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RESEARCH & CREATIVE ACHIEVEMENT WEEK

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Process Optimization – A Six Sigma DMAIC Approach

Abstract

Nap fabrics used in paint roller covers are required to meet nap height specifications measured as the overall fabric thickness from its backing to meet substrate paint application standards. Consistency in heat setting process is key to achieving customer specifications for nap fabrics. Excessive shrinkage or variation in shrinkage during heat setting will lead to non-conforming nap fabric heights and costly adjustments, tweaking for quality or downgrading in downstream finishing processes.

An exploratory analysis in the measure phase revealed significant difference in yarn shrinkage levels between suppliers. Effect of supplier and heat setting temperature levels on yarn shrinkage was statistically significant, $F(2,42)=19.78$, $P= .000$. These exploratory results reveals evidence of significant vendor factor contribution to process variability. This paper will discuss the six sigma DMAIC tools applied in this project and highlight results and opportunities for process optimization, improvement and controls applied to meet expected annualized savings.

Introduction

Introduction: Woven nap fabrics are produced by simultaneously weaving two layers of fabrics linked together at a pre-determined gap or gauge by a set of warp stitching threads. The stitching threads are then cut between the two layers to produce two napped fabrics with sum of tuft lengths equal the height of the gap. Napped fabrics are then subjected to heat setting process followed by finishing operation to produce a finished woven nap length in figure 1. Very high temperatures in heat setting results in higher nap shrinkage leading to higher yarn consumption, excessive lint loss and, wear and tear in finishing equipment.

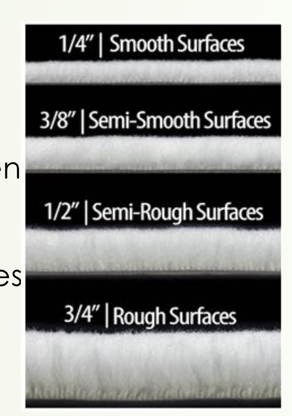

Figure 1: Roller Cover nap lengths

Define

Cost of imported yarns has steadily increased in the last few years. During 2015 financial year pile yarn grossed over US$ 4,398,000. It is envisaged that a 3% decrease in pile yarn shrinkage could accrue estimated annual savings of ~US$400K on pile yarn costs. This project seeks to optimize heat setting process to achieve optimum yarn shrinkage and minimize finishing action using . A cross-functional problem solving team using Six Sigma DMAIC methodology conducted a review of heat setting process using process flow charts, brainstorming, and SIPOC chart to identify potential factors for optimization in a DOE analysis.

S	I	P	O	C
Suppliers	Inputs	Process	Outputs	Customers
Providers for the process	Inputs into the process	Top-level process description	Outputs of the process	Receivers of the process outputs
Weaving Section	Grey cloth	Pre-Heat Setting (HS) Range	Heat Set Cloth	Shearing / Finishing Ranges
Piedmont Electric	Electric Energy	Sew-in Grey fabric to Leader Cloth	Off-Pins Cloth defects	Defect collection Bins
AmeriGas	Propane Gas	Set range parameters (Range Zone temperatures, Speed, Fan Speeds, Cloth width,)	Overheat Cloth defects	
Vendor 1 Yarns	Cloth feed speed	Start (HS) Range	Pile Yarn Shrinkage	
Vendor 2 Yarns	Range Temperature	Doff Leader Cloth	Cloth width shrinkage	
Vendor 3 Yarns	Cloth Width	Sew-in Leader Cloth	Filling Yarn Melt	
Vendor 4 Yarns		Doff HS Cloth		
Vendor 5 Yarns				
Vendor 6 Yarns				

Figure 2: SIPOC diagram

Measure

In the measure phase factors critical to quality (CTQ) were identified and evaluated. A set of metrics that best captured the process baseline conditions were proposed. Yarn shrinkage difference between vendors shown in Figure 3 was significant $F(2,42)=19.78$, $P= .000$ at all different temperature ranges. Two new metrics – Pile Ratio (PR) and Finish Ration (FR) were proposed to allow for comparative process performance across fabric styles. PR is defined as the ratio of Kenyon heat setting pile height (KPH) to weaving pile height (WPH) and FR is defined as ratio of finish pile height (FPH) to heat setting pile height (KPH).

FR is a measure of change in fabric loft or pile height (nap length) due to finishing action. PR was then adopted as the primary metric for gauging heat setting process performance while FR will be used in DMAIC improve phase for determination of suitable PR levels to meet finished product specifications. Figure 4 demonstrates pile height mismeasurement system.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Vendor	1	2484.96	2484.96	10273.15	0.0000
Temp	2	937.02	468.51	1936.89	0.0000
Error	44	10.64	0.24		
Lack-of-Fit	2	5.16	2.58	19.78	0.0000
Pure Error	42	5.48	0.13		
Total	47	3182.36			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.491822 9	9.67%	99.64%	99.60

Figure 3: ANOVA between Temperature and Yarn Vendor

Measure (continued)

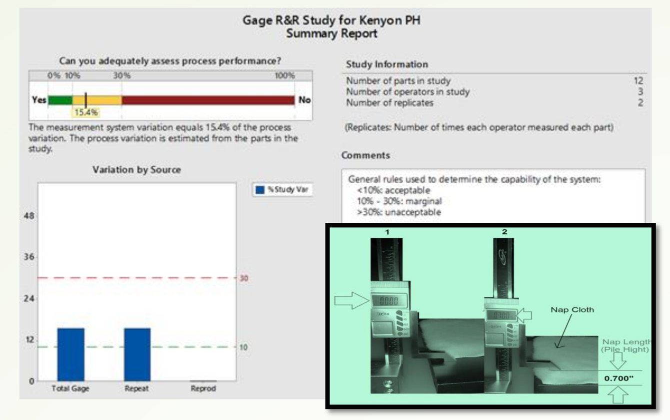

Figure 4: Measurement System Analysis using Gage R&R
Inset Picture: Pile Height Measuring Gauge

An MSA shown in figure 4 was done and at 15.4% variation, the system was found suitable for use in this study.

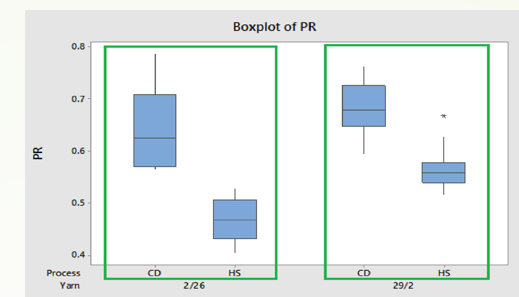

Figure 5: Box plot of HS and CD styles in 2/26 & 2/29 yarns

Current styles were grouped into heat set (HS) and coated (CD)and PR values determined. A box plot shown in Figure 5 suggested that even styles from the same yarns were at different PR levels

There were no historical **PR** data or specifications for determining the prevailing Kenyon **Z score**. A well-established product -VCB that consistently meets customer expectations was sampled and used to established specifications for acrylic styles under this study. Figure 6 Shows Heat setting capability performance in terms of PR based on PR values 0.515 and 0.665 specifications for VCB. From the abridged "6-Sigma" conversion tables, a PPM defect level of 378,930 translates to a sigma level of 1.8 and a yield of 61.8%. This yield value suggest that 38.2% of acrylic styles are either at higher (lower shrinkage) or lower (high shrinkage)levels PR.

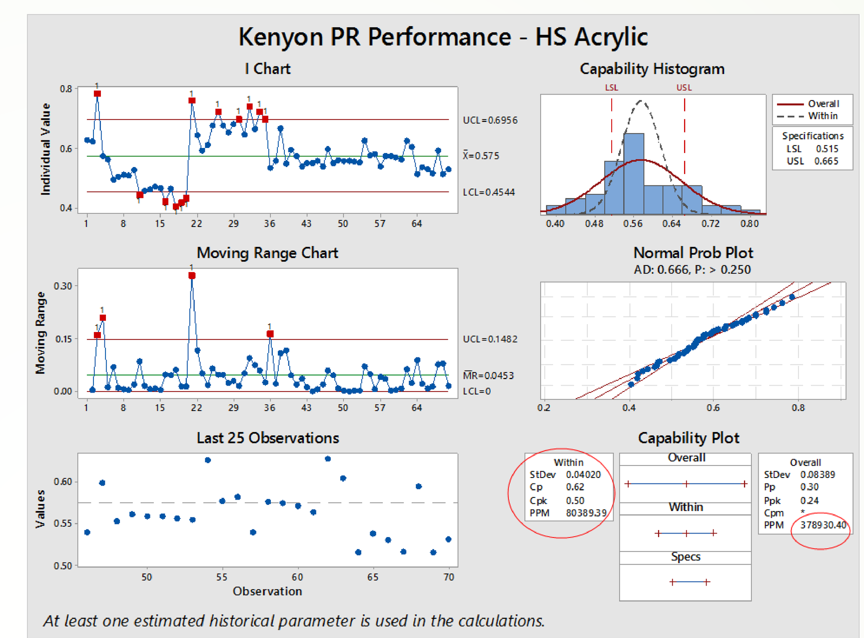

Figure 6: Capability assessment of Heat setting process

Analyze

To carry out process optimization the study team elected to use design of Experiment (DOE) on four factors considered critical to process **PR**. A full factorial design with 3 replicates was used for the following factors: Fabric Tuft length (mm); Fabric Picks per inch (PPI), Range Temperature (°F) and Range Speed (ypm). Two runs were used to obtain the final model shown in figure 8 below.

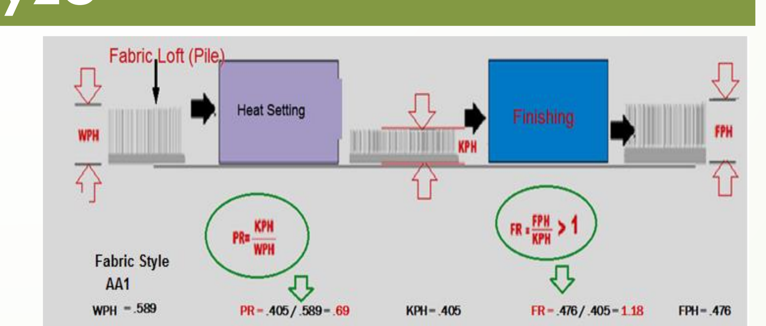

Figure 7: Nap fabric Pile Height Transition to Final Nap (*FPH*)

Factorial Regression: PR versus Temp (deg F), Speed (ypm), Tuft (mm), PPI

```
Analysis of Variance

Source                            DF    Adj SS    Adj MS  F-Value  P-Value
Model                              9  0.438083  0.048676   114.10    0.000
  Linear                           4  0.420624  0.105156   246.50    0.000
    Temp (deg F)                   1  0.415110  0.415110   973.09    0.000
    Speed (ypm)                    1  0.000010  0.000010     0.02    0.881
    Tuft (mm)                      1  0.000011  0.000011     0.03    0.872
    PPI                            1  0.005493  0.005493    12.88    0.001
  2-Way Interactions               4  0.011127  0.002782     6.52    0.000
    Temp (deg F)*Speed (ypm)       1  0.002503  0.002503     5.87    0.020
    Temp (deg F)*PPI               1  0.000326  0.000326     0.76    0.388
    Speed (ypm)*PPI                1  0.000379  0.000379     0.89    0.352
    Tuft (mm)*PPI                  1  0.007920  0.007920    18.57    0.000
  3-Way Interactions               1  0.006332  0.006332    14.84    0.000
    Temp (deg F)*Speed (ypm)*PPI   1  0.006332  0.006332    14.84    0.000
Error                             38  0.016210  0.000427
  Lack-of-Fit                      6  0.004759  0.000793     2.22    0.067
    Pure Error                    32  0.011452  0.000358
Total                             47  0.454293

Model Summary

        S    R-sq  R-sq(adj)  R-sq(pred)
0.0206540  96.43%     95.59%      94.31%
```

Figure 8: Reduced Model DOE Factorial ANOVA

```
Regression Equation in Uncoded Units

PR = -11.97 + 0.0449 Temp (deg F) + 0.839 Speed (ypm) - 0.0585 Tuft (mm) + 0.2719 PPI
     - 0.002508 Temp (deg F)*Speed (ypm) - 0.000961 Temp (deg F)*PPI
     - 0.01719 Speed (ypm)*PPI + 0.001168 Tuft (mm)*PPI
     + 0.000051 Temp (deg F)*Speed (ypm)*PPI

Alias Structure   I A B C D AB AD BD CD ABD

Factor  Name

A       Temp (deg F)
B       Speed (ypm)
C       Tuft (mm)
D       PPI
```

Figure 9: Selected Regression Model

Main effects of speed, and Tuft are not significant but exhibit significant 2 and 3 way interactions. These effects are therefore included in the model. Figure 10 is a Pareto chart of significant effects. After optimizer is run , a variation solution of the solution was used to run a prediction of PR as shown in figure 11.

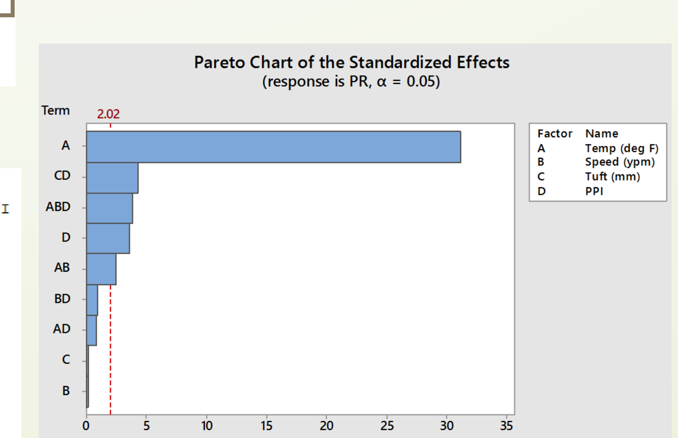

Figure 10: Selected Regression Model

Analyze (Continued)

Residual plots for PR confirmed normality assumptions were not violated

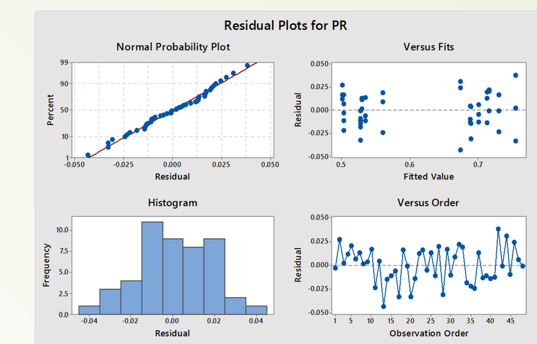

Figure 11: Normality Check on DOE Data

By using a target ***PR*** value and ***FR*** of 1.3 (determined from coated Process), an estimate gross annual savings of US $ 621,185.00 will accrue as a result of reduced tuft length as shown in Table 1.

Table 1: Estimated Annual Savings Analysis from affected Styles

Group	No. of Styles	Current Tuff	New Tuff	WPH	PR	KPH	FPH	FR	Yarn Lbs Saved	$ Saved
A	3	65.62	53.70	1009	0.65	656	853	1.3	5,720	$21,718
B	1	61.86	50.00	941	0.65	612	795	1.3	1,168	$3,476
C	2	52.93	46.69	879	0.65	572	743	1.3	455	$1,476
D	7	46.16	38.42	720	0.65	468	609	1.3	15,592	$59,777
E	8	41.37	34.71	659	0.65	429	557	1.3	24,270	$72,405
F	12	33.74	28.61	545	0.65	354	461	1.3	123,179	$387,124
G	5	30.21	26.96	514	0.65	334	434	1.3	8,795	$26,185
H	2	26.44	20.09	378	0.65	245	319	1.3	1,032	$3,074
I	7	22.98	18.22	342	0.65	222	289	1.3	9,124	$29,536
J	6	20.53	15.02	309	0.65	201	261	1.3	5,472	$16,413
								Total	**382,983**	**$621,185**

Improve

To achieve target ***PR***, Minitab optimizer was run based on the final reduced model in figure 9. Optimizer solution is shown in figure 13 for a target ***PR*** of 0.65, temperature and speed factors in range and tuft length and picks per inch (***PPI***) were fixed. These prediction model is thus used to target a PR level that will best meet customer expectations for final pile height (***FPH***) by running a prediction to a PR close to 0.65 as shown in figure 14.

Response Optimization: PR

```
Parameters

Response  Goal    Lower     Target  Upper     Weight  Importance
PR        Target  0.480533  0.65    0.793919  1       1

Variable Ranges
Variable      Values
Temp (deg F)  (275, 370)
Speed (ypm)   (15.5, 16.5)
Tuft (mm)     41
PPI           48

Solution

          Temp     Speed  Tuft            PR  Composite
Solution  (deg F)  (ypm)  (mm)  PPI  Fit   Desirability
1         304.165  16.5   41    48   0.65             1
```

Figure 13: Minitab Optimizer Solution

Figure 14 indicates a prediction of PR=0.634. Three fabric styles have been sampled to be run under the specified conditions in the prediction. Finished FPH will be checked against customer specified fph.

Prediction for PR

```
Regression Equation in Uncoded Units

PR = -11.97 + 0.0449 Temp (deg F) + 0.839 Speed (ypm) - 0.0585 Tuft (mm) + 0.2719 PPI
     - 0.002508 Temp (deg F)*Speed (ypm) - 0.000961 Temp (deg F)*PPI - 0.01719 Speed
     (ypm)*PPI + 0.001168 Tuft (mm)*PPI + 0.000051 Temp (deg F)*Speed (ypm)*PPI

Variable      Setting
Temp (deg F)      315
Speed (ypm)        16
Tuft (mm)          41
PPI                52

     Fit     SE Fit              95% CI                   95% PI
0.634212  0.0071583  (0.619721, 0.648704)  (0.589961, 0.67846
```

Figure 14: Minitab Prediction

Control

As shown in table 1 above, each group will be sampled and both *PR* and *FR* values determined using equations 1 and 2 . The appropriate control for this study will be X bar – R charts. Selected styles falling under the scope of this study will be sampled on daily basis for *kph, fph, kw* and *fw* before and after each finishing processes when they are scheduled for production as illustrated in figure 15. Each style is sample only once for 3 specimens. To monitor lint losses each specimen is also weighed before (kw) and after finishing (*fw*). Lint losses, *PR* and *FR* ratios are calculated as shown in figure 1. The study will construct X bar-R charts and analyze data using Minitab. A target PR and FR values with range data from measure phase will be used create conditional limits as shown if figure 16 .

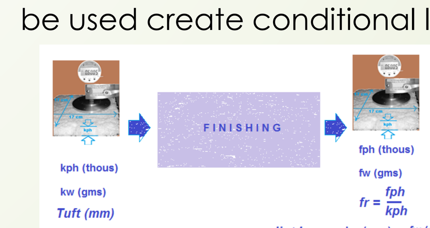

Figure 15: Sampling Finishing Process

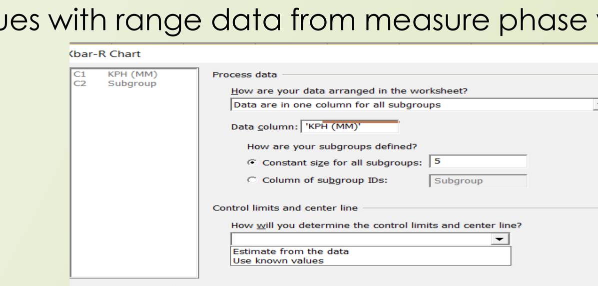

Figure 16: Minitab X bar-R Chart dialog box

Conclusions

DOE factorial ANOVA in figure 8 revealed that there was main effect of TEMPERATURE type on PR ($F(1, 38) = 973.09$, $p < .05$), significant main effect of PPI on PR ($F(1,38) = 12.88$, $p< .05$), indicating that Temperature and picks per inch has significant impact on pile ratio (PR), however Tuft effect ($F(1,38)=0.03$, $p>0.05$) and Speed ($F(1,38)=0.02$, $p>0.05$) had no significant influence on PR without interactions. 2-way interactions of temperature and speed ($F(1, 38) =5.87$, $p<0.05$) and tuft and PPI were significant. 3-way interactions of temperature, speed and PPI ($F(1, 38) =14.84$, $p<0.05$) was also significant. A significant model was found ($F(9, 38) =114.10$, $p<0.05$) with an R of 0.956. These results are further supported by an estimated annual cost savings on yarn consumption of US $ 681, 185.00

Acknowledgments

I take this opportunity to express my profound gratitude to my project champion Mr. Dave Hughston and my entire team at P&A Industrial Fabrications for their invaluable support, investment and dedication to lean six sigma principles. Thank you.

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