

Increasing Singulation Machine UPH Through Characterization and Standardization of Saw and Handler Parameters through DMAIC Methodology

ABSTRACT

This study aims to address the problem of machine saturation and low capacity at package singulation, caused by increasing product loading and new devices that requires frequent machine setups and conversions.

With this evaluation, the process and equipment engineering group collaborated to improve the machine unit per hour (UPH) of package singulation machines at the manufacturing assembly. Target improvements were divided into three phases, so that the team could focus more on each phase and was able to define robust parameters without compromising the product quality. DMAIC methodology was used to improve the productivity of package singulation machines. With the help of our methodology, we identified the root cause and contributing factors to the problem.

UPH improvements per machine were validated and assessed in terms of machine efficiency and product quality, because of characterization and standardization of every parameter in each phase of the project. The achieved total improvement was of 17.64%.

Keywords: UPH (unit per hour), DMAIC (Define Measure Analyze Improve and Control), Package Singulation

1. INTRODUCTION

Semiconductor industry represents the group of companies involved in the design and assembly of semiconductors. Over the years, it has become a viable business and has turned the driving force behind the wider electronics industry with billion-dollar annual sales revenue.

Therefore, semiconductor industry is widely recognized as a key driver and technology enabler for the whole electronics value chain. The global semiconductor industry is dominated by different countries all over the world in various sectors, like microprocessors, logic, memory, power semiconductors, transceivers, network processors, sensors, etc.

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There are many processes in assembly of semiconductor devices, one important step being the Package Singulation. It is the cutting process of dividing a molded lead frame or substrate into an individual packaged semiconductor device by a dicer engine, as shown in Fig 1. Then, they are picked-up individually by a handler system and stored in a tray.

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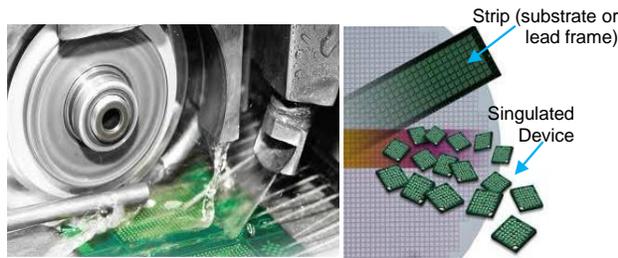


Fig. 1. Package Singulation Process

Machine UPH is the number of units produced within one hour by any equipment in a production area in a specified machine setting and parameters, when operated by trained personnel. One of the best singulation machine platforms in terms of output and quality that was equipped with an integrated handler and vision system. This machine was known to be more productive and efficient in terms of cutting and cleaning of sawn units. It also has the vision system, capable to detect common top and bottom defects. Singulation machines nowadays have a built-in vision system on their handler, as shown in Fig 2.



Fig. 2. Package singulation machine with integrated Handler and Vision system

Driven to support the business opportunity on top of the current package loadings at the manufacturing assembly, the management team decided to liberate capacity by UPH improvement to support future growth and cost competitive edge. Productivity and cost improvement can be accomplished by maximizing UPH by 10 to 20%. This increase is based on current IE(Industrial Engineering) standards by considering equipment capability and package complexity. One of the major assembly processes, which can increase the UPH, is package singulation.

There are currently 18x Package Singulation machines which are fully utilized by production group processing packages, like LGA-MEMS, QFN/BGA and QFN-mr packages, as listed in Table 1.0.

Table 1.0 Package Singulation Matrix

| ESP M/C | PACKAGE | ESP M/C | PACKAGE |
|---------|---------|---------|------------------|
| ESP073 | MEMS | ESP058 | QFN-MR |
| ESP051 | MEMS | ESP055 | QFN-MR |
| ESP070 | MEMS | ESP052 | QFN-MR |
| ESP061 | MEMS | ESP076 | QFN-MR |
| ESP043 | MEMS | ESP060 | QFN-MR BGA117 |
| ESP050 | MEMS | ESP059 | QFN-MR QFN |
| ESP049 | MEMS | ESP056 | QFN-MR QFN |
| ESP066 | MEMS | ESP071 | QFN-MR QFN |
| ESP064 | MEMS | ESP072 | QFN |

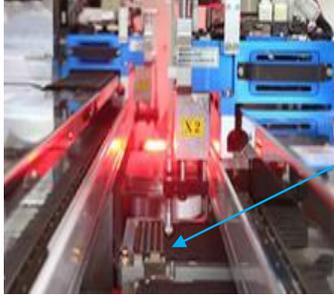
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lings continue to frequent machine

setups and conversions. Currently installed equipment was already saturated based on IE calculation.

Previous improvement actions were initiated by the equipment engineering group to speed-up the machine and increase its capacity to sustain production to meet daily delivery requirements. These initiatives included the reduction of pick and place z-picker vacuum on/off delay from 100 ms to 10 ms. Despite these actions for packages with high strip density, the bottleneck remained the handler's pick and place, as shown in Fig. 3 and Table 2.0.

Table 2.0 Package Singulation Bottleneck Process



| Strip Illustration | Strip Density | BOTTLENECK | |
|---|----------------------|------------|---------|
| | | SAW | HANDLER |
|  | 2800 units per strip | NO | YES |
|  | 600 units per strip | YES | NO |

Fig. 3 Handler's Pick and Place Process

To improve the machine UPH and increase its capacity, identification of bottleneck process at package singulation is important prior to proceeding with improvement actions. The latter are baselining of machine's actual performance, characterization, and standardization of parameters.

Our proposed solution is different from previous improvement actions, in that no additional cost should be involved and cost avoidance of purchasing new package singulation equipment can be realized.

2.0 REVIEW OF RELATED LITERATURE

DMAIC is a data driven improvement cycle designed to be applied to business processes to find flaws or inefficiencies particularly resulting to output defects and to prevent them. This methodology is not meant to be a quick fix approach, the logical use of the tools over time will save resources and maximize production. DMAIC methodology is to:

1. Define some very critical questions, like the errors in the production process and how they affect the production operations.
2. Measure their current production systems. When everything is evaluated, an organization can know what the root cause of their production problem is and start looking for ways to solve it. Having a data collection plan is very useful, when conducting this phase.
3. Analyze data gathered during the measurement phase about their production process. After analyzing available data, the organization can narrow down the cause of their production problems and figure out ways to maximize the production efficiency.
4. Improvement phase is the stage, where an organization tests, assesses, and implements all their ideas in terms of improving production.

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5. Control phase is meant to secure that all improvement actions are maintained. The last stage of the continuous improvement process and it is all about strategies to maintain high level of production.

Overall, the process of DMAIC is all about improving the process with least variations.

A study conducted in steel industry on low productivity rate as compared to the target output, addressed the use of Six Sigma DMAIC approach to define problems, opportunities, and requirements, measure process performance, analyze the root cause, and propose improvements. With the help of this methodology, the root cause of the bottleneck in the production process was identified along with factors that contribute to this problem.

An action plan was put together to address all these factors, through rearrangement of process and fabrication of stopper to yield higher productivity rate. Improvement was sustained through monitoring and changing the work instructions for the targeted process.

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3.0 METHODOLOGY

In this study, DMAIC methodology was used to achieve the objective of increasing the overall UPH of package singulation machines by 13% from an average UPH of 7707 to 8652 by the end of Q3'19, which covers all QFN, QFN-mr, and LGA packages.

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3.1 Define Phase

Fig.4 displays the current assembly monthly loading, LGA tops with 48mpcs followed by QFN at 16mpcs and QFN-mr at 13mpcs. 50% of the total package singulation machines were allocated to LGA, while 22% to QFN and QFN-mr, respectively.



Fig. 4 Monthly Loading and Package Allocation

3.2 Measure Phase

Critical processes at package singulation identified in the framework of this project were the saw and handler cleaning and drying steps, along with handler motor speed and sawing processes, as displayed in Fig.5.



Fig. 5 Package Singulation: a Detailed Process Flow

In identifying the process input variables, the team used the Input and Output Worksheet (I/O worksheet) to account for all variables in each process step that may potentially affect the machine UPH. 52 KPIV's (Key Process Input Variable) were found as potential X's (see Table 3.0.)

All input variables listed in the I/O worksheet were filtered through the Cause-and-Effect Matrix (C&E Matrix as shown on Table 4.0), and the effects of each variable were scored with respect to the output response. By using the scoring matrix, we have identified the critical X's that impact the low machine UPH.

Table 3.0 Input and Output Worksheet **Table 4.0 Cause and Effect Matrix**

| Input - Output Worksheet | | Key Output Process Variables | | | Cause and Effect Matrix | |
|--|--|--|-----|----------------------|------------------------------|-------------------|
| Characteristics of Process Outputs (KPOVs) | | Characteristics of Process Outputs (KPOVs) | | | Cause and Effect Matrix | |
| Key Output | Characteristic of Output (KPOV / Y / Miss Y) | Specification | MSA | Z-Score (Short Term) | Specification Limits (for Y) | Customer Priority |
| Low UPH | Machine Capacity | | | | | |

| S.No | Process Step | Input | Characteristic of Input (KPIV / X) | Scoring | Total | Is X Continuous / Discrete? | Count 3's | Count 5's | X Selected / Discarded? |
|------|--|-------|---------------------------------------|---------|-------|-----------------------------|-----------|-----------|-------------------------|
| | | | | | | | | | |
| 16 | Cutting of strip at chuck table | Setup | Cutting speed | 9 | 90 | Discrete | 0 | 1 | Select the X |
| 17 | | Setup | Cutting accuracy | 9 | 90 | Discrete | 0 | 1 | Select the X |
| 18 | | Setup | Cutting Mode (Dual/Single Spindle) | 9 | 90 | Discrete | 0 | 1 | Select the X |
| 19 | | Setup | Chuck table return speed (air cartan) | 9 | 90 | Discrete | 0 | 1 | Select the X |
| 20 | | Setup | Cutting clearances | 3 | 30 | Discrete | 1 | 0 | Select the X |
| 21 | | Setup | kg/Cut wash settings | 9 | 90 | Continuous | 0 | 1 | Select the X |
| 23 | Pick-up of sawn units from chuck table | Setup | Unit picker alignment | 1 | 10 | Continuous | 0 | 0 | Discard the X |
| 24 | | Setup | Unit picker pick-up speed | 3 | 30 | Discrete | 1 | 0 | Select the X |
| 28 | Cleaning /Brushing of sawn units | Tool | Brush Condition | 0 | 0 | Discrete | 0 | 0 | Discard the X |
| 31 | | Setup | Brush count | 9 | 90 | Continuous | 0 | 1 | Select the X |
| 32 | | Setup | Brush cleaning speed | 9 | 90 | Discrete | 0 | 1 | Select the X |
| 33 | Water/Wr Rinsing | Setup | Water/Wr rinsing count | 9 | 90 | Continuous | 0 | 1 | Select the X |
| 34 | | Setup | Water/Wr supply on clean bin | 0 | 0 | Discrete | 0 | 0 | Discard the X |
| 36 | Drying of Units | Setup | Dry block air blow count | 9 | 90 | Discrete | 0 | 1 | Select the X |
| 37 | | Setup | Dry block air blow speed | 9 | 90 | Discrete | 0 | 1 | Select the X |
| 42 | Picking of units from turn table | Setup | HP Rubber pickheads | 1 | 10 | Discrete | 0 | 0 | Discard the X |
| 45 | | Setup | Pick-up speed | 9 | 90 | Discrete | 0 | 1 | Select the X |
| 46 | Placement of units on Tray (P&P) | Setup | HP Rubber pickheads | 1 | 10 | Discrete | 0 | 0 | Discard the X |
| 51 | | Setup | Placement speed | 9 | 90 | Discrete | 0 | 1 | Select the X |

Reported below is the statistical validation of potential cause of the productivity problems, based on identified critical X's from the KPIV's that affect the low machine UPH.

A quick win was easily executed through machine baselining of saw and handler wash/dry parameters from the best performing machine (in terms of output). Fig.6 shows the 4 process steps to which wash and dry parameters were baselined fast, from the identified best machine by package type. A 10.95% UPH increase was attained after implementation of the quick win, considered as Phase 1 of the project. Each improved machine executes a 5x lots visual validation with respect to UPH increase, without any detectable quality issues.

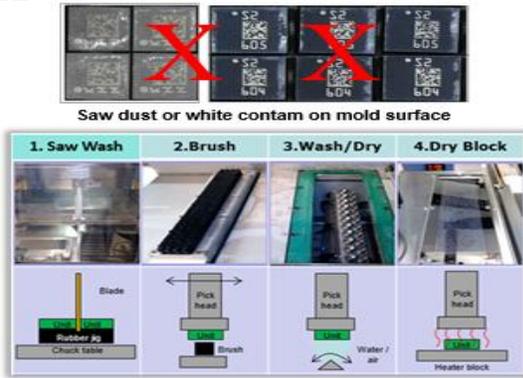


Fig. 6 Saw and Handler Wash/Dry Process Steps

3.3 Analyze Phase

A test plan was set to validate the existing wash and dry, handler speed and saw parameters that contribute to low machine UPH. Statistical testing using 2-proportion test and regression analysis were applied to validate potential causes.

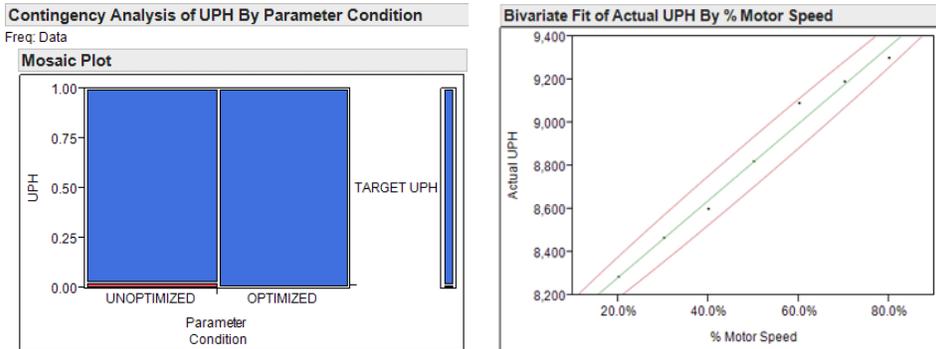


Fig. 7 2-Proportion and Regression Statistical Testing

Validation results based on statistical testing shows that the potential factors contribute to low machine UPH of package singulation machines.

3.4 Implementation Phase

Baselined wash and dry parameters were implemented during the analyze phase, as a quick win. Handler motor speed and saw parameter improvement (Fig. 8) was also executed and implemented across all applicable package singulation machines, after these parameters were validated as top contributors of the problem.

Potential problem analysis was also conducted, after implementation of corrective actions, to assess possible effect to product quality. This was done by performing visual inspection on lots processed from all the improved singulation machines.



Fig. 8 Handler Motor Speed and Saw Parameters

3.5 Control Phase

After standardization of identified saw and handler parameters, the team has continued to monitor results of improvements via visual inspection at post process, with passing result as

shown on Table 5.0. All improvement actions and standardization of parameters were documented and deployed to all shop floor personnel handling these package singulation machines. Continuous UPH improvement is being done to fan-out these improvements on the other machine platforms.

Table 5.0 Post Visual Inspection Validation

| Machine I.D. | Package Size | UPH IMPROVEMENT | | | SUMMARY |
|--------------|--------------|--------------------|--------------------|--------------------|---------|
| | | PHASE 1 | PHASE 2 | PHASE 3 | |
| ESP049 | 2.5x3.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP050 | 2.5x3.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP051 | 2.5x3.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP073 | 2.5x3.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP061 | 2.0x2.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP043 | 2.0x2.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP070 | 2.3x2.3 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP066 | 3.0x3.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP052 | 7.0x7.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP055 | 7.0x7.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP056 | 7.0x7.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP058 | 7.0x7.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP059 | 3.0x3.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP060 | 9.0x9.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP071 | 5.0x5.0 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |
| ESP072 | 5.0x5.1 | 5x lots validation | 5x lots validation | 5x lots validation | PASSED |

4.0 RESULTS AND DISCUSSION

4.1 Phase 1: Wash and Dry Parameter Validation

This phase of the work was done after machine baselining of saw and handler wash and dry parameters from the best performing machine (see Table 6.0). Validation of machine UPH was acknowledged by IE, after standardization of parameters. 5x lot validation was performed through visual inspection, without quality issues. UPH improved from 7700 units to 8463 units or a total of 10.95% improvement.

Table 6.0 Saw and Handler Wash and Dry Parameters

| Machine I.D. | Package Size | Saw | | | | Handler | | | | | | | | | |
|--------------|--------------|--------------------------|-----|---------------------------|-----|----------------------------------|----|-----------------|----|--------------------|----|----------------|-----|-------------|-----|
| | | Wash on Saw | | | | Wash on Brush/Cleanbox/Dry Block | | | | | | Pick and Place | | | |
| | | Jig wash count (CH1/CH2) | | Work wash count (CH1/CH2) | | Brush Clean count | | Clean Box count | | Dry Air blow count | | X1 Assy (%) | | X2 Assy (%) | |
| | | FROM | TO | FROM | TO | FROM | TO | FROM | TO | FROM | TO | FROM | TO | FROM | TO |
| ESP049 | 2.5x3.0 | 6/6 | 5/5 | 6/6 | 5/5 | 10 | 10 | 20 | 20 | 40 | 20 | 100 | 100 | 100 | 100 |
| ESP050 | 2.5x3.0 | 6/6 | 5/5 | 6/6 | 5/5 | 10 | 10 | 20 | 20 | 20 | 20 | 100 | 100 | 100 | 100 |
| ESP051 | 2.5x3.0 | 6/6 | 5/5 | 6/6 | 5/5 | 10 | 10 | 20 | 20 | 20 | 20 | 100 | 100 | 100 | 100 |
| ESP073 | 2.5x3.0 | 6/6 | 5/5 | 6/6 | 5/5 | 15 | 10 | 40 | 20 | 25 | 20 | 100 | 100 | 100 | 100 |
| ESP061 | 2.0x2.0 | 6/6 | 5/5 | 6/6 | 5/5 | 50 | 20 | 40 | 30 | 20 | 20 | 100 | 100 | 100 | 100 |
| ESP043 | 2.0x2.0 | 6/6 | 5/5 | 6/6 | 5/5 | 30 | 20 | 50 | 30 | 20 | 20 | 100 | 100 | 100 | 100 |
| ESP070 | 2.3x2.3 | 6/6 | 5/5 | 6/6 | 5/5 | 25 | 20 | 20 | 20 | 30 | 20 | 100 | 100 | 100 | 100 |
| ESP066 | 3.0x3.0 | 6/6 | 5/5 | 6/6 | 5/5 | 15 | 10 | 25 | 20 | 25 | 20 | 100 | 100 | 100 | 100 |
| ESP052 | 7.0x7.0 | 1/1 | 1/1 | 1/1 | 1/1 | 8 | 8 | 10 | 10 | 8 | 8 | 100 | 100 | 100 | 100 |
| ESP055 | 7.0x7.0 | 1/1 | 1/1 | 1/1 | 1/1 | 8 | 8 | 10 | 10 | 8 | 8 | 100 | 100 | 100 | 100 |
| ESP056 | 7.0x7.0 | 1/1 | 1/1 | 1/1 | 1/1 | 8 | 8 | 10 | 10 | 8 | 8 | 100 | 100 | 100 | 100 |
| ESP058 | 7.0x7.0 | 1/1 | 1/1 | 1/1 | 1/1 | 8 | 8 | 10 | 10 | 8 | 8 | 100 | 100 | 100 | 100 |
| ESP059 | 3.0x3.0 | 6/6 | 5/5 | 6/6 | 5/5 | 25 | 10 | 15 | 15 | 25 | 15 | 100 | 100 | 100 | 100 |
| ESP060 | 9.0x9.0 | 1/1 | 1/1 | 1/1 | 1/1 | 20 | 8 | 15 | 10 | 20 | 8 | 50 | 100 | 50 | 100 |
| ESP071 | 5.0x5.0 | 2/1 | 1/1 | 2/1 | 1/1 | 15 | 10 | 10 | 10 | 15 | 15 | 90 | 100 | 90 | 100 |
| ESP072 | 5.0x5.1 | 2/1 | 1/1 | 2/1 | 1/1 | 10 | 10 | 10 | 10 | 20 | 15 | 100 | 100 | 100 | 100 |

NOTE: All parameters are within specification

4.2 Phase 2: Handler Motor Speed Validation

This validation was done after machine standardization of handler speed parameters baselined from the best performer machine (Table 7.0). Validation of machine UPH was verified by IE. 5x lot validation through visual inspection was performed without detectable quality issue. UPH improved from 8463 units to 8818 units or a total of 4.72% improvement.

Table 7.0 Handler Motor Speed Parameters

| Packages | QFN-MR 7x7 | | VIKINGS | | QFN3x3 | | UM16 | | MEMS 3x3 | | MEMS 2x2 | | NEWTON | | MEMS 2.5x3 | |
|----------------------------|------------|-----|---------|-----|--------|-----|--------|-----|----------|-----|----------|-----|--------|-----|------------|-----|
| Machines | ESP052 | | ESP060 | | ESP059 | | ESP071 | | ESP066 | | ESP043 | | ESP070 | | ESP050 | |
| Improvement | From | To | From | To | From | To | From | To | From | To | From | To | From | To | From | To |
| MZ UP/DN | 60% | 80% | 70% | 80% | 60% | 80% | 30% | 80% | 60% | 80% | 50% | 80% | 20% | 80% | 5% | 80% |
| Rail Slow Down | 10% | 10% | 5% | 10% | 5% | 10% | 2% | 10% | 1% | 10% | 5% | 10% | 5% | 10% | 10% | 10% |
| Rail Slow Up | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 2% | 5% | 1% | 5% | 5% | 5% | 5% | 5% |
| Chuck Table Slow Down (SP) | 10% | 50% | 20% | 50% | 5% | 50% | 2% | 50% | 20% | 50% | 5% | 50% | 20% | 50% | 20% | 50% |
| Chuck Table Slow Up (SP) | 5% | 10% | 10% | 10% | 10% | 10% | 1% | 10% | 20% | 10% | 5% | 10% | 5% | 10% | 10% | 10% |
| Chuck Table Slow Down (UP) | 10% | 20% | 30% | 20% | 10% | 20% | 10% | 20% | 8% | 20% | 5% | 20% | 10% | 20% | 5% | 10% |
| Chuck Table Slow Up (UP) | 5% | 5% | 3% | 5% | 5% | 5% | 5% | 5% | 2% | 5% | 3% | 5% | 5% | 5% | 5% | 5% |
| Brush Left | 20% | 50% | 50% | 50% | 20% | 50% | 20% | 50% | 20% | 50% | 10% | 50% | 15% | 50% | 15% | 50% |
| Brush Right | 20% | 50% | 50% | 50% | 20% | 50% | 20% | 50% | 20% | 50% | 10% | 50% | 15% | 50% | 15% | 50% |
| Package Loading | 80% | 80% | 50% | 80% | 80% | 80% | 60% | 80% | 20% | 80% | 80% | 80% | 20% | 80% | 60% | 80% |
| Package Unloading | 80% | 80% | 20% | 80% | 80% | 80% | 60% | 80% | 20% | 80% | 80% | 80% | 20% | 80% | 60% | 80% |
| Water Remove Left | 30% | 50% | 50% | 50% | 20% | 50% | 50% | 50% | 20% | 50% | 10% | 50% | 40% | 50% | 50% | 50% |
| Water Remove Right | 5% | 10% | 5% | 10% | 10% | 10% | 10% | 10% | 15% | 10% | 5% | 10% | 5% | 10% | 20% | 10% |
| Dry Block Slow Down | 5% | 10% | 50% | 10% | 2% | 10% | 5% | 10% | 10% | 10% | 10% | 10% | 30% | 10% | 5% | 10% |
| Dry Block Slow Up | 5% | 10% | 5% | 10% | 5% | 10% | 5% | 10% | 5% | 10% | 10% | 10% | 10% | 10% | 10% | 10% |
| Turn Table Down | 70% | 80% | 80% | 80% | 80% | 80% | 80% | 80% | 80% | 80% | 50% | 80% | 50% | 80% | 50% | 80% |
| Turn Table Slow Up | 3% | 10% | 5% | 10% | 10% | 10% | 5% | 10% | 5% | 10% | 5% | 10% | 2% | 10% | 10% | 10% |

NOTE: All parameters are within specification

4.3 Phase 3: Saw Parameter Validation

After the standardization of saw parameters baselined from the best performer machine per package type (shown in Table 8.0), validation of machine UPH was acknowledged by IE. 5x lot validation through visual inspection was performed with no quality issues. UPH increased from 8818 to 8975 units, which corresponds to a total of 1.98% improvement.

Table 8.0 Saw Parameters

| Machine | Package Type | Channels | Feed/Cutting Speed | | Cut Entry Clearance (CH1/CH2) | | Blade Cutting Mode (Spindle) | | Air Curtain Sweep Speed | |
|---------|------------------|----------|--------------------|------------|-------------------------------|------|------------------------------|--------|-------------------------|------------|
| | | | FROM | TO | FROM | TO | FROM | TO | FROM | TO |
| ESP058 | VQFN-mr 7x7 | CH1 | 150 mm/sec | 150 mm/sec | 2 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| | | CH2 | 150 mm/sec | 150 mm/sec | 2 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| ESP055 | VQFN-mr 7x7 | CH1 | 150 mm/sec | 150 mm/sec | 2 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| | | CH2 | 150 mm/sec | 150 mm/sec | 2 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| ESP052 | VQFN-mr 7x7 | CH1 | 150 mm/sec | 150 mm/sec | 2 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| | | CH2 | 150 mm/sec | 150 mm/sec | 2 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| ESP056 | QFN Repat 3x3 | CH1 | 20 mm/sec | 20 mm/sec | 5 mm | 2 mm | Dual | Dual | 60 mm/sec | 150 mm/sec |
| | | CH2 | 20 mm/sec | 20 mm/sec | 5 mm | 2 mm | Dual | Dual | 60 mm/sec | 150 mm/sec |
| ESP060 | Vikings 9x9 | CH1 | 120 mm/sec | 130 mm/sec | 5 mm | 2 mm | Single | Single | 150 mm/sec | 150 mm/sec |
| | | CH2 | 120 mm/sec | 130 mm/sec | 5 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| ESP060 | Yosemite 3.5x4.5 | CH1 | 15 mm/sec | 15 mm/sec | 2 mm | 2 mm | Dual | Dual | 60 mm/sec | 150 mm/sec |
| | | CH2 | 15 mm/sec | 15 mm/sec | 2 mm | 2 mm | Dual | Dual | 60 mm/sec | 150 mm/sec |
| ESP059 | QFN Repat 3x3 | CH1 | 20 mm/sec | 20 mm/sec | 2 mm | 2 mm | Dual | Dual | 60 mm/sec | 150 mm/sec |
| | | CH2 | 20 mm/sec | 20 mm/sec | 2 mm | 2 mm | Dual | Dual | 60 mm/sec | 150 mm/sec |
| ESP071 | VFQFPN28 (UM16) | CH1 | 25 mm/sec | 25 mm/sec | 5 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| | | CH2 | 25 mm/sec | 25 mm/sec | 5 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| ESP072 | VFQFPN28 (UM16) | CH1 | 25 mm/sec | 25 mm/sec | 5 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| | | CH2 | 25 mm/sec | 25 mm/sec | 10 mm | 2 mm | Dual | Dual | 150 mm/sec | 150 mm/sec |
| ESP066 | MEMS 3.0x3.0 | CH1 | 30 mm/sec | 30 mm/sec | 5 mm | 2 mm | Single | Single | 60 mm/sec | 150 mm/sec |
| | | CH2 | 60 mm/sec | 60 mm/sec | 5 mm | 2 mm | Dual | Dual | 60 mm/sec | 150 mm/sec |
| ESP064 | MEMS 3.0x3.0 | CH1 | 70 mm/sec | 70 mm/sec | 2 mm | 2 mm | Single | Single | 60 mm/sec | 150 mm/sec |
| | | CH2 | 70 mm/sec | 70 mm/sec | 2 mm | 2 mm | Dual | Dual | 60 mm/sec | 150 mm/sec |

4.4 Summary of UPH Improvements

After completing all 3 phases of improvements, a total of 17.64% UPH improvement was achieved versus the project target of 13%. These improvements yielded the production of a total of 461K units per day, manufactured as additional machine capacity (Table 9.0).

Table 9.0 Phase Improvement Summary

| Rawline | Old UPH | Phase 1 New UPH | Phase 1 % Improvement | Phase 2 New UPH | Phase 2 % Improvement | Phase 3 New UPH | Phase 3 % Improvement |
|--------------|---------|-----------------|-----------------------|-----------------|-----------------------|-----------------|-----------------------|
| CCFZ*UAW1AC2 | 4,314 | 5,026 | 16.49% | 6,227 | 23.90% | 6,374 | 2.36% |
| 88X0*UP31BA5 | 7,690 | 8,244 | 7.21% | 8,268 | 0.29% | 8,369 | 1.22% |
| EAZX*UM16BCS | 4,192 | 4,284 | 2.20% | 4,303 | 0.44% | 4,303 | 0.00% |
| EAZX*UM16BCS | 6,143 | 6,185 | 0.68% | 6,223 | 0.61% | 6,380 | 2.52% |
| G53N*MV36BFA | 7,322 | 10,140 | 38.48% | 10,158 | 0.18% | 10,164 | 0.06% |
| G53N*MV36BFA | 12,207 | 12,972 | 6.27% | 12,999 | 0.21% | 13,020 | 0.16% |
| 77BA*MV3WBAA | 10,150 | 11,433 | 12.16% | 13,514 | 18.20% | 14,440 | 6.85% |
| 77AA*MV4YABA | 12,038 | 12,197 | 1.32% | 12,358 | 1.32% | 12,431 | 0.59% |
| 77NN*MV7UACC | 12,476 | 13,605 | 9.03% | 13,660 | 0.40% | 13,749 | 0.65% |
| CU)U*UAC7ABD | 6,014 | 6,313 | 5.58% | 6,494 | 2.87% | 6,494 | 0.00% |
| CCZH*UAQ3BEC | 2,230 | 2,699 | 21.03% | 2,793 | 3.48% | 2,997 | 7.30% |
| | | PHASE 1 | 10.95% | PHASE 2 | 4.72% | PHASE 3 | 1.98% |
| | | | 10.95% | total (P1+P2) | 15.67% | (P1+P2+P3) | 17.64% |

| Old DLC K/day | New DLC K/day | Add'l Capacity K/day | Total per Macro package | Macro package |
|-----------------------------|---------------|----------------------|-------------------------|----------------|
| 80 | 119 | 38 | 51 | QFN < 5x5 |
| 143 | 156 | 13 | | |
| 75 | 77 | 2 | | |
| 105 | 109 | 4 | | |
| 150 | 208 | 58 | 363 | LGA - MEMS |
| 250 | 267 | 17 | | |
| 208 | 296 | 176 | | |
| 247 | 255 | 8 | | |
| 256 | 282 | 104 | | |
| 112 | 121 | 27 | | |
| 42 | 56 | 14 | 41 | QFN - MULTIROW |
| Total Capacity Added | | 461 | | |

Figure 9 and 10 shows how machine UPH increases in every phase of the project.

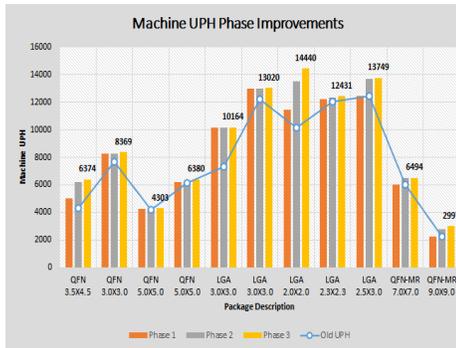
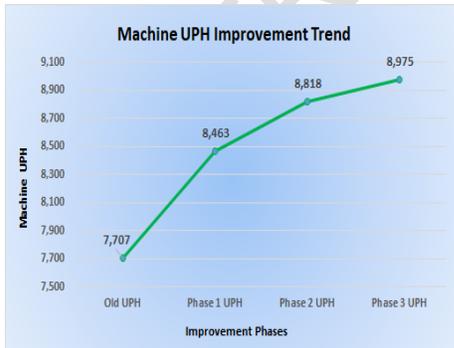


Fig. 9 Machine UPH Improvement Trend by Phase Fig. 10 Machine UPH Phase Improvement by Package Type

4.5 Process or Quality Control Results

This phase was based on the actual data, gathered from the process control group regarding defects trapped during quality control gating. Fig. 11 shows results of the only few

occurrences of white contam and package chipout at PC gate, but the cause is not machine related.

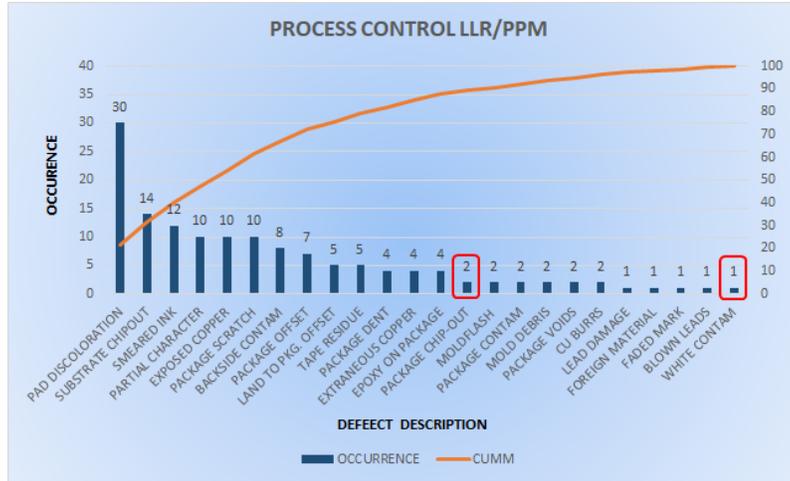


Fig. 11 LRR/PPM Pareto Graph

4.6 Validated Cost Savings

More than one thousand USD cost savings were achieved, which is equivalent to 2 quarters of Preventive Maintenance consumable parts replacement.

5.0 CONCLUSION

Increasing the UPH of package singulation machines using the DMAIC methodology is an effective and inexpensive solution to address low production capacity of machines. Measurement of current machine condition and validation of potential causes plays an important role in identifying the problem.

6.0 RECOMMENDATIONS

Machine baselining was initially executed to identify the best machine to be the model machine in standardization of machine parameters. It is recommended to check first the frequencies of cleaning and drying cycles, which was proven to be the top contributor of the problem addressed in this study. Machine handler speed and saw parameters also contribute to the increase of UPH. DMAIC methodology is highly recommended for being used in solving machine productivity.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly utilized products in our area of research and country. There is no conflict of interest between the authors and product manufacturers because we do not intend to use these products as an avenue to any

litigation, but strictly for advancing the knowledge. Also, the research was not funded by the producing company, but it was rather funded by personal efforts of the authors.

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