054402 Design and Analysis

LECTURE 14: INTRODUCTION TO PRODUCT MANUFACTURING

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Ref: Seider, Seader and Lewin (2004), Chapter 19

Instructional Objectives

When this part of the course is completed, the student will:

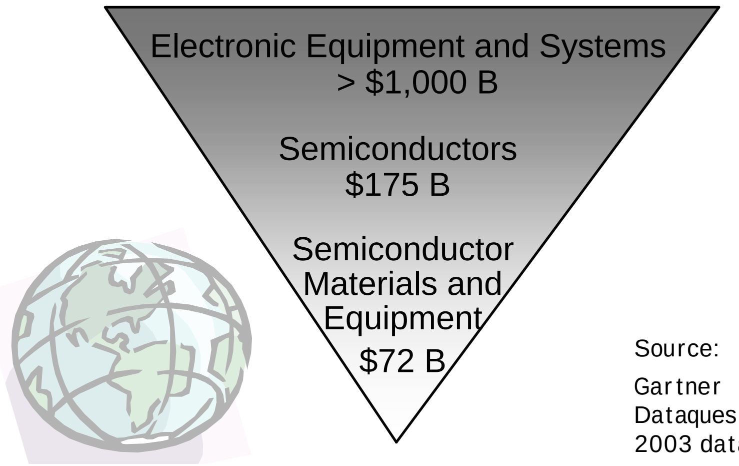
- ✰ Be able to define the Sigma Level of a manufacturing process
- ✰ Know the steps followed in product design and manufacture (DMAIC)
- ✰ Be able to qualitatively analyze a process for the manufacture of a product and know how to identify the CTQ step using DMAIC

Example Market – IC Industry

What do the following have in common?

- ☆ Discman
- ☆ VCR
- ☆ Video camera
- ☆ Digital Camera
- ☆ Cell phone
- ☆ Laptop

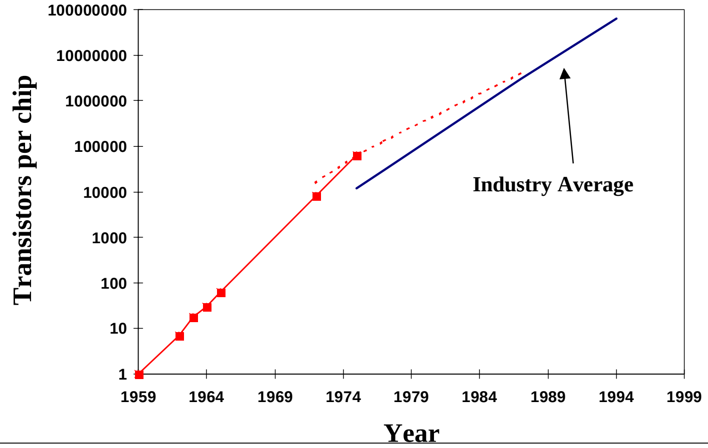
The Electronics "Food Chain"



Source:
Gartner Dataquest 2003 data

IC Production Capability

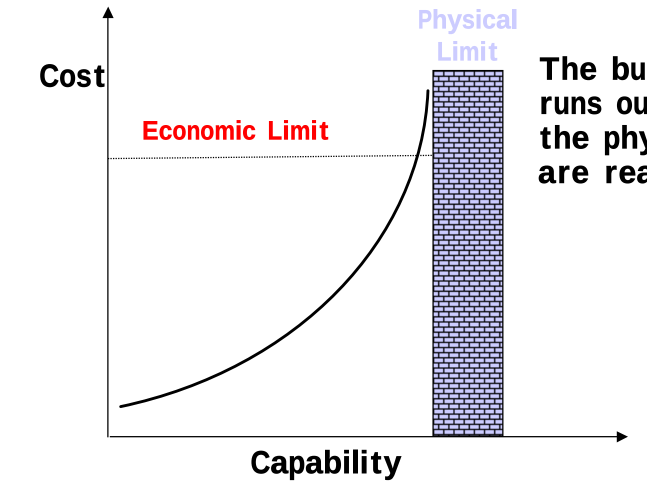
"Moore's Law"



Device Complexity Trends

Device	Year	Transistors	Chip Area per Chip (cm^2)
8086	1978	30K	0.34
80286	1981	120K	0.77
80386	1985	400K	1.0
486	1990	2M	1.8
Pentium	1993	3.5M	2.9
Pentium Pro	1995	5.5M	2.9

Technology vs. Economics



The budget always runs out before the physical limits are reached.

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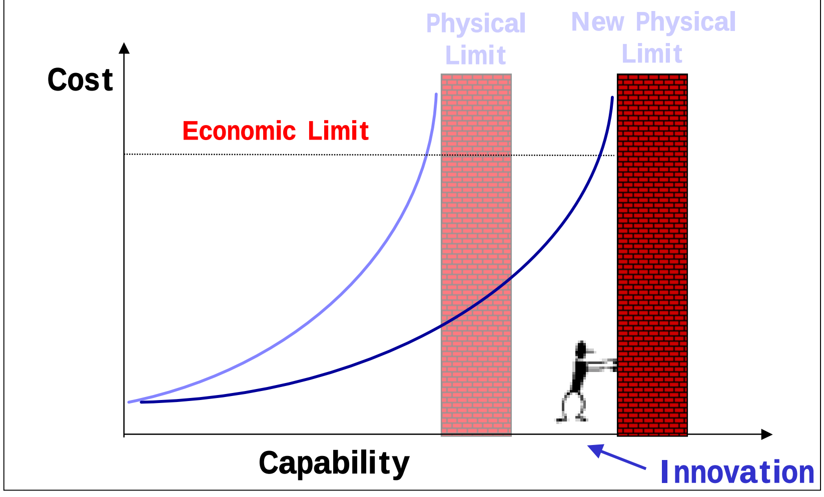
Technology vs. Economics



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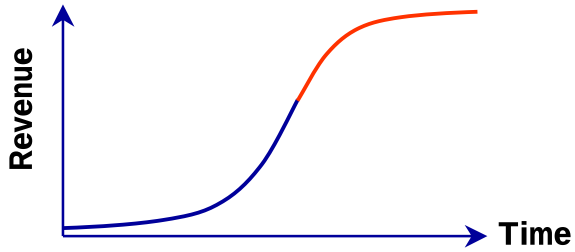
Implications of Moore's Law

What are the implications of blind faith in Moore's Law?

Our Fear:

- Exponential growth is just the first half of an "S" shaped curve



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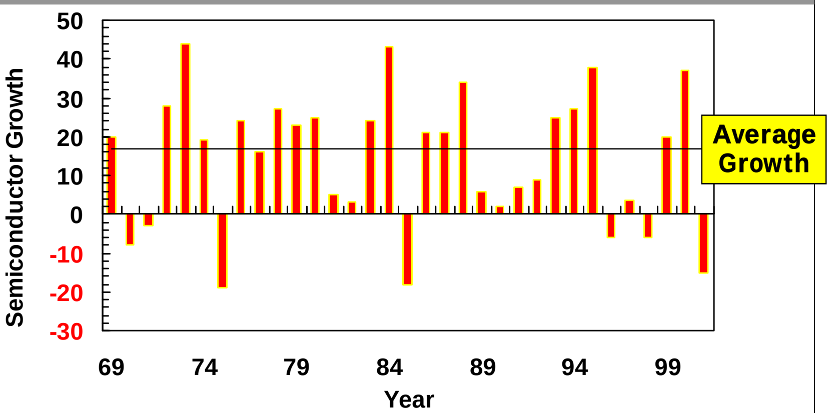
Implications of Moore's Law



Demand rise time: 3 - 6 months

Production rise time: 2 - 3 years

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Semiconductor Growth

Average Semiconductor Growth Rate:

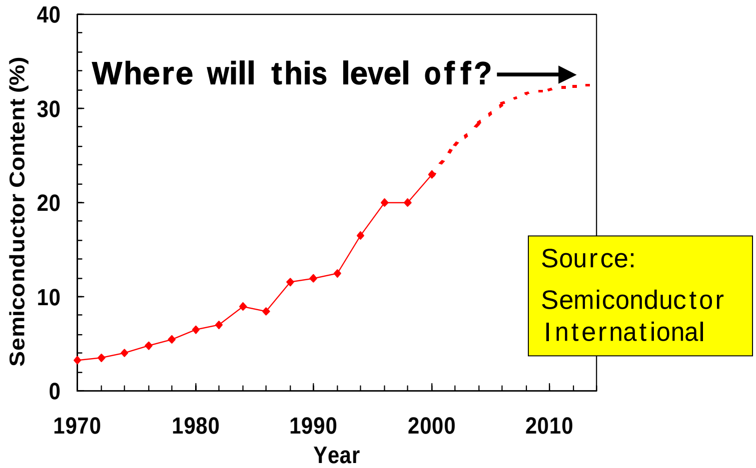
– 18%

Average Electronics Growth Rate:

– 9%

How long will this disparity last?

Semiconductor Content of Electronics



Industry Drivers – Push vs. Pull

- Market requires (push):
  - Smaller feature sizes desired
  - Larger chip area desired
  - Improved IC designs lead to innovations
- IC industry delivers (pull):
  - Lower cost per function (higher performance per cost)
  - New applications are enabled to absorb chips with new capabilities
  - Higher volumes produced

Class Exercise 1: Help Sell Chips!

Discuss the IC content of the following list of products, and suggest how the proportion of IC components can be increased in the next product release (three suggestions per product):

- ☆ Discman
- ☆ VCR
- ☆ Video camera
- ☆ Digital Camera
- ☆ Cell phone
- ☆ Laptop

Six-sigma in Product Manufacture

Definition: 6σ = “Six Sigma”

- a structured methodology for eliminating defects, and hence, improving product quality in manufacturing and services.
- aims at identifying and reducing the variance in product quality, and involves a combination of statistical quality control, data analysis methods, and the training of personnel.

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Six-sigma in Product Manufacture

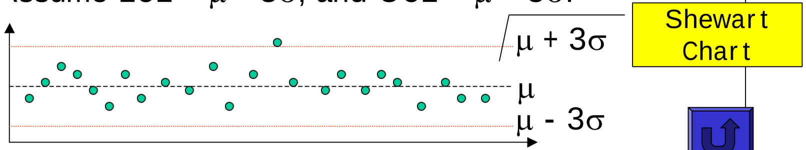
Definition: σ is the standard deviation of the value of a quality variable, x, a measure of its variance, assumed to be normally distributed:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$$

Average

Standard Deviation

Assume LCL = μ - 3σ, and UCL = μ + 3σ:



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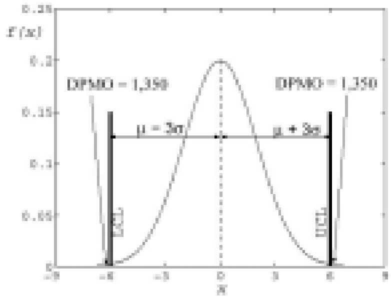
Six-sigma in Product Manufacture

At SD = σ, the number of Defects Per Million Opportunities (DPMO) below the LCL in a normal sample is:

$$\text{DPMO} = 10^6 \int_{\mu-3\sigma}^{\infty} f(x)dx = \tfrac{1}{2}10^6\left(1 - \int_{\mu-3\sigma}^{\mu+3\sigma} f(x)dx\right) = 1,350$$

The same DPMO will be above the UCL is a normal sample. The plot shows f(x) for σ = 2.



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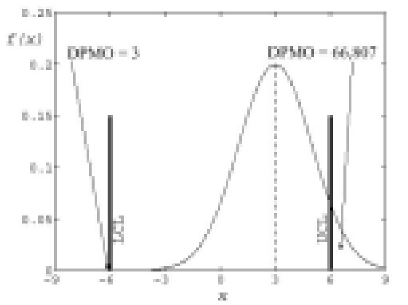
Six-sigma in Product Manufacture

In accepted six-sigma methodology, a worst-case shift of 1.5σ in the distribution of quality is assumed, to a new average value of μ + 1.5σ

In this case, the DPMO above the UCL = 66,807, with only DPMO = 3 below the LCL (σ = 2).



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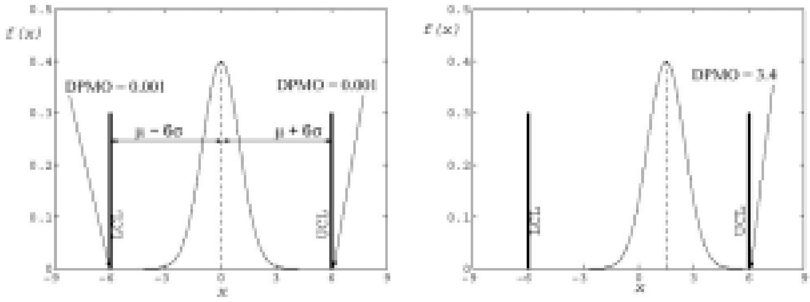
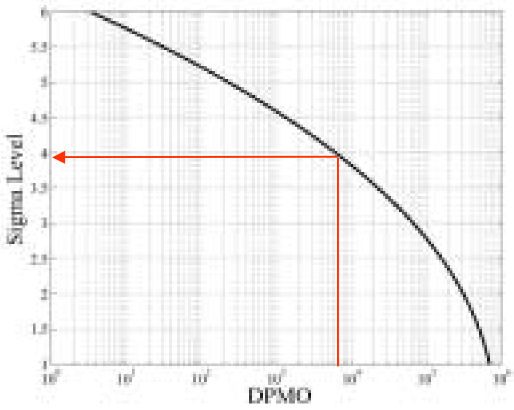
Six-sigma in Product Manufacture

However, if σ is reduced by ½ (σ = 1), so that LCL = μ - 6σ, and UCL = μ + 6σ, the DPMO for normal and abnormal operation are now much lower:



Sigma Level vs. DPMO



Sigma Level	DPMO
1.0	697,672
2.0	308,770
3.0	66,810
3.5	22,750
4.0	6,210
4.5	1,350
5.0	233
5.5	32
6.0	3.4

Computing the Sigma Level

Example: On average, the primary product from a distillation column fails to meet its specifications during five hours per month of production. Compute its sigma level.

Solution: $$\text{DPMO} = 10^6 \times \frac{5}{30 \times 24} = 6,944$$

The chart on slide 20 gives the Sigma level as 3.8.

Computing Throughput Yield

For n steps, where the number of expected defects in step i is DPMO_i, the defect-free throughput yield is:

$$\text{TY} = \prod_{i=1}^{n}\left(1 - \frac{\text{DPMO}_i}{10^6}\right)$$

If the number of expected defects in each step is identical, then TY is:

$$\text{TY} = \left(1 - \frac{\text{DPMO}}{10^6}\right)^n$$

e.g., in the manufacture of a device involving 40 steps, each operating at 4σ ($\equiv$ DPMO=6,210), then:

$$\text{TY} = (1 - 0.00621)^{40} = 0.779$$

i.e., 22% of production lost to defects! (overall 2.3σ)

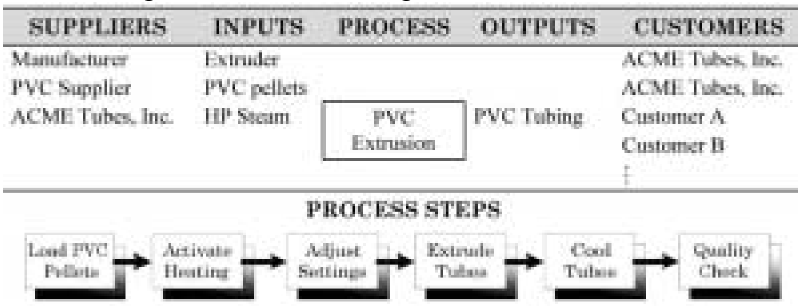
Monitoring and Reducing Variance

A five-step procedure is followed - Define, Measure, Analyze, Improve, and Control - DMAIC:

- o Define: A clear statement is made defining the intended improvement. Next, the project team is selected, and the responsibilities of each team member assigned. To assist in project management, a map is prepared showing the suppliers, inputs, process, outputs and customers (referred to by the acronym, SIPOC).

Monitoring and Reducing Variance

For example, a company producing PVC tubing by extrusion needs to improve quality. A SIPOC describing its activities might look like this:



Monitoring and Reducing Variance

- Measure: The CTQ variables are monitored to check their compliance with the UCLs and LCLs. Most commonly, univariate statistical process control (SPC) techniques, such as the Shewart chart, are utilized. The data for the critical quality variables are analyzed and used to compute the DPMO and the sigma level.

Continuing the PVC extrusion example, suppose this analysis indicates operation at 3σ, with a target to attain 5σ performance.

Monitoring and Reducing Variance

- Analyze: To increase the sigma level, the most significant causes of variability are identified, assisted by a systematic analysis of the sequence of manufacturing steps. This identifies the **common root cause** of the variance.

In the PVC extrusion example, make a list of possible causes for product variance:

- Variance in quality of PVC pellets
- Variance in volatiles in pellets
- Variance in steam heater operating temperature

Monitoring and Reducing Variance

- Improve: Having identified the common root cause of variance, it is eliminated or attenuated by redesign of the manufacturing process or by employing process control.

  Continuing the PVC tubing example, suggest how the variance in product quality can be reduced.
  - Redesign the steam heater.
  - Install a feedback controller to manipulate the steam valve to enable tighter control of the operating temperature.
  - Combination on the above.

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Monitoring and Reducing Variance

- Control: After implementing steps to reduce the variance in the CTQ variable, this is evaluated and maintained. Thus, steps M, A, I and C in the DMAIC procedure are repeated to continuously improve process quality. Note that achieving 6σ performance is rarely the goal, and seldom achieved

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Six Sigma for Design

The DMAIC procedure is combined with ideas specific to product design to create a methodology that assists in applying the six-sigma approach to product design. Again, a five-step procedure is recommended:

Step 1: **Define Project:** The market opportunities are identified, a design team is assigned, and resources are allocated. Typically, the project timeline is summarized in a Gantt chart.

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Six Sigma for Design

Step 2: **Identify Requirements:** As in DMAIC, the requirements of the product are defined in terms of the needs of customers.

Step 3: **Select Concept:** Innovative concepts for the new design are generated, first by "brainstorming." These are evaluated, with the best selected for further development.

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Six Sigma for Design

Step 4: **Develop Design:** Often several teams work in parallel to develop and test competing designs, making modifications as necessary. The goal is to prepare a detailed design, together with a plan for its management, manufacture, and quality assurance.

Step 5: **Implement Design:** The detailed designs in Step 4 are critically tested. The most promising design is pilot-tested and if successful, proceeds to full-scale implementation.

Example: Design Espresso Machine

Espresso coffee is prepared in a machine that injects high-pressure steam through a cake of ground coffee. In a conventional machine, the user manually loads ground coffee into a metal filter cup, locks the cup under the steam head, and the opens the steam heater.

- ✰ Identify all of the sources of variance in the quality of the coffee produced using the above machine.
- ✰ Suggest improvements in the design to reduce the variance in the quality.

Example: Design Espresso Machine

For example, this is a SIPOC for a company making espresso machines that seeks to release a new model that guarantees higher quality product.

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
Customers	Coffee beans	Making Espresso Coffee	Ground Coffee	Customers
Our company	Espresso machine		Espresso coffee	Customers

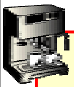
PROCESS STEPS

Grind Coffee → Pack Portafilter → Set Pressure → Dispense Water → Quality Check

Example: Design Espresso Machine

Measure: The CTQ variables are monitored to check their compliance with the UCLs and LCLs. Most commonly, univariate statistical process control (SPC) techniques, such as the Shewart chart, are utilized.

The data for the critical quality variables are analyzed and used to compute the DPMO and the sigma level.



Continuing the espresso machine example, suppose this analysis indicates operation at 3σ, with a target to attain 5σ performance.

Example: Design Espresso Machine

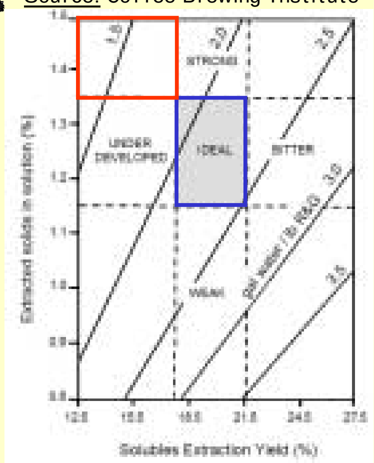
Analyze: To increase the sigma level, the important causes of variability are identified, assisted by a systematic analysis of the manufacturing sequence. This identifies the **common root cause** of the variance.

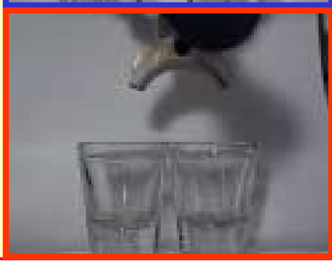
In the espresso machine example, the following is a partial list of possible causes for product variance:

- Variance in **freshness** of coffee beans
- Variance in **degree of grinding** of beans
- Variance in **packing** and **amount** of ground coffee used
- Variance in **water pressure**
- Variance in **quality** and **quantity of water** used

Example: Design Espresso Machine

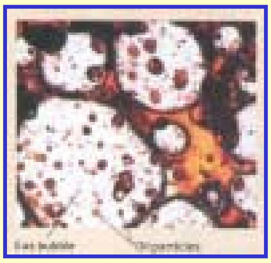
Source: Coffee Brewing Institute



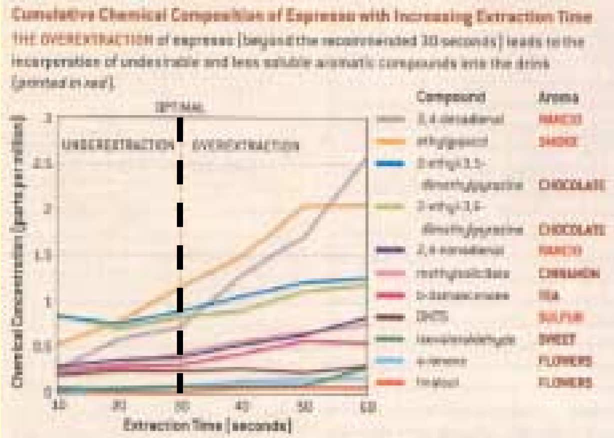


Example: Design Espresso Machine

Source: Ernesto Illy, Scientific American, June 2002, 72-77



Enlarged photograph of crema.



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Example: Design Espresso Machine

Improve: On identifying the common root cause of variance, eliminate or attenuated it by redesign of the or by employing process control.

Continuing the espresso machine example, how the variance in product quality can be reduced ?

- Install a water filter
- Install a water flow metering system to control the quantity of water used
- Install a pressure control loop to reduce the variance in pressure
- The other sources of variance that are not under the control of the manufacture of the espresso machine as described above. This suggests a new product…

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Class Exercise 2: Fortune Cookies

The movie shows the production line at the Golden Gate Fortune Cookie Company. Note that final "assembly" is manual, with the fortune slip placed inside the wafer, which is then folded.

- ✰ Identify all of the sources of variance in the quality of the fortune cookies produced using the above procedure.
- ✰ Suggest improvements in the design to reduce the variance in the quality.

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Summary

This part of the course has provided instruction on how to:

- ✰ Define the Sigma Level of a manufacturing process (Increased losses [DPMO] means decreased sigma level).
- ✰ Apply DMAIC in product design and manufacture.
- ✰ Qualitatively analyze a process for the manufacture of a product and know how to identify the CTQ step using DMAIC

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