in one go		Method	Lack of standard operation procedures	- Review procedures to make it clearer and easier for operators to understand and follow.
Fail to engrave on surfaces with curvature		Method	Choose wrong laser type	- Design Poka Yoke device to mistake proof improper part setup
Acrylic material has uneven surface finish / thickness		Material	Insufficient quality checks on incoming acrylic raw material	- Tighten incoming quality checks (IQC) to be more stringent to ensure only good quality raw material parts of the required dimensions according to specifications are
Wood material chip off after laser cut / engrave		Material	Insufficient quality checks on incoming wood raw material	- Tighten incoming quality checks (IQC) to be more stringent to ensure only good quality raw material parts of the required dimensions according to specifications are
Part warp after kept in storage over a period		Environment	High Humidity	Install humidity control system to regulate humidity level in material storage area
Part surface covered with dust after kept in storage over a period		Environment	Dusty environment	Perform 5S to minimize dust from collecting on surface of material

Pre-Control Lines (part width)

Part length: 15+/-0.2mm

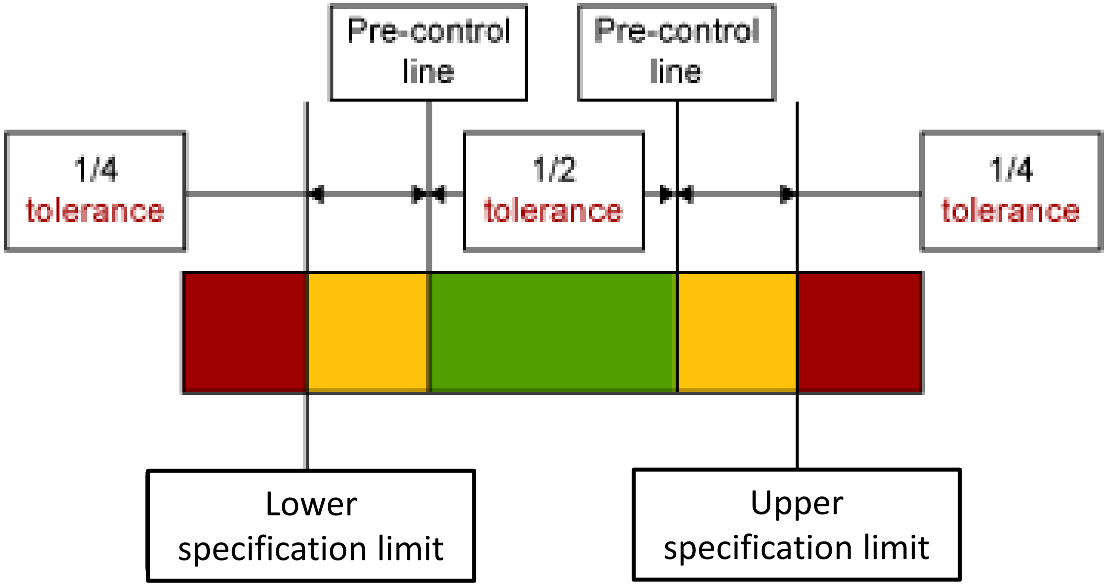
Lower spec limit : 14.8mm

Upper spec limit : 15.2mm

Pre-control tolerance = 0.2/2 mm= 0.1mm

Pre-control lower limit = 15 – 0.1mm = 14.9mm

Pre-control upper limit = 15 + 0.1mm = 15.1mm



Pre-Control Lines (part length)

Part length: 45+/-0.6mm

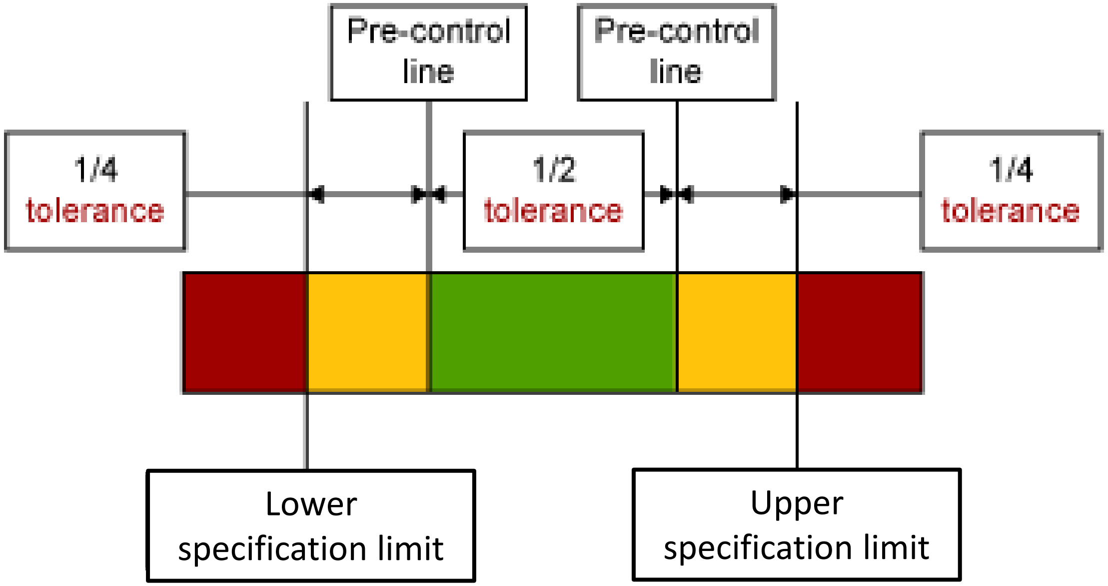
Lower spec limit : 44.4mm

Upper spec limit : 45.6mm

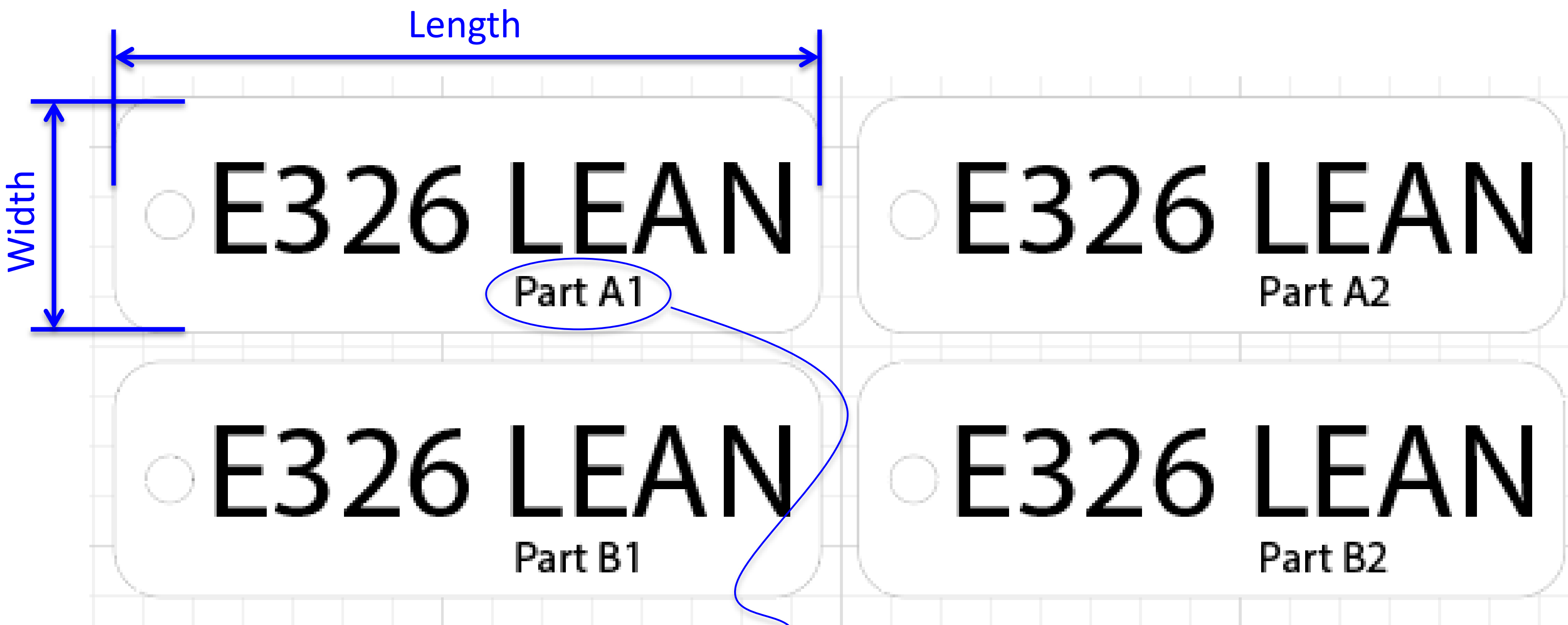
Pre-control tolerance = 0.6/2 mm= 0.3mm

Pre-control lower limit = 45 – 0.3mm = 44.7mm

Pre-control upper limit = 45 + 0.3mm = 45.3mm



Pre-Control Plan (measure length, width of parts)



					LSL	PCLL	Nominal	PCUL	USL
		Length							
		Width			14.80	14.90	15.00	15.10	15.20
Inspector Name	**Batch**	**Dimension**	**Part 1**	**Part 2**	**Red**	**Yellow**	**Green**	**Yellow**	**Red**
	A	Length			LSL	PCLL	Nominal	PCUL	USL
		Width			14.80	14.90	15.00	15.10	15.20

Pre-Control Plan

Specifications: Part Length: 45.0+/-0.6mm **USL:** Upper Specification Limit = Nominal + Tolerance **PCUL:** Pre-Control Upper Limit = Nom + 0.5 Tolerance
Part Width: 15.0+/-0.2mm **LSL:** Lower Specification Limit = Nominal - Tolerance **PCLL:** Pre-Control Lower Limit = Nom - 0.5 Tolerance

Decision (for X and Y):
a. Continue process
b. Stop process, Adjust
c. Stop process, Adjust, parts from last sampling be inspected
d. Call for help to review process

	LSL	PCLL	Nominal	PCUL	USL
Length	44.40	44.70	45.00	45.30	45.60
Width	14.80	14.90	15.00	15.10	15.20
	Red	Yellow	Green	Yellow	Red

Inspector Name	Batch	Dimension	Part 1	Part 2		Decision
David	Example	Length	45.40	44.80	44.80, 45.40 (LSL, PCLL, Nominal, PCUL, USL)	a
		Width	15.00	15.00	15.00, 15.00 (14.80, 14.90, 15.00, 15.10, 15.20)	a
Everyone	Practice	Length	45.60	45.20	45.20, 45.60 (LSL, PCLL, Nominal, PCUL, USL)	c
		Width	15.10	15.15	15.10, 15.15 (14.80, 14.90, 15.00, 15.10, 15.20)	b
	A	Length	45.70	45.00	45.00, 45.70 (44.40, 44.70, 45.00, 45.30, 45.60)	c
		Width	15.00	15.30	15.00, 15.30 (14.80, 14.90, 15.00, 15.10, 15.20)	c
	B	Length	44.50	44.50	44.50, 44.50 (44.40, 44.70, 45.00, 45.30, 45.60)	b
		Width	14.70	14.70	14.70, 14.70 (14.80, 14.90, 15.00, 15.10, 15.20)	c
	C	Length	44.50	45.40	44.50, 45.40 (44.40, 44.70, 45.00, 45.30, 45.60)	d
		Width	14.70	14.90	14.70, 14.90 (14.80, 14.90, 15.00, 15.10, 15.20)	c
	D	Length	45.00	45.40	45.00, 45.40 (44.40, 44.70, 45.00, 45.30, 45.60)	a
		Width	15.00	14.90	14.90, 15.00 (14.80, 14.90, 15.00, 15.10, 15.20)	a
	E	Length	45.70	45.00	45.00, 45.70 (44.40, 44.70, 45.00, 45.30, 45.60)	c
		Width	15.00	14.70	14.70, 15.00 (14.80, 14.90, 15.00, 15.10, 15.20)	c

Control Plan

CONTROL PLAN				
Control Plan Number SP1288-23		Key Contact/Phone David / 91234567	Date (Orig.) 2/1/2018	Date (Rev.) 1/1/2018
Part Number/Latest Change Level 2323-00 Rev 1		Core Team Lionel Lim, Titus Lee, James Lai, David Neo	Customer Engineering Approval/Date (If Req'd.) 12/1/2018	
Part Name/Description Souvenir		Supplier/Plant Approval/Date 2/1/2018	Customer Quality Approval/Date (If Req'd.) 12/1/2018	
Supplier/Plant Epilog	Supplier Code R11	Other Approval/Date (If Req'd.) N/A	Other Approval/Date (If Req'd.) N/A	

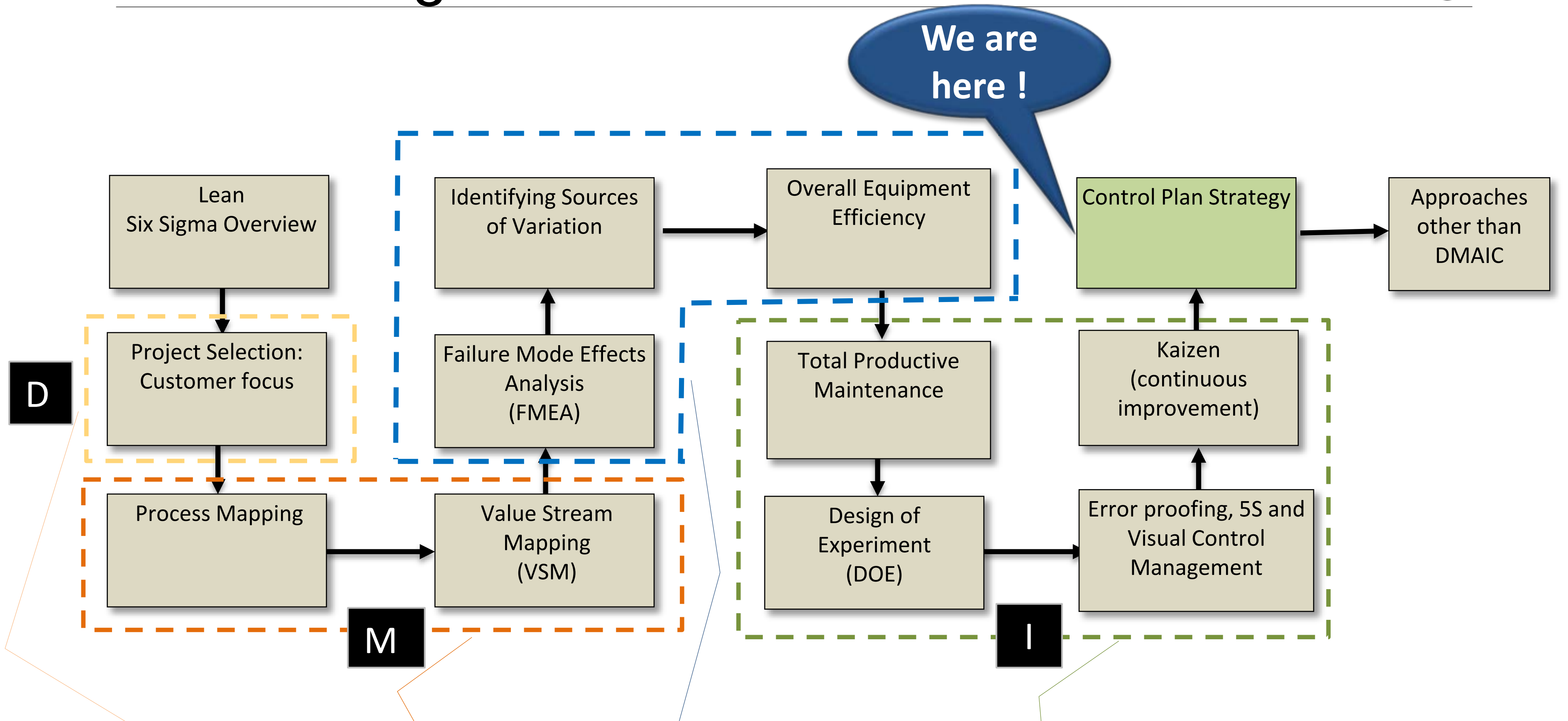
PART/ PROCESS NUMBER	PROCESS NAME/ OPERATION DESCRIPTION	MACHINE, DEVICE JIG, TOOLS FOR MFG.	CHARACTERISTICS			CTQ?	METHODS					REACTION PLAN
			NO.	PRODUCT	PROCESS		PRODUCT/PROCESS SPECIFICATION/ TOLERANCE	EVALUATION/ MEASUREMENT TECHNIQUE	SAMPLE SIZE	SAMPLE FREQ.	CONTROL METHOD	
1	Part bias and aligned to edges	All engraving / cutting jobs	NA	Alignment	Part setup	Y	Part aligned accordin	Visual Check	NA	During every new	Supervisors to ensure	Remove part and re-setup properly.
2	Inspection of unusual shapes / edges	All engraving / cutting jobs	NA	Part dimensions	Laser cutting	Y	X: 45.0 +/- 0.6mm Y: 15.0 +/- 0.2mm	Coordinate-Me	3 pcs	Every hour	In-Process Quality Check	Stop production and investigate root cause.
3	Replacement of machine toolings like lens	Machine	NA	Wear & Tear	Tool, lens change	Y	New toolings, lens to	Tool life chart	NA	Daily (Every Mornin	Supervisors to ensure	Worn out toolings to be replaced as soon as possible.
4	Machine tooling temperature control	All engraving / cutting jobs	NA	Thickness	Thickness mon	Y	Thickness as per ste	Thickness Mor	NA	Continuously	Automatic control by in-built sensors	Alarm sound off if exceed the thickness limit, operator to stop operation, check thickness of raw part.
5	Incoming inspection of raw materials	NA	NA	Defects & dimensions	IQC	Y	According to specific	Visual inspect	1	For every new batches of raw materials delivered by new suppliers	Material Quality Certification required from suppliers	Return to supplier
6	Humidity Control	Air-Conitional System	NA	Humidity	Air-Quality Con	Y	RH <35%	Humidity / Tem	NA	Continuously	Automatic control by in-built sensors	Alarm sound of if exceed the RH limit contact Estate Officers to verify and rectify.
7	Maintaining cleanlines of storage area	Storage area	NA	Cleanliness	Dust control	Y	Clear of dusts	Visual check	NA	Before starting each job	5S	Operators to clear any observed dusts off the parts

- Complete all necessary documentations in the Control Plan to guide the production on how to maintain the improved state, going forward.

Learning Objectives

- Describe the process of Six Sigma project handover to the process owner
- Recognize the Control Phase in Six Sigma methodology
- Apply Pre-Control and Process Control Plan in Six Sigma Control Phase
- Monitoring and supervision of improved processes

Overview of E326 Lean Manufacturing and Six Sigma



Identify improvement opportunity
Define-M-A-I-C

Establish project baseline and measurable
D-**Measure**-A-I-C

Extract useful information and identify variation in data
D-M-**Analyze**-I-C

Improve process/operations
D-M-A-**Improve**-C