Enhancing Production Capacity at Manufacturing Test Company Using Lean Six Sigma

Putra Ananda Nopri Andi* and Mursyid Hasan Basri

ABSTRACT

One of the things that generally happens is a growth in production capacity, and under ideal conditions, a corporation must have enough space to accommodate an increase in output. However, what if this occurs during a period of solid output demand and needs that must be optimized quickly? Of course, this is a significant difficulty that requires a higher level of analysis to achieve an effective and economical answer. Based on the past three years’ statistics, demand from customers will rise to 528,000 in 2023, up from the highest capacity/year of only 409,000. To find the best answer, businesses must examine aspects such as business competitiveness, changing circumstances, and large fluctuations. Improvement and optimization of low-output processes will aid in achieving output. Applying the Lean Six Sigma method in evaluation yields substantial results and leads to the best solution for selecting a productivity-boosting strategy. Strategies for increasing production capacity include eliminating non-value-added operations (lean concept) and integrating processes with other processes to reduce process variability (Six Sigma concept). The results demonstrate that the increase in production capacity exceeds the target (more than 20% from 2022). It is built on the theory of constraint concept approach, which solves the core problem while moving on to the next challenge.

Keywords: Lean, Production Capacity, Six Sigma, Theory of Constraints.

1. Introduction

Manufacturing and assembly processes involve the production of vast quantities of products, which are subsequently tested and packed before being delivered to the customer. All processes a product goes through must be measured for production capacity (output) to identify each process’s capability limits.

Following research from the last three years, customer demand has steadily increased (see Fig. 1). Customer demand would rise from 508,000 in 2022 to 528,000 in 2023, according to the forecasting approach utilized to observe conditions in 2023. Of course, preparing capacities to deal with this scenario is a difficulty.

In general, the manufacturing process is divided into three stages: frontline assembly (second floor), backline testing (second floor), and packing production (first floor). However, because there is a substantial difference in duties and responsibilities between the assembly and testing process on the second floor and the packing process on the first floor, the author will focus on analyzing the second floor only.

Fig. 2 displays the precise sawing and cap assembly operations running in tandem to assist and feed the die attach and pre-weld processes. After the screening signal test process, the welding process will begin. The remaining operations on another level (first floor) are packing AQL and visual mechanical. When there is no increase
in demand, everything appears to be good, and everyone becomes complacent/forgets to optimize already steady processes. To develop effective and efficient solutions, the analysis technique will employ the DMAIC framework and tools from Lean Six Sigma to identify strategies that are not optimal.

2. Literature Review

2.1. Lean and Six Sigma

Lean Manufacturing (LM), a management philosophy for world-class manufacturing, was created due to this thinking (Womack et al., 1990). According to Hopp and Spearman (2004), lean was viewed as a basic framework in the manufacturing sector for improving productivity, cutting waste, and minimizing variation. Reducing waste will impact optimizing processes by removing steps that do not bring value to the procedure.

Sigma is a statistical term that refers to a process or service with 99.9997% accuracy from start to finish. This methodology will reduce faults by reducing process variance, resulting in benefits such as cheaper costs, saved time, less scrap, and improved customer satisfaction. For achieving and sustaining business success, the formal concept with a Six Sigma methodology approach will use DMAIC and a set of tools such as SIPOC, Cause and Effect diagram, Pareto Chart, Scatter diagram, Box Plot, Histogram, Flowchart, Statistical process control, 5 Whys analysis, Fishbone diagram, Measurement System Analysis, and T-Test/F-Test (Heizer et al., 2017).

The Lean + Six Sigma combination will improve the manufacturing process’s performance effectively and efficiently (see Fig. 3).

2.2. Theory of Constraint

Dr. Eliyahu Goldratt conceived the Theory of Constraints (TOC) and introduced it to a wide audience through his bestselling novel, The Goal (Goldratt, 1984). After that, TOC has continued to evolve and develop, and today, it is a significant factor within the world of management best practices.

The Theory of Constraints is a methodology for identifying the most important limiting factor (i.e., constraint) that stands in the way of achieving a goal and then systematically improving that constraint until it is no longer the limiting factor. There are five focusing steps of TOC (see Fig. 4). In a manufacturing company, the constraint is often called a bottleneck. The Theory of Constraints takes a scientific approach to improvement. Using this approach will help solve bottlenecks and reflect in increasing capacity with no investment needed (Rahmawati et al., 2019).
3. Research Method

3.1. Conceptual Framework

The conceptual framework is depicted in Fig. 5. All the factors listed have the potential to affect production capacity and should be thoroughly investigated. If it is shown to be the source of the problem, we will endeavor to find a solution.

3.2. Research Methodology

The notion of research design displays a systematic problem to be studied using the chosen approach to reach the goal. As shown in Fig. 6, the research design framework will examine and optimize existing manufacturing capacity.

As the aim improvement, the Lean Six Sigma approach was chosen to examine and improve present capacity output. There are numerous tools in the Lean Six Sigma concept from which to choose, and the DMAIC technique will be used as a methodical framework in this research. The Lean Six Sigma strategy can enhance production capacity.
4. DMAIC METHODOLOGY

4.1. Define Stage

It is fairly uncommon for there to be a considerable difference between the actual and the data when it is collected for the first time in each step. This necessitates the authors retrieving the data that will be utilized as initial observations. Fig. 7 depicts the data collected during each process.

Referring to Fig. 7 once more, the elevated offset test screening signal test is the process with the lowest overall output. Grouping the processes will result in a frontline process and a backline process, and comparing the two will reveal that the backline process produces less output per shift time than the frontline process.

There is a 6,000-piece gap per shift (see Fig. 8). Hence, optimizing the backline operations, particularly the elevated offset and screening signal tests, is possible. According to the output data per shift, the defined stage will focus on the backline process as inferior to the frontline process.

The SIPOC diagram (Fig. 9) will assist in identifying each process and obtaining clear information about process details, inputs, and outputs in the backline process.

Based on the SIPOC diagram, the emphasis will be on the backline area, particularly the testing.

4.2. Measure Stage

Because problems have been found in the backline area, monitoring every process in the backline is vital. Each process is represented by a Pareto diagram (see Fig. 10).

The biggest problem revealed that the elevated offset test (40 °C–70 °C) is the top one, creating a constraint in the backline process. The second problem identified is the screening signal test at the top two. Table I presents some explanatory data.

The new regulations require 21 days of production every month. Section II states that overtime days in production are calculated at 26 days per month. According to Table I,
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### TABLE I: Output Calculation and Data Comparison

<table>
<thead>
<tr>
<th>Backline process</th>
<th>Cycle Time/pcs Shiftily capacity (IE–10%)</th>
<th>Output/Hour (UPH)</th>
<th>Optimum Output/Shift (pcs)</th>
<th>Output/Day (pcs)</th>
<th>Output/Month (pcs)</th>
<th>Output/Year (pcs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leak test</td>
<td>0.3</td>
<td>71,990</td>
<td>11,033</td>
<td>79,989</td>
<td>239,968</td>
<td>5,039,323</td>
</tr>
<tr>
<td>Screening signal test</td>
<td>43.4</td>
<td>542</td>
<td>83</td>
<td>602</td>
<td>1,805</td>
<td>37,910</td>
</tr>
<tr>
<td>Signal test</td>
<td>21.6</td>
<td>1,090</td>
<td>167</td>
<td>1,211</td>
<td>3,632</td>
<td>76,277</td>
</tr>
<tr>
<td>Noise test</td>
<td>4.6</td>
<td>5,096</td>
<td>783</td>
<td>5,674</td>
<td>17,022</td>
<td>357,457</td>
</tr>
<tr>
<td>Elev. offset test (40 °C–70 °C)</td>
<td>92.3</td>
<td>254</td>
<td>39</td>
<td>283</td>
<td>848</td>
<td>17,813</td>
</tr>
<tr>
<td>Pin cutting</td>
<td>4.4</td>
<td>5,387</td>
<td>826</td>
<td>5,989</td>
<td>17,966</td>
<td>377,276</td>
</tr>
</tbody>
</table>

#### Fig. 11. Fishbone diagram analysis.

### TABLE II: Root Cause Analysis by Using 5 Why Diagram

<table>
<thead>
<tr>
<th>Problem</th>
<th>Why 1</th>
<th>Why 2</th>
<th>Why 3</th>
<th>Why 4</th>
<th>Why 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual measurement by DMM at board PCB</td>
<td>Operator performed by digital multi meter (DMM)</td>
<td>Validate the offset value after assembly is PASS or FAIL</td>
<td>There are rejected products in each lot running in production</td>
<td>Data raw material (JFET) out spec and assembled from the assembly process</td>
<td>Internal specification product is tighter than spec raw material*</td>
</tr>
<tr>
<td>Process measurement is still manual per channel</td>
<td>The operator is only capable of measuring one channel per cycle test</td>
<td>It is impossible to measure two channels per cycle test</td>
<td>Using board/DMM and performed by operator</td>
<td>No equipment or tooling that is capable of measuring both channels simultaneously</td>
<td>Need to invest to create new system/machine*</td>
</tr>
<tr>
<td>Oven too old</td>
<td>Temperature unstable</td>
<td>It takes a long time to reach the set point temperature</td>
<td>The oven heater and sensor readings are not accurate</td>
<td>Hardware outdated*</td>
<td>–</td>
</tr>
</tbody>
</table>

Note. *True root causes.

the elevated offset and screening signal tests must be improved to increase the overall capacity (20% as a target). Increasing the overall capacity by 20% is comparable to 528,000 per year. Because of that, the elevated offset test and screening signal test processes should be improved to achieve that target.

#### 4.3. Analyze Stage

Two issues will be evaluated to obtain the necessary improvement. The analysis will begin with an elevated offset test (40 °C–70 °C) because of the lowest output in this process.

The fishbone diagram will be used to discover the possible root cause (Fig. 11). Low output at elevated offset test process (40 °C–70 °C) has seven potential root cause concerns and will continue for verification and validation.

Three potential root causes are validated, so three potential root causes will continue to be analyzed using a 5 Why diagram to understand the real root cause problem (see Table II). According to Table II, there are three potential root causes of the problem that have been verified and four potential root causes of the problem that have not been verified. The suspected root cause of the problem will be further investigated utilizing the 5 Why analysis to determine the root cause of the problem.

The 5 Why diagram was used to investigate the problem’s three potential root causes, and the true root causes are explained in the following subsections.

#### Requirement of Investing in a New System/Machine

The price of the testing machine is roughly $15,000–25,000; this will be more challenging since a proposal must be created, and the corporate in top-level management
must be convinced to release budgeting. ROI and lead time will be considered for this investment.

**Outdated/Obsolete Hardware**

The Elevated Offset Test will be carried out utilizing a Digital Multimeter, a PCB board as a terminal, and an oven to control the temperature at 40 °C before elevating to 70 °C.

Before the operator measures the product, the temperature will be reached using an oven machine and must be in the point level temperature requirement. It is significant because the unstable temperature will affect the reading offset value and client product requirements. The temperature tolerance range is 0.2 °C. However, because the oven machine/sensor oven is too old, the process may have an unstable temperature. Another consideration is that the additional microcontroller’s temperature setting is inaccurate. Microcontrollers sometimes have delays while reading/writing temperature point settings.

Detail breakdown as analysis to validate the problem using a value stream mapping diagram. Validating low output at elevated offset will demonstrate a complete breakdown procedure utilizing value stream mapping to understand the elevated offset test process step by step (see Fig. 12).

In line with the value stream mapping elevated offset test process, non-value add is exceptionally high in waiting for temperature stabilization before monitoring both channels (SA/SB), which results in a low add ratio of only 2.9%. Similar to the fishbone diagram analysis, one of the potential causes of poor output during the elevated offset test process is an oven machine that is too old, with the main reason being an outdated hardware oven machine.

### 4.4. Improve Stage

The analysis stage identifies three fundamental reasons for the problem, which must be addressed to enhance capacity at the backline process, particularly

<table>
<thead>
<tr>
<th>TABLE III: PROS AND CONS SPECIFICATION PRODUCT VS. RAW MATERIAL JFET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Problem:</strong> “Internal specification product is tighter from specification raw material JFET.”</td>
</tr>
<tr>
<td>Alternative solution</td>
</tr>
<tr>
<td>Order/request new material with minimum requirement should be higher than the current specification offset production to the supplier.</td>
</tr>
<tr>
<td>Review internal offset specification product to revise the product specification lower than raw material JFET specification.</td>
</tr>
</tbody>
</table>
TABLE IV: TESTER CAPABILITY PRODUCT

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Noise tester</th>
<th>Signal tester</th>
<th>Elevated offset test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>40 °C–80 °C</td>
<td>25 °C only</td>
<td>40 °C–70 °C</td>
</tr>
<tr>
<td>Temperature setting</td>
<td>Automated by program</td>
<td>Fixed</td>
<td>Manual</td>
</tr>
<tr>
<td>Offset voltage tests</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Offset channel measurement</td>
<td>2 channels/tested with 2 temp (per cycle)</td>
<td>2 channels/tested with 1 temp (per cycle)</td>
<td>2 channels/tested with 1 temp (per cycle)</td>
</tr>
<tr>
<td>Channel test</td>
<td>100 CH</td>
<td>1 CH</td>
<td>16 CH</td>
</tr>
<tr>
<td>Test decision</td>
<td>By software</td>
<td>Manual; depends on the operator</td>
<td>Manual; depends on the operator</td>
</tr>
<tr>
<td>Traceability data</td>
<td>Local tester</td>
<td>Manual record</td>
<td>Manual record</td>
</tr>
</tbody>
</table>

Fig. 13. Comparison of the offset value low temperature.

Fig. 14. Capability comparison (before and after).

The elevated offset test process. Increased capacity as an improvement requires a high non-value add process and a redundant process. All scenarios that will improve must consider effective and efficient solutions. Additional expenses must account for ROI (Return on Investment), which is tough to explain to top-level corporate management.

**Case No. 1—Internal Specification of the Product is Tighter than the Specification of Raw Material JFET**

Two alternatives are ideal to adopt if the internal specification of the product is stricter than the specification of the raw material JFET.

1. Order/request new material from the supplier with a minimum need greater than the present specification...
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Fig. 15. Cycle time process comparison (sec).

Fig. 16. Shiftily capacity/process (pcs) after improvement.

TABLE V: OUTPUT CALCULATION AND DATA COMPARISON (AFTER IMPLEMENT SOLUTION)

<table>
<thead>
<tr>
<th>Backline process</th>
<th>Cycle Time/pcs</th>
<th>Shiftily capacity (IE–10%)</th>
<th>Output/Hour (UPH)</th>
<th>Optimum Output/Shift (pcs)</th>
<th>Output/Day (pcs)</th>
<th>Output/Month (pcs)</th>
<th>Output/Year (pcs)</th>
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</thead>
<tbody>
<tr>
<td>Leak test</td>
<td>0.3</td>
<td>71,990</td>
<td>11,033</td>
<td>79,898</td>
<td>239,968</td>
<td>5,039,323</td>
<td>60,471,873</td>
</tr>
<tr>
<td>Screening signal test</td>
<td>Eliminated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal test</td>
<td>21.6</td>
<td>1,090</td>
<td>167</td>
<td>1,211</td>
<td>3,632</td>
<td>76,277</td>
<td>915,327</td>
</tr>
<tr>
<td>Noise test</td>
<td>4.6</td>
<td>5,096</td>
<td>783</td>
<td>5,674</td>
<td>17,022</td>
<td>357,457</td>
<td>4,289,478</td>
</tr>
<tr>
<td>Elev. offset test (40 °C–70 °C)</td>
<td>Integrated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pin cutting</td>
<td>4.4</td>
<td>5,387</td>
<td>826</td>
<td>5,989</td>
<td>17,966</td>
<td>377,276</td>
<td>4,527,306</td>
</tr>
</tbody>
</table>

Fig. 17. Before and after comparisons for shiftily capacity per process.

offset product. Some wafers can be ordered based on special requirements (min offset 0.46 V) by looking at the supplier’s previous CoC (certificate of conformity) data. However, the specific requirements order will raise the price of raw material JFET from the supplier. JFET material is a common material that is used in a variety of products and businesses. Other firms also use specifications from JFET materials. Thus, the specifications are common. Therefore, customized specifications will result in a higher price.

2. Reviewing internal offset specification product to revise the product specification to be less stringent than the raw material JFET standard. The R&D team should be helping to review product analysis with smaller specification offset, including the product needs of the customer’s level. Updating internal specifications based on R&D team analysis is possible without compromising the functioning product. Alternative solutions will be chosen based on evaluating the pros and cons in Table III, and the solution must be effective and efficient.

The screening signal test method prevents high defects, low offset, and overconsumption of filter material (customer material). A product with a broader specification
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will aid in eliminating the screening signal test process as non-value added in the backline area.

Case No. 2–Investing to Create New System/Machine

When a new system or machine must replace the operator's manual measurement of each channel, we must purchase a new one, which is challenging since investment must consider customer requirements in 3–5 years with an uncertain business. Investing in new machines is another option for increasing capacity, but all solutions must be effective and efficient. As an alternative, before investing in a new system/machine, I perform some testing comparisons to assess the possibility of a similar measurement method. A similar system will be considered for continued qualification after offset measurement as validation.

As indicated in Table IV, a noise tester may evaluate things with an elevated offset test, so integrating elevated offset testing into a noise tester is an excellent alternative to investing in a new machine/system. In another case, the noise tester must test 100 sockets per cycle; therefore, boosting the output is more efficient.

4.5. Implementation Stage

Reviewing Internal Offset Specification Product to Update it to a Lower Specification than the Raw Material JFET Specification

The proposed new standard will be based on $3\sigma$ from existing data points at a lower spec limit, DPMO of at least $\leq6210$, and a minimum Cpk of 1.33 (company standard).

Integrating Elevated Offset Testing into Noise Tester: Internal Assessment and Qualification

Comparison plotted in Fig. 13 shows that all samples evaluated at manual and noise tester measurements offset are not significantly different, either at high or low temperatures. However, a statistical test using the T-test/F-test revealed that the mean value is significantly different ($p < 0.1$), increasing 0.06 V from 0.58 to 0.64.

The statistically significant discrepancy in t-test results is due to variable temperature testing at high temperatures. The manual elevated offset test runs at 70 °C, whereas the noise testing runs at 80 °C. The functional JFET material will affect the temperature measurement, and machine testing will reduce the possible losses offset voltage. In this case, the distribution data shifted to the upper specification limit and reflected a potential reduction of reject $\pm94\%$ out

Fig. 18. Capability results of the manual vs. machine measurement comparison.

Fig. 19. Theory of constraint implementation.
of spec at a lower spec limit. For offset testing, it would yield a better result than manual measurement.

Potential Cpk distribution offset data using a noise tester appears to be better than the manual measurement from 0.81 to 1.29, and the potential chance DPMO (defect per million opportunities) decreases from 7325 to 57 (see Fig. 14).

5. Results

There are three fundamental causes and two solutions for increasing total capacity production, particularly in the backline process. The solutions selected to increase the capacity production are reviewing existing product specifications to be less stringent than the raw material JFET standard and integrating the bottleneck process into another process for tremendous advantage.

5.1. Control Stage

The control stage is vital to monitor the outcome after implementing the solution to ensure that it is effective and that the condition is better than previously.

Increasing Capacity with Integrate Elevated Offset Test

Integrating the elevated offset test into the noise test process is one approach that will help to eliminate total test time from the elevated offset test itself, increasing the overall optimal capacity in the backline testing process.

Figs. 15 and 16 displayed the screening signal test and elevated offset test processes with no cycle time/output data because they had been deleted and merged into another test process. Table V shows that the output after implementing the integrated elevated offset test to noise test and eliminating the screening signal test method is calculated.

Overall graph comparison between before and after, as mentioned in Fig. 17, revealed that frontline and backline processes showed improvement.

Eliminate Non-value-added Processes

The requirements should be reviewed and changed to be wider than raw JFET material parameters to help keep the reject rate at a low level of consistency.

The low reject rate is a measure used to reduce the screening signal test process, indicating a non-value-added process. Fig. 18 shows that capability comparison is better.

Another factor is that when there is a greater rejection rate, production must retest the product again in the final testing process, which reduces the tester’s capacity.

6. Conclusion and Recommendations

The issue in this case must be resolved as swiftly as possible because the company would lose customers if it could not meet the customer’s expectations regarding product delivery. Customers will be dissatisfied since the delivery of products to them is not consistent, and this circumstance will contribute to the company’s vulnerability. Using the Lean Six Sigma methodology for root cause analysis and improvement assists in developing an effective solution.

7. Conclusion

The following is a summary and conclusion of what has been done to improve production capacity, particularly in the backline process:

1. Increasing capacity production due to increasing demand and customer voice, so the company must consider effective solutions to accomplish this objective. Either build a brand-new plant machine or run production on an ongoing basis to ensure the continuity of the company’s operations.
2. Decisions made as a part of the company’s strategy will affect revenue and, of course, the ROI in spending costs.
3. After examining the underlying cause of low capacity at the backline process, it is possible to raise capacity output from 409,000/year in 2022 to 528,000 (a 20% increase) in 2023.
4. As a solution, two improvements have been made: a. Integrating a bottleneck process into another process (elevated offset test process to noise test process) so that the elevated offset test process can be completed in a single step with the noise test process.
   b. Eliminating non-value-added processes by reviewing the specification product and broadening the specification from raw material so that the screening signal test procedure is no longer required since the reject rate remains low (0%).
5. The bottleneck process in testing may be eliminated and integrated. The increase in capacity to be accomplished (528,000 as a target) exceeds the projected up to 915,000 (up to 73% higher than the target). This is because the enhancements additionally emphasize the Theory of Constraints methodology approach, as shown in Fig. 19 for detail step by step.
6. As the elevated offset to the noise test process was successful, and the Screening Signal test process could be omitted, this project saved two pieces of the workforce that will be allocated to another process.
7. The improvement that applying the DMAIC technique brings to the true root cause will deliver an effective solution at a low cost, resulting in no spending or investment to solve the problem in this research.

8. Recommendations

The proposed recommendations for the next stage upgrade are as follows:

1. Integrating elevated offset testing results by the operator (human reliant, so justification remains human dependent). The program tester must continue and generate auto justification to prevent the quality issue.
2. When the total frontline and backline processes are compared, the backline process still has a lower and lower output at the signal test process. Expanding capacity for this process should be investigated as a continuous improvement to achieve a balance between frontline and backline output.
3. The line-balancing approach is one of the ways to make the best use of available resources to create the most products. A yearly evaluation of all operations should be undertaken to identify deviations from actual circumstances and act if any gaps exist in each production line phase. This action will also be triggered if any process may be abolished or incorporated into another.

4. Reward and recognize those who have contributed to this initiative.

**Conflict of Interest**

The authors declare that they do not have any conflict of interest.

**References**