Development of an Efficient Compound Stress Noise Matrix for Electrophotographic Systems Robustness Development

Jeffrey Blood, David Hockey and George Walgrove
Heidelberg Digital L.L.C.
Rochester, New York

Abstract

For the robustness development of electrophotographic systems, a stress noise matrix is needed to allow for efficient and repeatable experimental runs. A complete set of system noise factors includes a list in excess of 40 factors. Simple, intuitive compounding of these noise factors can not be done since the output characteristics for image quality are numerous and their interaction with these noise factors is complex. This paper will discuss the process used to reduce this list of noise factors to two setup conditions that represent noise compounding that significantly stresses the overall system response. This small noise matrix was simple to manage and provided for very rapid and efficient execution of parameter design studies.

Introduction

The robustness process, or parameter design, involves minimizing system sensitivity to noise conditions so that performance in a customer environment is consistent and on target. The success of the parameter design process relies on the proper selection of noise conditions to use during experiments. This is efficiently accomplished by compounding noise factors such that a significant “stress’’ is applied to the system under test. In addition, controlling only the noises that are needed to sufficiently stress the system design minimizes testing cost and time. Many times, the necessary information needed to correctly compound noise factors is not available; therefore a test must be run in order to gain this information.

Identifying a compound noise test matrix was the specific objective for the study discussed in this paper. Noise factors were selected and studied using an L-12 orthogonal array. The test results provided the information needed to properly compound the significant noise factors creating a two point noise matrix that stressed the image quality output of an electrophotographic process.

Identification of Quality Characteristics

An image quality team was assembled for the purpose of identifying which image quality characteristics should be evaluated during this test. Over a few meetings, three objective quality characteristics were selected. They were:

- Half Tone Reproduction Curve
- Linewidth [1 pixel - 4 pixel]
- Compliance [2 pixel - 5 pixel E’s]

Even though the committee felt that these characteristics were closely connected to the basic function of the marking engine, they still felt it was important to include images that would lend themselves to subjective evaluation. The test was designed so that both objective and subjective evaluation of image quality could be accomplished. In this report, only the subjective evaluation is discussed.

For subjective image quality evaluation, six image quality attributes were selected for the study. These attributes are listed below:

- Half Tone Pictorial Quality
- Background
- Maximum Solid Area Density
- Mid Tone Solid Area Density
- 10 Point Text
- 6 & 8 Point Text

A single document was constructed which incorporated the pictorial information needed to allow for both objective and subjective analysis.

Development of the Experimental Test Matrix

A multifunctional team was assembled for three sessions to develop a list of noise factors that would be studied during this experiment. A list of over 30 noise factors was identified based on the team’s understanding of the electrophotographic process and their past experience. This list is shown in Table 1.

Table 1: Initial Noise Factor List

List from Brainstorming Session
Environment
Jobstream
Charger Uniformity
Film Life
Toner Charge to Mass
Transfer Efficiency
Cleaning Efficiency
Film Voltage
Material Life
Paper Surface
Charger Life
Contamination
Dark Decay
Document Type
Film Regeneration
Image Direction
Paper Weight
Cleaning Erase Level
Drum Resistivity
Internal Machine Temperature
Run/Rest Cycle
Toner Particle Size Distribution
Air Management
Erase Spectral Response
Front vs Rear Erase
Paper Size
Run Time
Toner Concentration
Writer Exposure

Once the list was assembled, the noise factors were prioritized by pareto voting. The factors that comprised the top 80% of the total votes were considered first. Starting with this list, noise factors were compounded in situations where interrelationships between these factors were understood. For example, consider the compounding of noise factors associated with the development station. Lighter development is obtained typically when a high station spacing, low developer concentration and high charge to mass toner particles are combined in one setup. Heavier development will occur for a combination of low spacing, high developer concentration, and low charge to mass toner particles. There is no need to study these noise factors separately. The correct compounding combination is known based on knowledge of the process.

The goal of this activity was to condense the noise factor list to a number of eleven or less. This number would allow the noise experiment to be of manageable length without significantly limiting the number of important factors. It is believed that with a balanced team consisting of research, design, manufacturing, and service representatives, an adequate list of significant noise factors was obtained using this approach.

The final list is shown in Table 2. Note that 10 major noise factors were selected. By compounding factors from the original list, a large majority of the noise factors identified by the group were incorporated into this test. Once the list of noise factors was completed, two levels were selected for each noise factor. The factors were then assigned to an L-12 orthogonal array.

Table 2: Final List of Compounded Noise Factors

Factor	Level 1	Level 2
Environment	75°F/75% RH	80°F/10% RH
Jobstream	• 50 Copies • Heavy Takeout Document • Jam Machine on Copy 45 • Run Keepers Immediately • Install Aged Detack Charger	• 500 Copies • Light Takeout Document • Normal Cycle Down • 30 Min. Cool Down Before Running Keepers • Install New Detack Charger
Film Voltage Uniformity	High	Low
Film Life	New	Aged
Development	Light Development	Heavy Development
Paper Properties	• Light/Nom Paper Weight • Landscape Mode • Rough Surface	• Heavy Paper Weight • Portrait Mode • Smooth Surface
Transfer Efficiency	High Transfer Efficiency	Low Transfer Efficiency
Cleaning Efficiency	High Cleaning Efficiency	Low Cleaning Efficiency
Post Development Exposure	Low Exposure	High Exposure
Fusing	High Fusing Stress	Low Fusing Stress

Experimental Setup and Procedure

The experiment was conducted on a digital copier with design parameters set to nominal conditions for the noise test. For each experimental run, the noise conditions were setup and then 24 duplex copies were run under the conditions of the test matrix. Data was then taken from these 24 copies. The experimental time for each run was less than five minutes. The setup time for each experiment however was considerable, ranging from a few minutes to a few hours. This points out the significant advantage in compounding only the noises that significantly stress the system. Noises that are not significant can be eliminated allowing for significant timesaving during parameter design testing.

Data Analysis - Subjective Ranking of Test Copies

Each test run set was inspected and one representative copy selected for copy quality evaluation. The image quality variability from run to run was much greater than the variability within a run. This fact allowed an accurate analysis to be obtained even though replicate copies were not evaluated. Further simplification of the analysis was obtained by evaluating only the duplex side of each copy. Past experience has shown that duplex copy quality is generally worse than the simplex quality.

Masks were created so that only one subjective image type (Text, Solid, etc.) could be viewed at a time. Six judges were asked to rank the images from best to worst. The ranking done by each judge was then broken down into four categories. The three best runs were given a rating of 1, the next three runs a rating of 2, the next three runs a rating of 3, and the three worst runs a rating of 4. These ratings were then used as input to an accumulation analysis for each of the image attributes

Accumulation Analysis Results

The analysis revealed the directionality (from poor to good image quality) for each noise factor. For example, the dependence on environment for the solid area density attribute is shown in Figure 1. It shows that the image quality has a higher probability of being better under an 80°F/10% relative humidity environment.

ANOVA (**An**alysis **o**f **Va**riance) was also performed on the data to determine the significance of each noise factor. The significance is expressed by the contribution ratio, which is the percentage variability a factor contributes to the total variability observed during the entire experiment.

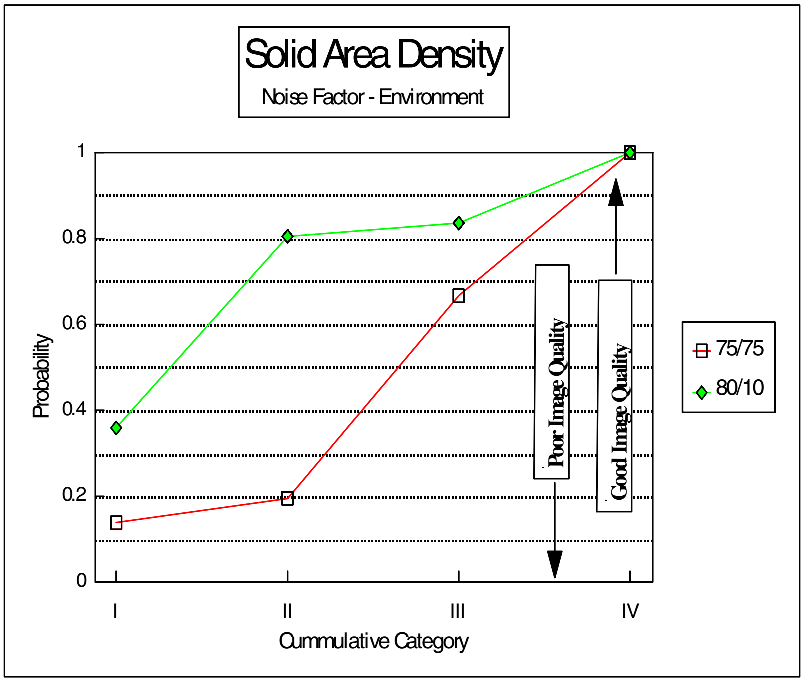


Figure 1: Noise Response Due to Environmental Conditions

Table 3: Compounded Noise Factor Combinations

FACTORS	N1: Better Quality	N2: Worse Quality	Fixed
ENVIROMENT	80/10	75/75	
TRANSFER EFFICIENCY	Low	High	
FILM LIFE	New	Used	
JOBSTREAM	Job # 1	Job # 2	
CLEANING EFFICIENCY			Low
FILM VOLTAGE UNIFORMITY	High	Low	
DEVELOPMENT			Light
PAPER PROPERTIES	Paper # 1	Paper # 2	
POST DEVELOPMENT EXPOSURE			Low
FUSING			Fuser # 1

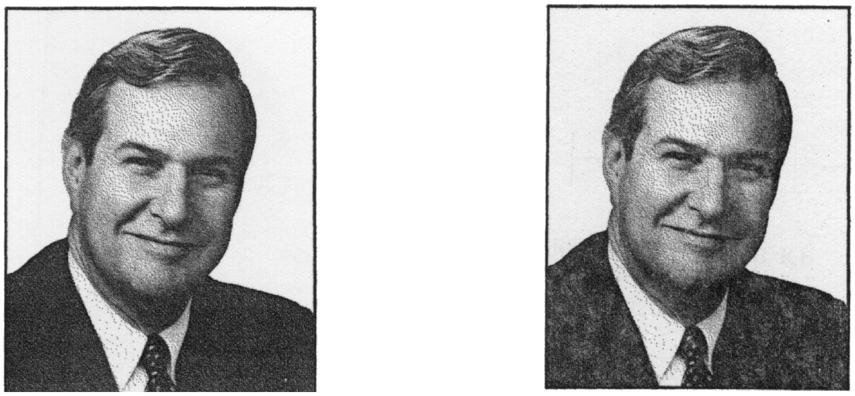
Compounding of the Noise Factors

The next step was to combine the noise factors properly into two compounded noise conditions. The first combination would drive the image quality of the six image attributes in the direction of good performance (designated noise condition N1). The other combination would drive copy quality towards poor performance (designated noise condition N2). In selecting the noise factor combinations only the noises that contributed to a significant percentage of the overall variability were used. Factors that had little effect, such as the setup of the fusing system, were held constant for both N1 and N2. Table 3 gives the settings for the N1 and N2 combinations. This analysis showed that four out of the original ten noise factors did not contribute significantly to the image quality variability. For parameter design testing, these factors will be held at a single level.

Confirmation Experiment

The final step in this noise experiment was to conduct a confirmation experiment. The purpose of the confirmation experiment is to validate the analysis. If the compounded noise conditions result in the predicted wide range in copy quality for each of the six image attributes, then strong interactions do not exist and the main factor effects predicted are accurate.

Four repetitions were run for the N1 and N2 noise conditions. Repetitions were done to demonstrate that the influence of the noise was large in comparison with the run to run variability.



N1 Pictorial –
Good Uniformity, Tone Scale

N2 Pictorial –
Poor Uniformity, Tone Scale

Figure 2: Comparison of pictorial quality under N1 and N2 compounded noise conditions

Confirmation Experiment Results

The confirmation runs produced the predicted performance. The spread in copy quality between N1 and N2 was extremely large in comparison to the variability within a run or from one repetition to the next. A pictorial image quality example is shown in Figure 2.

Conclusions

The conclusions drawn from these results are:

1. It was shown that all image attributes could be sufficiently stressed with only two compounded noise conditions. Before running the noise experiment, there was concern that each of the image types would need different noise conditions to provide a sufficient level of performance stress. Although the range in performance for each image attribute was not the largest possible, the N1 - N2 difference was large enough to adequately stress the system for parameter design studies.
2. The confirmation experiment results demonstrate that the noise effects are repeatable.
3. There now exists a noise matrix for the electrophotographic process that can be used repetitively in future testing. As long as no major concept changes occur, there is no need to repeat a noise experiment for this electrophotographic system.
4. There is now an in-depth knowledge of the significant noise factors for this electrophotographic system. This enables us to confidently eliminate 4 noises from future testing due to the fact that they contribute little to image quality variability. This will make testing in the future more efficient and cost effective.

References

Phadke, Madhav 1989, Quality Engineering Using Robust Design. Englewood Cliffs, New Jersey: Prentice Hall, pp. 121-127.

Taguchi, Genichi 1991, System of Experimental Design, Volume I. Dearborn, Michigan: ASI Press, pp. 78-95.

Acknowledgements

This article is a condensed version of a paper that was originally presented at the 3rd Total Product Symposium, Dearborn, Michigan in November 1997. American Supplier Institute's permission to print this article for this conference is appreciated.

A special thanks to Carla VandeRostyn for completing the painstaking task of typing and formatting this article.

Biography

George Walgrove currently is Manager, Advanced Development with Heidelberg Digital LLC in Rochester, New York. George has spent almost his entire 21 year career involved in electrophotograhic technology development at Heidelberg and previously at Eastman Kodak Company. In 1990, George joined the Product Engineering Department where his assignments expanded to the development of electophotographic systems for state of the art digital copier systems. During the early 90's he was instrumental in introducing and developing the use of Taguchi Methods in the product development community.

Dave Hockey currently is Chief Engineer with Heidelberg Digital LLC in Rochester, New York. Dave has been with Heidelberg and previously Eastman Kodak Company for 19 years, holding positions in Manufacturing Engineering, Product Testing, Research, and Product Development. The majority of the assignments involved electromechanical system integration and electrophotographic system development for digital copiers and printers. Dave was among the first at Heidelberg to employ Taguchi Methods in system level optimization for electrophotography.