DMAIC Case Study:
First Pass Yield Improvement in Manufacturing of Industrial Sewing Machine

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Tactegra applied the DMAIC Process, a data-driven variation reduction process, for its the client, TC, a leading industrial sewing machine manufacturing company, to improve the manufacturing first pass yield. The goal was to improve sewing machine manufacturing efficiency by reducing the number of defects found during the assembly process. Doing so would allow TC to increase both the return on investment (ROI) and customer satisfaction.

Company Business Background

TC manufactures and assembles industrial sewing machines used for a variety of industrial fabric sewing and stitching applications in the global marketplace. Subcontractors and suppliers source 97% of the parts and sub-assemblies used for creating different sewing machine configurations. However, a key component for every sewing machine, known as the loop taker (shuttle), is produced internally on one of the TC's sites.

TC has several manufacturing sites around the world, each producing different types of sewing machines to serve their local and global customer accounts. On any given day, each manufacturing site determines how many sewing machines to assemble based on customer orders. Each sewing machine order typically has five to six major sub-assemblies, which are assembled following a specific manufacturing process, and then attached to the loop taker required by the sewing machine.

Understanding First Pass Yield

Any defect identified during the sewing machine assembling process is called a First Pass Failure. The First Pass Yield (FPY) is the ratio of the number units that have no issues divided by the number of units that went into the process.

First Pass Yield = (units produced with no rework) / (total units of products entering the process)

FPY is an important manufacturing metric that measures quality and production performance. The First Pass Yield can:

- Help measure the effectiveness of a process
- Help eliminate waste from the process
- Account for the cost of rework
- Indicate probability of failure at customer site
- Measure the success of improvement initiatives

Company Concerns About the First Pass Yield

The FPY of the key sewing machine product line in 2016 for one of the TC's manufacturing sites is 83%, which is lower than the reported numbers of other TC sites, and far below the business target of 97%. This 14% gap translates into the following:

α) An increased production lead time
β) An unnecessary load of rework

χ) The reduction in installation startup success rate at customer locations for this key sewing machine product line
δ) Increased intervention rate for this product line once at the customer's location
ε) Significant production cost overrun

TC came to Tactegra with the following questions:

1. Why does this site have such a low First Pass Yield?
2. What are the root causes for the low FPY?
3. What solutions can be implemented to improve the FPY?

Based on these questions, Tactegra determined that the DMAIC process would be the most beneficial methodology to determine root causes and find and implement solutions.

DMAIC Process Background Information

The DMAIC acronym stands for the five phases of the cyclical process: Define, Measure, Analyze, Improve, and Control. This structured problem-solving method builds from phase to phase with the goal of finding and implementing solutions to problems. The Define phase will help determine what to measure. The Measure phase will provide the information to analyze. The Analyze phase will determine what needs improving. The Improve phase identifies what needs to be controlled. DMAIC is the correct method for process improvement when the problem is complex or the risks are high.

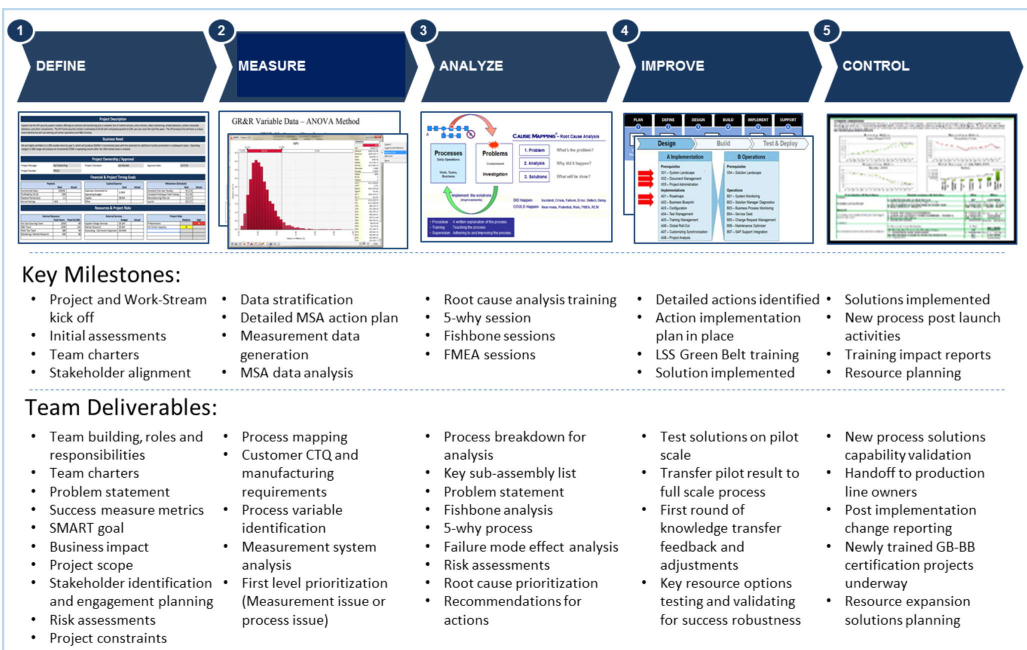


Figure 1. DMAIC process with milestones and deliverables

- *Define*: Lays the foundation for the project by defining what the issue is and its business impact if the issue is not resolved. Boundaries for the project are determined, as is the process flow. Team members and resources for the project are identified. A communication plan with team members and stakeholders is established. Each of these components leads directly to a focused project problem statement and an agreed-upon project timeline.

- *Measure:* Determines how and what to measure to see current process performance and find the deficits of the process. Measurement relies on understanding the process steps, validating the measurement system, defining performance standards, determining the capability of the process, and identifying gaps between the process performance and performance standards.

- *Analyze:* Defines performance objectives. Determines when, where, and how the defects occur using such tools as Pareto charts, fishbone diagrams, histogram, SIPOC, and others.

- *Improve*: Identifies gaps between current performance and desired performance. Screens for potential causes of variation and discovers interrelationships between them using a tool such as the Design of Experiment (DOE) to set processes that interact to produce the desired result. Potential solutions are selected and prioritized. Solutions are trialed, often on a pilot scale, to test the hypothesis and optimize the process for maximum potential. Improvement conditions are transferred to the full-scale process for implementation and optimization to realize the targeted improvement result.

- *Control:* The process of validating the measurement system and evaluating capability is repeated to ensure that improvement continues and keeps the process from reverting back to old methods. Steps are then taken to control the improved processes, by establishing long-term measurement, monitoring, and reaction plans to transition process to owner. Tools used at this stage include statistical process control, mistake proofing, and internal quality audits.

TC FPY Define Phase

Objective: To clearly define the problem, build a cross-functional team, and mobilize resources to work towards a committed goal.

The Focused Project Problem Statement: The First Pass Yield of a selected sewing machine product line at a specific site is 83%, much lower than the 97% target goal.

Question to Consider: What are the root causes that make this site 14% below the target goal?

Goal: Improve the First Pass Yield of the selected sewing machine product line at this site from 83% to 97%.

Method: Tactegra chose to use the DMAIC methodology to achieve this goal in order to identify, document, and prioritize key root causes and provide potential solution recommendations for improving the First Pass Yield to the 97% goal.

Reasoning: Improving First Pass Yield from 83% to 97% would not only increase the effectiveness of overall processes and eliminate non-value added activities, but key findings from this project would be leveraged to other sewing machine lines and additional facilities. It will also support the company's vision to convert all commodity sewing machines to a customer self-installation model, a significant step to improve customer satisfaction and reduce company service costs.

Resources: The TC management chose team members from their internal organization to work with Tactegra specialists to drive this project. The team is a cross-function team consisting of experts in the area of First Pass Yield (incoming parts, supply chain, internal manufacturing process, manufacturing engineers, quality engineers, R&D, sourcing, etc.) as well as key stakeholders such as supervisors, managers, and executives through the VP level.

TC FPY Measure Phase

Objective: To make sure that the process performance can be measured correctly and accurately, and these measurement systems can be utilized to identify the gap of the current performance and the performance target.

Main Metric: Percentage First Pass Yield (% FPY) as measured by this equation:

% FPY = (Number of units tested without defects and rework)/(Number of units tested).

Sub Metric: Daily Failure Occurrences as measured by this description:

Daily Failure Occurrences = Daily number of units failed during First Pass Yield test

Process Mapping: During this phase, Tactegra used process mapping to define and identify First Pass Yield process variables and importance. Team members also visited a part supplier, toured assembly lines, reviewed quality test steps and methods, reviewed assembling procedures, and observed several key test demonstrations.

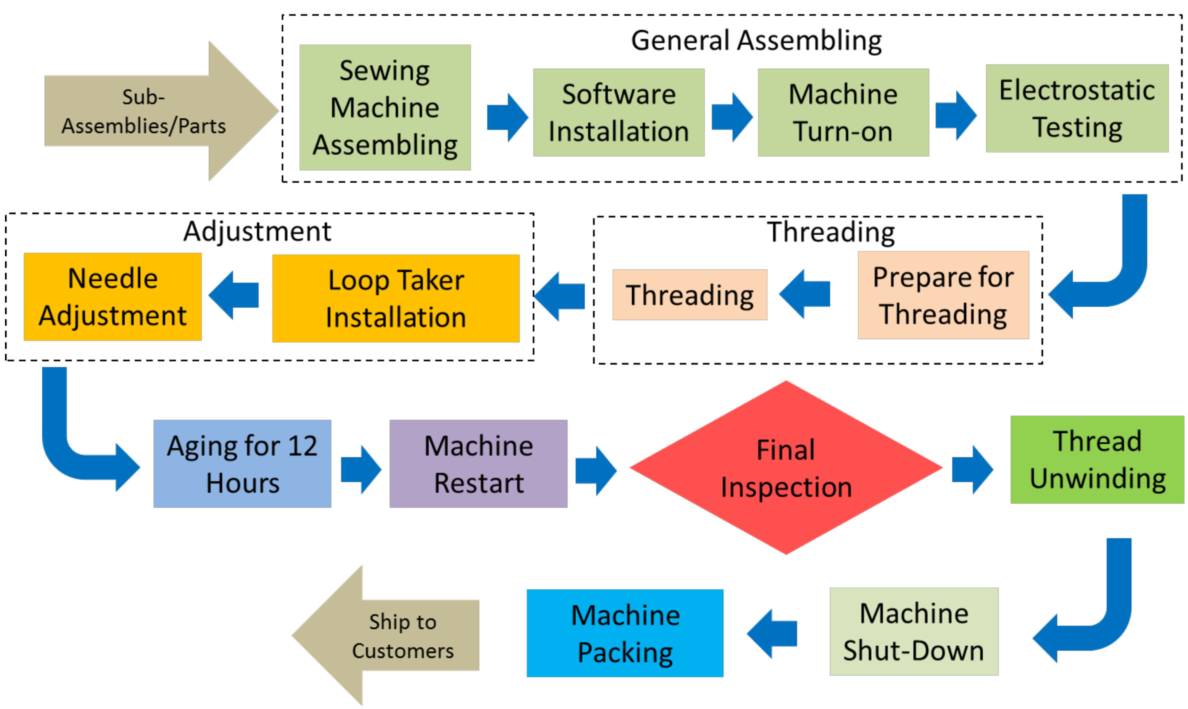


Figure 2. TC sewing machine manufacturing process flow

First Pass Yield Measurement Metrics: TC has established a set of metrics to detect failures during its manufacturing process. The metrics are listed in the table below:

Table 1: TC First Pass Yield Measurement Metrics

Step	FPY Manufacturing Activity	Testing Metrics
1	Sewing machine Assembling	Visual, Mechanical
2	Software Installation	Installation Procedure (error free)
3	Machine Turn-On	Start-up Procedure (no stoppage)
4	Electro-static Testing	Electrical Grounding (no static buildup)
5	Threading	Threading Procedure (no breakage)
6	Needle Adjustment for Sewing	Sewing Quality (binding, no breakage)
7	Aging for 12 Hours	Process Spec Monitoring (no control stoppage)
8	Machine Restart	Restart Procedure (error free startup)
9	Final Inspection	Visual, Turn-on and Turn-off, Sewing (error free)
10	Unwinding	Unwinding Procedure (100% unwinding)
11	Machine Shut-Down	Shut-Down Procedure (error free shut-down)
12	Sewing machine Packing	Packing Spec (no missing components)

Current First Pass Yield Performance: The daily failure occurrences data, Figure 3, shows that the variation of the sewing machine FPY is driven by both natural (within 3 standard deviations) and assigned causes (outside 3 standard deviations).

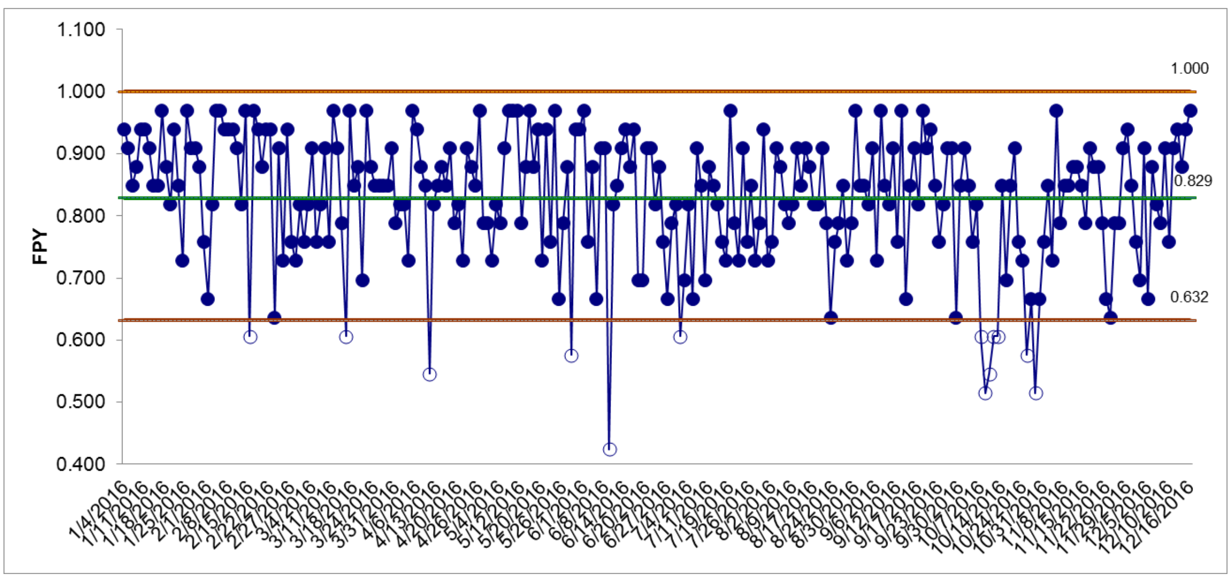


Figure 3. TC daily failure occurrences in sewing machine manufacturing process

If the requirement is for the manufacturing process to reach the 97±2% daily FPY goal, the current process capability is depicted in Figure 4. It can be clearly seen that the current process has been performing below the lower spec limit of 95% FPY in 91% of the production days (Actual % > USL = 90.63%) during the period studied.

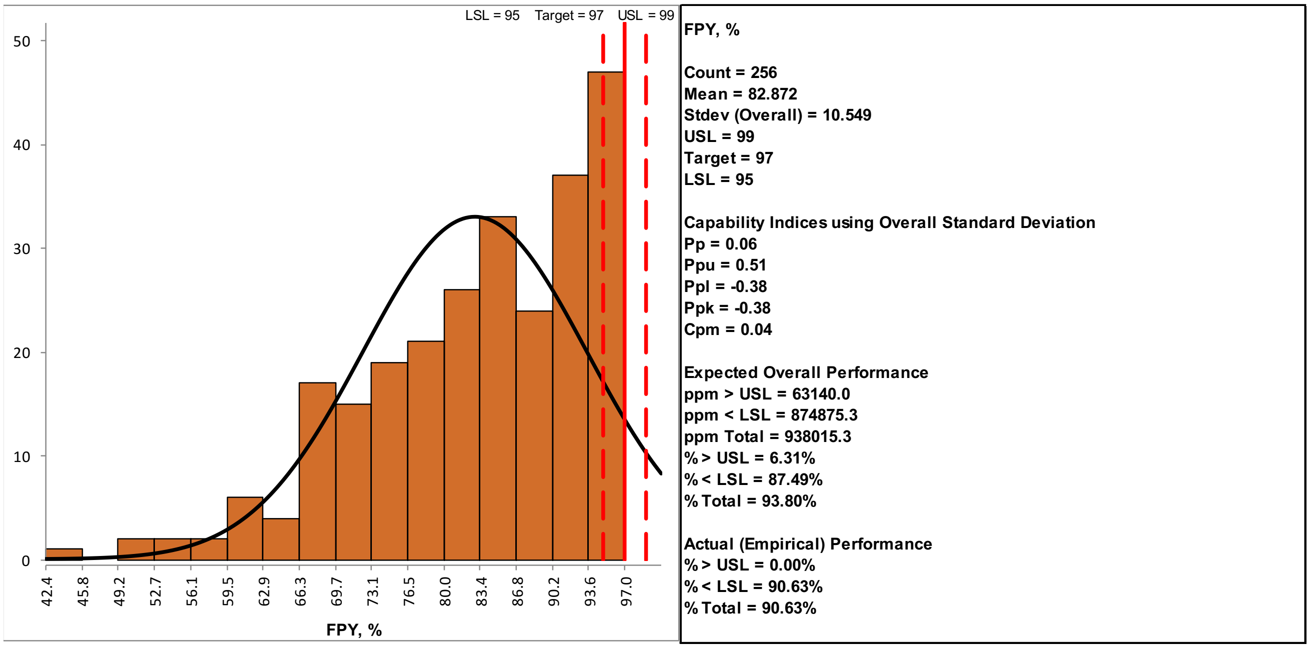
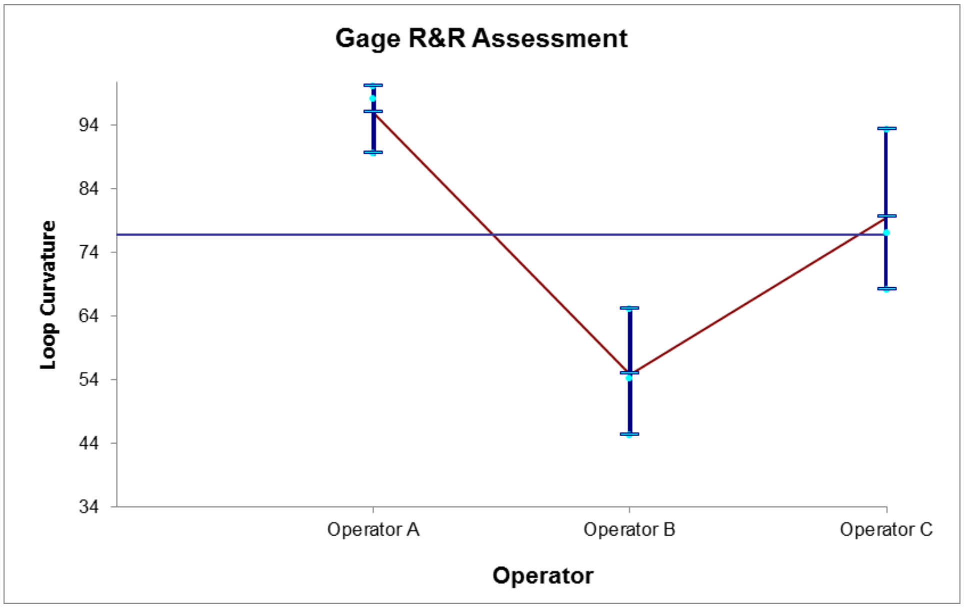


Figure 4. TC First Pass Yield manufacturing process capabilities

Measurement System Analysis (MSA): When evaluating the measurement system precision, two main characteristics include repeatability and reproducibility. Repeatability means that the measurement result is repeatable by the same operator on the same part with the same measurement method and equipment. Reproducibility means that the measurement can be taken by different operators each getting similar results. If the variation from repeatability and repeatability is at the same level or higher than the actual process variation, the measurement system is deemed as incapable of measuring the First Pass Yield variation.

Example Of MSA: One of the weaknesses in this TC sewing machine product line is that too many measurements are highly human dependent. For example, one of the measurements, sewing loop quality, requires an operator to read the sewing loop and make a decision on pass/fail. Results of the evaluation of this measurement method conducted on site are listed in Figure 5. The statistical analysis shows that both repeatability (within operators) and reproducibility (between operators) showed high variation. The interaction between operator and part also showed high variation. The total gage of repeatability and reproducibility was at 83.31%, higher than the 30% the limit. This would be considered as poor measurement system precision, and shows that there are discrepancies due to human judgment that generate errors that not caused by sewing machine itself. Since every sewing machine must pass this test and many other human dependent test methods in the process, the number of falsely generated rejects can be substantial. Therefore, the measurement system issue needs to be addressed first before getting too deeply into the analysis and improvement phase to avoid making incorrect decisions.



Gage R&R Metrics	Variance Component	% Contribution of Variance Component
Gage R&R:	251.30	83.31
Operator:	9.182	3.04
Part * Operator:	103.69	34.38
Reproducibility:	112.87	37.42
Repeatability:	138.42	45.89
Part Variation:	50.328	16.69
Total Variation:	301.62	100.00

Figure 5. TC measurement system evaluation of sewing loop quality test

Observations:

- The TC's internal manufacturing process mainly consists of two major activities: sewing machine assembling and sewing machine operation simulation.
- A set of test metrics is designed in each of the manufacturing steps to detect failures.
- Production data shows there is a significant gap between the current performance and business target.
- Variation of First Pass Yield is driven by both natural and assignable causes.
- Some of the measurement systems are highly human dependent and have issues in both repeatability and reproducibility.
- Measurements used to control processes often led to adjustments that increased variation.
- Correlation between variables could be confounded by excessive errors in measurement.

TC FPY Analyze Phase

Objective: To define performance objectives and identify sources of process variation.

Process Performance: According to the project goal specified in the Define phase, the site studied needs to achieve 97% of First Pass Yield within a time frame agreed upon by the team. It can be translated to one failure occurrence each day with the average assembling rate of 33 sewing machines each day.

Tools Used for Analyze: The team performed a 5-Whys analysis, SIPOC, Fishbone analysis, and Risk analysis to determine why the FPY problems existed and to find the most significant reasons or causes.

- *5 Whys Analysis*: Repeatedly (at least five times) ask the question "Why" to peel away the layers to get to the root cause of a problem and determine the relationship between different root causes. It is most useful when problems involve human interactions.

- *SIPOC*: The acronym SIPOC stands for suppliers, inputs, process, outputs, and customers which form the columns used to analyze a problem. This diagramming tool helps identify the relevant elements to improve a process.

- *Fishbone Analysis*: Diagram used to identify variations, with causes grouped into categories, such as people, methods, machines, materials, measurements, and environment.

- *Risk Analysis*: A step-by-step approach for identifying all possible risks of failure in a design, a manufacturing or assembly process, or a product or service.

First Pass Yield Failure Sources: Analysis results indicate that the failures in the manufacturing come from four major sources: quality of supplier sub-assemblies and parts, improper design for manufacturing, defects generated by the process, and operators. The percentage of each category is illustrated in the pie chart below (Figure 6).

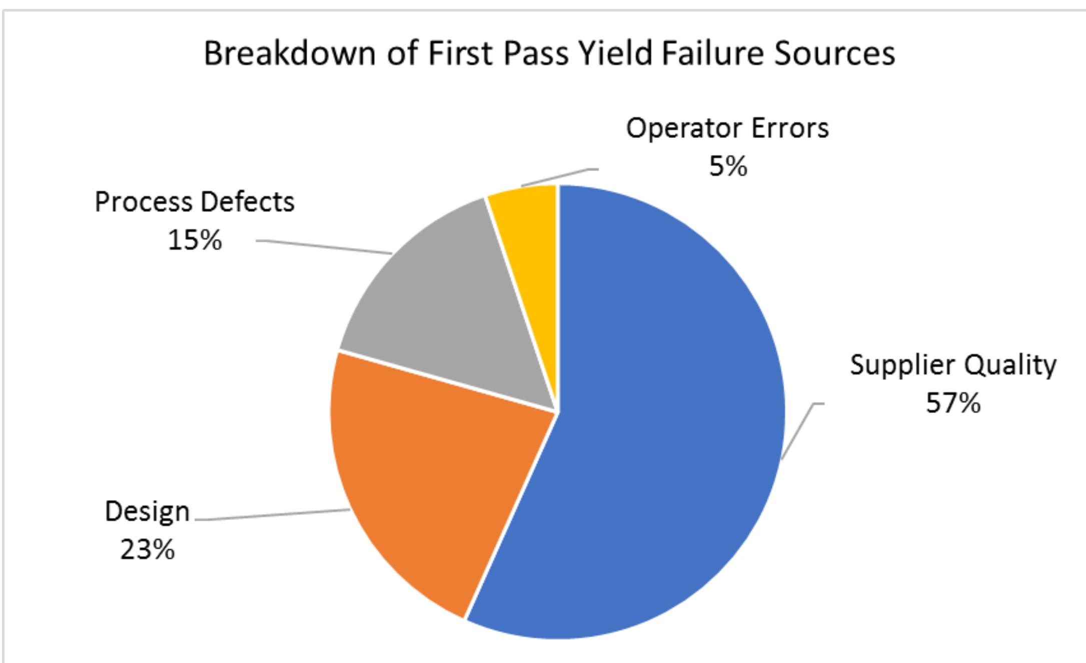


Figure 6. TC First Pass Yield failure sources

Results from some of the deep-dive analysis showed that improving the First Pass Yield from 83% to 97% would have its challenges. Tactegra determined that:

- There was an absence of rigorous testing standards for suppliers to prevent defective parts from entering TC's assembly lines.
- Current manufacturing operations required significant human intervention.
- There was significant variation in manual operations and measurement systems.
- Standard Operating Procedures were not being adhered to by operators.
- There was a knowledge gap between product technical requirements and operator's knowledge base.
- Proper tools were absent or non-functioning in some assembly stations.

Risk Analysis: Measurements during the previous phase showed that Sewing Head and Bobbin Case accounted for 56% of all First Pass Yield defects. Therefore, a risk analysis was conducted on both components to assure that potential failure modes and their associated causes were considered and addressed.

The risk analysis showed that Sewing Head accounted for 40% of total FPY. Defects included:

- Defective covers and sleeves
- Operator errors

Additionally, the analysis showed that Bobbin Case accounted for another 16% of total FPY. Defects included:

- Thread detection sensor failure
- Poor case inner wall quality

Cross functional project teams were created to tackle these root causes, focusing primarily on these two components.

TC FPY Improve and Control Phase With Recommendations

The top technical issues for First Pass Yield identified from the Analyze phase are supplier quality, design, and defects generated in the manufacturing process. These issues, however, are considered a lesser issue compared to some systematic issues that were also identified during the on-site investigation. These systematic issues stem from company culture and strategy.

Recommendations: The following recommendations were forwarded to TC in order to move forward to the Improve and Control phase of work.

Cultural: Establish frameworks for functional collaborations, learning systems, and expectations for internal and external partners. Ensure all stakeholders buy-into the need for change and common methodology.

Strategic: Institute standards of excellence driven by a data methodology as well as measurable metrics for internal as well as supplier performance for middle management.

Tactical /Technical: The following initiatives were presented:

- Create a quality initiative that prevents defective parts created at supplier's from getting into TC's assembly lines.

- Replace and automate manual measurement systems to the extent possible. The high level of human interaction drives a disproportionately large portion of the process variation. In the short term, measurement errors can be normalized by taking multiple measurements and averaging the results.
- Develop and implement simple Standard Operating Procedures (SOP) for measuring process input and output variables. Operator training and the adherence to Standard Operating Procedures is critical.
- Partner with strategic suppliers to develop proper quality and testing standards and establish incentive driven targets.
- Establish a common "language" in the identification and classification of defects, as well as a common methodology in problem solving.

TC FPY Path Forward

With root causes identified and solutions identified, the path forward for TC to achieve 97% First Pass Yield is to continue the DMAIC process by focusing on three distinct projects:

1. Improve Incoming Sub-Assembly and Part Integrity – focusing on preventing defective parts from reaching TC's assembly line - increasing FPY by 6.2%.

2. Improve Design for Manufacturability - increasing FPY by 4.2%

3. Reduce Manufacturing Defects - increasing FPY by 3.6%

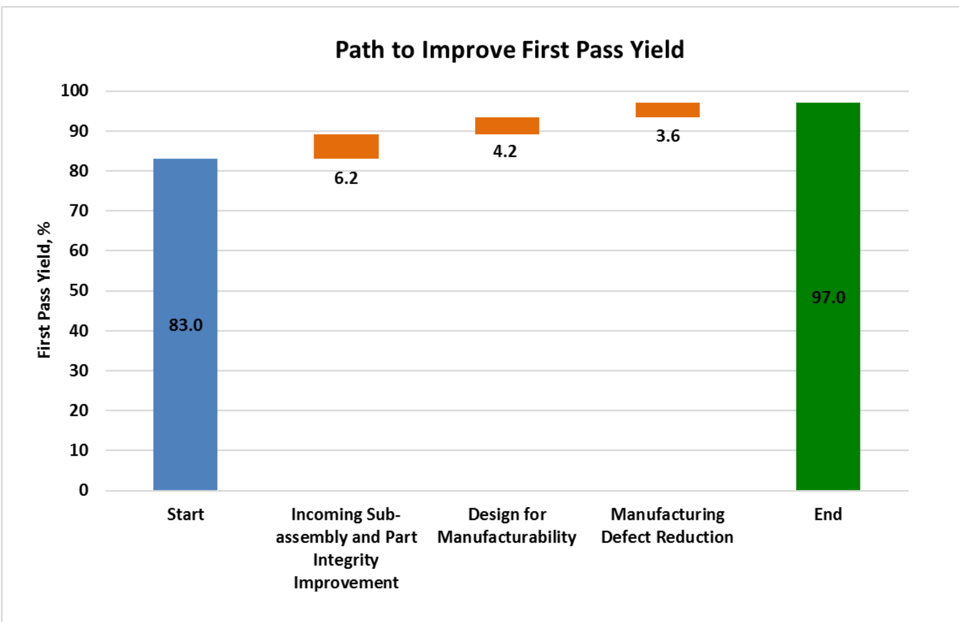


Figure 7. TC path to improve First Path Yield

As TC integrates solutions found during the DMAIC process, they will see First Pass Yield improvement.