# *Quality Improvement of a Paint and Restoration Process in the Remanufacturing Industry*

*Gabriel E. Llanos Henriquez*
*Master of Engineering in Manufacturing Engineering*
*Jose A. Morales, Ph.D.*
*Industrial Engineering Department*
*Polytechnic University of Puerto Rico*

***Abstract*** *— In a remanufacturing operation it was required to improve the first pass yield of a Paint and Restoration process that handles plastic and metallic parts. The raw material for the process is recovered from used household electronic equipment; all parts present scratches and/or dents. The process, Paint and Restoration, was able to recover 78% of the parts, and it was generating around $90K of scrap; it was also possible to loss the customer ($1.4MM annual sales) if overall recovery rate was not improved. The Seven Step problem solving approach and Six Sigma tools were used in order to systematically increase the first pass yield of the Paint and Restoration process. The process was improved and it was demonstrated via 2 Sample t Test at a significance level of 0.05; the first pass yield was improved to from 78% to 92%. This project demonstrated that improvement actions can be taken at low cost by going back to basic process definition and control, many times underestimated in mature processes.*

***Key Terms*** *— Paint and Restoration, Remanufacturing Operation, Seven Step Problem Solving and Six Sigma.*

## INTRODUCTION

The current paint process (Paint and Restoration department) is a critical component of a larger remanufacturing operation of used household electronic device. The process handles all plastic and metallic parts. The raw material for the paint and restoration process is material that is recovered from used units. All parts present scratches and/or dents. The department should be able to recover-reuse-recycle the available material and send it back to the assembly portion of the remanufacturing process.

It is required to sort and prepare parts suitable for sanding. The sanding and painting processes for a metallic and a plastic part are different. Over 80% of the volume handled in the area was plastic and 20% metallic parts, recently, this mix radically changed to 70% metallic parts and 30% plastic parts.

Current process performance is causing delays in deliveries to customers at the repair/production lines where metallic parts are used, delivery plans are being missed by 8% due to painted products stock outs; the paint process is generating 22% of defective parts (78% first pass yield) that would cost around $90K a year (scrap dollars). The projected lost in sales is $24K per month ($288K per year), including the possible loss of the customer, which represents $1.4MM in annual sales.

The process will be measured and analyzed in order to determine the most relevant defects, and establish its root cause, to effectively reduce the observed defect rate. The Paint and Restoration department is responsible of preparing the parts and painting them. This project will impact all parts of the process.

As mentioned before, all parts present scratches and/or dents. The main challenge of the process is to be able to re-work parts and correct the cited defects. Several types of defects have been observed after the paint (restoration) process and fall under the categories showed in Figure 1.

This work will apply the Seven Step problem solving technique and Six Sigma tools, in order to improve the current quality performance of the paint and restoration process for metallic parts.

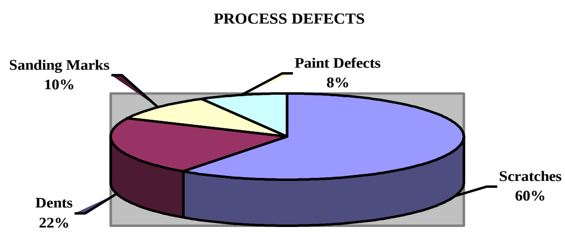


**Figure 1**
**Defects Distribution Paint Process**

## LITERATURE REVIEW

As per the American Coatings Association, it is not until the industrial revolution when the paint and coatings industry became a recognized element of the American economy [1]. Today, many of the paint and coatings may go unnoticed by customers, but they play an immeasurable valuable role in delivering high-quality foodstuffs, pharmaceutical products, housing, durable goods, furniture, etc. Total sales for the industry in US were approximately $20.9 billion in 2006 [1]. Paint and coatings have evolved from being used with decorative purposes on cave walls into a primary protective barrier between the environment and the things we normally use.

Paint processes are constantly experimenting changes mainly driven by custom application requirements, economics and environmental factors. Every paint process will generally consist of part preparation (sanding and cleaning), paint application, curing and quality control. See Figure 2.

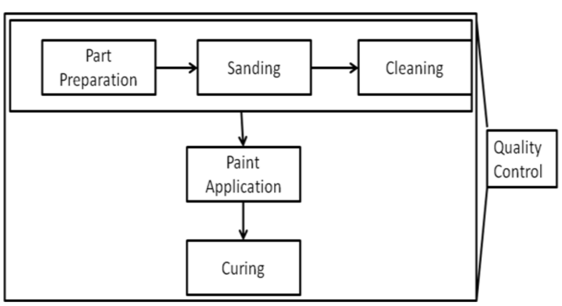


**Figure 2**
**Paint Process Chart**

The material (substrate) nature, the final use of the product, and the desired quality level are the main factors to determine the overall process to use [2]. The spectrum of process alternatives available in the market are considerably high; this project aims at contributing in developing steps to be applied at small industrial paint shops to face quality challenges that may arise at the paint process; it is not the intent of this project to go over all possible quality challenges in all kind of paint processes. The following are the main aspects of the process that concerns to the present project:

- Part preparation. The substrate is the material (i.e. metal, plastic, compound materials) over which the coating will be applied. An organic coating will act as a physical barrier for environmental agents, but if the coating surface is damaged, the bare metal is exposed, and corrosion can form and spread. The adhesion of the coating, as well as the corrosion resistance, will first able be associated to the preparation of the part [2]. The preparation processes (pretreatment) used to process metallic parts are two: one is mechanical (sanding) and the other is chemical (solvent wipe). The purpose of the sanding process is to mechanically remove the actual paint and smooth any present scratches in the surface of the part. The sanding (use of orbital-electrical and/or palm-pneumatic sanders with a sand paper attached to it) is the very first preparation process that concerns to this project.
  There it is a second preparation phase (chemical) that consists in a manual wiping application of an aqueous (water based) cleaning solution that eliminates silicones, grease and creates an antistatic effect that repels dust.
- Paint application. The paint application technique is manual air-spray. A HVLP (High Volume Low Pressure) spray gun uses a high volume of paint at low pressure (under 25 psi). This method provides excellence finish appearance, produces low overspray and provides a transfer efficiency, defined as the

"the amount of coating applied to the work piece divided by the amount sprayed" [3], of 30-60%.

- Curing. As stated by Talbert [2] this process consists of "converting the applied wet paint to a dry film. The paint may cure by solvent loss". In the current process, parts are cured in a room with no temperature or humidity controls. As per the author previously cited, "Air-dry paints rely on solvent evaporation into the surrounding atmosphere".
- Quality control. The quality of the final painted product is affected at every step of the process. It is important to use the appropriate coating material, pretreatment process, good application equipment, and sufficient curing time. Process control factors: scheduling, to reduce waste of material; racking system, proper rack design to present parts to the application equipment, parts should be hung precisely and in consistent position with good exposure to the spray equipment; pretreatment, is one of the most important steps in getting a quality finish, it is required to follow an specific process for the mechanical and chemical phases of the process; paint application (spray gun adjustments), there are basic spray principles that should be taken in consideration to understand how the paint will behave when sprayed. Many wet paint defects are related to paint flow-out, for this reason it is crucial the ability to control droplet size; and curing time per product, if a product is packed before the coating has fully dry, the product will presents defects at the point of use as a result of the contact of the packaging material with the, still wet paint.

The causes of defects in a paint process are numerous; it is very difficult and very costly to cut defects to zero. Some of the common problems are associated with materials and poor processes. Most of the common defects come as a result of a deficient paint process are:

- Orange peel: the paint will normally feel smooth but will present small depressions when viewed at an angle. Orange peel is affected by excess film thickness or paint that is not sufficiently atomized.
- Sagging: occurs when there is too much wet film applied. This happens when there is much solvent present in the paint or it is applied to thickly. This defect could be prevented by increasing the air pressure, decrease the paint pressure, move the gun more rapidly, increase the gun to part distance, use faster solvents or use multiple coats paint.
- Fish eyes and silicone craters: fish eyes are round depressions in the film. They are caused by surface contamination (oil, grease and silicone lubricants) that the paint cannot adhere to. In order to avoid this defect, it is required to always use the specified product for removing the identified contaminants in the substrate.
- Dirt and contamination: dirt usually comes from the air around the spray environment, from the application equipment, or even the paint. The following list will name some of the common sources:
    - People- 80% of the air-borne contamination come from clothing, hair, and shoes of personnel.
    - Nature- pollen, road dust, etc. brought into the plant through doors, windows, and unfiltered air supplied systems.
    - The building- concrete floors may give off dust.
    - Manufacturing- processes that generates dust (sanding process), metal shavings or wood dust.
    - Process equipment- conveyor, racking system or other operation within the paint booth that generates and concentrates dirt. It is important to restrict the access to the paint area or clean room to certain personnel. Have all entrants put on hairnets, nonlint paper suits and shoe covers. All surfaces must be cleaned in order to avoid accumulation of dust.

## METHODOLOGY

The seven step approach will be used in order to obtain the goal of the project (to increase the FPY of the paint process for the selected parts from 78% to 90%).

The seven steps are:

- Identify the issue
- Analyze the problem
- Identify the root cause(s) of the problem
- Generate potential solutions
- Select and plan a solution
- Implement the solution
- Evaluate success of the solution

In order to identify the issue(s) it is required to establish a data collection point at the paint department. The point where the data will be collected is at packing, just after the parts are painted. The selected personnel will be trained and (for three days) inspect 100% production of 5 SKUs. A form will be used in order to gather the data. After the three days of data collection, the assigned team will generate Pareto charts in order to analyze the data.

After capturing the data, the team needs to create Pareto charts in order to identify the relevant defects registered in both data collection points. After identifying the relevant defects the selected team will be assembled to generate cause and effect diagrams for each defect. The team will determine each possible factor under the following categories: machine, man, material, method and environment. The team will come to an agreement of which of those factor(s) is/are the potential root cause(s) for each of the relevant identified defects.

The next step is to assemble the selected team to generate possible solutions for each of the root cause(s) identified. Select the solution that the team understands will generate the greatest impact to the defect. An implementation plan will be created, were it is clearly stated what, who, how and when the solution will be implemented. The team needs to identify any possible risks of implementation and a method to track results/effects of the solution.

Only after thoroughly follow the above step, the proposed solution plan will be implemented, results/effects of the solution will be tracked and shared with the team in order to evaluate the success of the implemented solution.

This cycle will be followed in order to achieve the goal of achieving a FPY of 90% in the paint process is achieved.

### Step One

Identify the issue. The paint and restoration process has being unable to keep customer’s production requirements. It was found that total painted parts should be enough to cover actual demand. After collecting data to establish the current FPY of the paint process, it found that the FPY was 78%. Such high rejection level must be evaluated and the process improved in order to achieve a FPY of 90% for the selected parts.

A form was created to capture the occurrence of the following defects in 5 different part numbers made from similar material and shape: scratches, dents, sanding marks and paint defects.

### Step Two

Analyze problem(s). A Pareto chart (Figure 3) was created with the following results:

| Defect | Percentage |
|---|---|
| • Scratches | 60% |
| • Dents | 22% |
| • Sanding marks | 10% |
| • Paint defects (application) | 8% |

- Particles
- Orange peel
- Fish eyes and silicone craters
- Silking
- Over spray and dry spray
- Blushing

Sample characteristics:

- Lots inspected: 34
- Total parts inspected: 3590
- Total defects: 691
- Total Reject % = 19.25%

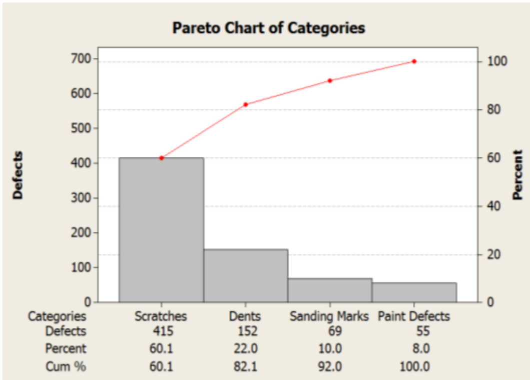


**Figure 3**
**Pareto of Defects Paint Process Before (Categories)**

The Pareto chart clearly shows that the issues scratches and dents represent ~80% of defects.

## Step Three

In order to establish possible root cause(s) the tool to apply is a cause and effect diagram for the scratches and dents defects (Figures 4 and 5 respectively).

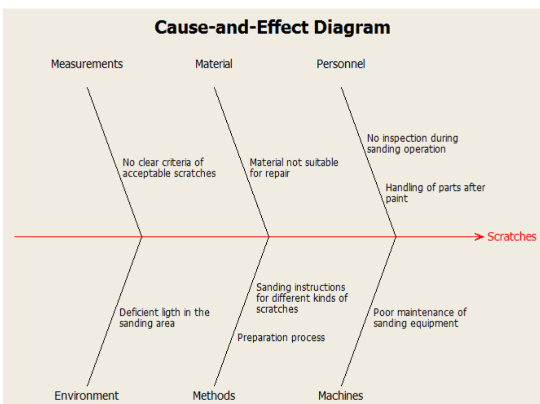


**Figure 4**
**Cause and Effect Diagram – Scratches**

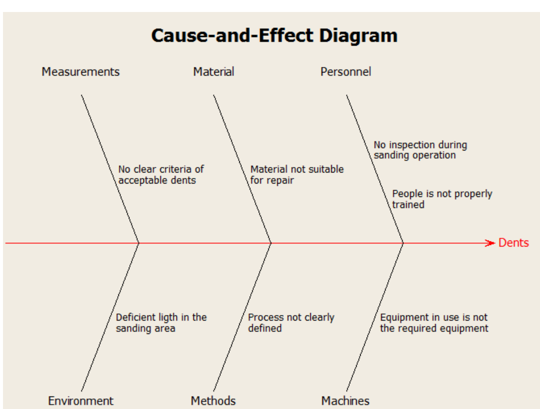


**Figure 5**
**Cause and Effect Diagram – Dents**

After completing the cause and effect diagram for the scratches and dents, the team found out that more data is required in order to determine which of the possible root causes contributes the most to the analyzed defects.

It is required to establish an inspection point after the sanding process and collect data of about how many parts "already sanded" present scratches. A simple form to collect the data, and a way to label parts in order to verify which sander completed the process was required. After 4 days of observation (1,646 parts) it was found that 22% of the sanded parts presented scratches and 8% dents. Since this is a significant amount of defects and the number is similar to the total amount of rejects found (22% overall reject percentage), it was decided to go deeper into the sanding process.

By observing the process it was found that:

- Scratches were all not being worked because operators considered that the coating would cover them.
- The sand paper was not always appropriate for sanding the scratches.
- Each employee had a different opinion on how to work the scratches on the part.
- During the sanding process, it was hard to tell if the "worked/fixed scratches" were indeed eliminated because the dust generated during the sanding process would cover the scratches.
- Clear work instructions and retraining was required.

## Step Four

The possible solutions generated by the team via brainstorming:

- Review sanding process and retrain personnel
- Apply a primer before painting the part
- Don't intent to recover parts with certain scratches
- Change paint to a thicker one in order to cover more scratches
- Automate sanding process
- Separate all defective parts and create a position to apply bond to the scratches

**Table 1**
**Decision Matrix Solution Selection**

| Criteria → / ↓ Solution | Root cause addressed? | Speed of solution | Team control of the solution | Low cost solution |
|---|---|---|---|---|
| Review sanding process and re-train personnel | High- all scratches are suppose to be detected and worked at sanding | High- experienced the team and management involvement | High- no external resources are required to implement this solution | Medium- it will require the team to meet and invest time, but no cost will be added to the production process |
| Apply a primer before painting the part | Low- Scratches are not being removed, just covered | Medium- team will have to evaluate different primer option in order to find the right one. Budget approval is required | Medium- there is access to primer suppliers but final process and budget approval is not under the team authority | High- Cost per piece would increase by 12% |
| Change paint to a thicker one in order to cover more scratches | Low- Scratches are not being removed, just covered | Medium- team will have to evaluate different options and paint supplier would have to be able to | Low- being able to find a paint that adjust to the needs of the shop highly depends on what is available | Medium- Cost per piece could be increased |
| Automate sanding process to reach standardization | High- Scratches could be removed more effectively if a state of the art technology is available | Low- It will require extensive research and approvals | Low- engineering and technical service team would have to lead this efforts | High- Cost of implementation for this kind equipment or technology is usually expensive |

- Separate the parts with hard scratches and send to an external supplier for them to sand parts and paint them

### Step Five

Selecting a solution(s) and planning its implementation was critical in order to appropriately reduce the FPY to the goal.

The selection process was conducted with the help of a decision matrix. The evaluation criteria for the current situation are:

- Root causes addressed by this solution
- Speed of solution
- Team control of the solution
- Low cost solution (money and time)

In Table 1 the decision matrix that was used can be found.

The selected solution was to review the sanding process and retrain the personnel. A series of activities were proposed and divided as presented in Table 2.

**Table 2**
**Improvement Actions per Area**

| Process | Tools | Quality |
|---|---|---|
| Pre-inspection at sanding | Sanding paper evaluation | Customer's quality criteria evaluation |
| Sanding techniques review | Additional tools required? | Acceptance criteria before painting |
| Sanding auditing | | Acceptance criteria after painting |

The team was divided in three sub-teams in order to effectively implement the solution. A timetable was established for each team in order to complete the solution implementation in two weeks.

### Step Six

Changes were proposed, evaluated and included for each category:

- All parts are to be pre-inspected before sanding. The objective is to determine if there are scratches that are not repairable with the current process.
- In order to effectively remove hard scratches, it is required to slightly incline the DA so the pressure is all applied to the scratch (the operator needs to avoid almost vertical position

of the DA because this will generate sanding marks after the part is painted).

- Documented a work instruction to sand each product.
- An inspection point was established after sanding. All defective parts are going to be returned to the sander operator that worked the part.
- Three types of sanding paper were specified for use in order to properly sand the part. All parts with scratches would require the use of an aggressive sanding paper and then the part needs to be "soften" with a lighter sand paper.
- It is required the use of a wet towel during the sanding process; all operators must hand wipe the part and sand it until no scratches are found.
- It was determined that small (1/32 D) deep points defects will be acceptable at the line.
- Pictures were taken of what kind of scratches will be covered by the coating and prep operators were instructed on not to return the parts to sanding.
- It was determined the overall acceptance criteria for scratches and dents after paint.

The solution was completely implemented in 1.5 weeks and all team members actively participated in the process. The engineering team was invited to participate in the process and tools evaluation teams. The quality and customers relations departments participated in clarifying and adjusting the criteria and establishing acceptance criteria for the painted products.

## Results & Discussion

Results are discussed in the last step of the methodology.

### Step Seven

The way the solution success was evaluated was exactly the way the original data was captured (100% auditing) and analyzed. Find Pareto chart at Figure 6.

Defect — Percentage

- Scratches — 46%
- Sanding marks — 21%
- Dents — 19%
- Paint defects (application) — 14%
  - Particles
  - Orange peel
  - Fish eyes and silicone craters
  - Silking
  - Over spray and dry spray
  - Blushing

Sample characteristics:

- Lots inspected: 118
- Total parts inspected: 10974
- Total defects: 879
- Total Reject % = 8.01%

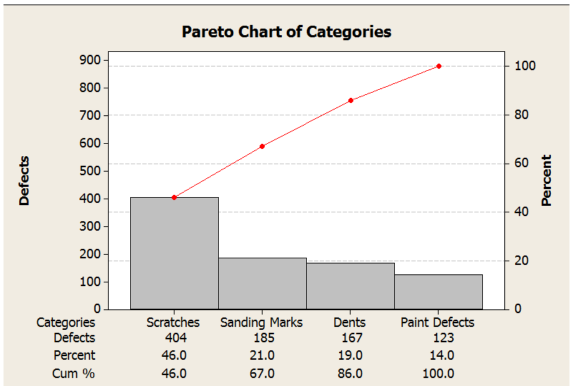


**Figure 6**
**Pareto of Defects Paint Process After (Categories)**

Results summary and data comparison showed in Table 3.

**Table 3**
**First Pass Yield Data Comparison**

| Defect Description | Before | | Sample Size (3,590) | Defect Description | After | | Sample Size (10,974) |
|---|---|---|---|---|---|---|---|
| | Defects Qty | Defects [%] | % (sample) | | Defects Qty | Defects [%] | % (sample) |
| Scratches | 415 | 60 | 11.56 | Scratches | 404 | 46 | 3.68 |
| Dents | 152 | 22 | 4.23 | Sanding Marks | 185 | 21 | 1.69 |
| Sanding Marks | 69 | 10 | 1.92 | Dents | 167 | 19 | 1.52 |
| Paint Defects | 55 | 8 | 1.53 | Paint Defects | 123 | 14 | 1.12 |
| | 691 | 100 | 19.25 | | 879 | 100 | 8.01 |

In order to establish if there is a statistical significance in the data after the changes done to the process, a 2-Sample t Test was performed for the mean of the percentage of defects. Find results in Table 4. It was found that the mean before is greater than after at the 0.05 level of significance ($p < 0.05$). The confidence interval states that there is 90% confident that the true difference in means is between 0.048 and 0.1249. See Figure 7 for Boxplot.

**Table 4**
**2-Sample t Test % Before vs. % After**

| ***Statistics*** | ***% Before*** | ***% After*** |
|---|---|---|
| *Sample Size* | *34* | *388* |
| *Mean* | *0.19068* | *0.10399* |
| *90% CI* | *(0.1529, 0.2285)* | *(0.09826, 0.10971)* |
| *Standard Deviation* | *0.13029* | *0.068428* |

Difference between means* 0.086693
90% CI (0.048457, 0.12493)
*The difference is defined as % Before - % After

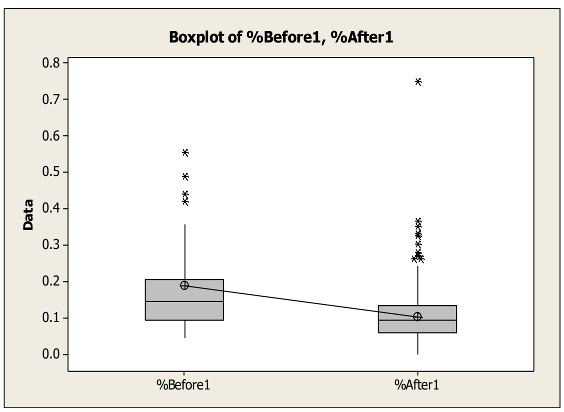


**Figure 7**
**Boxplot Percentage of Defects Before & After**

## Conclusions & Recommendations

This project has shown that going back to basics in process analysis and improvement always pays off. Taking advantage of employees knowledge and experience, and by utilizing the right tools in order to make sure that data is the main criteria for improvement actions can deliver significant improvements to companies at low cost and in a speed matter. In this case, there was not an impact in the cost per unit.

It is required to keep a pulse of the processes even if they seem to be mature. Production processes can be affected by inertia and eventually the organization will suffer major consequences in cost or customer satisfaction. In the case evaluated in this project, the business loss output to customers ($288K per year) and scrap cost ($90K per year).

In order to obtain further reductions in scrap dollars it is required to look for paint options that could cover more scratches. It could be also required to apply a primer in order to avoid the occurrence of defects after paint. Any change should always be evaluated taking in consideration the nature of the industry and economical implications.

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