Towards an Optimized Process for Directory Printing using Statistical Methods

Richard R. Durand Jr.[1] and Dale Freeman[2]

Keywords: Process; Optimization; Statistical; Printability; Productivity

Abstract: Printer and ink supplier have partnered to use a variety of statistical based approaches to optimize the printing of telephone directories. Many of the techniques currently part of Six-Sigma continuous improvement programs were used to enhance the four-color process printing of yellow pages. Tools such as measurement system analysis, design of experimental and statistical process control will be highlighted. Our results lead us to important relationships among printing variables that allow the quality of finished product to be improved, maintained and repeated regardless of production location.

Introduction

Under competitive economic conditions, there is a critical need for improvements in quality and productivity while maintaining or reducing costs associated with high volume printing. These efforts require a comprehensive assessment of all elements of the printing system. The goal of optimizing the overall quality of a product and the process that delivers this quality requires the elements in the system to be accurately specified in order to achieve and maintain the best results. The mechanism for accomplishing such an optimization is a Six-Sigma Program. R.R. Donnelley had embraced these concepts in order to bring a disciplined data driven approach to continuous improvement. This Six-Sigma framework can also be the structure for various suppliers to work within the optimization process. This paper will summarize some examples of the techniques that can lead to optimization.

[1] Sun Chemical Corporation
Carlstadt, NJ

[2] RR Donnelley and Sons Company
Chicago, IL

The Optimization Process

There will be several phases associated with the optimization process. We will outline the generic process here and the associated tools that might be used at various stages as noted in the scheme in Figure 1. As one would expect, we need to start with a clear definition of the problem or goal. This singular statement then has a series of branches from which analyses of various components to the system must be rigorously examined for the various interplays that may affect the outcome. The particular branches are analyzed within the printing system and back to subsystems of manufacture (process maps used here) and raw material (specification of material used here). From the analysis, an X-Y matrix will result with inputs that relate to possible outputs in the process. The use of Failure Mode Evaluative Analysis (FMEA) (AIAG, 2001) techniques will further dissect individual process and material features and allow us to quantitate the potential likelihood for inclusion in the actual problem solving phases.

The experimental approaches to tackle the problem or meet the goal will now have to be inclusive of various important variables in the process. We decide on the measures of properties of sub systems and output responses that we will use to assess the outcome of our experiments. Each measurement should be a reliable gage that can accurately distinguish several levels of behavior. Measurement System Analysis (MSA) (AIAG 1995) will be the critical tool to use to determine which measures can be reliably used in our experiments.

In order to be efficient in the experimental pursuit of optimization, we rely heavily on Design of Experiments techniques. This approach allows us to statistically create a design space that can accommodate a wide variety of variable types including both quantitative and categorical changes. The variables will also be representing press and consumable variables in the same design. Three case studies are presented that emphasize the various types of approaches that can be used. In all cases, the design process allows for well-defined testing protocol to be followed so that we can catalog a variety of relationships that need to be established in order to optimize the printing process. The statistical analysis of these designs lead to verifiable models that can determine the best way to optimize the process with respect to performance criteria that is being sought.

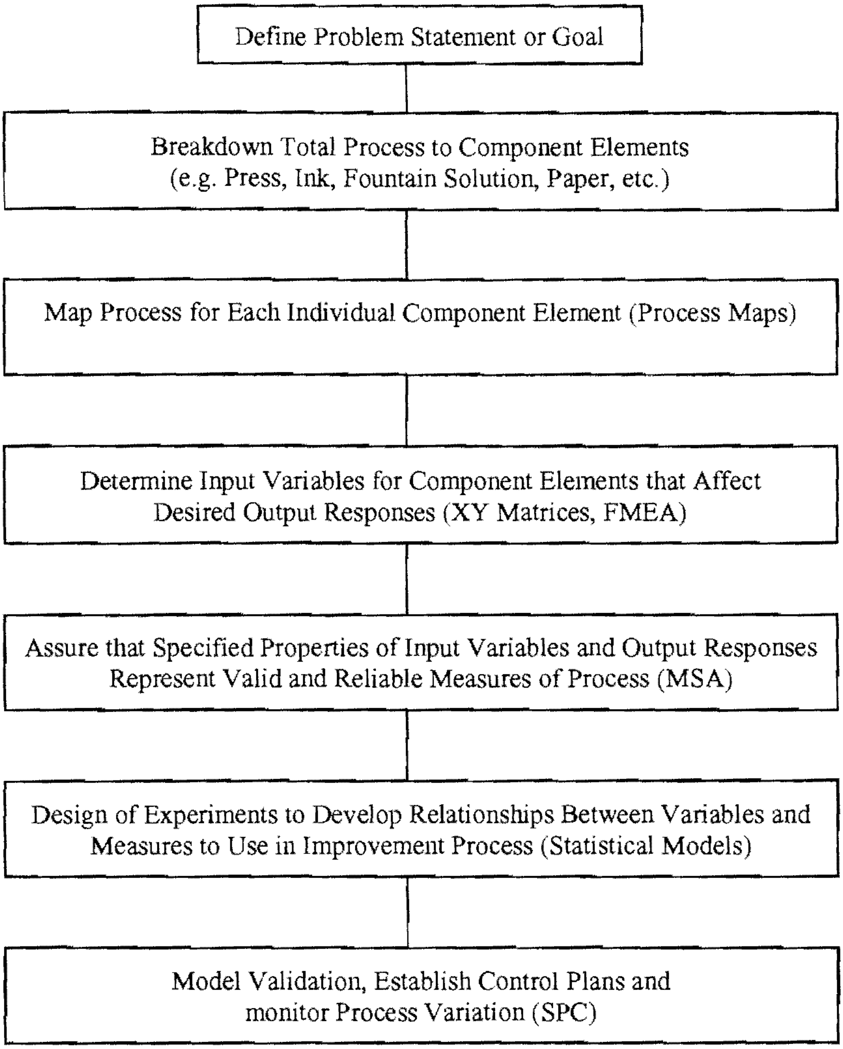

Figure 1 –Schematic Representation of the Optimization Process

Experimental Conditions and Print Measurements.

All inks were made on commercial production scale in manufacturing plants. The press runs were also conducted during live commercial conditions on a Harris 9000 lithographic offset directory press. Running speed was typically 2600 feet/min with two hours of run time for each treatment. The papers were standard directory stock (typically 22-24lb). Signatures were taken at mid-run to use for print analyses. The software used for the experimental design studies was Design-Expert from Stat-Ease, Minneapolis, MN.

The print mottle was assessed using an image analysis procedure as described by Lim and Mani (1999). The density and dot gain was obtained from a Prismatic. Misting was assessed by collection for one hour on foil sheets across web above the inking unit. The differential weight on the foil was then measured. This was done on the same printing form throughout the runs. The rub procedure used a modification of ASTM D5624-98 using a Sutherland rub tester.

Case Study 1 –Improving Black Ink Laydown on Directory Newsprint

Goal - To improve the solid ink lay of black ink and minimize mottling without adversely affecting other printability issues.

Objective - Determine ink, fountain solution and press variables that impact the ink laydown and create a better performance on directory newsprint

Approach -The tools (process maps, XY matrices, FMEA, etc.) discussed in the introduction were used to arrive at a small set of variables to include in our press testing.

Experimental Variables and Design -There were four total variables chosen with two for ink, one for fountain solution, and one for the press. The design chosen was a four factor d-optimal type model (with replicates) using ink composition and printing process variables.

Ink – A compositional and a processing variable were chosen for variance in the ink. The compositional variable was the actual carbon black loading in the ink supplied to press. The black level was maintained at high, medium, and low levels where the medium level represents the normal loading supplied for this product. The processing variable was the liquid/solid ratio during the actual grinding of the black pigment. This variable was also examined at three levels (high, medium and low) with medium representing the normal processing scheme.

Fountain Solution – The amount of wetting agent in an etch concentrate was adjusted to three levels. In this way, the amount of wetting agent available during printing could vary from high, medium to low (medium is typical value) even when used at the same dosage.

Water Feed – the level of water supplied to the printing plate was adjusted by using a visual gage of plate wetness relative to a predefined attribute scale that the press operators could clearly distinguish. The assignments were for L for dry, M for moderate, and H for wet running conditions.

The experimental design was established to test all these variables using a d-optimal model that would require 9 inks and 25 press runs (including replicates).

Run	Ink	% Pigment	L/S	Wetting Level	Water Feed
1	1	H	L	M	H
2	8	H	L	M	M
3	8	H	L	L	L
4	8	H	L	H	H
5	8	H	L	H	L
6	8	H	L	H	H
7	8	H	L	L	H
8	5	H	H	H	M
9	5	H	H	L	H
10	5	H	H	H	M
11	5	H	H	L	L
12	5	H	H	L	H
13	7	M	M	M	M
14	3	H	M	M	L
15	3	H	M	M	H
16	3	M	M	L	M
17	4	M	L	H	L
18	9	L	L	H	M
19	9	L	L	L	L
20	9	L	L	M	H
21	9	L	L	L	L
22	2	L	H	L	M
23	2	L	H	H	H
24	6	L	M	M	L
25	6	L	M	L	H

Table 1 – Experimental runs and associated variables for black mottle study

Results - The measured data was analyzed using experimental design software to determine relationships between response and variables. Figures 2 and 3 show graphs in which three variables are examined in how they affect mottle behavior under two water setting conditions. It is clear that there are some complex relationships governing the possible scenarios for minimizing this value (i.e. low values are preferred).

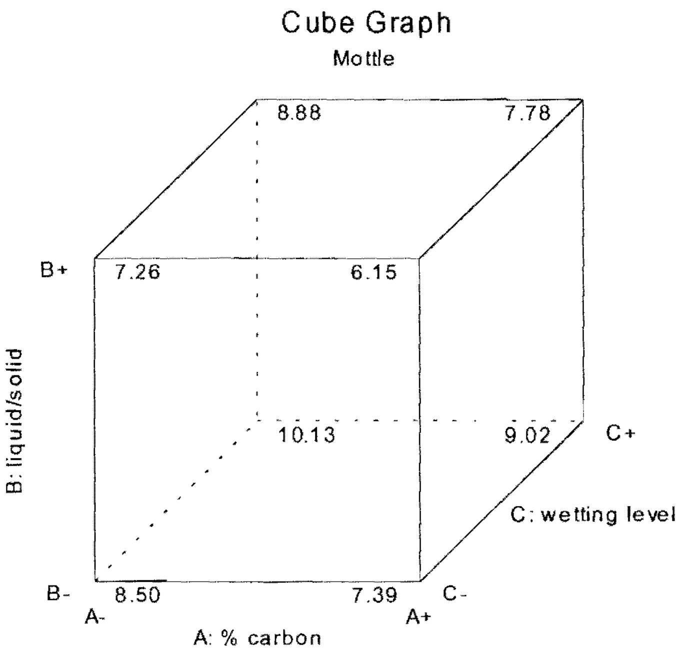

Figure 2 – Representation of mottle values for three variables at high water setting

Under the high water setting condition, the preferred scenario for improving mottle would be high carbon loading, high liquid solid ratio, and low wetting level. Whereas under more typical low water settings, the preference changes to low carbon loading, high liquid/solid ratio, and high wetting level. This suggests that adjustments in ink and fountain solution will be needed to optimize the performance issue of mottle. However, for each measured property, the relationship to these variables needs to be examined. This has been done for this experimental design.

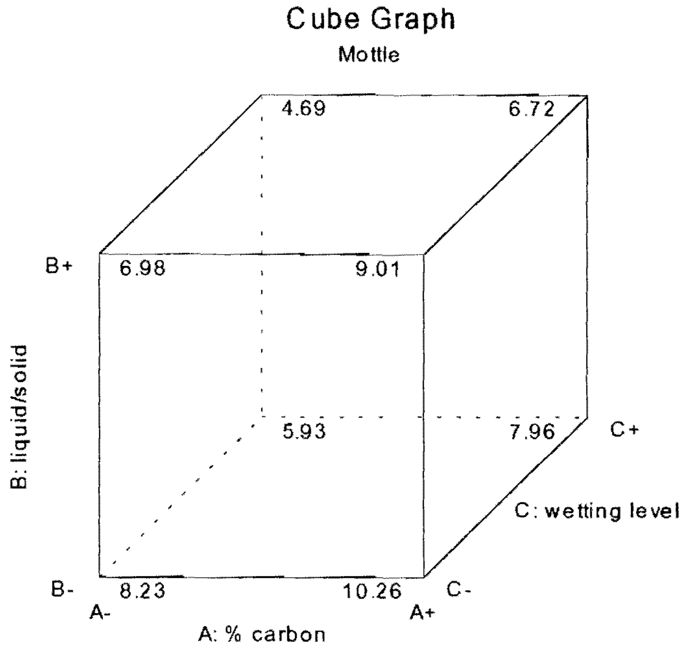

Figure 3 – Representation of mottle values for three variables at low water setting.

Table 2 is a summary of the best conditions from the model to minimize individual properties. Note how they do not converge in one direction and thus a compromise solution that emphasizes the most critical properties is needed and can be derived from the statistical model. The predicted formulation of best fit emphasizing print mottle while maintaining other properties within accepted tolerances was manufactured and run to verify that the model from the designed experiments was accurate. It should be noted that for continuous variables such as pigment load, the software does target a specific quantitative optimum level that for proprietary reasons is noted simply as a discrete H, M, and L in the table. The results from this test did indeed demonstrate that an optimized performance could be managed. Once the model is confirmed, we have additional flexibility in predicting behavior for future needs.

Optimized For	% CB	L/S Ratio	Wetting Level	Water Feed
Misting	H	L	H	H
Rub Off	M	M	M	M
Mottle	L	H	H	L
Dot Gain	H	L	L	L
Mottle, Mist, Rub	L	H	H	L

Table 2 – Predicted optimization for various print properties

Case Study 2 –Improving Cyan Ink Print Performance

Goal –Minimize mottle in solid cyan prints.

Approach – The first set of experiments were set up to efficiently screen important ink components and their interaction with fountain solution.

Experimental Variables - There were four total variables chosen with three for ink and one for fountain solution, press conditions were kept constant. A factorial design was chosen in which responses where made higher or lower relative to a standard product and run condition as well as use of a categorical variable.

Ink– Three compositional variables were chosen for cyan ink. One compositional variable was the actual pigment loading in the ink supplied to press. The second compositional variable was the amount of a rheological modifier that is used to control the flow properties of the ink. The third variable was a categorical variable as the extender used was altered between Type A and Type B.

	Ink	Pigment	Rheol Mod	Extender	Wetting
1	**1**	H	H	Type A	H
2	**2**	H	H	Type B	H
3	**3**	L	L	Type A	L
4	**3**	L	L	Type A	H
5	**4**	L	H	Type A	L
6	**5**	L	H	Type B	H
7	**6**	H	L	Type A	H
8	**1**	H	H	Type A	L
9	**7**	H	L	Type B	L
10	**8**	L	L	Type B	H
11	**5**	L	H	Type B	L

Table 3- Screening Design for Cyan study

Fountain Solution – In this case, the wetting agent was altered by adjusting dosage and running at a low and high conductivity (1000 umhos or 1500 umhos).

Water Feed –This was maintained at a constant level by the operator.

Results -The measured data was analyzed using experimental design software to examine relationships.

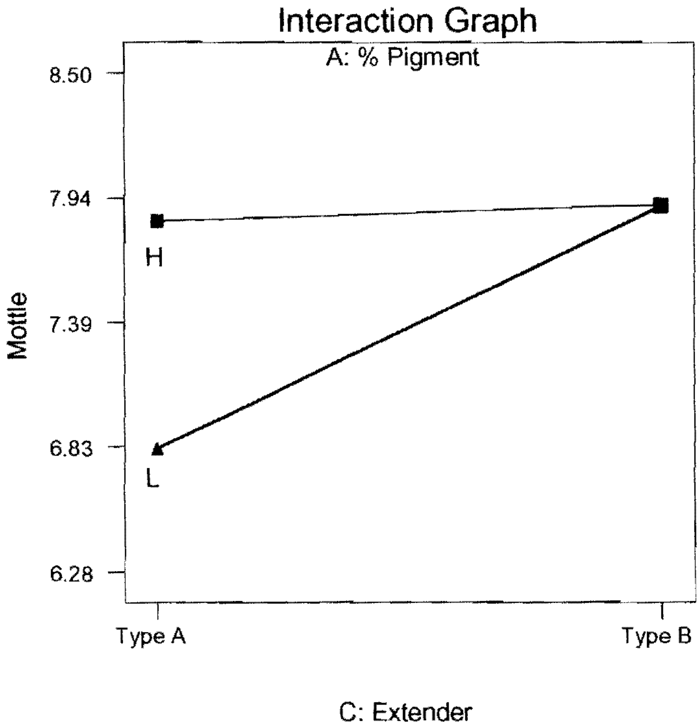

Figure 4 - Interaction Plot for Mottle for Variables
(Extender Type and % Pigment)

First, the analysis suggested that the rheological modifier plays little role in the print quality and it was eliminated as a meaningful variable. As noted in Figure 4, the choice of extender and level of pigment show a complex interaction. If we use Type B extender, then it appears to be insensitive to pigment loading. The use of Type A extender, however, in conjunction with low pigment loading provides a means of significantly reducing mottle without negative effects on any other print properties. As one can imagine, the physical effects on flow are likely to be manifested through these changes.

At this stage, we choose to do a further optimization study to probe this interaction by examining four inks in which the amount of extender and type of extender was varied. This further led to definition of pigment loading, extender type, and amount and fountain solution concentration to optimize performance on press.

Case Study 3 –Reducing Ink Waste during printing

Problem Statement– There are excessive ink drips through the fountain into a collection pan. (This problem is clearly not related to print quality, but influences productivity and can produce added costs due to maintenance issues.)

Experimental Variables - Factorial design was chosen in which responses where made higher or lower relative to a standard product and run condition as well as use of categorical variables.

Ink – The rheological profile of the inks were altered by slight modifications of formulations to provide high and low shear viscosities as determined on a Brookfield Viscometer.

Ink	High Shear	Low Shear
A	H	H
B	L	L
C	H	L
D	L	H

Table 3 – Ink variables for drip waste study

Fountain Solution – In this case, all runs were done at one level of fountain solution concentration throughout the experiment.

Water Feed – was adjusted to assess the window of performance of the inks and the impact of these changes on the drip waste was noted. It was not originally set up to be a variable, but rather a response. The drip behavior, however, was found to be sensitive to these water setting changes and thus was considered a variable in the subsequent statistical analysis.

Results – Figure 5 shows that the one ink factor found to control the ink waste was the low shear viscosity. During the test, it was recognized that water settings changed to get a sense of water window or balance for the inks were different and might influence results. Figure 6 shows the same plot as Figure 5 after adding an additional variable related to water setting. Note that high water settings significantly increase the waste factor regardless of viscosity, but the slope of change due to low shear viscosity is similar. Thus, at low water settings, there is a preferred ink low shear viscosity to minimize waste. This is an example of a specific ink property that is correlated to an important press performance characteristic that is not print related.

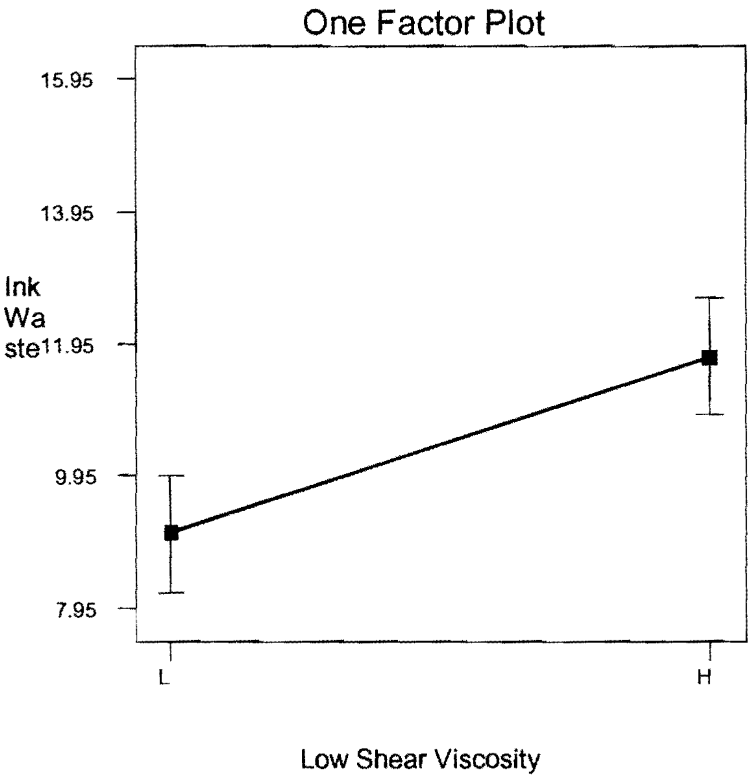

Figure 5– The effect of low shear viscosity on ink waste (lbs) generated.

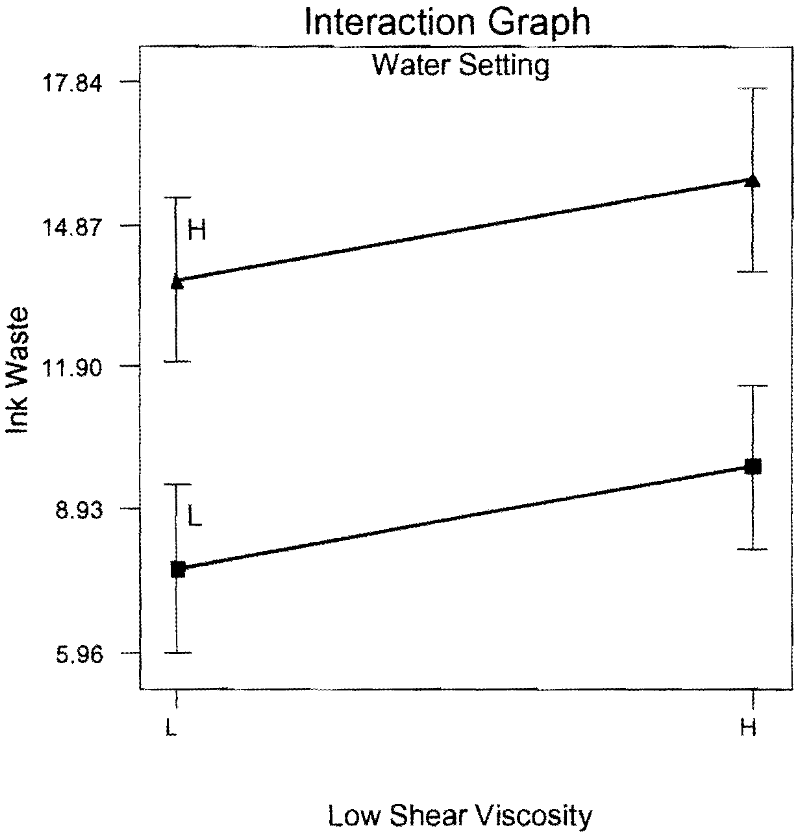

Figure 6 – Interaction of water setting with ink waste (lbs) generated.

Control Plans

Once the optimized solution has been identified, there is a need to develop control plans (AIAG, 1994) that insure stable performance on a daily basis. For each system component there may be a need for a control plan to insure that beyond normal process variations, we are able to maintain the advantages of the various optimization studies. The control plan provides a written summary of the systems used to minimize process and product variation. The control plan document outlines the actions required at each phase of the process to assure that process outputs will be in a known state of control. In conjunction with prudent statistical process control practices (AIAG, 1992), the overall process variation is managed properly to quickly respond to non-random events.

For example, from an ink standpoint, the control plan will establish that the materials used in the ink are properly specified and their suppliers have control plans to maintain these critical specifications. Similarly, the ink manufacturing process also has a control plan that insures efficient, effective manufacture of these products as well as the use statistical process control to constantly monitor process variation. From the press and printing standpoint, the specific control plan will highlight maintaining conditions and preventing drifts that will alter product quality. We have been able to demonstrate that the results of our statistical models can be effectively translated to various printing locations to deliver uniform performance.

Summary

This paper has outlined a data driven approach to optimization of the directory printing process. A variety of statistical tools have been used to derive meaningful production scale relationships in consumable aspects of the printing as well as the daily printing processes that produce the final directory product. This rigorous process leads to better management of the vast number of variables present and catalogs relationships that can be further explored for future product and process improvements.

Literature Cited

AIAG Reference Manual
2001 "Potential Failure Mode and Effects Analysis", 3rd Edition

AIAG Reference Manual,
1995 "Measurement Systems Analysis", 2nd Edition

AIAG Reference Manual
1994 "Advanced Product Quality Planning and Control Plan"

AIAG Reference Manual
"Statistical Process Control"

Lim, W. and Mani, S.
1999 "Application of Digital Image Analyses to Measure Print Quality" J. Coatings Tech., vol. 71, no. 894, pp. 73-78.

Acknowledgments

We would like to thank a large number of individuals at various locations within R.R. Donnelley Telecom Group and Sun Chemical (including US Ink) without whose efforts this project would not have been successful. The team approach brought together a diverse group of backgrounds (i.e. sales, manufacturing, R&D, quality assurance, technical service) but the commonality of all was the diligence, commitment and willingness to work in a new world of data driven decision making.