# TWO - WAY RADIO LINE PRODUCTIVITY IMPROVEMENT USING LEAN SIX SIGMA

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**Abstract**

The objectives of this study are to identify the bottleneck in this assembly line follows by the optimization for the process Two-way radio production line. Lean Six Sigma methodology has been applied to this study. Six Sigma methodologies DMAIC which is Define, Measure, Analysis, Improve and Control are used to measure the process capability and problem solving while Lean methodology used to optimize the process. The application of Work Element Scrubbing which is Elimination, Re-arrangement, Automation, Combination and simplification helps to reduce to bottleneck and waste. As the result, there are reduction on standard hour time from 0.0581 hour to 0.0232 hour and head count of operator was reduced from five operators per shift to two persons per shift with total cost reduction per year USD$52229. This improvement is sufficient enough to cover during 40% production ramp up time.

**Keywords:** Lean Six Sigma, Work Element Scrubbing, Optimization, Bottleneck.

## 1. INTRODUCTION

Two-way radio or usually known as “Walkie Talkie” is a communication device use to connect people using wireless transmission of electromagnetic radio frequency signal. VS01 production line consists several product of portable twoway radio to be manufactured. There are ten different product are specify to this line. The products are differentiating with the design of the radio itself such as it shape, features, specification and the software that programme into it. The assembly process were categorized into different assembly line according to product families and it variants. VS01 produce very high runner volume product for every week. The customer forecast and demand are varied for every week. At the peak time especially in quarter four end of every year, which is the demand exceed the capacity, the production volume unable to compensate with the capacity of line. Based on statistic from logistic department, the volume increase for 40% in quarter four compare with other quarter in year 2014. The company had to run overtime to their operator and reshuffle the shift from three shifts to four shifts to encounter of this issue.

There are several limitation on this scope of study which is it only involve on process improvement from the highest volume product in VS01. The line improvement also only covered FE BTC area which is Nome offline and test process. This line is located between SMT and Back End Assembly. Based on the problem statement above, the objectives of this research had been set:

- To identify the bottleneck on the assembly line of the two way radio.
- To optimize the process and reduce the process time in the assembly line of the two way radio.

In order to overcome this constraint, line improvement has to be done by reducing the overall process cycle time without sacrifice the quality of the product. There are several method and methodology that can be applied to this study. Research on the literature review is needed to be conduct.

## 2. LITERATURE REVIEW

Lean is a set of practices that is used to continually eliminate the waste. The occurrence of bottleneck may due to inexperience operator or complex task in the workstation. In this case, jigs, fixture, automation may be introduced to reduce the cycle time of the process (Arun et al., 2015). Once the manual assembly line achieving a sensible time and balance, the optimum number of operator needed in the manual assembly line can be determined. This will solve the idling of operators waiting for previous workstation to complete or the other way which is overcrowded of the assembly line. Below equation could be used to calculating the number of operator needed (Low et al., 2012):

*Number of operator needed = Total cycle time needed to produce 1 part / Takt Time*

The improvement of the line balancing with the needed number of operator can be determined by using ECRS or Work scrubbing method approach which is Eliminate, Combine, Rearrange and Simplify. Each of the workstations were reviewed either can be eliminate, combine the workstation with other workstation, rearrange the sequence of the workstation or simplification of the process in the workstation. This improvement will ensure the production flow smoothly and idling time is reduced. It also helps to optimize the utilization of the operator, reduce the space and increase productivity.

Six Sigma is systematic problem approach originated from Motorola focus on quality improvement through continuous reduction of process variation. The six sigma methodologies are based on the value of (6σ) which is used to calculate process capability. The process standard deviation of a six sigma should be six time smaller than the range between process mean to the upper or lower specification limit. As a results, defect will be limited to an estimated 3.4 parts per million. Six Sigma methodologies is the right tools to be apply because of several factor including which is Six Sigma's principles of customer orientation, resource dedication, standard method and benefit tracking are identical with the means and goals of the project. It is a process improving project which is targets at reducing cycle time. DMAIC methodology also is a well-known methodology in reducing process errors (Liu et al., 2011).

Six Sigma applied five phases of activities namely Define, Measure, Analyze, Improve and Control (DMAIC). This DMAIC methodology is a framework that outlines a clear cut sequence of steps that would guide an organization through its implementation of Six Sigma. The Define phase includes the project selection, statement of the problem identified, and goal of the project. Objective of this phase is to describe the problem statement based on customer's requirements and needs also to define the project scope and plan (Orbak, 2012). In this phase, Team charter, SIPOC (Supplier, Input, Process, Output and Customer) will usually be used. Next is Measure phase. The key of the Measure phase is to measure the current process capability in order to improve it.

The step in a measurement phase (Yun, 2011);

- Measure the baseline performance and verify the project need.
- Identify Input, Process and Output indicators.
- Plan for data collection.  Measure the process capability

There are many tools that can be applied to gather data collection to determine the input, process and output measures such as Process Mapping, Ishikawa / Fishbone Diagram, Measurement System Analysis (MSA), FMEA and SPC namely Pareto Chart, Scatter chart and histogram. Phase 3 is Analyze which is related to the system in order to find out the root cause of the critical problems. The problem can be identified based on simulating the current process and assessing the critical process. Analysis phase consists of three main steps (Orbak, 2012):

- Process and multivariate analysis
- Identifying possible causes
- Verification through hypothesis tests

Several analytical tools can be used to identify process problem including Cause and Effect diagram, FMEA and Measurement System Analysis (MSA) which is including Capability Study, Control Chart and Gage R&R. (Shahada & Alsyouf , 2012). Phase 4 is Improver. This phase will develop a proposed solution and test or pilot the solution in a real environment. This piloted solution allows collecting real time data to verify that the sources of variation are fixed and solution will work on a larger scale. The implementation of various tools namely Design of Experiment (DOE), Poke Yoke and visual control helps to ensure the solution by prevention, detection or prediction in place to reduce the variation of the process. The study helps to understand the relationship among different factors and the gap factor may be considered and important source of variation. (Banuelas et al., 2005). Last phase is Control. Control Phase has the objective of implementing ongoing measures and action to sustain the improvement by monitoring, standardizing, documenting and integrating the new process on a daily basis. The achieved profit level after the improved tools are evaluated in order to keep the business profit stable and increase and scrap percentage level should be reduced. Training should be in place and the improvement action should be documented in a Control Plan.

Lean and Six Sigma are two widely used improvement processes that are adopted to improve their cost, quality and customer satisfaction. Lean and Six Sigma concepts have some similarities as both are seeking improvement by minimizing waste and resources, customer satisfaction and financial results. According to these two concepts when used alone fail when a complete process improvement is considered. Lean concepts when used alone fails to bring the process under statistical control and the Six Sigma concepts fails to drastically improve speed or reduce invested capital by itself. Six Sigma problem solving tools were used to improve process quality by reduction of process variation while Lean tools were used to focus on process efficiency improvement (Shahada & Alsyouf , 2012). Adopting solely Six Sigma or Lean can bring about many benefits in an organization. However, when used together, the two systems become even more effective as their strong point are able to cover the other’s gap. Thus, the integration between Lean and Six Sigma techniques is a good strategy to develop a framework that enables decision maker, root cause analysis and problem solving effectively. Based on literature review, the integration between Lean improvement and Six Sigma is selected. By using Lean Six Sigma concept, there are needs to design a framework to suit both methodologies to suit in the study.

## 3. METHODOLOGY

Figure 1 shows the methodology process flow for this study. In Define and Measure stage, by application of Six Sigma methodology, it is targeting to complete objective 1 which is to identify the bottleneck. Meanwhile, process optimization in objective 2 will be discovered in Analyze and Improve phase which both methodology, Lean and Six Sigma will be applied.

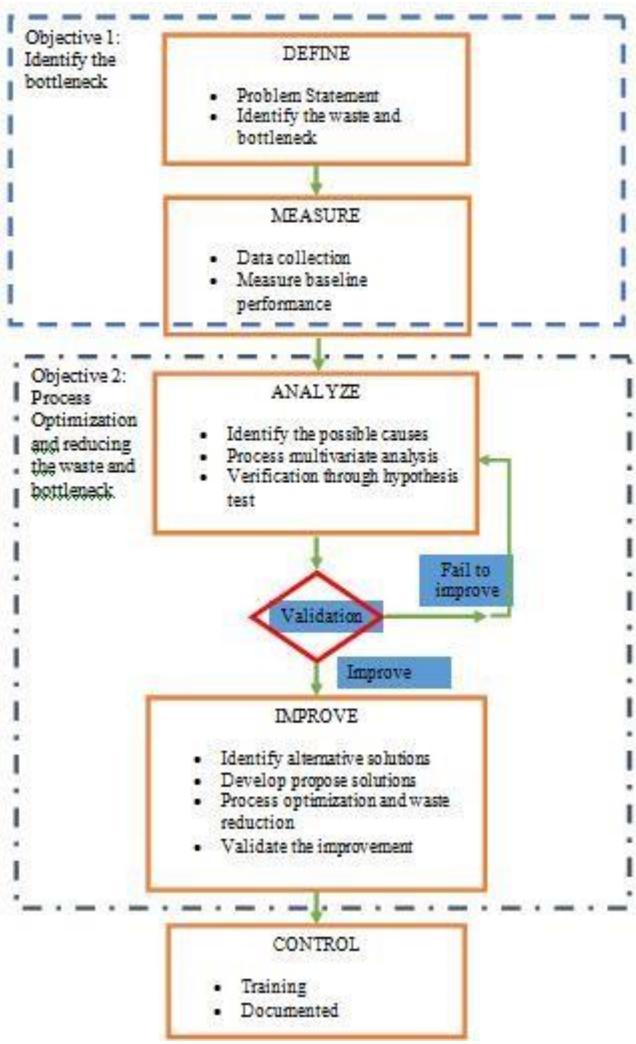


Figure 1: Methodology process flow

## 4. RESULT AND DISCUSSION

### Define phase

A compilation of all products in VS01 production line standard hour and headcount usage for each product are taken. Figure 2 shows the Comparison of product according to Standard hour and headcount usage.

Based on the Pareto diagram, Nome is the highest standard hour needed to run in production line which is 0.0581 and the highest headcount needed which requires five operators. This product will be identifying as the product scope of case study for improvement. Nome process flow consist 6 processes namely Burr Cutting, Crystal Scan, Proscan, Chassis Assembly, Screwing and Compats.

**Measure phase**

Two set of data collection were taken for each Nome processes. Method of data collection is using Stop Watch and Video Camera. Total 30 readings are taken for sample size. The board are run through all process and the times are taken. The data are the cycle time of each process for Nome process flow and the standard hour taken for every process. Currently the Nome product output per hour is 86 units and daily output is 1800 units. The takt time is 39 second. Figure 3 shows the cycle time by each process.

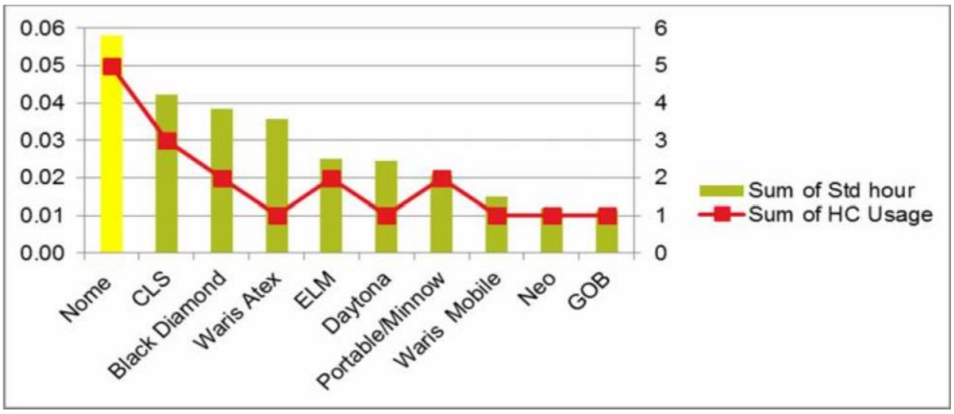


Figure 2: Comparison of product according to Standard hour and headcount usage

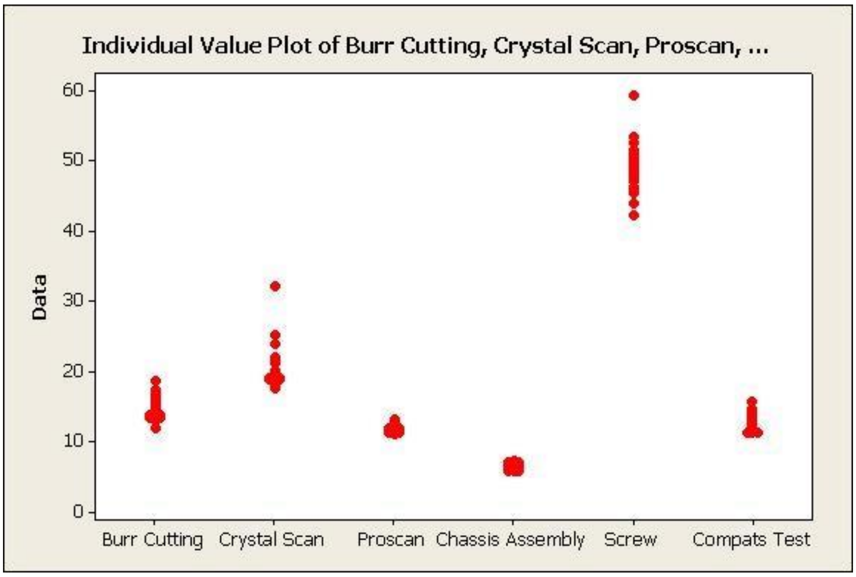


Figure 3: Cycle time by each process

Based on the data, screwing process is the highest time taken to complete. The screwing process cycle time is the highest and become the bottleneck for Nome product. Two operators needed to performscrewing process in order to achieve the output due to more than the takt time. Based on the result, times taken for every operator are distributed according to the process. Crystal Scan and Proscan time were combined because it is done by same person. Figure 4 shows existing time by each operator.

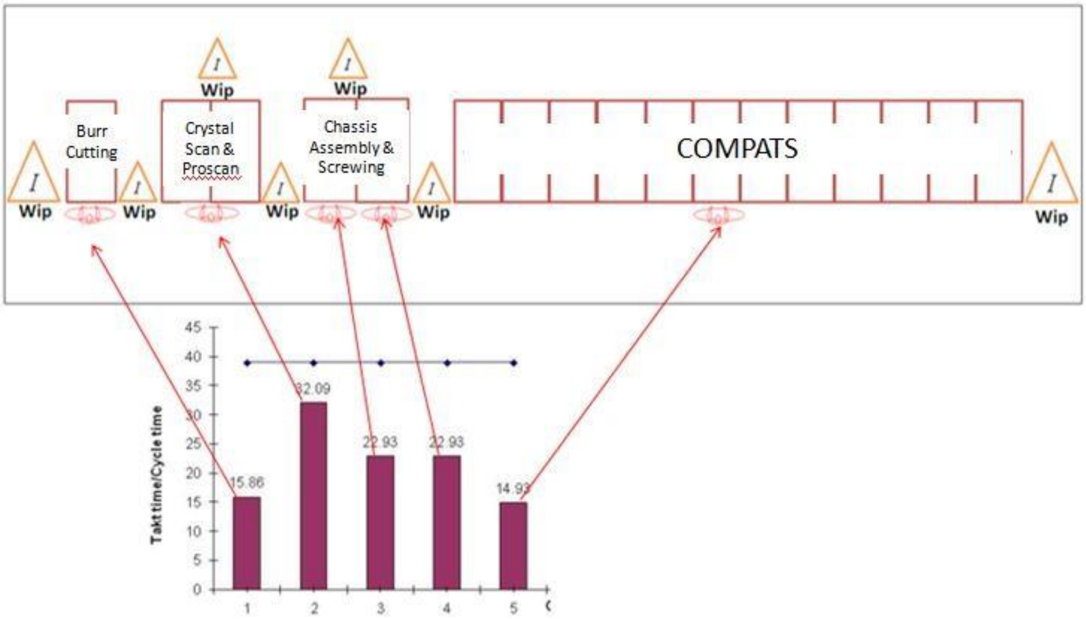


Figure 4: Manual time for every operator according to each process

The standard hours were calculated based on the output and head count allocation.

$$Standard\ Hour = Head\ Count\ Allocation / Output$$

This mean,

$$Standard\ hour = 5\ operator / 86 = \mathbf{0.0581}$$

**Analyze Phase**

In Analyse phase, using Work Element scrubbing that can be applied at every stage of process to reduce bottleneck and waste. The elements are Elimination, arrangement, Automation, Combination and Simplification.

Elimination is to remove the unnecessary process in the line. Based on the three stations in Figure 5, elimination process unable to perform for Crystal Scan and Proscan due to limited minimum equipment required. Thus, potential test station to be eliminated base on the requirement is Compats.

**Current Test Station Capacity**

| Test Station Name | Average Manual + Auto Time | Takt Time | Minimum Equipment Required | Existing Equipment |
|---|---|---|---|---|
| Crystal Scan | 23.39 sec | 39 sec | 0.5997 | 1 head |
| Proscan | 39.65 sec | 39 sec | 1.0167 | 2 head |
| Compats | 542.34 sec | 39 sec | 13.906 | 24 heads |

Figure 5: Test station capacity

Re-arrangement process can be done for Burr Cutting process. The purpose of Burr Cutting process is to remove the burr at the edge of the PCB. The process has similarity with previous process from SMT process which is Board *De-panelization*. At Board *De-panelization* process, the PCB will be *de-panelize* by removing the tie bars surrounding the PCB. New cutting machine need to fabricate to combine both process. This arrangement will remove one operator from the process and not requires any additional operator from SMT process.

As for Automation, screwing process is the suitable process to convert from manual to automation. Brainstorming was conducted to identify the potential causes and improvement that can be done to the screwing process. Based on the brainstorming in Causes and Effect Diagram, all ideas are ranked into Decision Metrics Analysis. There are five parameters should be considered for decision making as per agreement in team discussion which is time, cost, quality, consistent and flexible. Relative importance factor setting from 1 to 10 which is the highest is time with 10 point follows by cost with 9 point, quality with 7 point, flexible with 6 point and lastly consistent with 3 point. In process indicator, rank are given from 1 is for low, 3 is for moderate and 9 is for strong indicator. The Decision Metrics analysis is shown in Figure 7. Auto screw robot is the highest calculation for total importance rating. Thus, auto screwing robot is selected to be implement to reduce the screwing cycle time.

Once the Auto screwing robot has been implement, the screwing time should be reduce. As Crystal scan, Proscan and chassis assembly requires high cycle time, Screwing process and Compats are the potential process that can be combines.

As for simplification, after the implementation of Work Element Scrubbing which is elimination, re-arrangement, automation and combination to the process, the production flow line should be restructure back and the simplification of the process should be observe. The process should be reduced the bottleneck and waste in the production line.

## Improve Phase

In this phase, all action will be taken and implement. This is phase where the validation on the improvement takes place. That is why the data after improvement shall be taken and analyse back to confirm it effectiveness. A mistake proofing (Poke Yoke) and Visual Control shall need to be in place. The most important is the changes of the improvement shall not impact on the quality of the product. Figure 8 shows the comparison before and after improvement by implementing Lean methodology Work scrubbing method.

**Cause and Effect Matrix**

| Output Indictors --> | Time | Cost | Quality | Consistent | Flexible | Y6 | Y7 | |
|---|---|---|---|---|---|---|---|---|
| Relative Importance (0-10) | 10 | 9 | 7 | 3 | 6 | Importa | Importa | |
| Input / Process Indicators | Scale: 1 = Low, 3 = Moderate, 9 = Strong | | | | | | | Total Importance Rating |
| Training | 3 | 9 | 3 | 1 | 1 | | | 141 |
| Dedicated Operator | 3 | 3 | 9 | 3 | 3 | | | 147 |
| Less Rotation Screw | 3 | 1 | 1 | 1 | 1 | | | 55 |
| Reduce screw number | 9 | 3 | 1 | 1 | 1 | | | 133 |
| Use Snap Fit | 3 | 3 | 1 | 1 | 1 | | | 73 |
| Use Heavy Duty Adhesive | 1 | 3 | 1 | 1 | 1 | | | 53 |
| Auto Screw Robot | 9 | 1 | 9 | 9 | 3 | | | 207 |
| Auto Screw Feeding | 3 | 3 | 3 | 3 | 3 | | | 105 |
| Faster Fastening Speed | 3 | 3 | 3 | 3 | 1 | | | 93 |
| Perform by Technician | 3 | 1 | 3 | | | | | 60 |

Figure 7: Decision Metrics Analysis

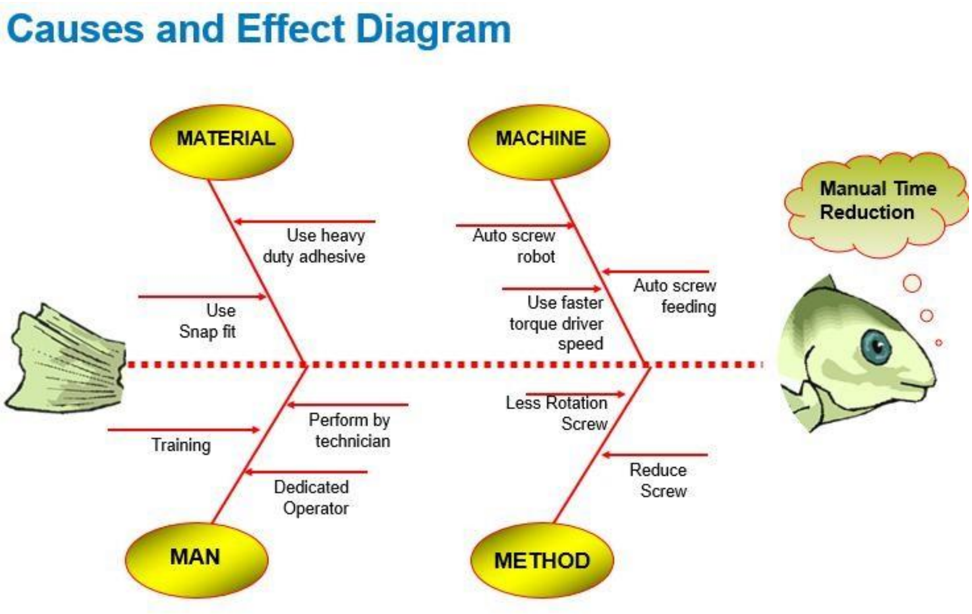


Figure 6: Cause and Effect Diagram from screwing process

Nome production flow line becomes shorter and simpler. Burr cutting process is moved to SMT process which is combines with *de-panelization* process. Both processes are done by using a single machine cutter. Unusable Compats test station are been remove from the production line and the two manual screwing fixture are replace by Automation screwing robot. The effectiveness for after improvement process is measure by the total standard hour and head count needed for each process. Thus, the after improvement times measurement need to be conducted for comparison and the analysis need to be done on after improvement data. Similar with before improvement gathering data methodology, 30 samples were taken and hourly output were recorded to calculate the standard hour.

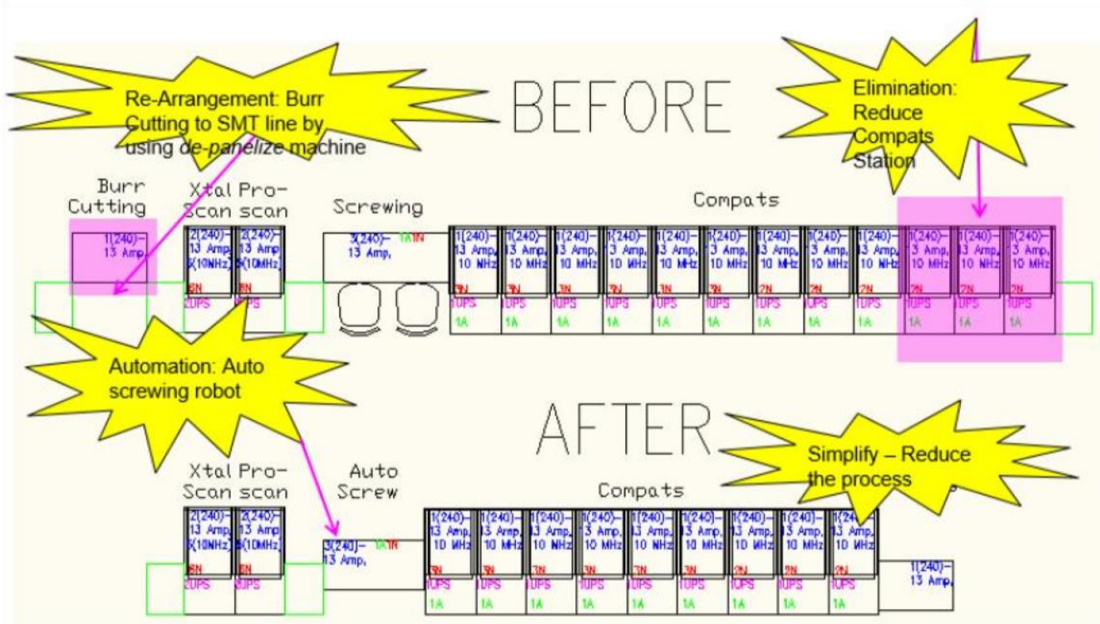


Figure 8: Before and after improvement layout

Figure 9 shows the process time before and after improvement for Nome. As Burr Cutting process is removed, left five processes which are Crystal Scan, Proscan, Chassis Assembly, Screwing and Compats Test. There are no changes on process cycle time for Crystal Scan, Proscan, Chassis Assembly and Compats test but observe significant time reduction on Screwing process from 22.93 seconds each with combination both operator total 45.86 to 17.88 seconds. Plus, excluding the Burr Cutting process that required 15.86 seconds is been removed from process flow. Total time reduction are 27.98 seconds from Screwing process and 15.86 seconds from Burr Cutting process contributed for total time reduction of 43.84 seconds.In order to balance the process and determine the operator, the process should not exceed 39 seconds which is exceed the takt time, Crystal Scan, Proscan and Chassis Assembly can be group into one operator while Screwing and

Compats can be group to second operator. Figure 10 shows the balancing process for each operator.

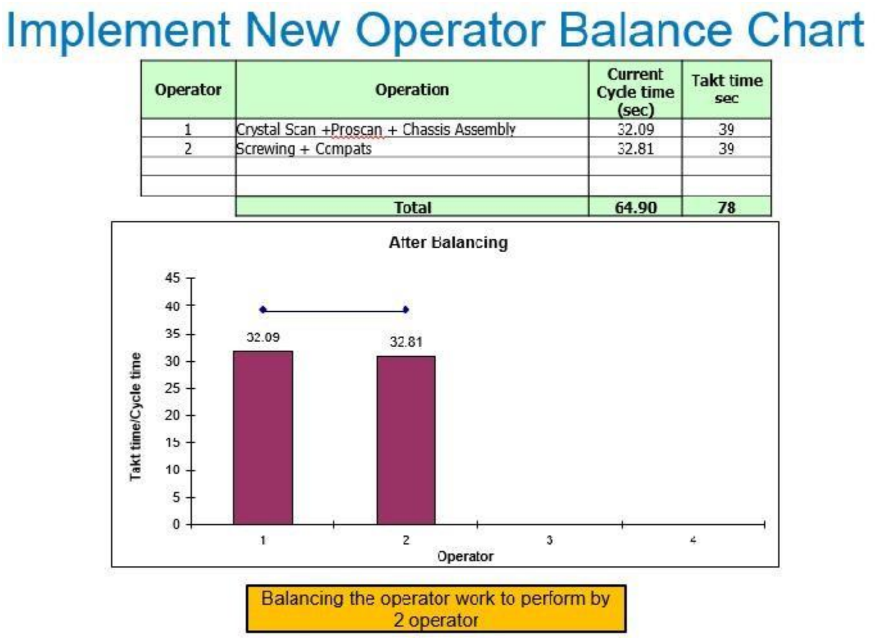


Figure 10: Balancing the process according to operator

Figure 11 and Figure 12 shows the implementation of Auto screwing robot and *De-panelize* machine combine with burr cutting. This machine also equipped with Safety Guard device which is the installation of emergency stop device easily accessible location. By this implementation could reduce reduced system-level operator exposure to manual assembly work, and thus system-level WMSD risk. It also helps to increased productivity, reduce cycle time and improve product quality.



Figure 11: Auto screwing robot

Figure 12: *De-panelize* & Burr Cutting machine

| Operation | Cycle time Before (sec) | Cycle time After (sec) |
|---|---|---|
| Burr Cutting | 15.86 | 0 |
| Crystal Scan | 14.25 | 14.25 |
| Proscan | 11.32 | 11.32 |
| Chassis Assembly | 6.52 | 6.52 |
| Screwing | 22.93 +22.93 | 17.88 |
| Compats | 14.93 | 14.93 |
| **Total** | 108.74 | 64.90 |

Figure 9: Process time before and after improvement

The standard hours were calculated based on the output and head count allocation.

*Standard Hour (After) = Head Count Allocation / Output*

This mean,

*Standard hour = 2 operator / 86 =* ***0.0232***


Figure 13: CNPK comparison between before and after improvement

Process capability evaluates the process normal variation against the requirement or specification. Processes are said to be capable if the normal process variation is less than the amount of their variability allowed by the specification. Comparison between CNPK before and after improvement shows improvement as before improvement only -3.49792 increase to 0.3. The process variation shows that the data already shifted the nominal however there are still point that above the USL (Upper Spec Limit). It is recommended that further improvement should be conducted to improve the CNPK from 0.3 to 1. Figure 14, the test shows that there are different of the variance standard hour before and after improvement by using *Levene's* statistic.
There different obviously can be observe on the time taken to complete the process and the spread of the variance. After improvement process requires less time taken compares with before improvement and the spread of the variance smaller that after improvement. It indicates that the process is more stable and more capable.

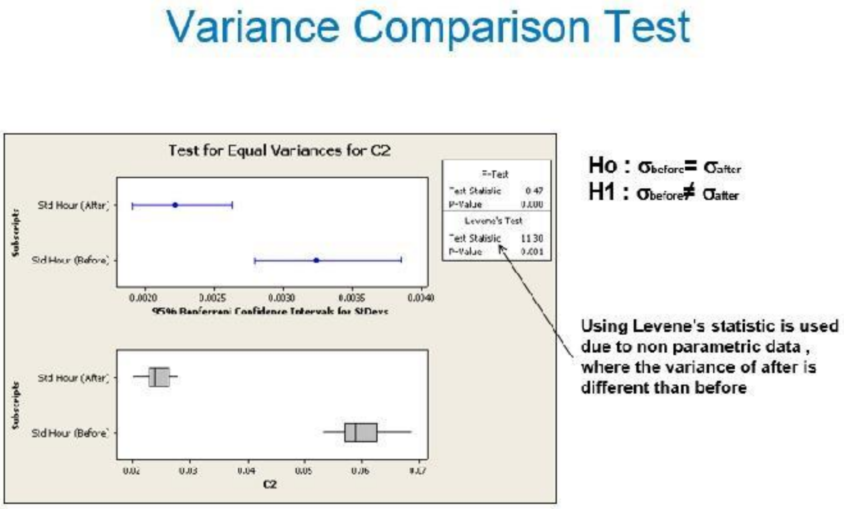


Figure 14: Variance Comparison Test

**Control Phase:**
In control phase, the implemented improvement process ongoing to be measures by monitoring, standardizing, documenting and integrating the new process onto a daily basis. The achieved profit level after improved tools is evaluated. Training should be in place and improvement action should be documented.

Cost saving is the priority to company reduction for headcount/operator and floor to ensure either their improvement project space reduction. The calculation should be effective or failed. Figure 15 shows the cost considered by cost per year.

The calculations for the operator are taken by four shift crew. Before improvement five operators are needed to operate the process which means twenty operators in total. Similarly for after improvement, two operators are needed which mean eight operators in total are needed to run the operation.

*Cost Saving = Cost reduction – investment cost*

Therefore,

*Cost saving = 73562 – 21333 =* ***USD$ 52229*** *per annum*

The investment cost mostly come from Auto screwing robot which is USD$18000 and fixture for burr cutting process combine with *de-panelization* board process which cost USD$ 3333. Training cost is excluded from this calculation as the training is done internally. The difference between head count and space cost reduction compared by investment cost is the cost saving that gives impact to the company.

**Cost Reduction**

| Item | Before | After | Total Reduction | Rate | Calculation | Cost Savings (USD per Year) |
|---|---|---|---|---|---|---|
| Headcount Reduction | 20 Operators | 8 Operators | 12 Operators | USD 6000 per operator per year | 12 x USD 6000 | 72000 |
| Floor Space Reduction | 266sqft | 195sqft | 71 Sqfeet | USD 22 per sqfeet per year | 71 x USD 22 | 1562 |
| | | | | | TOTAL | 73562 |

Figure 15: Cost Reduction Impact

## 5. CONCLUSION AND RECOMMENDATION

In summary, using Lean Six Sigma, the bottleneck and waste are able to be identified and the improvement was able to be implemented. The highest possibility product that requires improvement had been identified which is Nome. Nome is the highest among all products in VS01 for the standard hour time and highest number of operators. This project is able to reduce the Nome process standard hour from 0.0581 to 0.0232 and reduce the head count of the operator needed to operate the total Nome line from five people to two people. Based on all Nome process flow which is Burr Cutting, Crystal Scan, Proscan, Screwing and Compats, screwing process is the highest standard hour required to complete one task. In order to reduce the standard hour, Automation Screwing Robot had been introduced. By applying Work Element Scrubbing method, elimination on unnecessary station number, re-arrangement of Burr Cutting process to SMT process, combination, simplification on total Nome process line and automation able to help to reduce of standard hour and headcount for Nome process. The implementations of Lean Six Sigma improvement are able to help company for cost saving USD$52229 per year. This is happen due to the reduction of the three operators to complete the process and the saving of production space from line simplification. Control and monitoring should be in place after improvement. This is to ensure no other issue happen and affected the new process flow line. Training and certification should be provided to the operator and the technician to ensure they understand the new process before operates. All procedure needs to be documented for guideline to operator to refer and further improvement enhancement. By the improvement of standard hour time and headcount operator, it is sufficient enough to cover during 40% production ramp up time.

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