Six Sigma

Case Study

Using Six Sigma Tools to Evaluate Pigment Dispersant Demand Performance

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A useful and relatively new methodology for reducing cost and improving quality is Six Sigma. Applying Six Sigma to product design and/or process control has been done on a routine basis. We would like to take this approach into the lab and offer the coatings formulator the same opportunity to explore the benefits of Six Sigma. Therefore, in this work, we focus on evaluating dispersant demand of four pigments using a Six Sigma approach. Specifically, we show how to define which parameters are important to measure, how to perform the measurements, analyze the data, and make conclusions regarding the relative difference in dispersant demand between the test pigments all with a Six Sigma data-driven approach. The goal of this work is to demonstrate how coatings formulators can find benefits in using Six Sigma tools. Then, the coatings formulator can expand with confidence the use of Six Sigma to other applicable formulating processes.

INTRODUCTION

From a methodology standpoint, Six Sigma is readily applied to processing plants where product quality and consistency are key production drivers. The well-defined step-by-step Six Sigma methodology lends itself to manufacturing facilities and the quest for reducing defects while maintaining product quality. However, Six Sigma is also a powerful methodology that can be applied to various aspects of many industries. Even though the coatings industry is mature, it is the author's opinion that this industry is prime for Six Sigma. Coatings formulators have always been keen to try new and novel methods to improve the current industry. Therefore, this work offers the coatings formulator the opportunity to see how Six Sigma can be applied to couple innovation with current good industry practice.

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Pigment is a major component of the coatings formulation. Properly using and gaining full value of the pigment is imperative in today's cost-conscious society where cost is balanced with performance. Dispersion is key to good pigment performance.[1] Poorly dispersed pigment can be directly related to poor coatings performance.[2] Therefore, the coatings formulator would like to evaluate pigment dispersion on a routine basis and in terms that relate to his/her practical needs. A typical industry method to evaluate pigment dispersion is the dispersant demand test. The information gained by performing the dispersant demand test can be related not only to pigment dispersion, but also used as an aid to determining the initial dispersant level needed in the coatings formula. Determining the correct dispersant amount required to adequately disperse a pigment leads to good formulating practice. Six Sigma is a tool that the coatings formulator can use to aid in this process.

SIX SIGMA

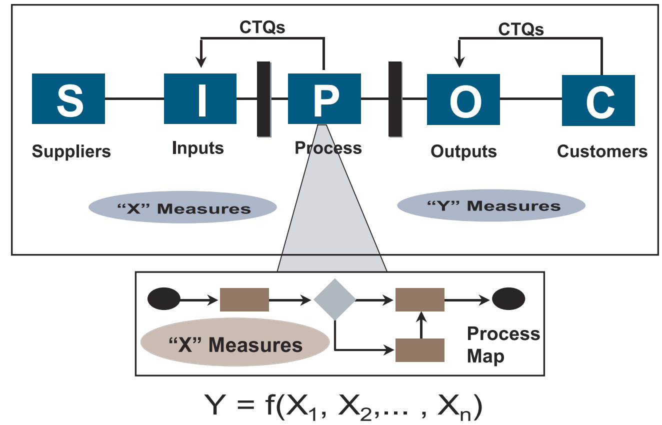
In this work, we use Six Sigma tools to determine dispersion performance of four TiO_2 pigments. Although we apply the Six Sigma methodology to understand the difference between pigments, this same methodology could easily be applied to understand performance aspects of other coatings raw materials or overall coatings product performance. Since this work concentrates on pigment evaluation, dispersion performance is selected as the key product attribute to be evaluated.[1]

The first step is to understand the Six Sigma concept.[3] Simply put, Six Sigma is a statistically based methodology that reduces variation in a product or process to less than 3.4 defects in one million parts. It is interesting to note that our common ideas of quality generally regard 99% capability, a three-sigma capability, as an extremely viable process. However, in day-to-day practice this would translate into an unacceptable tolerance. A three-sigma process applied to energy would give about seven hours per month of downtime. Not many customers would be willing to accept this on a routine basis.

The improvement from three sigma to Six Sigma means the virtual elimination of defects in the short term. The process moves from 99.7% to about 100%. In the long term, the process moves from 93.3% to about 99.9997%.

Six Sigma's objective is to reduce variation, resulting in fewer defects. One of the main goals of Six Sigma is to derive immediate benefits from statistical analysis. It is not uncommon for businesses to receive cost benefits from Six Sigma within a relatively short time period, on the order of months.[4-6]

Figure 1—SIPOC process map.



The basic components of Six Sigma are to (1) *Define* the problem and relate it to the internal/external customer, (2) *Measure* how the process is performing and determine defects, (3) *Analyze* the root causes for poor performance/defects, (4) *Improve* the process and, (5) *Control* the problem so it does not recur.[7] This is called the DMAIC Process.[7] The DMAIC process is a data-driven methodology that can be used virtually everywhere to improve a product or a process, but the work reported here takes only certain elements from Six Sigma and applies them to understand differences in dispersion performance between the selected pigments.

IDENTIFYING KEY PARAMETERS

The first tool that can be used quite readily by the coatings formulator is the SIPOC or high-level process map. It is an important tool that shows the formulator the large overview of the project. In general, the coatings formulator would like to see what his/her process

Figure 2—General dispersion performance SIPOC.

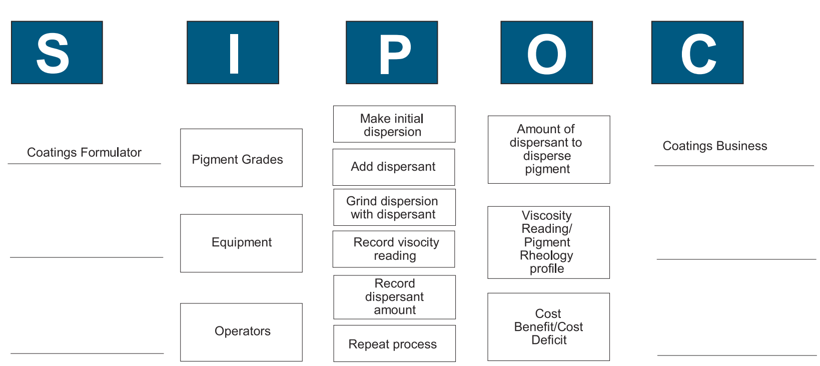


Figure 3—Cause and effect matrix.

Importance to Customer	9	3	9	
Output Number	1	2	3	
Process Input (cause)	Amt of Dispersant	Viscosity	Time for Pigment to Disperse	TOTAL
TiO2 Type	9	9	9	189
Dispersant Type	9	9	9	189
Weight Percent Solids of Dispersion	6	6	9	153
Dispersing Test Equipment	0	3	9	90
Operator	0	0	9	81
TiO2 Lot	3	3	3	63
Viscosity Test Equipment	0	9	0	27
Scales	3	0	0	27

Cause and Effect Relationships Scale Ratings

No relationship = 0
to
Strong relationship = 9

-or-

Weak = 1; Moderate = 3;
Stong = 9

would entail to evaluate dispersion performance of several pigments. A generic process map is shown in *Figure* 1 with a more relevant map given in *Figure* 2.

From the SIPOC, the formulator gets a large overview of what resources are required to complete the dispersion performance evaluation. The SIPOC gives direction to the formulator as to what information needs to be collected to get his/her desired outcome—output Y. If one thinks of the output Y as a function of input variables, X, then one can use a process to determine the measurable inputs needed. This connection between inputs and outcomes is highlighted in the Process section of the SIPOC in *Figure* 1. Therefore, one starts by defining possible Xs.

It may not be obvious what the Xs and Ys are for in our dispersion performance example. However, another Six Sigma tool can be used to help determine the input variables or Xs for our desired Y of dispersion performance. The cause and effect matrix can help determine which potential Xs are important for a given Y. Here is an example of the matrix (*Figure* 3) that a formulator could use for determining the potential Xs that are im-

Figure 4—Generic data collection plan.

Data Collection Plan

Data Collection Objective:
“To collect data to Measure Dispersant Demand (purpose, goal or expected outcome) for the Four Sample Pigments (process or product).”

What to Measure				Develop Operational Definitions and How to Measure							
				Operational Definition		Sampling Plan				Collection	
Measure	Type Measure	Type Data	Stratification	What	How	What	Where	When	How Many	Collection Method	Employee Name
Wt% Dispersant	Output	Continuous	Operator	Amt in grams	Mettler Scale	Dipsersant Amount Added	each sample	measure at time of addition	take readings after each addition and then take 4 readings after minimum viscosity reached	Manual	Operator 1
Viscosity	Output	Continuous	Operator	Amt in cps	Brookfield	cps reading	each sample	1 min after each addition	take readings after each addition and then take 4 readings after minimum viscosity reached	Manual	Operator 2

Table 1—Dispersion data for four TiO_2 pigments.

Operator	TiO2	Lot	Replicate	Wt%Dis		Operator	TiO2	Lot	Replicate	Wt%Dis
O1	SampleA	L1	R1	0.102		O2	SampleA	L1	R1	0.097
O1	SampleA	L1	R2	0.121		O2	SampleA	L1	R2	0.111
O1	SampleA	L1	R3	0.208		O2	SampleA	L1	R3	0.095
O1	SampleA	L2	R1	0.154		O2	SampleA	L2	R1	0.090
O1	SampleA	L2	R2	0.109		O2	SampleA	L2	R2	0.086
O1	SampleA	L2	R3	0.126		O2	SampleA	L2	R3	0.132
O1	SampleA	L3	R1	0.113		O2	SampleA	L3	R1	0.110
O1	SampleA	L3	R2	0.162		O2	SampleA	L3	R2	0.136
O1	SampleA	L3	R3	0.116		O2	SampleA	L3	R3	0.102
O1	SampleB	L1	R1	0.180		O2	SampleB	L1	R1	0.211
O1	SampleB	L1	R2	0.177		O2	SampleB	L1	R2	0.181
O1	SampleB	L1	R3	0.222		O2	SampleB	L1	R3	0.151
O1	SampleB	L2	R1	0.196		O2	SampleB	L2	R1	0.178
O1	SampleB	L2	R2	0.226		O2	SampleB	L2	R2	0.182
O1	SampleB	L2	R3	0.184		O2	SampleB	L2	R3	0.171
O1	SampleB	L3	R1	0.250		O2	SampleB	L3	R1	0.213
O1	SampleB	L3	R2	0.247		O2	SampleB	L3	R2	0.238
O1	SampleB	L3	R3	0.439		O2	SampleB	L3	R3	0.221
O1	SampleC	L1	R1	0.111		O2	SampleC	L1	R1	0.124
O1	SampleC	L1	R2	0.119		O2	SampleC	L1	R2	0.129
O1	SampleC	L1	R3	0.132		O2	SampleC	L1	R3	0.126
O1	SampleC	L2	R1	0.128		O2	SampleC	L2	R1	0.118
O1	SampleC	L2	R2	0.134		O2	SampleC	L2	R2	0.139
O1	SampleC	L2	R3	0.151		O2	SampleC	L2	R3	0.104
O1	SampleC	L3	R1	0.116		O2	SampleC	L3	R1	0.093
O1	SampleC	L3	R2	0.147		O2	SampleC	L3	R2	0.169
O1	SampleC	L3	R3	0.175		O2	SampleC	L3	R3	0.096
O1	SampleD	L1	R1	0.054		O2	SampleD	L1	R1	0.056
O1	SampleD	L1	R2	0.084		O2	SampleD	L1	R2	0.068
O1	SampleD	L1	R3	0.077		O2	SampleD	L1	R3	0.062
O1	SampleD	L2	R1	0.123		O2	SampleD	L2	R1	0.101
O1	SampleD	L2	R2	0.119		O2	SampleD	L2	R2	0.104
O1	SampleD	L2	R3	0.122		O2	SampleD	L2	R3	0.102
O1	SampleD	L3	R1	0.084		O2	SampleD	L3	R1	0.060
O1	SampleD	L3	R2	0.132		O2	SampleD	L3	R2	0.061
O1	SampleD	L3	R3	0.127		O2	SampleD	L3	R3	0.075

portant to the desired outcome, Y. Using the cause and effect matrix, we are able to rank the order of importance for the input Xs and then focus our work on collecting data for these Xs to statistically determine which are the vital few Xs that determine dispersant demand and ultimately dispersion performance.

MEASURING IMPORTANT PARAMETERS

Now that the coatings formulator knows what information must be obtained, he/she must determine how to collect that information. Another Six Sigma tool is the data collection plan. This helps to keep all operators grounded on what to measure, how often to measure, and how to collect the data. The data collection plan is essential in obtaining good information. An example of a generic data collection plan is given in *Figure* 4.

With the data collection plan at hand, the data can be collected and then analyzed using a statistical program. For this particular work, a data collection plan was used and data collected for the four different pigments. Since we wanted to compare the different pigments in terms of dispersion performance, getting enough samples to analyze statistically was not an issue. The relevant data is given *Table* 1.

DATA ANALYSIS

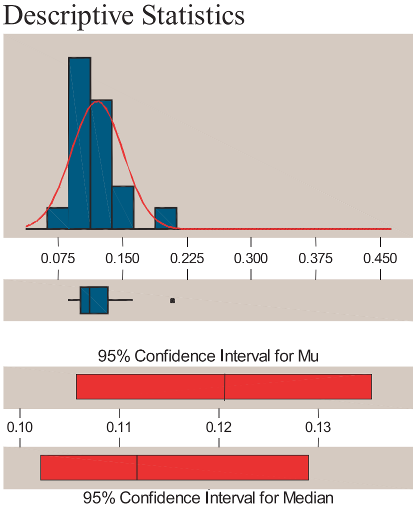
After the data is collected, the coatings formulator is ready to analyze the data. This can be analyzed using any basic statistical software. For this example, data was analyzed using the Minitab® program.[8] The first type of analysis is basic descriptive analysis. From this analysis, the weight percent dispersant mean and standard deviation are obtained for each sample. From the initial analysis, it appears that there is a difference in the pigments. Sample D requires the minimum amount of dispersant, followed by Sample A, then by Samples C and B, respectively.

Descriptive Statistics: Wt%Dis by TiO_2

Variable	TiO_2	N	Mean	Median	TrMean	StDev
Wt%Dis	Sample A	18	0.12059	0.11180	0.11727	0.03001
	Sample B	18	0.2147	0.2032	0.2047	0.0627
	Sample C	18	0.12838	0.12715	0.12768	0.02226
	Sample D	18	0.08944	0.08360	0.08901	0.02710

Variable	TiO_2	SE Mean	Minimum	Maximum	Q1	Q3
Wt%Dis	Sample A	0.00707	0.08640	0.20790	0.10085	0.13300
	Sample B	0.0148	0.1507	0.4386	0.1795	0.2288
	Sample C	0.00525	0.09290	0.17500	0.11463	0.14072
	Sample D	0.00639	0.05360	0.13210	0.06175	0.11948

Descriptive Statistics



Variable: Wt%Dis
Sample A

Anderson-Darling Normality Test

A-Squared:	0.803
P-Value:	0.030
Mean	0.120586
StDev	0.030008
Variance	9.00E-04
Skewness	1.62963
Kurtosis	3.18029
N	18
Minimum	0.086400
1st Quartile	0.100850
Median	0.111800
3rd Quartile	0.133000
Maximum	0.207900

95% Confidence Interval for Mu

0.105663 0.135508

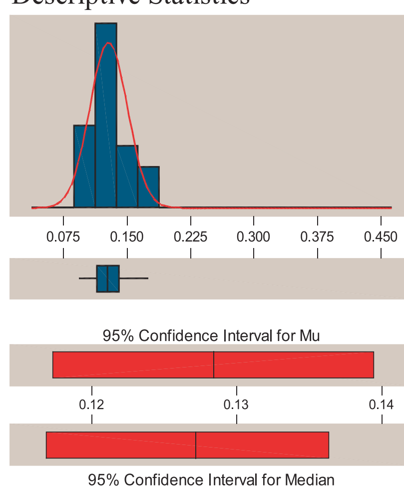
95% Confidence Interval for Sigma

0.022517 0.044986

95% Confidence Interval for Median

0.102122 0.129148

Descriptive Statistics



Variable: Wt%Dis
Sample C

Anderson-Darling Normality Test

A-Squared:	0.258
P-Value:	0.676
Mean	0.128378
StDev	0.022262
Variance	4.96E-04
Skewness	0.518415
Kurtosis	0.176405
N	18
Minimum	0.092900
1st Quartile	0.114625
Median	0.127150
3rd Quartile	0.140725
Maximum	0.175000

95% Confidence Interval for Mu

0.117307 0.139448

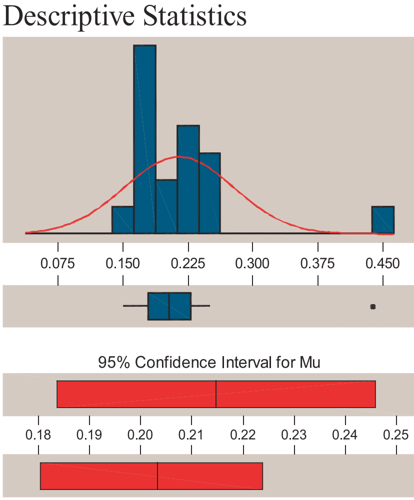
95% Confidence Interval for Sigma

0.016705 0.033373

95% Confidence Interval for Median

0.116840 0.136373

Descriptive Statistics



Variable: Wt%Dis
Sample B

Anderson-Darling Normality Test

A-Squared:	1.715
P-Value:	0.000
Mean	0.214717
StDev	0.062664
Variance	3.93E-03
Skewness	2.88037
Kurtosis	10.2207
N	18
Minimum	0.150700
1st Quartile	0.179475
Median	0.203200
3rd Quartile	0.228750
Maximum	0.438600

95% Confidence Interval for Mu

0.183554 0.245879

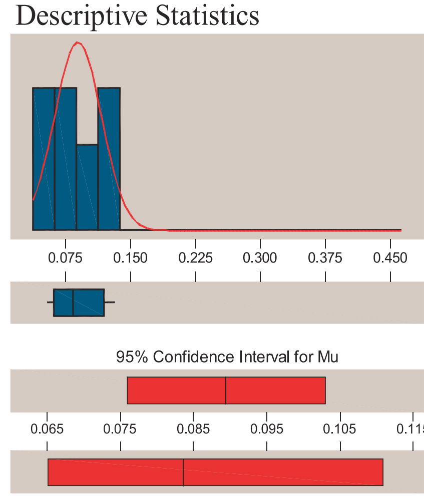
95% Confidence Interval for Sigma

0.047023 0.093943

95% Confidence Interval for Median

0.180363 0.223835

Descriptive Statistics



Variable: Wt%Dis
Sample D

Anderson-Darling Normality Test

A-Squared:	0.576
P-Value:	0.117
Mean	8.94E-02
StDev	2.71E-02
Variance	7.35E-04
Skewness	0.224976
Kurtosis	-1.49325
N	18
Minimum	0.053600
1st Quartile	0.061750
Median	0.083600
3rd Quartile	0.119475
Maximum	0.132100

95% Confidence Interval for Mu

0.075961 0.102917

95% Confidence Interval for Sigma

0.020338 0.040631

95% Confidence Interval for Median

0.065104 0.110830

A more definitive type of analysis is Analysis of Variance (ANOVA). ANOVA can be used to determine if there are differences between the sample populations (as evidenced by the pigment's dispersion performance) by comparing the means of the populations.

One-way ANOVA: Wt%Dis versus TiO_2

```
Analysis of Variance for Wt% Dis
Source     DF       SS        MS         F        P
TiO2        3   0.15550   0.05183     34.23    0.000
Error      68   0.10298   0.00151
Total      71   0.25848
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N     Mean     StDev   ------+---------+---------+---------+
Sample A   18  0.12059   0.03001          (---*---)
Sample B   18  0.21472   0.06266                            (---*---)
Sample C   18  0.12838   0.02226            (---*--)
Sample D   18  0.08944   0.02710   (---*---)
                                   ------+---------+---------+---------+
Pooled StDev =  0.03891                0.100     0.150     0.200     0.250
```

From the data shown above, it can be seen that to a 95% confidence level, the means of at least one of these pigment samples is different. Now if one would like to determine whether Sample D and Sample A are truly statistically different, another tool can be employed to distinguish between these two pigment samples: the two-sample t-test as shown below.

Two-Sample T-Test and CI: Wt%Dis_1, TiO_2_1

```
Two-sample T for Wt%Dis_1

TiO2_1       N      Mean     StDev   SE Mean
Sample A    18    0.1206    0.0300    0.0071
Sample D    18    0.0894    0.0271    0.0064

Difference = mu (Sample A) - mu (Sample D)
Estimate for difference:  0.03115
95% CI for difference: (0.01176, 0.05054)
T-Test of difference = 0 (vs not =): T-Value = 3.27
  P-Value = 0.003  DF = 33
```

In this case, with the P-value < 0.05, the two-sample t-test indicates that the mean Wt% Dis of Sample D and Sample A are not equal. Using Six Sigma tools, we have with confidence determined that there is a statistical difference between the pigments. Now, the coatings formulator can use this information to adjust the dispersant level in the formula based on the pigment in the formula.

In this study, we have used dispersion viscosity as a proxy for quality of dispersion. While in our experience this approach provides good direction for formulation development, the ultimate test remains evaluation of a fully formulated coating under typical application and drying conditions.

CONCLUSIONS

Six Sigma is a powerful methodology that has been successfully applied to many disciplines. Our goal with this work was to enable the coatings formulator to use Six Sigma in a lab situation. Now, the coatings formulator should see the value of Six Sigma as a powerful tool that can help in making statistically based decisions. In particular, this work has demonstrated how to define which parameters are important to measure, how to perform the measurements, analyze the data, and make conclusions regarding the relative difference in dispersant demand between four test pigments.

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