The Ink Delamination Experiment

Overview

CUink, Inc. is a company specialized on the printed graphics business, particularly for plastics and other similar materials. One of CUink's largest customers reported that the ink on the grid of one of their printed products was delaminating and that the customer's production line was stopped.

Define

The objective of this six-sigma project is to study and analyse the processes involved in the production of printed products, point out existing flaws and suggest appropriate improvements and control measures to maintain consistency of the product produced so that the customers will be satisfied. This involves extensive study and analysis of data. The report also focusses on quantifying the benefits of implementing the improvements/suggestions in terms of DPM.

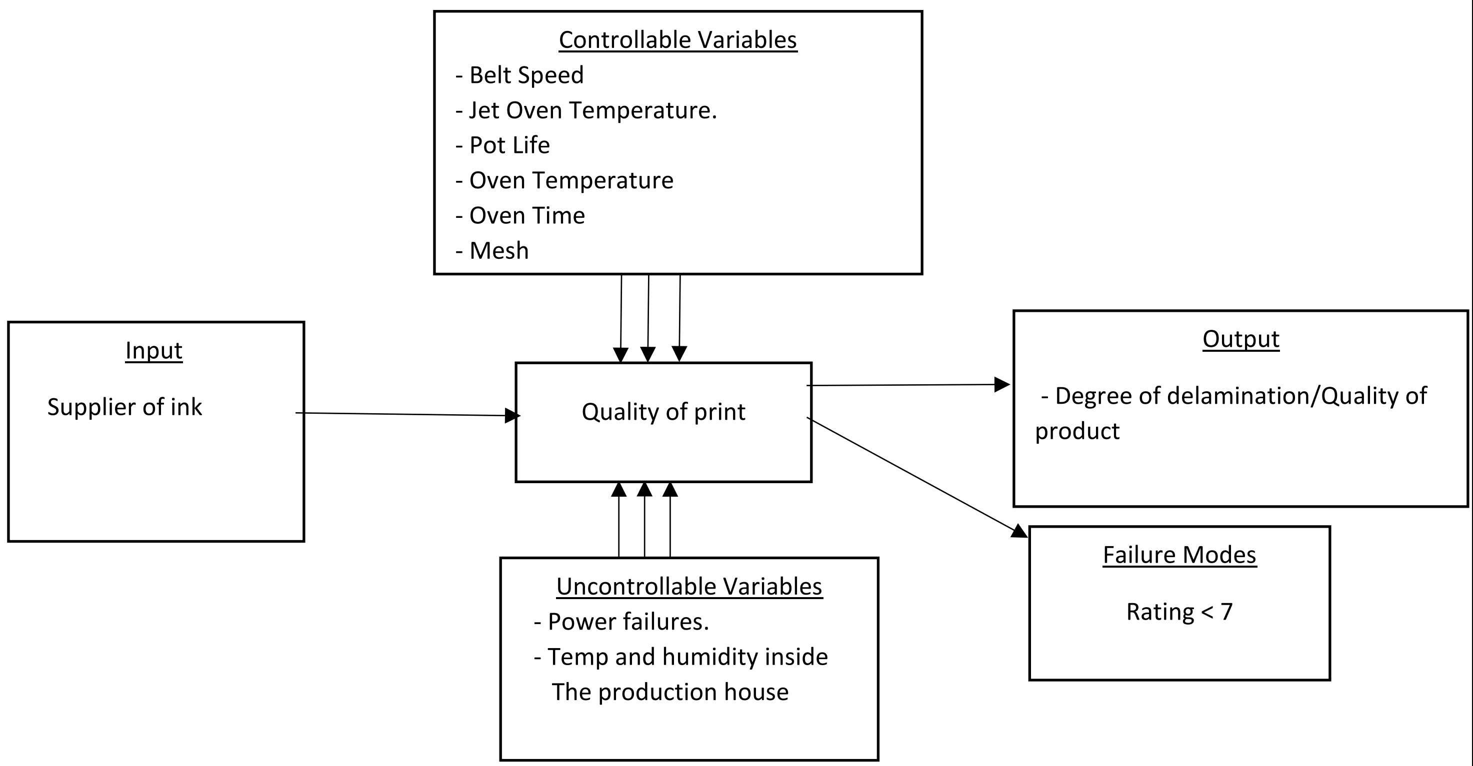
Project Charter

Project Information		**Resources**	
Project #	1234	Project Leader	William B
Project Name	CUInk	Black Belt:	Steven A
Project Start Date	xx-xxx-2021	Champion:	John R
Project End Date	xx-xxx-2022	Process Owner	CUInk
Team Members	Stuart, Allan, Son, Jake		
Problem Statement:			
One of CUInk's largest customers reported that the ink on the grid of one of their printed products was delaminating and that the customer's production line was stopped. We need to study, analyze and make improvements in the production process to ensure the product doesn't delaminate and hold properties as expected by the customers.			
Goal Statement:			
The objective of this project is to find the optimum factor settings to minimize delamination of their products and suggest improvement and control methods.			
Project Scope:			
This project is limited to the factor settings of the process with respect to the new ink supplier. Any further change in the ink supplier will have to be dealt with new analyses or replication of this project with updated data.			

Measure

Variables

There are multiple factors that influence the quality of the printed products. Most important variables are identified and categorized into –(a) Input Variables, (b) Controllable Variables, (c) Uncontrollable Variables and (d) Output. These variables are shown in the P – Diagram



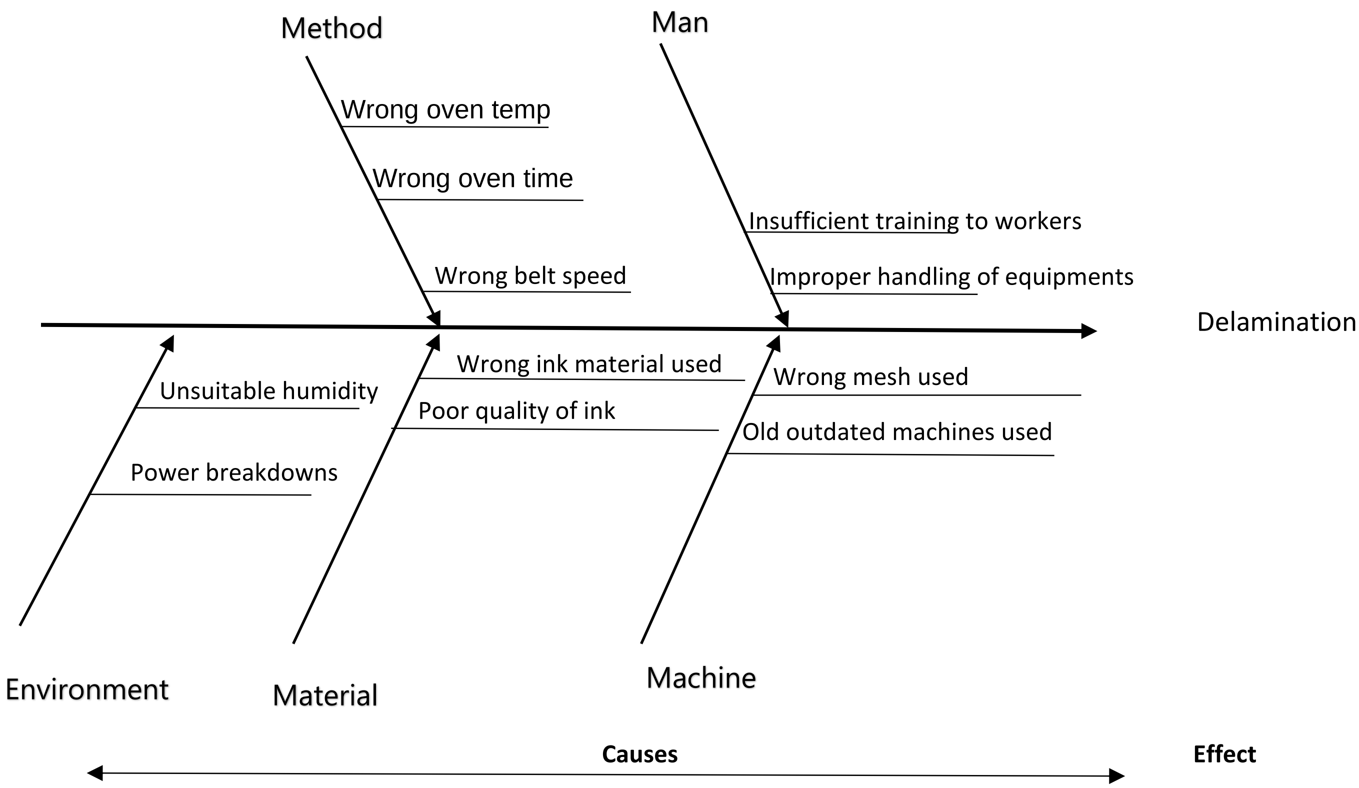
Key output or quality of the product is measured in terms of degree of delamination in a scale of 1-10 where 1 represents very high delamination which is bad and 10 represents a perfect part with no delamination. These ratings are established by the DOE.

Currently, out of the 25000 parts shipped to a customer, about 20% were delaminating to a level unacceptable to the customer. This means that the current **DPM** level of the process is **200000** which is high.

The degree of delamination of the products is measured by 3 inspectors according to the rating system established by the DOE team. A sample of 30 parts were rated by the 3 inspectors and compared against the master rating as per the DOE team guidelines. The operator ratings are analysed to check if the instructors' ratings are consistent with the master ratings.

After assessing the delamination rating scale, the DOE team design and conduct a 2-level factorial experiment with 3 replicates of a Resolution IV design to determine the most appropriate parameters to achieve a mean delamination target rating of 9 or above (rated by a consistent inspector) using the ink from the new supplier.

After hours of brainstorming based on measured data and input from the customers, potential root causes are identified and have been represented in the form of a fish bone diagram. The validity of the causes will be verified after deeper analysis of the data collected.



Analyze

Study(1)

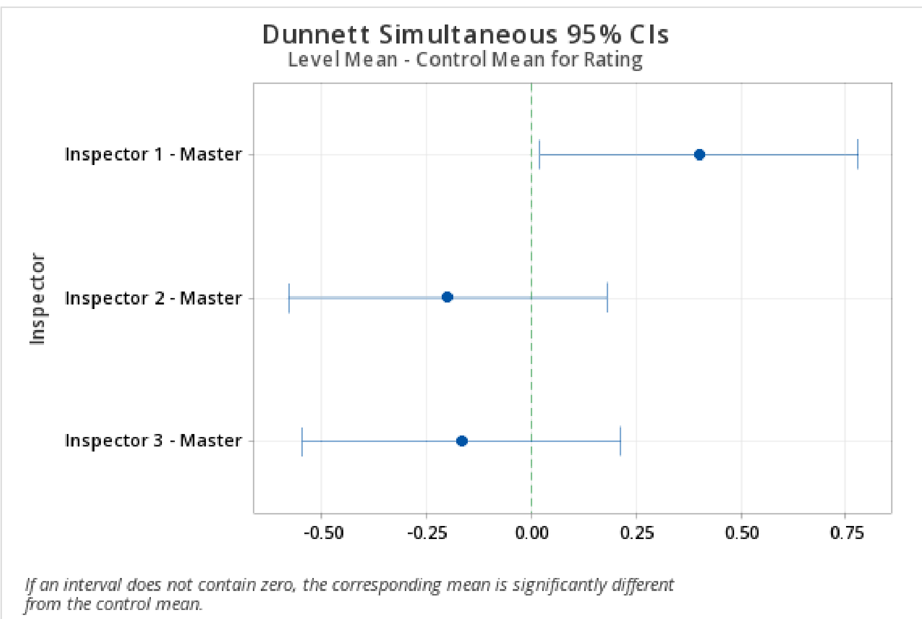
First the consistency of the inspectors' ratings against the master rating is analyzed. ANOVA analysis is done for the 30 data samples rated by 3 different inspectors.

Dunnett Multiple Comparisons with a Control: Inspector

Grouping Information Using the Dunnett Method and 95% Confidence

Inspector	N	Mean	Grouping
Master (Control)	30	5.23333	A
Inspector 1	30	5.63333	
Inspector 3	30	5.06667	A
Inspector 2	30	5.03333	A

Means not labeled with the letter A are significantly different from the control level mean.



As can be clearly seen from the above analysis**, Inspector 1** rating is not consistent.

ANOVA analysis can be done with only inspector 2 and 3 against the master rating to see for the new consistency.

Dunnett Multiple Comparisons with a Control: Inspector

Grouping Information Using the Dunnett Method and 95% Confidence

Inspector	N	Mean	Grouping
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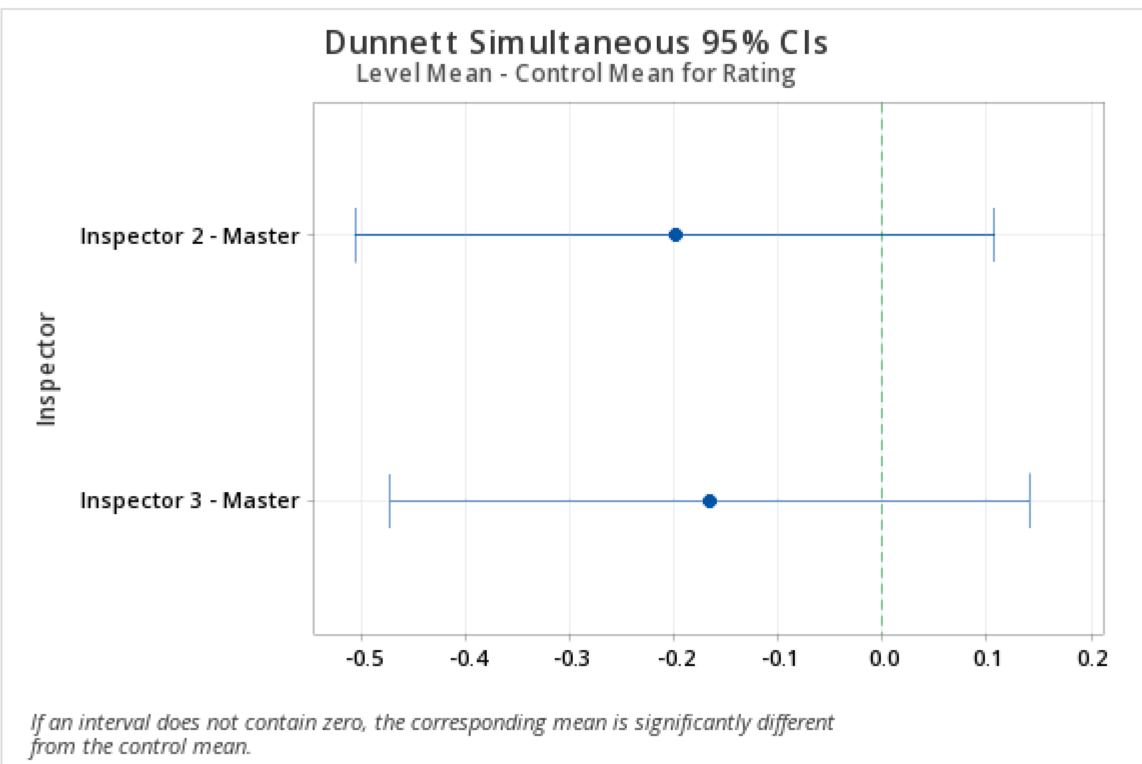


As can be seen from the above analysis, **Inspector 2 and Inspector 3** are consistent with the master rating.

Fractional Factorial Design (Study 2)

2-level factorial experiment was conducted with 3 replicates of a Resolution IV design to determine the most appropriate parameters to achieve a mean delamination target rating of 9 or above. The output of the analysis is studied to find the significant terms.

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		6.5469	0.0660	99.23	0.000	
A	-0.3229	-0.1615	0.0660	-2.45	0.020	1.02
B	-0.1146	-0.0573	0.0660	-0.87	0.392	1.01
C	-1.4896	-0.7448	0.0660	-11.29	0.000	1.02
D	-2.8646	-1.4323	0.0660	-21.71	0.000	1.01
E	-1.2812	-0.6406	0.0660	-9.71	0.000	1.01
F	0.0937	0.0469	0.0660	0.71	0.483	1.02
A*B	-0.0313	-0.0156	0.0660	-0.24	0.814	1.01
A*C	-0.0729	-0.0365	0.0660	-0.55	0.584	1.02
A*D	0.0521	0.0260	0.0660	0.39	0.696	1.01
A*E	0.1354	0.0677	0.0660	1.03	0.312	1.01
A*F	0.0104	0.0052	0.0660	0.08	0.938	1.02
B*D	1.5104	0.7552	0.0660	11.45	0.000	1.02
B*F	-0.1146	-0.0573	0.0660	-0.87	0.392	1.01
A*B*D	-0.0729	-0.0365	0.0660	-0.55	0.584	1.02
A*B*F	-0.0312	-0.0156	0.0660	-0.24	0.814	1.01

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.453574	96.38%	94.68%	91.57%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	175.333	11.6889	56.82	0.000
Linear	6	151.667	25.2778	122.87	0.000
A	1	1.232	1.2321	5.99	0.020
B	1	0.155	0.1551	0.75	0.392
C	1	26.217	26.2167	127.43	0.000
D	1	96.955	96.9551	471.28	0.000
E	1	19.396	19.3962	94.28	0.000
F	1	0.104	0.1038	0.50	0.483
2-Way Interactions	7	27.745	3.9635	19.27	0.000
A*B	1	0.012	0.0115	0.06	0.814
A*C	1	0.063	0.0628	0.31	0.584
A*D	1	0.032	0.0321	0.16	0.696
A*E	1	0.217	0.2167	1.05	0.312
A*F	1	0.001	0.0013	0.01	0.938
B*D	1	26.955	26.9551	131.02	0.000
B*F	1	0.155	0.1551	0.75	0.392
3-Way Interactions	2	0.077	0.0385	0.19	0.830
A*B*D	1	0.063	0.0628	0.31	0.584
A*B*F	1	0.012	0.0115	0.06	0.814
Error	32	6.583	0.2057		
Total	47	181.917			

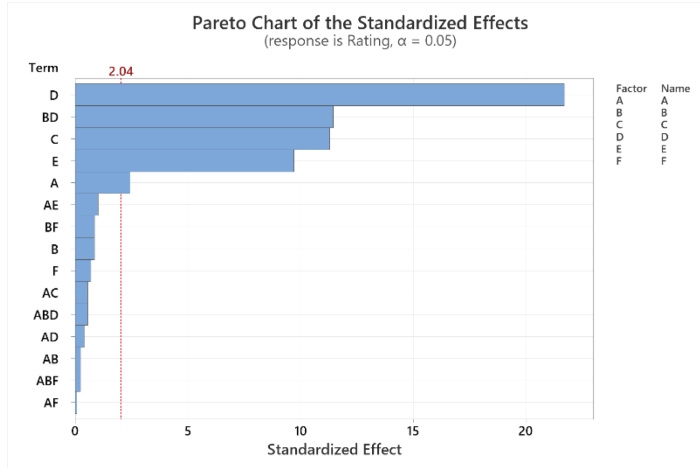
Alias Structure

Factor	Name
A	A
B	B
C	C
D	D
E	E
F	F

Aliases
I + ABCE + ADEF + BCDF
A + BCE + DEF + ABCDF
B + ACE + CDF + ABDEF
C + ABE + BDF + ACDEF
D + AEF + BCF + ABCDE
E + ABC + ADF + BCDEF
F + ADE + BCD + ABCEF
AB + CE + ACDF + BDEF
AC + BE + ABDF + CDEF
AD + EF + ABCF + BCDE
AE + BC + DF + ABCDEF
AF + DE + ABCD + BCEF
BD + CF + ABEF + ACDE
BF + CD + ABDE + ACEF
ABD + ACF + BEF + CDE
ABF + ACD + BDE + CEF

Regression Equation in Uncoded Units

Rating = 6.5469 - 0.1615 A - 0.0573 B - 0.7448 C - 1.4323 D - 0.6406 E + 0.0469 F
- 0.0156 A*B - 0.0365 A*C + 0.0260 A*D + 0.0677 A*E + 0.0052 A*F + 0.7552 B*D
- 0.0573 B*F - 0.0365 A*B*D - 0.0156 A*B*F



From the analysis output above we can see that the significant factors of the process are: **A,E,C,D &BD.**

Again, by analysing the factorial design with only the significant factors, we get the following output:

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		6.5447	0.0607	107.75	0.000	
A	-0.3272	-0.1636	0.0607	-2.69	0.010	1.00
C	-1.4938	-0.7469	0.0607	-12.30	0.000	1.00
D	-2.8656	-1.4328	0.0608	-23.55	0.000	1.01
E	-1.2823	-0.6411	0.0608	-10.54	0.000	1.01
B*D	1.5062	0.7531	0.0607	12.40	0.000	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.420098	95.93%	95.44%	94.68%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	174.504	34.9009	197.76	0.000
Linear	4	153.171	38.2928	216.98	0.000
A	1	1.280	1.2800	7.25	0.010
C	1	26.685	26.6847	151.20	0.000
D	1	97.852	97.8516	554.45	0.000
E	1	19.593	19.5928	111.02	0.000
2-Way Interactions	1	27.127	27.1268	153.71	0.000
B*D	1	27.127	27.1268	153.71	0.000
Error	42	7.412	0.1765		
Lack-of-Fit	10	0.829	0.0829	0.40	0.935
Pure Error	32	6.583	0.2057		
Total	47	181.917			

Regression Equation in Coded Units

Rating = 6.5447 - 0.1636 A - 0.7469 C - 1.4328 D - 0.6411 E + 0.7531 B*D

Uncoded coefficients are not available with non-hierarchical model.

Alias Structure

Factor	Name
A	A
B	B
C	C
D	D
E	E
F	F

Aliases

I + 0.04 B + 0.04 AB + 0.04 AD + 0.04 AE + 0.04 BC + 0.04 BF + 0.04 CD + 0.04 CE + 0.04 DF + 0.04 EF + 0.04 ABF + 0.04 ACD + 0.04 ACE + 0.04 BDE + 0.04 CDF + 0.04 CEF + ABCE + 0.04 ABCF + 0.04 ABDE + 0.04 ACDF + 0.04 ACEF + ADEF + 0.04 BCDE + BCDF + 0.04 BDEF + 0.04 ABDEF + 0.04 ABCDEF

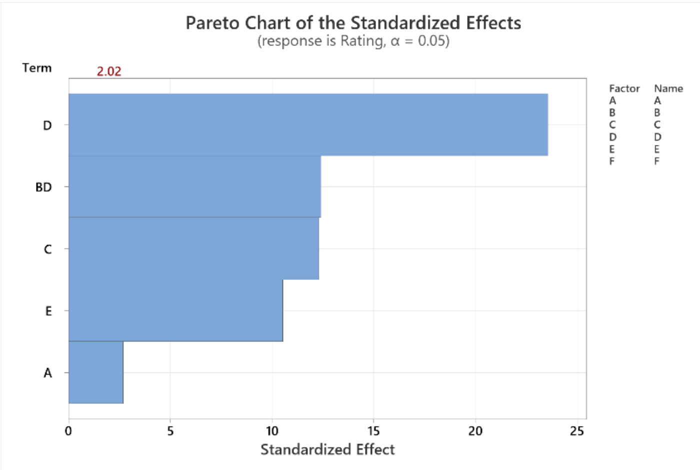
A + 0.04 B + 0.04 AB + 0.04 AD + 0.04 AE + 0.04 BC + 0.04 BF + 0.04 CD + 0.04 CE + 0.04 DF + 0.04 EF + 0.04 ABF + 0.04 ACD + 0.04 ACE + BCE + 0.04 BDE + 0.04 CDF + 0.04 CEF + DEF + 0.04 ABCF + 0.04 ABDE + 0.04 ACDF + 0.04 ACEF + 0.04 BCDE + 0.04 BDEF + ABCDF + 0.04 ABDEF + 0.04 ABCDEF

C + 0.04 B + 0.04 AB + 0.04 AD + 0.04 AE + 0.04 BC + 0.04 BF + 0.04 CD + 0.04 CE + 0.04 DF + 0.04 EF + ABE + 0.04 ABF + 0.04 ACD + 0.04 ACE + 0.04 BDE + BDF + 0.04 CDF + 0.04 CEF + 0.04 ABCF + 0.04 ABDE + 0.04 ACDF + 0.04 ACEF + 0.04 BCDE + 0.04 BDEF + 0.04 ABDEF + ACDEF + 0.04 ABCDEF

D - 0.01 B + 0.04 F - 0.01 AB + 0.04 AC - 0.01 AD - 0.01 AE + 0.04 AF - 0.01 BC + 0.04 BE - 0.01 BF - 0.01 CD - 0.01 CE + 0.04 DE - 0.01 DF - 0.01 EF + 0.04 ABD - 0.01 ABF - 0.01 ACD - 0.01 ACE + 0.04 ACF + 0.04 ADE + AEF + 0.04 BCD + BCF - 0.01 BDE + 0.04 BEF + 0.04 CDE - 0.01 CDF - 0.01 CEF + 0.04 ABCD - 0.01 ABCF - 0.01 ABDE + 0.04 ABDF - 0.01 ACDF - 0.01 ACEF - 0.01 BCDE + 0.04 BCEF - 0.01 BDEF + 0.04 CDEF + ABCDE + 0.04 ABCEF - 0.01 ABDEF - 0.01 ABCDEF

E - 0.01 B + 0.04 F - 0.01 AB + 0.04 AC - 0.01 AD - 0.01 AE + 0.04 AF - 0.01 BC + 0.04 BE - 0.01 BF - 0.01 CD - 0.01 CE + 0.04 DE - 0.01 DF - 0.01 EF + ABC + 0.04 ABD - 0.01 ABF - 0.01 ACD - 0.01 ACE + 0.04 ACF + 0.04 ADE + ADF + 0.04 BCD - 0.01 BDE + 0.04 BEF + 0.04 CDE - 0.01 CDF - 0.01 CEF + 0.04 ABCD - 0.01 ABCF - 0.01 ABDE + 0.04 ABDF - 0.01 ACDF - 0.01 ACEF - 0.01 BCDE + 0.04 BCEF - 0.01 BDEF + 0.04 CDEF + 0.04 ABCEF - 0.01 ABDEF + BCDEF - 0.01 ABCDEF

BD + 0.04 B + 0.04 AB + 0.04 AD + 0.04 AE + 0.04 BC + 0.04 BF + 0.04 CD + 0.04 CE + CF + 0.04 DF + 0.04 EF + 0.04 ABF + 0.04 ACD + 0.04 ACE + 0.04 BDE + 0.04 CDF + 0.04 CEF + 0.04 ABCF + 0.04 ABDE + ABEF + ACDE + 0.04 ACDF + 0.04 ACEF + 0.04 BCDE + 0.04 BDEF + 0.04 ABDEF + 0.04 ABCDEF



Now that we have successfully found out the significant terms, the best configuration to obtain the target rating of 9 is analysed by using response optimizer. The output of a target rating of 9 in response optimizer is shown below:

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Rating	Target	3	9	11	1	1

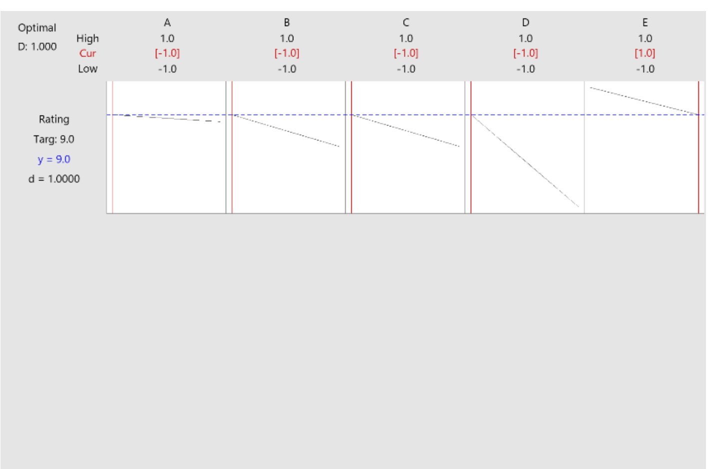
Solution

Solution	A	B	C	D	E	Rating Fit	Composite Desirability
1	-1	-1	-1	-1	1	9	1

Multiple Response Prediction

Variable	Setting
A	-1
B	-1
C	-1
D	-1
E	1

Response	Fit	SE Fit	95% Lower Confidence Bound	95% Lower Prediction Bound
Rating	9.000	0.149	8.750	8.251



The optimum configuration of the factors is shown in the solution of the analysis. Factor 'F' is insignificant and hence can take either low or high value and will not alter the rating/delamination of the product.

Optimum factor settings is as follows:

Factor	Variable	Setting
A	Belt Speed	Low (-1)
B	Jet Oven Temp	Low (-1)
C	Pot Life	2 hrs (-1)
D	Oven Temp	140 F (-1)
E	Oven Time	3 hrs (1)
F	Mesh	Narrow or Wide (-1 or 1)

Table 1. Factor Settings for Delamination Experiment

		Low	High
Factor	Variable	-1	1
A	Belt Speed	Low	High
B	Jet Oven Temp	Low	High
C	Pot Life (hrs)	2	4
D	Oven Temp (°F)	140	160
E	Oven Time (hrs)	2	3
F	Mesh	Narrow	Wide

With the above factor settings, the target rating of 9 is met!

Also, we know that a higher pot life is preferred by the company so that scrap loss will be less, hence optimum configuration is calculated to get a target rating of with Factor C settings held fixed at 1. Optimisation results are as follows:

Parameters

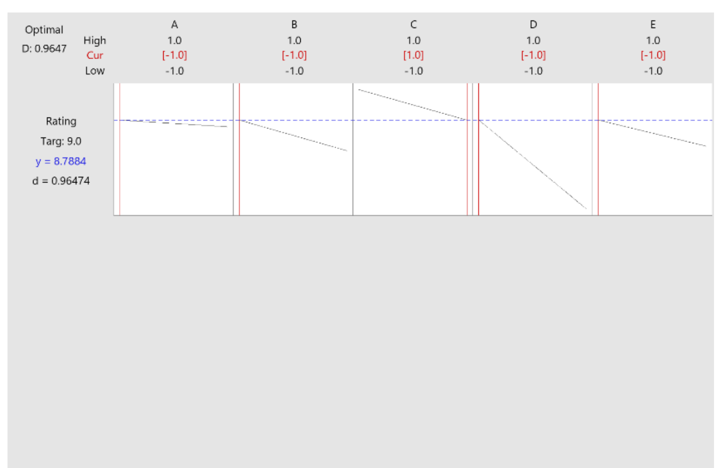
Response	Goal	Lower	Target	Upper	Weight	Importance
Rating	Target	3	9	11	1	1

Variable Ranges

Variable	Values
A	(-1, 1)
B	(-1, 1)
C	1
D	(-1, 1)
E	(-1, 1)

Solution

Solution	A	B	C	D	E	Rating Fit	Composite Desirability
1	-1	-1	1	-1	-1	8.78844	0.964740



Multiple Response Prediction

Variable	Setting
A	-1
B	-1
C	1
D	-1
E	-1

Response	Fit	SE Fit	95% Lower Confidence Bound	95% Lower Prediction Bound
Rating	8.788	0.153	8.531	8.036

For a high pot life process, optimum factor settings is as follows:

Factor	Variable	Setting
A	Belt Speed	Low (-1)
B	Jet Oven Temp	Low (-1)
C	Pot Life	4 hrs (1)
D	Oven Temp	140 hrs (-1)
E	Oven Time	2 hrs (-1)
F	Mesh	Narrow or Wide (-1 or 1)

Table 1. Factor Settings for Delamination Experiment

		Low	High
Factor	Variable	-1	1
A	Belt Speed	Low	High
B	Jet Oven Temp	Low	High
C	Pot Life (hrs)	2	4
D	Oven Temp (°F)	140	160
E	Oven Time (hrs)	2	3
F	Mesh	Narrow	Wide

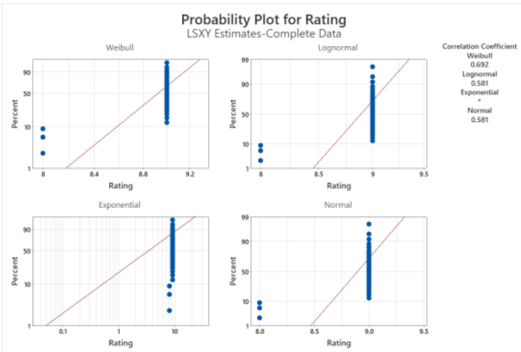
With the above factor settings, the rating is **8.83** which can be approximated to 9, and hence hits the target.

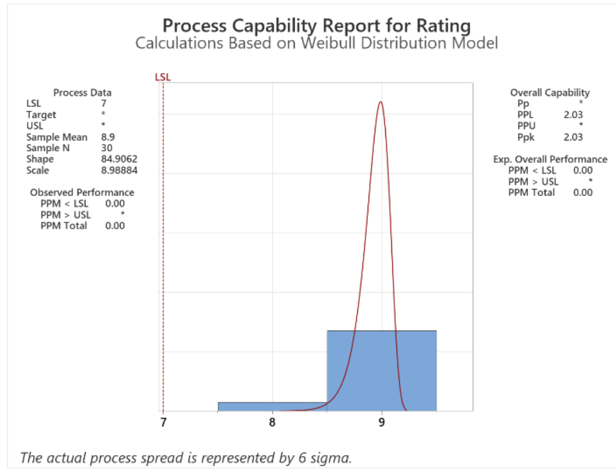
Improve

Based on the above analysis, the following improvements may be made in the process:

1. Belt speed is to be set at Low settings
2. Jet Oven Temperature is to be set a t Low settings
3. Pot Life to be set at 4 hrs
4. Oven Temp to be set at 140 hrs (high)
5. Oven Time to be set at 2 hrs (Low)
6. Mesh settings doesn’t significantly affect the delamination of the product, so may be set at a setting convenient to the operator.

Improved performance after applying the above recommendations (optimum factor settings) is calculated by doing capability analysis. The perf





The data follows Weibull Distribution model and we get an expected overall DPM of **0!.** This means that if we run the process with the recommended factor settings all products will pass the customer's minimum rating of 7!

Control

A few control measures that may be implemented to keep delamination minimum are:

1. While making agreement with new ink suppliers', check for the product performance with the current factor settings and make commitments only if a setting can be finalized which gives desired minimum delamination.
2. Training of workers- Workers to be trained regularly about standard operating procedures and new operation of new tools/machines
3. Before shipping products to customers, end point sampling to be done. Since the product is not highly sensitive sampling of atleast 5% products to be done to ascertain quality. This will help in maintain customer faith in CUInk Inc.
4. Regular inspection of raw materials to ascertain the quality.
5. Regular in-process inspections to be done to verify if the processes are taking place in the preferred factor settings.