**SEGR 4170 / EMGT 5170 – TOTAL QUALITY MANAGEMENT**

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*Project Report:*

***Defect Analysis of Electric Circuit Boards using Statistical Process Control (SPC) for Quality Management***

*Submitted to:*

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Team Calidad

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Abstract

This project is about considering a hypothetical company which manufactures Electric Circuit Boards (ECB). During the quality control the boards are checked for their quality and only two outcomes are expected: either the circuit boards are defective(have some defects/don’t work properly/do not pass the quality tests) or they pass the quality checks and are packaged to be shipped or placed in ready to use inventory. ECBs are important for any electrical equipment. Their quality statistics can make or break equipment and which in turn causes disruption in manufacturing, supply chain, logistics. The defective units are recorded, their output rate is monitored, and based on these analysis is done to check the quality of the ECBs. This analysis is done through the Statistical Process Control using the various quality tools and techniques for the enhancement of the quality control in the manufacturing. In today’s fast paced and cut-throat competition, delivering products at reasonable cost, consistent industry and customer quality standards is very important. In order to do this many companies have invested millions of dollars in their Quality Control (QC) division. Advanced machinery is utilized for doing quality tests and data is recorded. Using this vast data various quality management frameworks are implemented for keeping a tight grip over manufacturing quality and deliver products better than the competition and preserving one’s reputation in the market. This project aims to emphasize the use of Statistical Process Control (SPC) in electronics industry, manufacturing generic electric circuit boards in order to monitor their quality levels, discuss probable causes for their defective nature and provide solutions to them.

Introduction

In this project, there is no particular equipment (Mobile, Laptop, Industrial Machinery) that has been taken into consideration and generic type of defects found in the variety of circuit boards has been addressed and considered. The general defects of the ECBs have been addressed that are manufactured by a hypothetical company which gives the dataset for the defective units in the sampling of ECBs manufactured by that company. The analysis through the statistical process control using the different quality tools and techniques for enhancing the quality of the manufacturing and thus not leading to the disruption in the manufacturing process, supply chain and logistics is the main aim of this project.

When presented with a dataset having numeric defective rates, constant sampling rate for a product, how can the method of SPC, using control charts can be implemented for quality control is the vision of this project. After implementing the control charts, interpreting them for results and discussing the probable causes for these defective units being manufactured, providing solutions to these defective causes is part of this project vision. The team has also successfully performed Process Capability Analysis on the dataset to show if the actual process is performing good? Is stable? Its statistical significance, etc.

The project sufficiently encompasses all aspects of quality control and provides a comprehensive hands-on project experience for the entire team in the TQM domain. Also, the topic for the project belongs to a manufacturing setting which clearly aligns with the interest of most of the team members and can definitely play a vital point in their profile for future career opportunities.

Dataset and its Source

The dataset used for this project is of sample data on defects found in Electric Circuit Boards. The dataset does not belong to any particular device like mobiles, laptop, industrial machines. The dataset is of generic electric circuit boards consisting of electronic components like resistors, capacitor, transistors, diodes, etc. No specific company is associated with the manufacturing of the boards.

The dataset consists of 26 samples(S1...S26) each consisting of 100 products(n=100) tested with individual sample defective count. The dataset has been sourced from Statgraphics Stratus website. Statgraphics stratus is an opensource version of Statgraphics that runs within a web browser as online statistics analysis software. The company is located in The Plains, Virginia.

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Description automatically generated Company Website: https://www.statgraphics.com/

Data Analysis & Visualization

Table

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*Figure-1: Snapshot of Excel-Data*

* Total 26 Samples
* Each sample subgroup has 100 units
* Total units sampled 2600
* Total defects found in all 26 samples 516

# Basic Statistics of Data:

* Average defective units = 516/26 = 19.85 units/sample.
* Sample 20 has the maximum number of defective units = 39
* Sample 6 has the minimum number of defective units = 5
* Range = Max-Min = 34
* Median of data = 19
* Skewness = 0.57545
* Kurtosis = 1.09336

# Frequency Distribution of Data:

Chart

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* Using Pivot Chart function in Microsoft Excel we have plotted the frequency distribution of our data. We can see that 3 samples out of 26 have 16 & 24 defective units each.

*Figure-2: Freq. Distribution of*

*Data using Excel (Pivot Tabl*e)

# Test for Normality & Distribution Plot: **SAS 9.4v**

Using SAS 9.4 statistical software we have plotted the distribution of our data. SAS 9.4 has a single line code ‘proc univariate data’ for performing the test of normality to check the distribution of data. From the histogram and the whisker box-plot we can clearly see the data does not follow a normal distribution. But discrete (attribute) data usually does not follow a normal distribution. When we have an attribute data in which there are only two outcomes (Pass/Defective) it follows a **Binomial Distribution**. Also, the attribute sampling approach is valid regardless of the underlying of the data.

Chart

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Figure-3: Test of Normality and Histogram for Distribution of Data.

# Confidence Interval Calculations:

How many samples do you need to be “95% confident that at least 95%—or even 99%—of your product is good?

In ‘Attribute Sampling’ the sample size required to make a 95% confidence statement about a unit to be in-spec when your sample of size (n=100) has zero defectives is:-

For a reliability of 0.95 or 95%, n= 59 (rounding up)|For a reliability of 0.99 or 99%, n=299 (rounding up)

Hence for our sampling the reliability analysis yields a **97% Confidence**.

Selection Process for Control Chart

Diagram

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*Figure-4: Flowchart for Control Chart Selection*

There are various control charts. So, which one to use? The above flow chart helps to determine the right control chart to use for the right dataset. In the case of ECBs dataset, the type of data is attribute, it contains defective items, the sample size across all subgroups is constant (n=100). Hence P & nP charts are best suited for the dataset.

P-Chart

P-chart is a type of control chart used to monitor the proportion of nonconforming units in a sample, where the sample proportion nonconforming is defined as the ratio of the number of nonconforming units to the sample size, n [1].

# Assumptions while using P-Chart:

The binomial distribution is the basis for the p-chart and requires the following assumptions

* The probability of nonconformity p is the same for each unit.
* Each unit is independent of its predecessors or successors.
* The inspection procedure is the same for each sample and is carried out consistently from sample to sample.



Interpretation of Chart:

* 2 extreme points (Sample6 & 20) beyond control limits, i.e. 3σ: identifies subgroups that are unusual compared to other subgroups. Universally recognized as necessary for detecting out-of-control situations.
* Sets of 3 subgroups (sample 9 & 21) with at least 2 out of 3 points beyond 2σ: detects small shifts in the process.

# OC Curve:

Graphical user interface, histogram

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*Figure-5: Operating Characteristic Curve*

The operating characteristic curve shows the probability that the next point plotted on the control chart will remain inside the control limits as a function of the true process proportion. It therefore plots the probability that you will not get a signal from the chart, even though the process is not at the assumed center. It is useful in judging the effectiveness of the control chart in detecting drifts in the process away from the target. For example, suppose the true proportion moved to 0.375. The probability that the next point plotted on the chart will be within the control limits equals 0.163609.

# ARL Curve for p:

Graphical user interface, chart, histogram

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*Figure-6: Average Run Length (ARL) Curve*

This plot shows the average run length (ARL) for the selected control chart as a function of the process proportion. For example, if the process is actually running at the centerline, the chart will generate an out-of-control signal on average approximately every325 samples. If the process moves away from the centerline, the ARL will change as shown. You can use this plot to help select an adequate sampling plan to monitor your process.

nP-Chart

In [statistical quality control](https://en.wikipedia.org/wiki/Statistical_process_control), the np-chart is a type of [control chart](https://en.wikipedia.org/wiki/Control_chart) used to monitor the number of [nonconforming units](https://en.wikipedia.org/wiki/Nonconformity_(quality)) in a [sample](https://en.wikipedia.org/wiki/Sample_(statistics)). It is an adaptation of the [p-chart](https://en.wikipedia.org/wiki/P-chart) and used in situations where personnel find it easier to interpret process performance in terms of concrete numbers of units rather than the somewhat more abstract proportion [2].

The data pattern looks the same in both p an np charts. The difference is the vertical scale.

The difference between p and np-charts: np-charts are used for constant sample sizes only (for our dataset n=constant=100).



Interpretation of Chart:

• 2 extreme points (Sample6 & 20) beyond control limits, i.e. 3σ: identifies subgroups that are unusual compared to other subgroups. Universally recognized as necessary for detecting out-of-control situations.

• Sets of 3 subgroups (sample 9 & 21) with at least 2 out of 3 points beyond 2σ: detects small shifts in the process.

**Note: OC Curve and ARL Curve for nP chart will be same as P-Chart.**

Process Capability Analysis using Minitab

Process capability is defined as a statistical measure of the inherent process variability of a given characteristic. One can use a process-capability study to assess the ability of a process to meet specifications [3].

During a quality improvement initiative, such as [Six Sigma](https://asq.org/quality-resources/six-sigma), a capability estimate is typically obtained at the start and end of the study to reflect the level of improvement that occurred [3].

**Process Capability Study Objectives:**

The objective of a process capability study is to establish a state of control over the manufacturing process and then maintaining that state of control through time. Actions that change or adjust the process are frequently the result of some form of capability study [5].

With the modern technology and state of the art software’s like Minitab, jmp pro 15, crystal, etc. one can easily do capability analysis on large datasets. Our team has used **Minitab** for doing the Process Capability Analysis on the available attribute data following binomial distribution. We get the output in form of various graphs in graph window and in the session window. After the process capability analysis, we will do interpretations of the results.

Graphical user interface, chart

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*Figure-7: Process Capability Output Graph Window on Minitab.*

Graphical user interface, text, application, email

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*Figure-8: Process Capability Output Session Window on Minitab.*

# Interpretation of Results:

* The cumulative % Defective graph shows that the estimate of overall defective rate appears to be settling down to around 19.8%.
* In the summary stats table, the Parts Per Million (PPM) more than 198000 Electric Circuit Boards out of 1 Million boards are expected to defective.
* The Lower and Upper Confidence Interval (CI) indicates that the firm can be **95%** confident that the defective unit’s number will lie between 182,540 to 214,170.
* The Process **Z-value** is **0.8488** which is less than 2. (Z-Value < 2 :- Minimum value for a capable process).

Identifying different causes leading to manufacturing of defective circuit boards

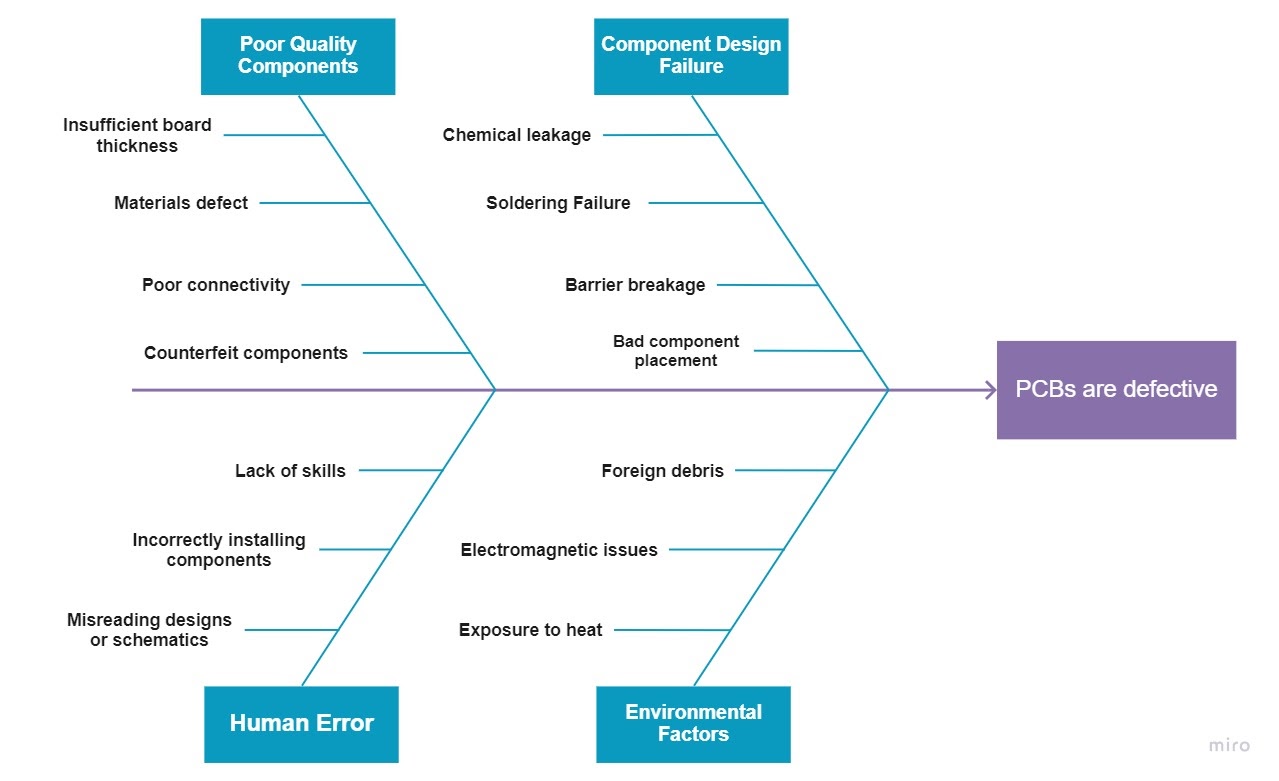
Once the data has been analyzed, respective control charts have been implemented and extreme points, trends, runs have been diagnosed, the next step in the Quality control Management is to find the root of the problem/cause leading to the defective board being manufactured. This step is called **Root Cause Analysis**. Most common root cause analysis tools are:

* Fishbone Diagram.
* The 5 Whys.
* Pareto Chart.
* Failure Mode and Effects Analysis (FMEA)

**For our project we will be using the Fishbone Diagram also called as Ishikawa Diagram.**

# Fishbone Diagram:

Fishbone diagram (Ishikawa Diagram) are cause and effect diagrams. Common uses are quality defect prevention to identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation. Causes are usually grouped into major categories to identify and classify these sources of variation [5]. The diagram is shaped as a fish bone with the problem at the fish’s head and the causes extending to the left as fishbones. The ribs branch off the backbone for major causes, with sub-branches for root-causes, to as many levels as required. The following fishbone diagram deals with the probable causes leading to defective electric circuit boards being manufactured.



*Figure-9: Cause and effect (Fishbone) diagram for defective circuit boards.*

Developing electronic circuit boards includes several stages which must be completed in a specific order. The process begins with a complete design in the form of a computer aided schematic. The design file is then used by automated machines to fabricate circuit boards from fiberglass and other raw materials. After holes are drilled into the circuit boards, they are assembled with electronic components, either by hand or automated machinery. Throughout the entire process it is critical to test for defects and make design improvements when necessary. Failing to address defects can lead to low yield rates, products prematurely failing in the field, or the inability to manufacture a circuit board at all. Let’s check the most common causes and provide a solution to each of these causes:

# Component Design Failure:

1.Soldering Failure

When looking at the many reasons why Electric Circuit Boards are defective, improper soldering is one of the most likely reasons as they might not work properly. The most common soldering defect is open joints. Open solder joints occur when the solder does not fully connect a component to the circuit board. There are multiple causes for why an open solder joint might occur. Three will be discussed here. The first cause is a lack of solder paste. If not enough solder is present, complete contact will not be maintained between the components and ECB during soldering. The next cause is allowing too much of a gap between the component and the board. If the component is fixed too far above the board, effective soldering becomes impossible. The last cause is defective solder paste. If the solder paste is not active enough, it will not heat up and adhere properly to the components and board. [6]

Solution: The best method to prevent open joints from occurring, is to ensure that the soldering “stencil” has the correct aspect ratio. This way, consistently, the correct amount of solder is applied to the ECBs.

2. Chemical Leakage

Chemical leakage is another of the common issues with ECBs and occurs due to the many different chemicals used during the manufacturing of ECBs. It is sometimes possible for tiny amounts of chemical residues to remain on the boards. Over time, the leakage of these chemical residues can corrode the metal components of the boards and cause the boards to short-circuit [7].

Solution: The way that chemical leakage is prevented is thorough cleaning of the boards. This is not guaranteed to prevent chemical leakage; however, it drastically reduces the chances of it occurring.

3. Component Barrier Placement

The barrier of a component is there to protect the component from the outside environment and also to give a way for the component to connect to the circuit. If this barrier is broken, then the component will become exposed to environmental factors such as oxygen and humidity, which can cause the component to age and then fail [8].

Solution: The way that breakages of the barrier are prevented, is to design the ECBs in a way that ample clearance is given to the barriers. That way, during the manufacturing process and transit, the barriers remain intact.

4. Bad Component Placement

ECBs have to be designed in a particular way in order for solder reflow to be performed smoothly. In some cases, component placement schemes will group passive parts together and orient the parts so that all of the common pins will connect to a single power bus. Passive parts with unbalanced metal connections between their two pins run the risk of floating on their pads or standing up in an effect known as “tombstoning” during solder reflow.

Solution: These defects can be prevented by properly designing the ECBs. “Tombstoning can be avoided by ensuring connection to the power bus is through a thinner connecting trace. This prevents large areas of metal flooding the pin. [9]

# Environmental Factors:

ECBs are used in countless different products and applications. As a result, ECBs face a variety of environmental factors when they are used as intended. For example, automobiles, which contain several ECBs, are exposed to outdoor conditions such as rain or below freezing temperatures. Some applications are more important than others, such as medical equipment, which requires a higher degree of performance. Understanding potential environmental risks, problems associated with those risks, and possible solutions is a critical aspect of quality assurance for ECBs.

1. Moisture and Debris

Inevitably, ECBs will come into contact with foreign debris at some point during its life cycle. This contamination can occur during assembly or when the product is used in the field. When dealing with the assembly of ECBs, the most common foreign debris are dust, fibers, hair, and moisture. When ECBs are introduced to foreign debris, it often results in malfunction or total product failure [10]. There are a few unique solutions to prevent the failure of electric circuit boards.

Solution: The best way to combat foreign debris in a **manufacturing setting** is to establish a safe environment for manufacturing. For example, ensuring that outsourced components and raw materials are stored in a climate-controlled area, free of any moisture or dust. When ECBs are being shipped or stored, they are more susceptive to moisture particles in the ambient air. Without proper packaging, moisture particles can diffuse into the layers of the boards, resulting in defects before the products make it through production.

2. Electromagnetic Issues

Two common terms associated with ECB defects and electromagnetism are electromagnetic compatibility (EMC) and electromagnetic interference (EMI). EMC refers to a device which does not experience interference from other objects within its electromagnetic environment, meaning the objects are compatible. Simply stated, EMC entails creating, spreading, and receiving electromagnetic energy (EME). **Every type of electronic device can potentially emit an electromagnetic field (EMF).** The phenomenon referred to as EMI, describes the case of unwanted interferences between devices in the same EMF. **The presence of too much EMI can result in defects such as radio disturbances, faulty navigation systems, or intermittent motion sensors** [11]. As electronic devices in everyday life are rapidly increasing, so is the desire for EMC in new products [12].

         There are two types of sources for EMI: human made and naturally occurring. Human made sources of EMI consist of manmade, electronic devices such as radios or microwaves. On the other hand, naturally occurring sources of EMI include acts of nature such as lightning or visible light. (Panagopoulos, Johansson, Carlo, 2015) [5]. **Essentially, the root cause of electromagnetic issues can be traced back to poor designs** [12].

# Poor Quality Components

ECBs use a wide array of materials and components in order to function properly. These components are made up of a variety of electrical elements including resistors, capacitors, diodes, transistors, and fuses. All of these components are held to a specific standard that promote their functionality and longevity. **The overall quality of these components can play a major role in the amount of defective circuit boards produced.**

1. Insufficient Board Thickness

For ECBs, the **board thickness is a very important quality standard**. Even though there is not an official standard for PCB board thickness, the range of common thicknesses for modern PCB fabrication is 0.78mm, 1.57mm, and 2.36mm [14]. **The most common cause of insufficient board thickness is when a PCB manufacturer uses boards with a thickness below the desired specifications from the customer**. Manufacturers do this in attempts to drop the production costs of the device while boosting profits. When a PCB is assembled with an insufficient thickness, the device is at a much higher risk of bending, cracking, and breaking. **Insufficient board thickness can lead to more defective parts during the manufacturing**.

Solution: The best way to prevent insufficient board thickness is to ensure that the thickness of the board meets the specifications of the contract manufacturer or customer, prior to assembly. Incorporating testing checkpoints for the board thickness during the manufacturing process can help prevent cracked/defective parts.

2. Materials Defect

The materials used for boards differ in order to achieve optimal performance based on the particular ECB function. Selecting materials that are inadequate for the ECBs function can lead to defective units being manufactured.

Solution: The best way to prevent material defects is to select the best suited circuit board materials based on the ECBs desired function, prior to assembly. Coordination between the manufacturer and the customer can aid in the prevention of insufficient materials being used. Manufacturers will commonly use reference charts for material comparison and selection [15].

These are some of the most common and most major causes leading to defective units being manufactured. We provided solutions to these problems but with new technologies and techniques emerging every day we can prevent some of these causes before taking place using **LEAN** methods.

Discussion on Lean tools & technique implementation to improve productivity and quality control

1. JIDOKA

The primary innovation Jidoka brought to lean manufacturing is the idea of examining a manufacturing issue in the middle of the process rather than at the end. Inspecting throughout the manufacturing process can play a key role in preventing defects and fixing problems before they cause significant damage [16].

Diagram

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*Figure-10: Jidoka Principles*

The principles can be broken down into four steps:

* Discover an abnormality or problem using Control Charts.
* Stop the operation process.
* Fix the problem at hand.
* Discover the root cause to prevent future issues.

1. Poka Yoke

Poke Yoke was developed by Toyota and is very similar to Jidoka. The idea of Poka Yoke is to prevent mistakes from becoming defects/defectives. Mistakes, it argues, are inevitable, but defects that actually reach customers are preventable. The **goal** is to create a form of **quality control** that highlights defects automatically and eventually takes humans out of the equation [16].

1. Kaizen

Kaizen is the Japanese word for “continual improvement.” The term refers to activities that improve every function of a business and is generally applied to manufacturing but can be used to make almost any business more efficient.

By definition, Kaizen includes the involvement of all employees, from upper management to assembly line workers and can be used to improve every process in a supply chain, production, quality control to logistics [16].

1. Gemba

In Japanese, Gemba means “the real place.” In business, refers to an area where there is value created. In manufacturing, it refers to the factory floor. The idea of Gemba in **lean manufacturing** is that management must go to factory floor to search and **fix visible problems**. Manufacturing problems, Gemba argues, cannot be solved from an office. They require an actual physical presence by problem solvers on the manufacturing floor [16].

Conclusion

In this project the team has successfully analyzed the attribute data on defective rates of circuit boards, implemented control charts for quality control purpose, successfully completed a process capability analysis of the manufacturing process and discussed major problems and causes leading to these defective units being produced along with solution. To conclude the project, one simple question arises and that is: **Is the Current Manufacturing Process Capable? Stable?**

**The answer is** **NO**. Based on the Control Charts interpretations we definitely know there are some small shifts in the process. The process capability analysis yields a Defective rate of 19.8 % which is large and needs to be addressed. Also, the Defective PPM number for the process is 198000. If compared to the LEAN SIX SIGMA standards the process is operating between 2-3σ (SIGMA) compared to the industry standard of 4σ where DPMO is 6210 units per million.

**Can the process be Improved?**

In order to improve this process we can do the Root Cause Analysis mentioned in the project using Fishbone Diagram Technique and find the cause and provide a solution to it and apply continuous improvement using mentioned LEAN techniques along with TQM, Value Stream Mapping, doing LEAN AUDITS from time to time, etc.

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