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APPLICATION OF SIX-SIGMA METHODOLOGY TO IMPROVE QUALITY AT A PAINT COMPANY

Pham Khanh Duy*1, Do Ngoc Hien*2

*1Department of Industrial Systems Engineering, Ho Chi Minh City University of Technology – Vietnam National University Hochiminh City, Hochiminh City, VietNam

*2Associate Professor, Department of Industrial Systems Engineering, Ho Chi Minh City University of Technology , Vietnam National University Hochiminh City, Hochiminh City, VietNam

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ABSTRACT

Painting is an important process in the finishing of most products to give it a more attractive appearance and to provide the layer of protection against corrosion and weathering. Paint quality directly affects construction and equipment. Therefore, it is required that each paint product delivering to consumers have to meet required quality. The objective of this paper is to identify and analyze the factors affecting the quality of painting process at a paint company. The study would concentrate on improving the quality problems of the finished product that the company was facing. After collecting and analyzing data, the root causes of the problem were identified. DMAIC (Define-Measure-Analyze-Improve-Control) approach was utilized in conducting the improvement activities. Through designed experiments were conducted to adjust the viscosity of the paint to suit 'Voice of Customer' (VOC). The studied project brough many benefits for the company to reduce the percentage of paints that fail to reach viscosity to less than 5%. 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 issues such as those of the paint industry problem.

Keywords: Six-Sigma, DMAIC, Voice of Customer (VOC), Design of Experiment (DOE), SIPOC, Fishbone diagram.

I. 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. Painting industry 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, 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). These problem-solving methods are performed by employing the seven tools of quality: cause-and-effect diagram, Pareto chart, histogram, check sheet, scatter plot, flow chart and control chart (J. Hill, A. J. Thomas, R. K. Mason-Jones & S. El-Kateb, 2018). 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 SIPOC diagram or affinity chart.

II. METHODOLOGY

Six Sigma has a statistical base and with proper utilization of methodologies can help to improve the quality of both product and process. In addition to providing data-driven statistical methods for improving quality, Six Sigma also focuses on some vital dimension of business processes, reducing the variation around the mean value of the process (Kanji, 2008). The highlight of Six Sigma model is the use of statistical techniques to control the production or service delivery process (Byrne, B.; McDermott, O.; Noonan, 2021). Processes are designed so

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that the transformation is achieved through statistical techniques, analyzing the factors that cause failure, and finding ways to make adjustments so that the process achieves a defined goal. In this study, the DMAIC approach would be used. The DMAIC is a process improvement cycle of Six Sigma program as well as an effective problem-solving methodology. Brewer et al. (2005) and BRIAN J. GALLI (2018) indicated that DMAIC is "the primary framework used to guide Six Sigma projects". Six Sigma projects are based on the DMAIC approach and "the role played by DMAIC in gaining the overall success of Six Sigma is equally critical" (Nilakantasrinivasan and Nair, 2005). DMAIC quality improvement process is defined clearly as in Table 1.

Table 1: The DMAIC methodology

D	Define	The top management shall identify the problem according to customer feedback, strategy and mission of company, define customer requirements, and set goal
M	Measure	Measurement is a key transitional step on Six Sigma road, one that helps the project team refined the problem and being the search for root causes which will be the objective of Analyze step in DMAIC. Therefore, the project team needs to validate problem/process, refine problem/goal, and measure key steps/input
A	Analyze	In analyze stage, the project team shall use data analysis tools and process analysis techniques to identify and verify root causes of the problem. For the reason, the project team needs to develop causal hypotheses, identify vital few root causes, and validate hypothesis
I	Improve	The goal of the improve stage is to find and implement solutions that will eliminate the causes of problems, reduce the variation in a process, or prevent a problem from recurring. So the project team needs to develop ideas to remove root causes, test solutions, and standardize solution/measure result
C	Control	Once the improvement has been made and results documented, continue to measure the performance of the process routinely, adjusting its operation. It is very important for the project team needs to establish standard measures to maintain performance and correct problems as needs. Without control efforts, the improved process may well revert to its previous state

III. CASE STUDY AT A PAINT COMPANY

This paint company is a small and medium-sized manufacturing enterprise specializing in the production of marine and industrial paints. The company has a strong market share in ship paint with more than 30 years in the industry and annually supplies more than 5 million liters of paint of all kinds to the market.

The factory is currently applying a pull-to-order system, but still holds stock with a predetermined safety stock level with product codes that are ordered frequently. The factory receives orders randomly daily, and the order can include a variety of paints with different color codes. Raw materials of paint production technology include resins, solvents, mineral powders, pigments, and additives. Figure 1 shows the paint production process. The research focuses on approaching the DMAIC cycle according to Six Sigma to improve the quality problems that the company is facing.

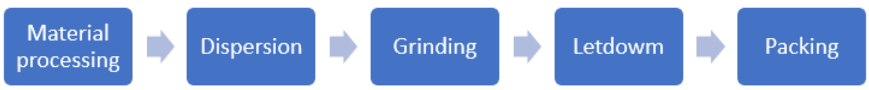


Figure 1: Paint production process

The company approached and initially applied Six Sigma to improve some aspects of quality at the company. There are many issues that need to be improved and one of them is the project to apply Six Sigma to improve the stability of the "viscosity" of the paint.

In paint production technology, viscosity is an important construction parameter, it determines the process of spraying paint on the surface to be protected and decorated. Low viscosity will cause the coating process to sag, causing defects in the dry paint film and also making the paint system not reach the required thickness. High viscosity will make the spraying process difficult and reduce the leveling of the paint film, consuming more solvent to mix the paint, etc. Normally, the viscosity of manufactured paint is controlled within the allowable limit for paint with each paint system. For example, for a single-component Alkyd paint system, the viscosity limit for primer is from 100 - 120 seconds, and for topcoat is 140 - 160 seconds, for a two-component epoxy system, the viscosity limit of the paint is limited lining is 70 - 80 KU, and coating is 60 - 70 KU.

Unfortunately, the company received many complaints about paint quality related to viscosity, so the company's management suggested improving the quality control of manufactured paint.

IV. RESULTS AND DISCUSSION

Define Phase

The project team identifies three tasks during this phase: determining a viable project scope, establishing project objectives, and estimating project constraints. In the process of analyzing customer feedback, the customer encounters several problems that are based on VOC analysis to show as in Table 2.

Table 2: Details of Customer problems

	Features			
Voice of customer	Paint sags when sprayed, and spray paint does not reach the thickness	Rough painted surface	Difficult to adjust spray gun wind due to high paint viscosity	Paint viscosity is not uniform between batches
CCRs (Critical Customer Requirements)	Low viscosity	Viscosity too high makes the paint film not spread	High viscosity, spray gun cannot shoot paint, must add solvent, which increases costs	The same construction and the same paint code but different batch number is the difference in viscosity
CTQs (Critical to Quality)	Moderately low-viscosity paint is suitable for application	The paint's high viscosity must be within the allowable limits, not thicker	Paint reaches viscosity, customers can use it immediately without needing to prepare more	The quality between adjacent batches must be uniform
Targets	Reduce the percentage of paint not reaching viscosity to less than 5%	Reduce the percentage of paint not reaching viscosity to less than 5%	Reduce the percentage of paint not reaching viscosity to less than 5%	Paint batches close to each other, the viscosity should not differ by more than 5 units

The VOC analysis shows that the goal is to satisfy customer satisfaction by ensuring that the viscosity of the paint is within acceptable limits.After setting the project objective, the company proceeds to create a project team and identify related issues and narrows the scope of the project since the implementation time is not more than 3 months, so the scope needs to be clearly defined.The project team selects the improvement issue using a Pareto Diagram. The first stage is used to determine the paint with the highest viscosity error rate with the help of Pareto charts. Although each color has a different defect rate, the main complaint from the customer was often problems with the coverage of the blue paint (Figure 2), so the project team decided to focus on the Alkyd blue paint (Figure 3, Figure 4).

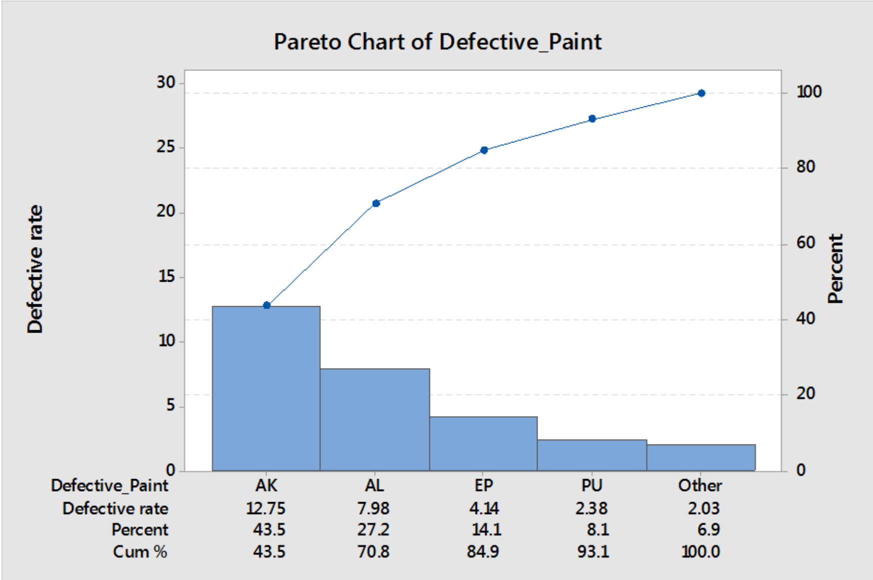


Figure 2: Pareto chart of viscosity defective paint

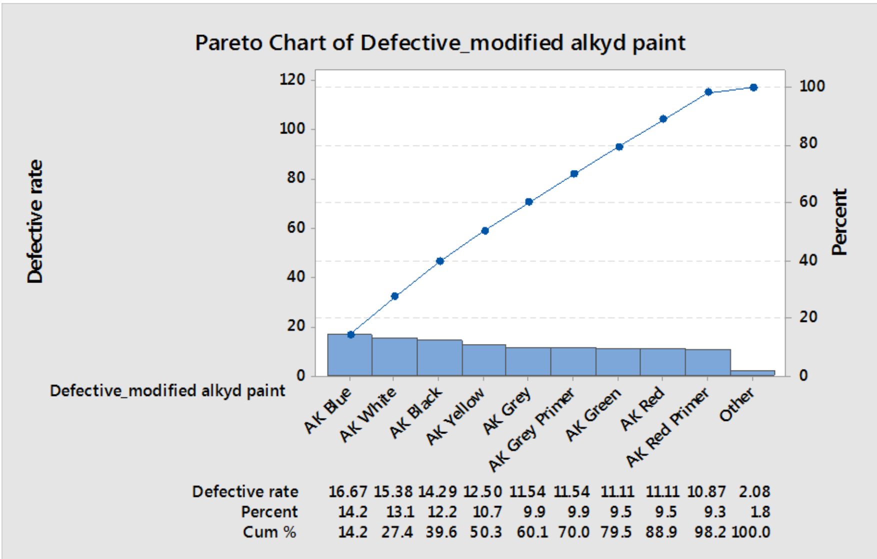
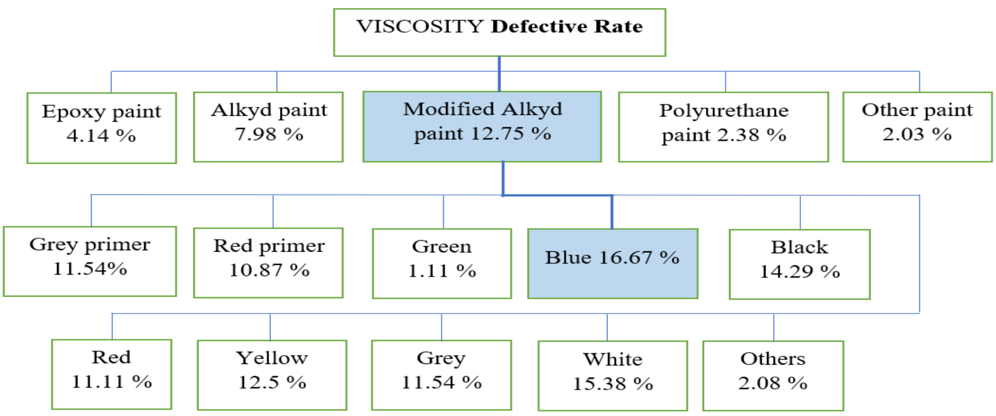


Figure 3: Pareto chart of color type



(The defective rate is calculated according to the number of defective batches of the total production batches of each paint type)

Figure 4: Project selection tree diagram

AK blue was selected as the subject of this project because it is the paint code with the highest cumulative failure rate. In addition, choosing a high error rate object for improvement helps to increase efficiency in terms of time due to the limitation of this project. The goal of the project is to reduce the defect rate of Alkyd blue paint from 16.67% to less than 5% by the end of the improvement period (estimated 3 months). Its defect rate is high due to the unstable of viscosity (as on Figure 5), which is expected in the range from 140 to 160.

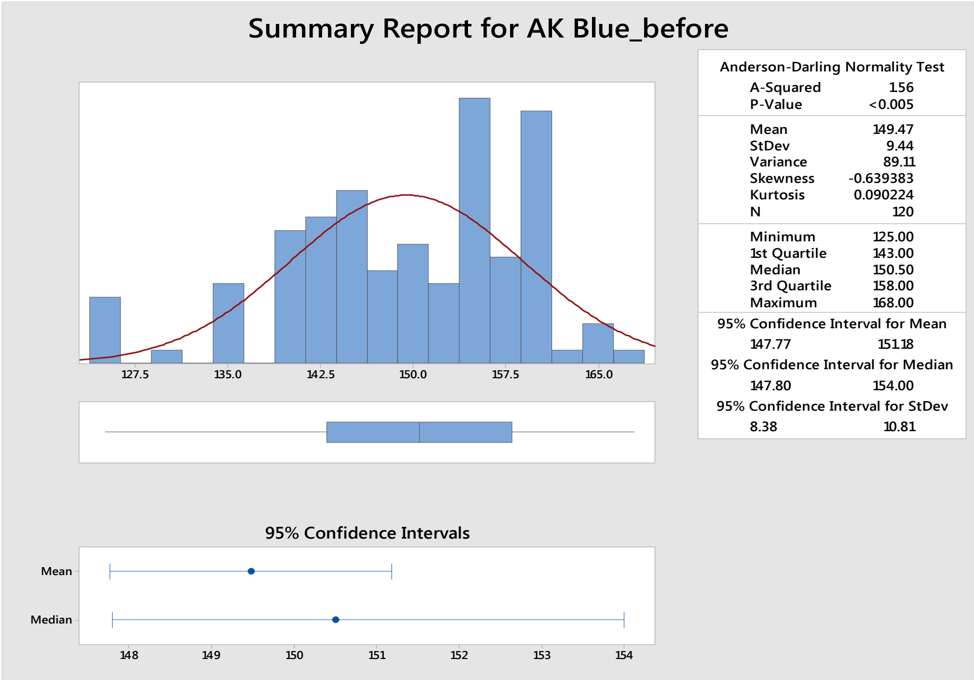


Figure 5: Summary report for AK blue before improving

Difficulties in implementing the improvement that the project team estimated include workers not following the new process, materials not meeting requirements, insufficient space in the improvement area, lack of staff monitoring the implementation of improvements and maintaining improvements, etc. The team recommends to managers for dissemination and support to grant enforcement permission throughout the improvement implementation process.

Measure Phase

To clearly analyze the factors involved in the project scope, use the SIPOC model to describe the paint manufacturing process steps and characterize each step as shown on Figure 6.

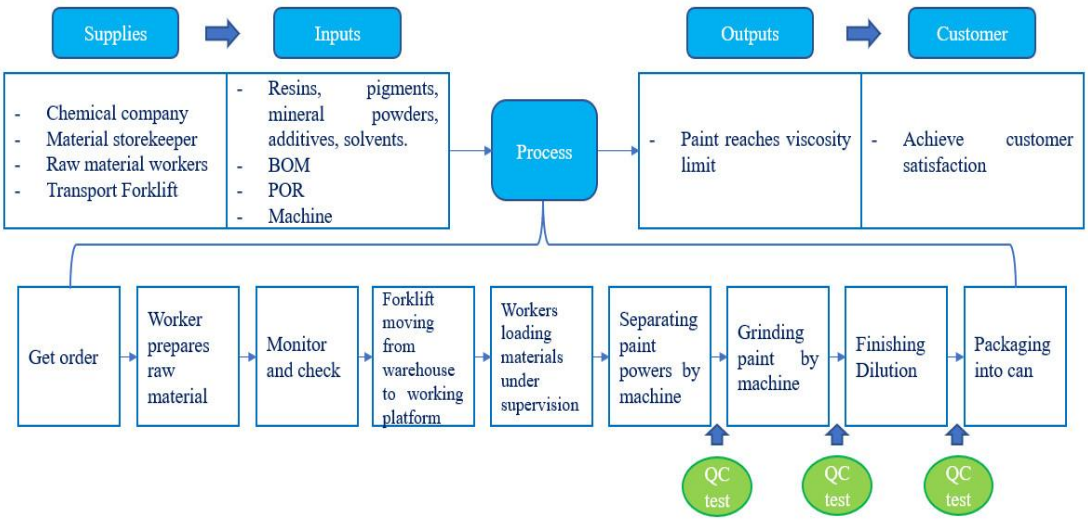


Figure 6: SIPOC model in the paint production process

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Based on the SIPOC model, each step in the paint production process was measured and checked. Immediately after each stage of "dispersing paint by machine", "grinding paint by machine" and "dilution of finishing paint", the viscosity is measured to detect early whether the paint has a viscosity error from these stages or not. At what stage is it wrong? For example, when measuring the viscosity at the stage of "dispersing paint by machine" and seeing abnormally high viscosity in one batch compared to another batch, it is necessary to check the previous stages such as whether there is a wrong plastic code, wrong balance, no rheology, etc. When measuring the viscosity at the stage of "crushing paint by machine" and seeing that the viscosity is low, and the paint is loose, it is necessary to check that the phase immediately before the disperser runs has the required time and the technology speed has reached the number of RPM according to the technological process, is the cooling system of the disperser working properly, etc. SIPOC modeling also gives an overview for the later analysis stage. The process of measuring parameters is summarized in Table 3.

Table 3: The process of measuring parameters

The process of measuring parameters	
1	Determine the exact paint tank to be measured. If it is a single component paint, the viscosity is measured in seconds, and for two component paints, the viscosity is measured in the KU system (Brookfield viscometer)
2	Ensure sampling at the specified time: Measure the viscosity of the initial dispersion stage to ensure that the machine is running for at least 3 hours, measure the grinding stage to ensure at least 2 hours, and measure the final dispersion stage, it is necessary to ensure that the batch of paint is mixed for 30 minutes from the time of last loading of materials
3	Paint temperature in the tank at the time of sampling is required from 45 – 55°C
4	Each measurement must take 3 samples and take each sample at least 2 minutes apart. The condition requires that the results of the 3 samples do not differ by more than 5 viscosity units, the paint batch result is the average result of the 3 samples.
5	Sample measurement should be performed in accordance with the instructions for measuring samples and instructions for using the laboratory equipment
6	Test equipment must be calibrated
7	Record all data in the report book

Analyze Phase

Use the Ishikawa fishbone diagram to analyze the causes of paint viscosity errors outside the allowable range.

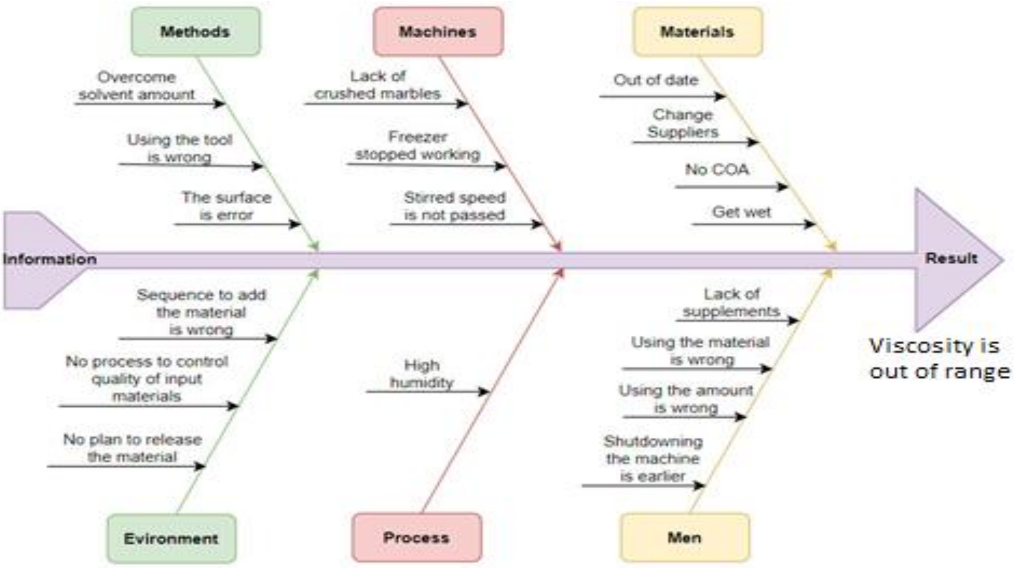

Figure 7: Fishbone diagram

After analyzing the causes, data was collected and a survey table to evaluate the influence of the causes on the viscosity parameter was done. The survey sheet was distributed to the relevant departments to conduct scoring.

The causes that affect the viscosity parameter on a 10-point scale were scored. If the causes had little effect on the viscosity index, they are given a low score; Otherwise, if the causes had a large impact on viscosity index, they were given a high score. Surveys were done by representatives of the technical department, the representative of the quality department, and the representative of the factory. The summarized results were shown in Table 4.

Table 4: The evaluation results table

No.	Causes	Dept. Technical	Dept. Quality	Workshop	Total score	Priority level
1	Content of Recycle Solvent	9	9,5	9,5	28	1
2	Wrong solvent content	9,5	9,5	9	28	1
3	Wrong rheological additive	9	9	9	27	1
4	Wrong dispersion phase time	8	8,5	8,5	25	1
5	The wrong running speed of the disperser	8	8	8	24	1
6	Missing ball mill	5	5,5	5	15,5	2
7	Material is wet	5	5	5	15	2
8	Outdated materials	4	4	4,5	12,5	2
9	Wrong order of feeding	5	4	4	13	2
10	Chiller not working	5	5	5	15	2
11	High humidity	4	4	4	12	2

After the evaluation results were available, the potential causes affecting the viscosity were classified into two distinct groups: The high-impact group (Recycle Solvent, solvent content, rheological additive, dispersion phase time, running speed of the disperser) and lower impact group (Out of date raw materials, chiller not working, air humidity,...). As a result, the project team decided to make improvements to the high-impact group.

Improve Phase

Design of Experiments (DOE) was used to study the influence of factors on the viscosity of paint. The DOE testing processes were all performed by running small test samples (the test machine and the process are equivalent to actual production).First, based on 5 factors that have a great influence on viscosity, modeling scenarios with 2 test modes for each factor would be conducted as shown in Table 5.

Table 5: Design of experiments model

No.	Properties change	Level
1	Content of Recycle Solvent	Replacement 5% pure solvent
		Replacement 10% pure solvent
2	Wrong solvent content	Shortage 5%
		Over 5%
3	Wrong rheological additive	0 - forgot to additive
		Mistaken from Bentone to Megatone (5)
4	Wrong dispersion phase time	Shortage 20 minute
		Over 20 minutes

5	The wrong running speed of the disperser (speed specified 1200 rpm)	1000 rpm
		1400 rpm

DOE was used to conduct experiments to evaluate their effects. Eight models based on DOE obtained corresponding viscosity results would be done as shown on Figure 8.

StdOrder	RunOrder	CenterPt	Blocks	R-Solvent	Solvent content	Rheological additive	Disper time	Speed of disper	Viscosity
4	1	1	1	10	5	0	20	1000	145
3	2	1	1	5	5	0	-20	14000	140
1	3	1	1	5	-5	0	20	14000	175
8	4	1	1	10	5	5	20	14000	165
5	5	1	1	5	-5	5	20	1000	163
2	6	1	1	10	-5	0	-20	1000	150
6	7	1	1	10	-5	5	-20	14000	144
7	8	1	1	5	5	5	-20	1000	135

Figure 8: DOE model in Minitab

The results of the evaluation of the factors affecting the viscosity parameters are shown as on following Figures:

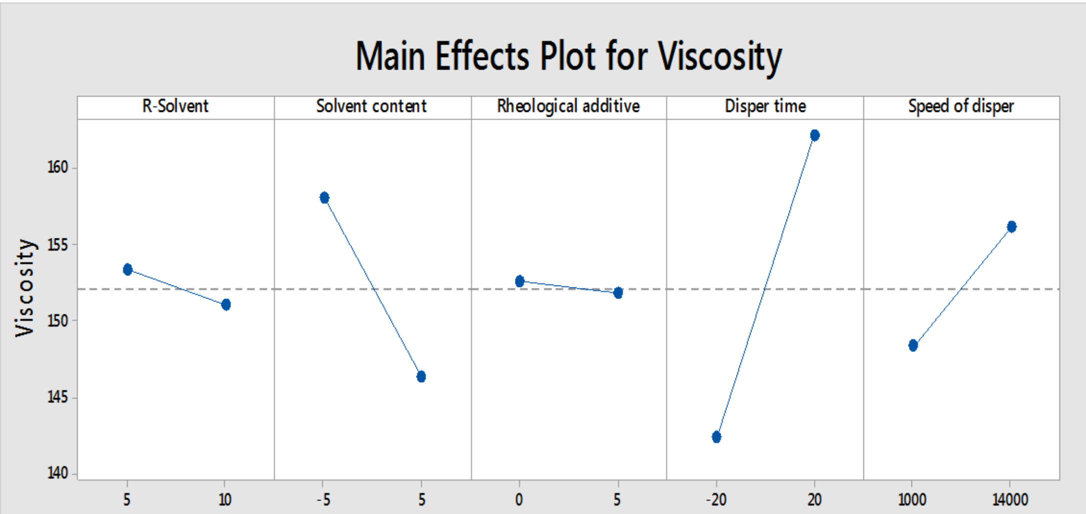

Figure 9: Main effects plot for each factor to viscosity defective

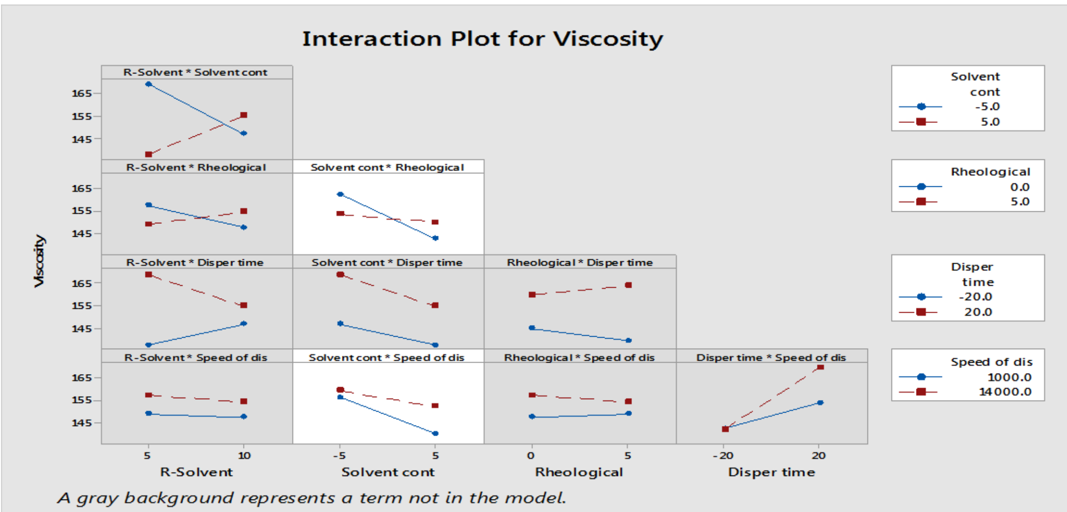

Figure 10: Interaction plot for viscosity (DOE in Minitab)

The analysis results (Figure 10) showed that 5 factors including the amount of Recycle Solvent (R-Solvent) used, the wrong solvent content, the wrong rheological additive, the wrong dispersion phase time, and the wrong running speed of the disperser all greatly affect the viscosity of the paint. Although Recycle Solvent and the wrong rheological additive have less impact on viscosity, when combined with other factors, they still have a great influence on the viscosity factor.Identifying the factors that have a great influence on the viscosity parameter plays an important role in realizing process improvement. These 5 factors are actually very difficult to control, so it is necessary to carefully conduct each element to standardize the process and convince relevant departments to follow. Thanks to the good DOE results, the basis to implement process improvement on a large scale was identified.

Process improvement is based on influencing factors:

1 - About the wrong solvent content: When taking the solvent, it is necessary to balance the meter, but not allow the worker to estimate as currently, how much solvent needs to be recorded on the technology sheet.

2 - About the error of time and 3 - speed of distributed machines: Adding to the process instructions, the required flow when turning on and stopping the machine as well as adjusting the speed must be agreed upon by the Technology Supervisor and the Production Team Leader co-sign and click in the corresponding box, if there is no signature of both parties, QC will not accept the next step.

4 - Regarding the amount of use of R-Solvent: Regulating the fixed use of Recycle Solvent, not allowing excess use of R-Solvent to replace new solvents that affect the viscosity of the paint (pure solvent drums, solvents) reuse should be distinguished by color and sub-label).

5 - About the error of rheological additives: Follow the instructions for taking odd ingredients, cover the ingredients to avoid dropping powder particles, and prevent the wrong type of additives and solvents by clearly marking them on the containers.

After improvement, the obtained results are as follows (The range of AK blue is 140 - 160 seconds):

Table 6: Results of viscosity after improvement

No.	AK Blue	No.	AK Blue	No.	AK Blue	No.	AK Blue	No.	AK Blue
1	156	16	154	31	160	46	148	61	148
2	158	17	142	32	148	47	142	62	155
3	158	18	155	33	150	48	140	63	142
4	155	19	145	34	140	49	**164**	64	159
5	158	20	160	35	155	50	147	65	140
6	148	21	144	36	**135**	51	150		
7	159	22	141	37	160	52	141		
8	155	23	149	38	152	53	155		
9	140	24	154	39	158	54	158		
10	157	25	146	40	150	55	145		
11	154	26	146	41	150	56	154		
12	154	27	160	42	155	57	145		
13	152	28	157	43	147	58	154		
14	155	29	**137**	44	154	59	145		
15	149	30	148	45	155	60	153		

From the aggregated data after 65 batches of improvement, the batch error rate has decreased to 4.62%, reaching the initial target of <5%. The variance is reduced as shown on Figure 11.

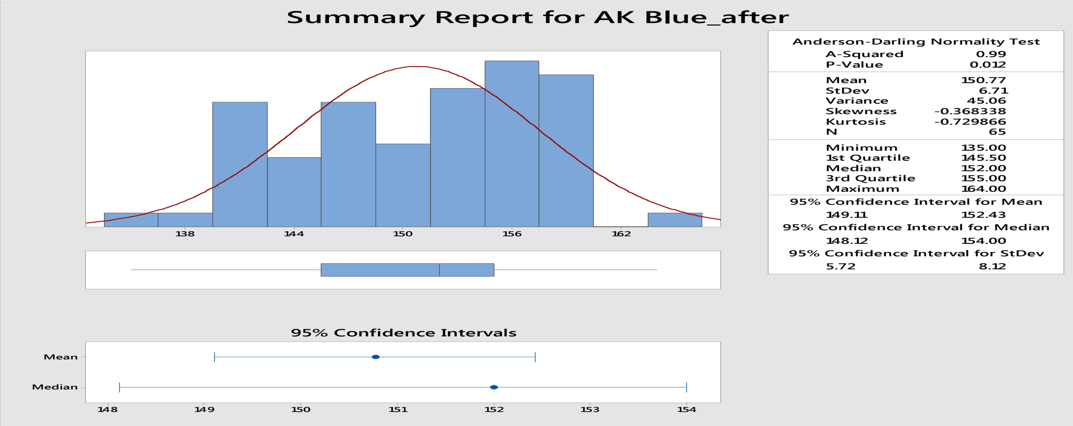

Figure 11: Summary report for AK blue after improvement

Control Phase

To ensure continuous improvement results, process control is very important. This stage of control needs to establish a control process, standardize the working process, set up a reward system for employees who do well in the process and have ideas for process improvement. To control the process well, it is necessary to use statistical control software. Using control charts to track quality improvement is a requirement of the project team.The use of quality control chart helps to detect deterioration and irregularities of paint viscosity during the production process for quick remedial action.Request to collect production data and use control chart of Minitab software to perform control as following figure.

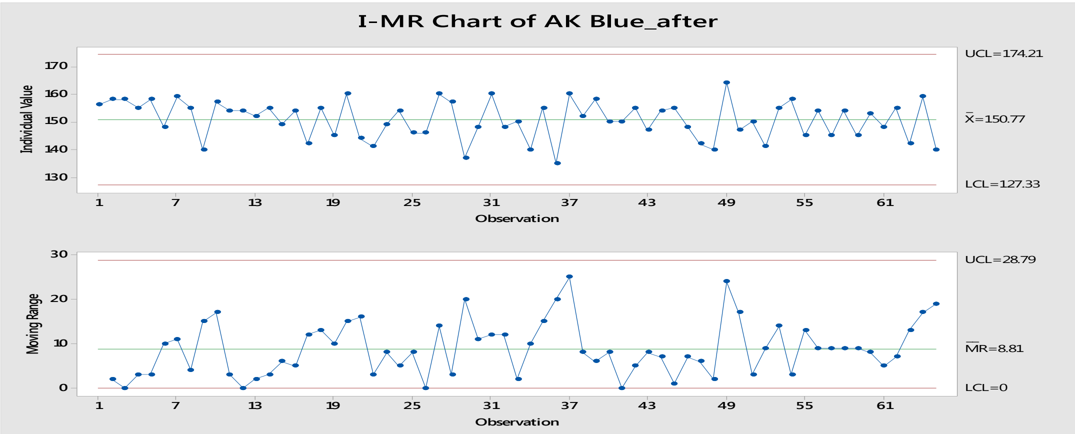

Figure 12: I-MR chart of AK blue

Internal training was conducted for all quality department staff to comply with new requirements and use Minitab for process quality control (as on figure 13). The control process requires the implementing departments to strictly follow the newly issued procedures.

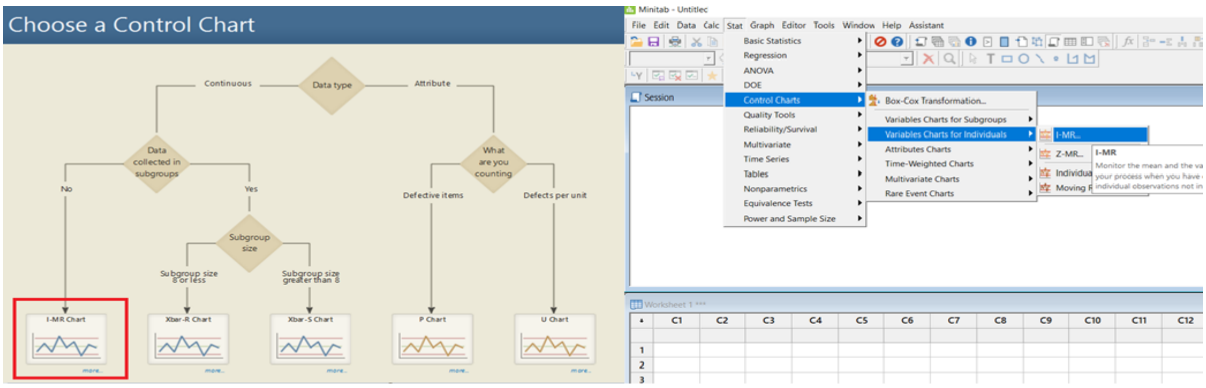

Figure 13: Introduction Minitab

V. CONCLUSION

The study shows the successfully case of applied DMAIC approach in practice to improve the error of paint viscosity parameters at the company. The error rate is reduce less than 5%.The successful application of DMAIC approach in improved practice at the factory contributes to strengthening the theoretical basis and experience in applying these tools to actual production. Improved paint viscosity control is within the allowable range to help meet customer needs and improve the company's paint quality. Therefore, the research could be considered as a pilot for improvement of quality for other company products. It would bring much benefits for the company.

In addition, the success of this study can also be considered as a case study in the coating industry applying Six Sigma Methodology in production, creating a premise for its development and widespread application in companies in the world industry and manufacturing companies in general. In addition, there are many types of wastes existing beside the defects, the lean technology should be implementing to help the company eliminate them in the future research.

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