© (2015) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.1115.596
Accepted: 2015-03-25

PAINTING PROCESS IMPROVEMENT THROUGH SIX SIGMA APPROACH IN A MALAYSIAN VEHICLE ASSEMBLY COMPANY

MOHAMED A Rahman[1, a], A.K.M. Mohiuddin[2], and HANANI Abdullah[3]

[1,3]Department of Manufacturing and Materials Engineering, [2]Department of Mechanical Engineering, Faculty of Engineering, International Islamic University Malaysia, Jalan Gombak, 53100 Kuala Lumpur, Malaysia

[a]mrahman@iium.edu.my

Keywords: Six Sigma, DMAIC, automotive assembly, painting process

Abstract. Painting is an important process in the automotive assembly to give more attractive appearance to the vehicles and to provide the layer of protection against corrosion and weathering. The objective of this paper is to identify and analyze the factors affecting the quality of painting process at Company RST's Paint Shop. The paint shop was unable to perform the painting process satisfactorily and deliver the painted vehicle bodies as per customer specifications. The study concentrated on the fiber defect detected at Top Coat Area as the major problem of paint deficiency. Using activities like Genba investigation, data collection, trials and data analysis, the root causes of the problem were identified. Six Sigma DMAIC approach was utilized in conducting the improvement activities. Through designed experiments conducted to determine the best parameter setting of the spray gun used in the painting process, it was found that 3.5 bars for air pressure and 450 ml/minutes for fluid delivery resulted in the lowest paint defect. The use of Six Sigma DMAIC approach had succeeded in helping the company to minimize paint fiber defect per unit (DPU) from 10 to less than 3 DPU. The results from the study have provided an insight on successful deployment of DMAIC through application of its various statistical tools and techniques, and as the systematic problem-solving framework on solving actual industrial issues such as automotive painting problem.

Introduction

The competition among organizations continues to get tougher as the result of globalization of economy. There is much pressure on manufacturing, product development, and service to become more efficient, effective and productive. Automotive manufacturers worldwide are under the same pressure to control costs, maintain high levels of safety and quality, meet regulatory requirements, and satisfy customers. Based on many successful stories on other organizations in the literature, in order to achieve these stringent requirements, they started using Six Sigma methodology which proved to be an effective strategy.

Nowadays, Six Sigma strategy is the combination of the Six Sigma statistical measure and total quality management. The method used in Six Sigma to solve problems is the DMAIC cycle, which stands for Define, Measure, Analyze, Improve and Control, the steps taken to achieve Six Sigma quality management. The DMAIC problem-solving methodology is particularly useful when the cause of the problem is unknown or unclear, the project can be completed in 4-6 months and the potential of significant savings exist (Banuelas et al, 2005).

The Six Sigma strategy is the combination of two sources: The Six Sigma metric invented by Motorola Corporation in the mid 1980s and total quality management (TQM). In TQM, the responsibility of quality management not only lies in the hand of quality control personnel but is distributed to everyone in an organization. Also TQM emphasizes on significant training in statistics, root cause analysis methods needed for problem- solving and focus on customer satisfaction. These problem-solving methods are performed by employing the seven tools of quality: cause-and-effect diagram, Pareto chart, histogram, check sheet, scatter plot, flowchart and control chart. These metric and TQM concepts are adopted by the Six Sigma strategy (Antony et al, 2005). These tools are employed in various stages of the DMAIC cycle (Woo & Wong, 2007). Other powerful tools include design of experiment (DOE) and KJ method or affinity chart.

Company RST is involved in assembly of motor vehicles, including most components, such as engines and bodies. The company principal products are passenger cars, light duty trucks and heavy duty trucks. Processes in manufacturing a vehicle in the assembly plant comprises assembly of body parts, painting, assembly of trim and mechanical parts, and final assembly. The end products are treated and protected with various color of paint coatings. The painting of the body parts and other hang-on parts such as bonnets, fenders, doors and trunk lid is one of the major cost factors in car assembly process. The cost of painting process may be even higher than that of the vehicle body itself. Production output from the RST Paint Shop is not meeting customer expectations due to poor quality of the body surface painting with paint defects contributing to the high rejection rates. It can be said that it is impossible to achieve zero defects in the whole painting processes therefore to improve the process is by reducing the defects or faults as low as possible.

The study focuses on minimizing the rejection rate in the Paint Shop by examining the existing methods used in the process and by applying Six Sigma DMAIC approach. The research provided an opportunity to further investigate how Six Sigma tools and techniques can be successfully implemented so as to improve the automotive painting process. The improvement study was held at one Company RST Paint Shop involving one passenger car model. The study was carried out between January 2012 until September 2012 in order to investigate the causes of fiber defect and the impacts of the steps taken for quality improvement at Top Coat Area.

Experimental Procedure. The research focused on only one automotive company using case study method. Existing painting process was defined and mapped to understand the process characteristics and capabilities. It was then analyzed to identify problem areas, variations and possible solutions were suggested with process coordination and control measures. Data collected in this study include observations, interviews and literature studies (Yin, 2003). Both primary and secondary data have been used during these improvement activities. Examples of primary data are factorial experiments conducted throughout the project. Internal reports and data automatically collected by a production monitoring system are examples of secondary data. To deal with the internal validity, statistical analysis of the data has been used. All personnel involved in the investigated process were interviewed continuously during the project and the outcomes of these interviews were documented right after the interviews. Most of the interviews were conducted unstructured with low level of standardization. Figure 1 show the methodology used in this study.

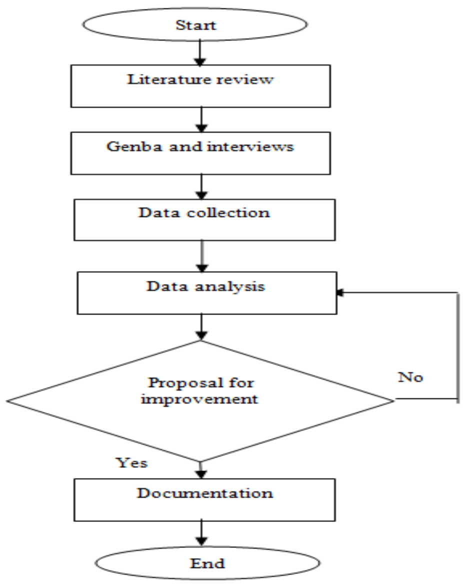

Figure 1: Flowchart of methodology

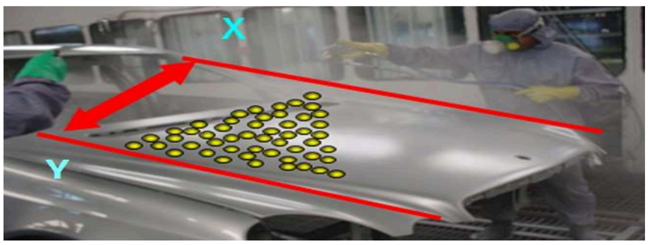

Figure 2: Fiber defect detection through Genba checks

Genba checks were carried out in the Top Coat spray booth during spraying process and it was found out that fiber defects were created in X - Y area (Figure 2).

Designed experiments were carried out with factor – level combinations as in Table 1. Minitab program was used to analyze the data resulted from the designed experiments.

Six Sigma methodologies consisting of the Define, Measure, Analyze, Improve, and Control phases were implemented with the relevant tools.

Table 1 Factors and levels used in DOE

Factor (X)	Low Setting	High Setting
A - Fluid delivery (FD) (ml/min)	450	550
B- Air pressure (bar)	3.5	5.5
C- Paint drying time (second)	0.5	1.5

Results and Discussion. KJ Method was used to rate the findings of the study by synthesizing different individual perspectives and experiences into a problem definition and solution that was acceptable to the group. As in Table 3, the decision was made to reduce fibers at Top Coat Booth for passenger car model due to highest score gained during discussion. Reduction of the fibers was extremely important due to (1) failure of Paint Shop to deliver the products to the customer as per requirement, (2) high rejection rate due to fiber defects which unlike other defects were not able to be reworked and (3) high re-spray cost.

Table 2: KJ method on potential painting problems

Problem \ Evaluation	Quality	Cost	Delivery	Morale	Safety	Total
To reduce sanding marks after Top coat	○	○	◎	△	△	13
To reduce primer foreign material	○	○	△	○	△	11
To reduce fibers at Top coat	◎	◎	◎	◎	○	23
To reduce excess oil of vehicle body in white	◎	○	○	◎	○	19
To reduce phosphate sludge at Pre-treatment & ED	○	○	△	△	△	9
To prevent sealant bubble for Passenger car model	△	△	◎	△	△	9
To prevent paint chipping for PBS to assembly line	△	△	◎	△	△	9
To improve ED appearance on horizontal area	○	△	△	△	△	7

Demerit points: ◎ 5points ○ 3 points △ 1 point

Analysis on the possible causes of fibers was carried out using the cause-and-effect diagram (Figure 3). Fibers could have been caused by dirty painter uniforms but the workers working in the Paint Shop were already given lint-free uniform. Changing the uniform periodically for one trial period also did not reduce the fiber count. Potential causes of fibers were associated with contamination in the material used in the painting process. Action taken to filter the paint up to three times the usual filtration rate also did not resolve the fiber defects. The tack rags which might create fibers were changed and their use controlled but to no avail. Dirty spray guns and skids were periodically cleaned but the problems persisted. For methods, possible causes include contaminated oven, imbalanced air pressure in the spray booth, insufficient air blow and defects carried over from previous painting. Measures taken including increasing frequency of oven cleaning, carrying out total booth refurbishment and re-balancing of spray booth, ensuring sufficient air blow and finally carrying out 100 percent inspection after primer sanding process failed to reduce the number of fibers detected.

Figure 3: Cause and Effect Diagram for fiber defect

Figure 4 illustrates fiber accumulation in top coat can from preparation station to baking process detected during inspection. After many trials, it was found that during the spraying process, paint overspraying, paint spitting and paint drying too fast had caused the accumulation of fibers on the painted body with the fibers originating from the paint material itself. The first root cause was too much overspray due to air pressure setting recommended by the supplier was too high (5 to 5.5 bars). High air pressure setting was for easy spraying i.e. paint coverage was high and spraying time short. The second root cause was paint spitting caused by inappropriate (high) fluid delivery setting for polyester-based paint. The third root cause was due to paint drying too fast thus unable to absorb paint overspray which then turned into fibers.

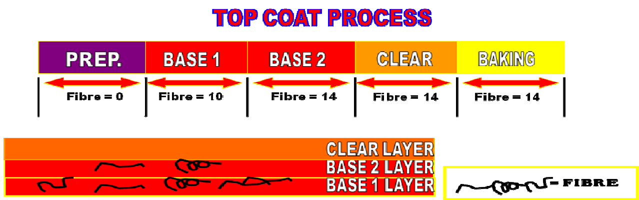

Figure 4: Accumulation of fibers during spraying process

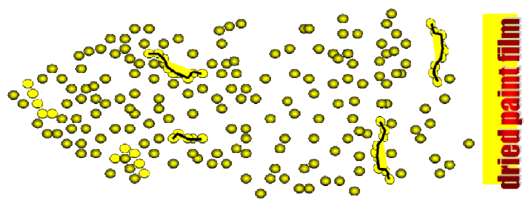

Figure 5: The forming of paint particle chain

High fluid delivery resulted in more paint particles triggered during spraying causing overspray and paint spitting (Figure 5). The paint particles will link to each other forming long chains of paint particles resulting in fibers. High air pressure induced the formation of more fibers through particles knocking each other. The long chain of paint particles turned into higher molecular weight fibers and dropped on the surface of semi-dried paint film and remained on the painted body and detected as fibers which can be clearly seen with naked eyes.

From the Pareto chart, the highest contribution for fiber creation was by fluid delivery. Air pressure effect was also quite significant as compared to paint drying time. It can be seen that effects associated with fluid delivery and air pressure need to be looked into and the interaction between fluid delivery, drying time and air pressure were important and need to be taken into consideration. The higher the fluid delivery (FD) the higher paint injection volume per minute hence more paint particles created and more overspray (excess paint particles that are not adhered to the body surface). In these measures, the optimum FD was analyzed to suit the painting application and to solve the current problem.

It can be concluded from the DOE that adjusting the parameter setting of the spraying gun had reduced the fiber count in the paint materials (Figure 6). The optimum combinations for the spray gun are (1) the fluid delivery was set at 450 ml/minutes, (2) the air pressure was set at 3.5 bar and (3) adjusting paint drying time from 0.5 second to 1.5 second by adding slow boiling thinner. As shown in Figure 7 the improvement activities was able to reduce fiber DPU from 10 to 1 DPU in September 2012 with DPU of foreign material also dropped from 100 to 50. The figures must be maintained through monitoring of the process by the personnels responsible. Before improvement, vehicles needed to be re-sprayed due to fibers present. Rework units needs to go through sanding process all over again and entered spray booth for the second time. After improvement, units no longer needed to be re-sprayed. Cost saving for that four (4) months was RM 184.25 x 835 units amounted to RM153,848.75.

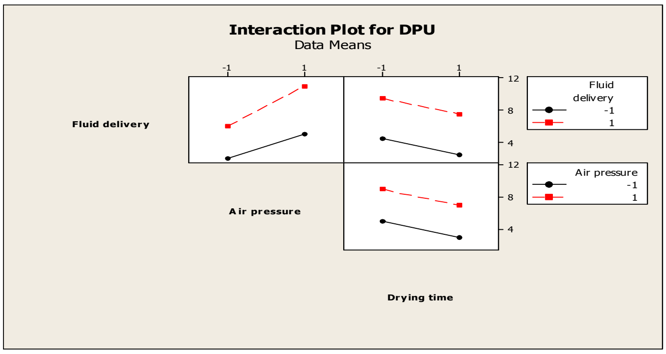

Figure 6: Interaction diagram for DPU

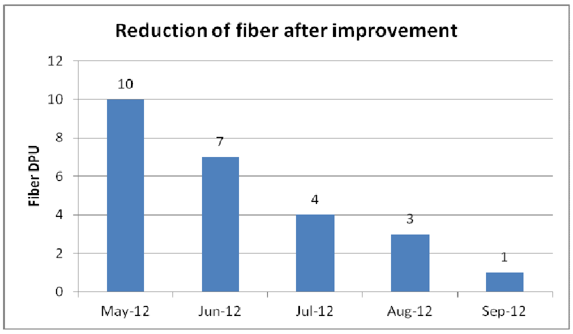

Figure 7: Reduction of fiber after improvement

The control phase began once improvements have been made and results documented. The process was considered in control when the situation was predictable, stable and succeeded in meeting customer requirements. Daily and continuous monitoring was carried out using control charts to ensure that performance of the painting quality met the DPU target. Daily check sheet was fully utilized to monitor air pressure and stablize fluid delivery of the painting process.

Conclusion

From the study many types of paint defects in the painting process were found to contribute to high defect per unit including foreign materials, fiber, dirt, orange peel, base mark, sanding mark, paint chipping, blister, paint run and others. However, fiber was the main cause of rejection as fiber defect cannot be polished thus requiring a re-spray. Factors contributing to defects were paint spitting, overspraying and fast paint drying. Designed experiments carried out resulted in optimum setting for spray gun and subsequent quality improvement. It was found that the Six Sigma methodology with its DMAIC approach was highly useful to improve the painting process in the Paint shop in terms of product quality, productivity and workplace safety. From the performance trend graph, it can be concluded that the target to reduce from average 10 DPU to less than 3 DPU was achieved within four months of DMAIC approach implementation. Cost impact as a result of no more body units requiring to be re-sprayed as compared to before improvement had total up to RM 153,848.75.

Acknowledgements

The authors are thankful to the Company RST for providing the opportunity to carry out the study at their premise.

References

[1] Banuelas, R., Antony, J. and Brace, M.: An Application of Six Sigma to Reduce Waste. Quality and Reliability Engineering International, Vol 21 (2005), pp.553-570

[2] Antony, J. Kumar, M. and Tiwari, M.K.: An Application of Six Sigma Methodology to Reduce the Engine-overheating Problem in an Automotive Company. *Proc.ImechE*. Vol. 219 (2005), pp 633-646

[3] Woo, D. and Wong, H.: An Application of Lean Six Sigma to Improve the Assembly Operations at a Wireless Mobile Manufacturing Company, (2007), 0 - 108.

[4] Yin, R. K.: Case Study Research: Design and Methods (3rd ed.). Thousand Oaks, CA: Sage Publications, Inc. (2003).