Get the Skinny on LEAN Manufacturing

Author: Diane Walsh, Coginchaug Regional High School

Intended Audience: High School Math Students

Learning Goals

- Students will understand the basics of Kaizen, Six Sigma, and LEAN methodologies as applied to Control Systems Engineering.
- Students will be able to define the terms of Six Sigma, create a frequency histogram, and calculate the standard deviation of a normalized data set.
- Students will participate in a simple manufacturing process to develop a LEAN implementation by identifying and eliminating waste.
- Students will recognize the value of a collaborative process.

Standards

Common Core State Standards, Mathematics (2010)

Summarize, represent, and interpret data on a single count or measurement variable:
CCSS.MATH.CONTENT.HSS.ID.A.1
Represent data with plots on the real number line (dot plots, histograms, and box plots).

CCSS.MATH.CONTENT.HSS.ID.A.3
Interpret differences in shape, center, and spread in the context of the data sets, accounting for possible effects of extreme data points (outliers).

CCSS.MATH.CONTENT.HSS.ID.A.4
Use the mean and standard deviation of a data set to fit it to a normal distribution and to estimate population percentages. Recognize that there are data sets for which such a procedure is not appropriate. Use calculators, spreadsheets, and tables to estimate areas under the normal curve.

Next Generation Science Standards, 9–12 (2013)

HS-LS3-3. Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible.

HS-PS2-1. Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.

Science and Engineering Practices. Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.

Science and Engineering Practices. Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.

ITEEA Standards (2000)

12.P. Use computers and calculators to access, retrieve, organize, process, maintain, interpret, and evaluate data and information in order to communicate (9–12).

10.I. Research and development is a specific problem-solving approach that is used intensively in business and industry to prepare devices and systems for the marketplace (9–12).

Key Terms

histogram, Kaizen, LEAN, mean, normal distribution set, Six Sigma, standard deviation

Motivation / Engineering Connection

Prior to college, most students do not know what is means to be an engineer. Even for those who plan to major in engineering, most typically think in terms of a well-known branches of engineering: mechanical, electrical, civil, chemical, biomedical, aeronautical, and possibly computer or materials science. Newer specialties have evolved such as:

- Environmental Engineering
- Food, Agricultural, and Biological Engineering
- Industrial Systems Engineering

By the very nature of their names, students can gain a sense of understanding of the first two. However, the third one probably stumps them or is not immediately appealing due to the lack of understanding.

Industrial Systems Engineering is an interdisciplinary field of engineering and management to solve complex problems that oversee a manufacturing process. The job goes beyond the assembly line but delves into the parts suppliers, the distribution of a product, the employees, the processes, the machines, and even the manner in which a facility is designed.

An Industrial Systems Engineer studies, and looks to improve upon, work measurement, methods and operations, ergonomics, and inventory.

Engineers tackle work measurement usually via a time study to determine the capacity of a facility in terms of realistic works orders, delivery dates, and costs. Not only does a facility use this knowledge to determine its initial manpower but also to propose alternative methods or to identify the possibility of underperforming employees. They consider things like repetitive versus non-repetitive tasks and what that means for an employee in terms of productivity and mandatory breaks.

Industrial systems engineers also take a broader look and perform an operational analysis looking for possible work simplification and ways to make continuous improvements. This analysis looks at tooling and machinery, individual process layouts, the overall plant layout, and the workplace environments in general through ergonomics. Some consider ergonomics the bridge between the

engineer and the end-user of the product as it encompasses both the safety and comfort of the employee as well as the consumer.

The field is also responsible for inventory to maintain the proper balance of stock to optimize a company's material handling process.

Although the following activity is primarily concerned with LEAN manufacturing, a mini-lesson on three-big buzzwords is in order: Kaizen, Six-Sigma, and LEAN manufacturing. Some companies use all three depending on the situation.

Kaizen is a broad approach to running a company developed by a Japanese theorist. It is often described as a business culture, philosophy, or a mindset. It is not a specific tool but a way of operations that rewards ingenuity while practicing to minimize/eliminate waste (muda), find and reduce variation or inconsistency (mura), and identify strain on employees and unnecessary burden on equipment (muri). All employees are trained to operate with a Kaizen state of mind.

Six-sigma was developed by Motorola and focuses specifically on a company's final product(s). Six sigma is a tool or set of statistical analysis techniques that are used to minimize defects per opportunity. Instead of an overall mindset like Kaizen, Six Sigma is more like an end goal to minimize variation in an effort to strive for near perfection.

LEAN Manufacturing was derived from the Toyota Management System and focuses on a process or a set of processes with a goal of reducing waste and increasing speed and efficiency. LEAN is a management process in which manufacturing efficiency and product quality are equally important. A LEAN facility checks to ensure that each step of a process adds value to efficiency and/or quality. In a LEAN facility, all employees have a voice and each person is valued for their contributions, large or small.

The Math Behind Six Sigma

Have you ever asked a teacher if a grade would be curved? In your mind, you probably think of it as free or extra credit points being added. But do you know what it really means? Many data sets create a bell curve in which 68% of the data falls within plus or minus one standard deviation from the average, 95% of the data falls within two standard deviations, and 99% falls within 3 standard deviations. When a teacher curves a test grade, that teacher fits the data into a bell curve. This means students who scored at the top of the class, could potentially lose points or receive a letter grade that is lower than what they equate their numeric grade to be. It's easier to understand the bell curve and standard deviation using some data.

Suppose you surveyed students in your school about the tail length of their pet cats and collected 100 samples.

Length (cm)	Frequency
12	1
16	1
18	1
20	2
21	3
22	7
23	22
24	28
25	23
26	5
27	3
28	2
30	1
44	1

The average tail length from our sample is 23.97 cm, or 24 cm which is calculated as follows:

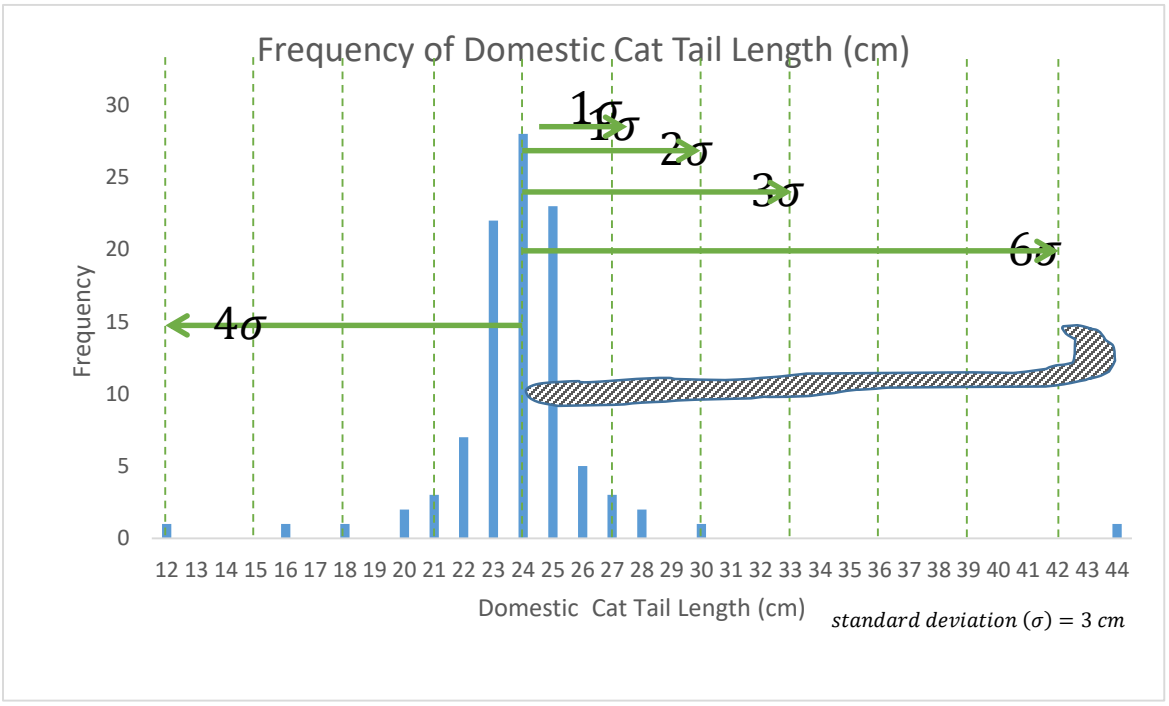
$$\frac{12 + 16 + 18 + 2(20) + 3(21) + 7(22) + 22(23) + 28(24) + 23(25) + 5(26) + 3(27) + 2(28) + 30 + 44}{100}$$

$$= 23.97 \approx 24$$

The standard deviation is calculated as follows:

$$\sigma = \sqrt{\frac{\sum(x - \bar{x})^2}{(n-1)}} = 2.99 \approx 3$$

Where $x = data\ sample$, $\bar{x} = sample\ mean$, and $n = sample\ size$



So what does this mean (no pun intended)? Standard deviation is a measure of spread from the average. If the standard deviation is low, it means the value is close to the average; if the standard deviation is high, it means the data is dispersed over a wide range of values. Note: standard deviation can only be used when the overall data resembles a bell curve. In other words, in a normal distribution, 68% of the data is generally within $\pm 1\sigma$, 95% within $\pm 2\sigma$, and 99% within $\pm 3\sigma$. If a data point falls within a few standard deviations, one can conclude that it is standard or typical. If a data point falls outside of a few standard deviations, one can also conclude that it is unusual or atypical.

Looking at the histogram and standard deviation markings, you should conclude that a 12 cm cat tail is unusual and a 44 cm cat tail is highly unlikely. According to the 2017 Guinness Book of World Records, the longest recorded cat tail belongs to Cygnus Regulus Powers, a silver Main Coon cat with a tail length of 44.66 cm!

Practice the Math

Provide everyone with a scrap of paper and a writing utensil. Give students one minute to list as many dog breeds as they can. Have students list the total on the board. After all of the data is collected and organized on the board, students should create a frequency histogram, calculate the mean and standard deviation and then determine how many standard deviations away from the average their own answer was. Was anyone outside three sigmas? Cautioning against any personal attacks, discuss why someone may be far below or far above the average in this activity.

If someone falls below, it might be due to an allergy or aversion to dogs. Perhaps someone suffered or witnessed a dog bite. Any of these cases may make someone disinterested in knowing particular dog breeds. On the flipside, someone may own several dogs, may attend dog shows, or even be employed by a veterinarian or kennel, or volunteer at a dog shelter.

Activity Pre-Assessment Questions

Picture a job you are familiar with (either your own or the job of someone you know well):

- Name an action that adds value to a process.
- Name an action that does not add any value and may be considered wasteful.
- Name a step in a process that a customer may consider wasteful but is necessary for a business.

Activity

Supplies:

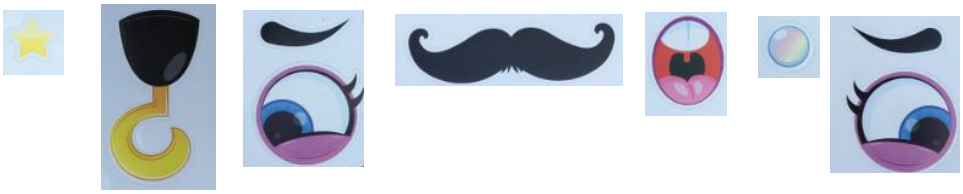
- Extra-large plastic Easter eggs
- Face stickers (eyes, nose, mouth, ears, glasses, mustaches)

Before the activity:

Divide students into groups and determine the number of necessary jobs: line supervisor, supplies handler, assemblers (as many as needed), quality control inspector, and warehouse associate. (You can add or subtract positions as needed.)

System 1

Have the system setup in a nonsensical manner so that students draw the conclusion that the workers/people are not the root problem but rather the organizational system. Place the materials far away from the assembly station, ideally in another room if possible. Have all of the different stickers cut apart from one another. For example, if pairs of eyes come together as one sticker, cut them apart so the materials handler has to search for the matching eyes. Place the warehouse of final products out in the hallway or in another room as well. Make sure there are many more stickers than are necessary.



- You have three minutes to assign jobs to positions and determine your system.
- The line supervisor cannot touch any materials except the final product
- Only the supplies handler can obtain materials for the assemblers.
- Record the time it takes assemble your line's four products.
- Only the warehouse associate can move the product to inventory.
- All products must be accompanied by the order ticket.

NOTE: All left/right designations are from the assembler's point of view. Do NOT use the large face/body sticker. Instead, use a plastic egg of the designated color for each product.

Clownfish	Dolphin	Elephant
		
Lion	**Monkey**	**Octopus**
		
Shark	**Tiger**	**Unicorn**
		

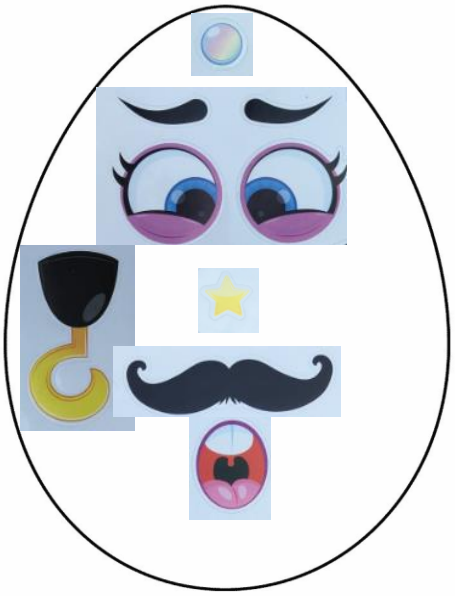
Group	Product 1	Product 2	Product 3	Product 4
1	Octopus: Purple egg Round eyes Oval mouth Star nose One bubble top of egg Left hook arm Mustache	Octopus: Yellow egg Red eyes Smile mouth One star above left eye Two bubbles right side of mouth Pirate hat	Unicorn: Pink egg Blue eyes Lipstick mouth Rainbow unicorn Crown Three hearts on right cheek Pink hair	Unicorn: Blue egg Pink eyes Plain unicorn White tooth smile Rainbow on forehead Rainbow hair Wand
2	Tiger: Yellow egg Green eyes White mouth Green tie Long bone across forehead Large blue star in middle of bone	Tiger: Blue egg Pink eyes Pink oval mouth Black hat Scars on left cheek RAWR sign right side of mouth	Elephant: Pink egg Green eyes Closed mouth sticking out tongue Hair bow Peanut on tongue Short trunk	Elephant: Purple egg Blue eyes Trunk with branch Black hat Gritted teeth mouth Yellow star centered in each eat
3	Shark: Blue egg Green eyes Captain's hat Red smiling mouth Two small fish in mouth Three bubbles to the right of mouth	Shark: Pink egg Blue eyes White mouth Seaweed under mouth Purple star on right cheek Three bubble to left of mouth	Monkey: Yellow egg Green eyes Banana hat Nose with round nostrils Mouth with tongue sticking out Banana bubble Mustache	Monkey: Purple egg Blue eyes Red bow in hair Nose with narrow nostrils One yellow star in the middle of each ear
4	Clownfish: Yellow egg Blue eyes Circular black mouth Snorkle with bubbles Purple shell on left fin Pink shell on right fin	Clownfish: Blue egg Goggles Smiling mouth Orange hat Blue fish facing left on left fin Blue fin facing right on right fin Three bubbles coming out of the right side of mouth	Lion: Purple egg Golden eyes Mouth without tongue Green bandana Whiskers on both sides One flower on each ear	Lion: Pink egg Blue eyes Mouth with tongue sticking out (no epiglottis) Safari hat One hear in each ear Scar on left cheek

Time:

Number of opportunities: (Students may need help in determining the number of opportunities. The egg and each sticker procured is an opportunity and the placement of each sticker is another opportunity. Example: Seven stickers and one egg procured and seven stickers placed results in 15 opportunities

Ratio of number of defects to total opportunities:

Determine any wasteful steps or problems with the process. List ways in which the process can be improved



System 2

Hopefully this system incorporates some, if not all, of the ideas students suggested for improvement. In System 2, the materials handler has an image to assist with procuring the necessary supplies. In addition, both the materials and final product locations are inside or near the classroom to save time. The stickers, while still jumbled, are slightly more organized in that sets of eyes are together. There should still be additional stickers.

However, to test that the improvements really are the process, and not the people, have the groups switch product lines!

Record the time to complete the four products.

Time:

Number of opportunities:

Ratio of number of defects to total opportunities: (Students may not realize that the eye stickers are together now thus eliminating one opportunity during procurement and one opportunity during placement.)

System 3

In this version, only the necessary parts are provided so there is no sorting. The supplies and warehouse areas remain inside or near the classroom. Groups should switch product lines again. However, this time, the line supervisor must eliminate at least two workers due to budget cuts! The line supervisor can also re-assign roles at this time in an effort to maintain or further streamline the process.

Record the time to complete the four products in the line.

Time:

Number of opportunities:

Number of defects per opportunity:

Post-Activity Assessment Write-Up

Summarize a process at your work or interview a family member about a process at their work. Write a paragraph about how you think the process could be improved or how they can eliminate waste. Be sure to include an introductory paragraph about the type of company (no names necessary) as well as the process you are critiquing.