Optimization of multi response problem of quality characteristics in offset press using experimental design

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Abstract

The offset printing press is widely used in commercial printing companies. The quantity of paper wasted in sheet-fed offset printing is a significant parameter affecting the cost of printed product. The main sources of paper waste are: paper used in machine setup, paper wasted during press running length, over production and printed paper rejected due to quality control. This paper focuses on studying two quality characteristics to reduce rejected printed paper. These quality characteristics are: colour variation and colour mis-registration. Color variation is gauged by variation in ink transfer of the four printing colours: Cyan (C), Magenta (M), Yellow (Y) and Black (K), which are governed by color difference ΔE.

In this study, color variation is measured as a multi response while colour mis-registration is measured as attribute data. The paper presents a study which examines the effect of three process parameters: paper category, batch size and human intervention on investigated quality characteristics of printed product on sheet-fed offset press. The spectrophotometer was employed to measure the color difference ΔE. A full factorial design of experiments was generated with sixteen runs for the above three process parameters with mixed levels. The experimental data was analysed using signal to noise (S/N) ratio, analysis of variance (ANOVA) and main plots to evaluate the factors and their interactions, and to determine the optimal factor level which delivers quality print with minimum paper waste and consequently reduce cost. It is found that the optimal factor level is paper of category 2 printed in small batches and with human intervention. Further, the results of ANOVA reveal that the paper category is the most significant factor affecting paper waste as well as the intervention between paper category and batch size.

Keywords:

Multi Response – quality of offset printing - full factorial design - S/N ratio – ANOVA – color variation – colour mis-registration

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1. Introduction

Printing industry is an important sector as it intersects with many other industries, whether directly through printing work or indirectly through packaging process. Offset printing is the most commonly used method in today's printing companies. The basic principle of offset printing is to transfer inked image from a plate to a rubber blanket and then to the printing surface. Image printed in offset machine is separated into its fundamental colours :Cyan, Magenta, Yellow and black (CMYK). Printing four color image means that the paper has to pass into four printing units and to put printing inks of different colours on top of each other to be able to produce the required image.

Color variation is among the most parameters influencing printing quality which cause product defects. Color variation is defined as the inconsistent color reproduction within printed job. There are three categories of color variations in piece part production: within piece variation, piece to piece variation and time to time variation (Besterfield, 2009). The sources of variation maybe any changes in process which include the changes in equipment performance, varying manpower competencies, differences in batches of raw materials and environmental changes. The second measured quality characteristic is colour mis-registration. It occurs when one or more colours do not fit with the others in a set. Despite mis-registration impacts the integrity of the final printed work, there are no official specifications for what can be acceptable tolerance for colour mis-registration.

2. Literature Review

The researches indicated that the quality of printing process is dependent on the optimization of many influencing factors (Sharma, 2016). Hsieh (1997) employed a randomized 2^4 factorial design to study the effect of four factors with two levels each on a quality characteristic; dot gain, printed on sheet-fed offset press. The four studied factors are: fountain solution "PH", paper types (coated vs. uncoated), plate to blanket pressure and blanket to paper pressure. He used main effect plot and normal probability plot as well as ANOVA to determine which effects were significant. His results showed that the main effect of paper was the dominant variable affecting press dot gain printing quality parameter.

Sarela (2004) examined the undesirable quality characteristic; set off, which could appear during four color printing of newspapers by using web offset press. A single color was studied to simplify the set off phenomena as four color printing brings to the problem more variables. Three factors with two levels each were investigated; paper grade, delay time and printing nip pressure by utilizing L_8 orthogonal array to obtain the optimum factor levels to reduce set off phenomena.

Vlachopoulos (2010) used a factorial experiment based on L_{18} orthogonal array technique to investigate the effect of six parameters, two levels each on misting and ribbing phenomena associated with ink film splitting at the rollers nip in offset press. The influence of these parameters was studied on the two phenomena, both separately. These parameters are: rollers ratio, thickness of ink film, temperature, speed of ink distribution, ink distribution time, and ink viscosity. Due to the dynamics of printing press caused by ink transients, he developed laboratory simulations to investigate the two phenomena under ideal conditions.

Rastko et al. (2014) studied the effects of press internal pressure on printed product using four color sheet-fed offset press. They investigated the effect of three levels of pressure applied between blanket and impression cylinders for the four color stations, on six print quality parameters (tone value increase, gray balance, ink density deviation, print contrast, color gamut and color differences ΔE). The results were quite conflict for evaluated parameters.

Nandakumar and Bose (2016) derived a mathematical model to understand the relationship between the ink density and color difference ΔE for uncoated paper printed on sheet-fed offset press. The correlation between ΔD as independent variable and color difference ΔE as dependent variable was as follows: $\Delta E = a + b\Delta D + c\Delta D^2$

The values of the parameters a, b and c were obtained on the basis of collected observations and the best fit parameters are estimated using the least square method.

Sharma (2016) studied the effect of four factors on color variation of the coated printed paper on offset printing machine. These factors are ink tack, percentage of alcohol, press speed and impression pressure, with two levels each. He used full factorial experiment design and the experimental data was analysed using main and interaction plots, and ANOVA to determine the optimal combination. The results indicated that all the main factors are significant.

Nam and Nguyen (2019) used full factorial design to investigate the effect of three factors, two levels each (impression pressure, percentage of alcohol and press speed) on color difference ΔE. They used ANOVA for graphical analysis of measured data and to obtain the interaction between the investigated factors and the response, as well as the optimal factor levels. The results showed that the interaction of pressure and alcohol percentage has the most significant effect on color variation.

Most of the literature paper and thesis which studied factors affecting offset printing quality characteristics dealt only with single response and they avoid handling multi response problem due to its complexity.

3. Multi response problem: An overview

Taguchi methods which are initially used in quality engineering are suitable for simple simulation optimization strategies allowing a reduction in the number of experimentations by using orthogonal array. However, Taguchi strategy doesn't provide a method for multi-response simulation optimization. Phadke (1989) has used engineering judgment to optimize the multi response in Taguchi approach. He studied a number of surface defects and variability in the thickness of a wafer in the polysilicon deposition process. Reddy et al. (1998) formulated a multi response methodology where they separately determined the control factors and their optimum levels corresponding to each response variable. If there is a conflict between the optimum levels, they suggested the use of engineering judgement to resolve the conflict. However, it is not good practice to cling to mere human judgement for optimization of multi responses, as this only increases the uncertainty in the decision making process (Antony, 2000). Bras and Mistree (1993) formulate a robust design problem as a multi objective decision using the compromise Decision Support Problem (DSP). Both control and noise factors are considered as potential sources of variation and constraints are modelled in a worst case formulation to ensure feasibility robustness. Separate goals of bringing the mean on target and minimizing variation for each design objective are included in a goal programming formulation

of the objective function. This provides flexibility for achieving compromises among multiple performance objectives as well as individual or collective compromises among mean values and variations for all objectives.
Tong et al. (1997) adopted the sum of the weighted normalized quality losses of all responses, then they used multi response S/N ratio to determine the optimal factor levels. Logothetics and Haigh (1998), and Pignatello and Joseph (1993) had discussed a manufacturing process characterized by five responses in a multiple univariate or one at a time manner, ignoring correlations between responses.
Su and Tong (1997), and Antony (2000) suggested a systematic procedure via Principal Component Analysis (PCA) to transform multi responses into few uncorrelated responses. Then, they utilized for solving the multi response problem. However, PCA has two shortcomings; 1- When multiple principal components of an eigenvalue, that is greater than one, are chosen, how to trade off to decide the feasible solution which is still unknown. 2- When the selected principal components have less variation than can be explained by total variation, the performance index of multi responses is not evident enough to replace the original response variables (Al Refaie et al. 2010).
Al Refaie et al. (2010) proposed a simple approach for solving the multi response problem in the Taguchi method. Each quality response is transformed into S/N ratio. The average S/N ratio is calculated for each factor level, and then weighted with respect to the level of the largest average S/N ratio for this factor. The average weight of each factor level or level weight is obtained from all responses. The factor level with the largest level weight is selected as the optimal level for that factor.

4. Proposed Approach

A set of experiments is designed to investigate the effect of three factors on quality characteristics of printed product: color variation and colour mis-registration. Color variation is measured as a multi response (four responses: black, cyan, magenta and yellow) while colour mis-registration is measured as attribute data. The three factors investigated are: (1) type and weight of paper (paper category), (2) Batch size, and (3) Human effect. The investigated paper categories are: category 1 is uncoated paper with weight 80g/m^2, category 2 is security paper with weight 90g/m^2, category 3 is coated paper with 250-270g/m^2 and category 4 is coated paper with weight 170g/m^2. For batch size, the small batch is up to 2000sheets while large batch begins from 5000sheets. Factors and their levels are shown in Table 1.

Table 1: Factors and their levels

Factor	Levels			
	1	2	3	4
Paper type and weight	Category 1	Category 2	Category 3	Category 4
Batch size	Small	large		
Human effect	Without human intervention	With human intervention		

In this study, positive thermal CtP plates were initially prepared. The printing experiments were implemented on a four color sheet-fed Heidelberg SX102 offset press. The ink sequence was

KCMY. Print image control of the machine was employed to measure the color variation according to ISO 12647-2, while colour mis-registration was measured visually using lens (eye loop) by a machine operator. Therefore, it is a qualitative evaluation. Color mi-registration is evaluated according to 3 levels: level 1 means good, level 2 means accepted and level 3 means bad. In each experiment, 6 samples are observed with sample subgroup size of 5 sheets to ensure consistency of results. The accepted ΔE is assumed to be ±1 from target values. Therefore, lower specification limit (LSL) is -1 and upper specification limit (USL) is +1.

The proposed approach for solving the multi response problem is outlined in the following steps:

Step 1: Design of experiment

Assume *k* experiments are conducted utilizing full factorial design. Let *r* be the number of responses in full factorial design. Let Y_{jk} (j=1,…, r) be the response observations. Full factorial design is applied permitting sixteen posible combinations of factor levels as shown in Table 2.

Table 2: Suggested full factorial design (4*2*2)

Exp. No.	Column number and factor assigned			Color variation values			
	A*	B*	H*	K	C	M	Y
1	1	1	1				
2	1	1	2				
3	1	2	1				
4	1	2	2				
5	2	1	1				
6	2	1	2				
7	2	2	1				
8	2	2	2				
9	3	1	1				
10	3	1	2				
11	3	2	1				
12	3	2	2				
13	4	1	1				
14	4	1	2				
15	4	2	1				
16	4	2	2				

* A: Paper category B: Batch size H: Human intervention

Step 2: Minimization of scaling effect

In multivariate analyses, the independent variables almost have different scales. Some of these variables may have large values while others are very small, the variables may not contribute equally to the analysis due to differences in scale. Therefore, in order to minimize the scaling effect, the original data can be transformed so the ranges of the new variables are comparable and data variability is reduced.

The deviation of the response from target is computed to scaling effect using the following formula: $X_{jk} = Y_{jk} - T_{jk}$ (1)

where: T_{jk} is the target value of each experiment.

Step 3: Estimation of responses scores (C_i^*)

Estimate the relative weight for each response according to the following formula:

The suggested weight of color: $$CS_i = \frac{C_i+1}{\sum(C_i+1)} \times 100 \quad (2)$$

Where The minimum value between colours is assumed to be the reference value of colours; C_{ref}=1

C_i = difference between the value of each ink color and the reference value.

The sum of the weight assigned is made to give a value of 1.

Step 4: Computation of S/N ratio

In process or product design, parameters affecting quality characteristics can be divided into 3 classes as shown in Figure 1. Signal factors which are set by user of the system, express the required output. The control factors are specified by the product designers in order to obtain the least sensitivity of the response to the effect of noise factors. The third parameter is the noise factors whose settings are difficult to control in real conditions or whose levels are expensive to control. The noise factors lead to deviations from quality targets.

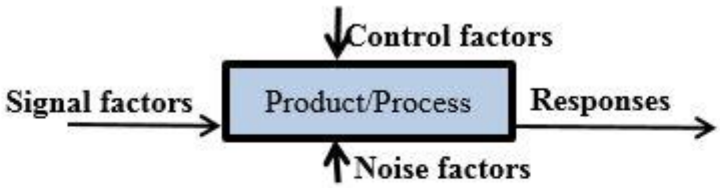

Figure 1: Parameters affecting quality characteristics

Signal to noise (S/N) ratio is used figuratively to refer to the ratio of useful information to false or irrelevant data. S/N ratio combines information about the mean and the variance of the response to minimize variability transmitted from the noise factors. A product quality characteristic or response is divided into three main types: (1) Smaller-the-better (STB) type response, in which the response is continuous nonnegative, and its most desired value is zero; (2) Nominal-the-better (NTB) type response, in which the response is continuous, nonnegative and its target is nonzero and finite; (3) Larger-the-better (LTB) type response. The quality options and different forms of signal to noise (S/N) ratio are presented in Table 3 (Nalini et al. 2016).

Table 3: Types of Signal to noise ratios, their goals, and formulas

N	S/N ratio	Goal of experiment	Data characteristics	S/N ratio formulas
1	Larger is better	Maximize the response	Positive	$S/N = -10 \times log\left[\sum\left(1/Y^2\right)/n\right]$
2	Nominal is best	Target the response and S/N ratio is based on σ only	Positive, zero, or negative	$S/N = -10 \times \log(\sigma^2)$

		Target the response and S/N ratio based on means and σ	Non negative with an absolute zero in which σ=0 when the mean =0	$S/N = 10 \times \log(\frac{\bar{Y}^2}{\sigma^2})$ and the adjusted formula is: $S/N = 10 \times \log\left[(\frac{\bar{Y}^2-\sigma^2}{n}) \div \sigma^2\right]$
3	Smaller is better	Minimize the response	Non negative with a target value of zero	$S/N = -10 \times log\left[\sum (Y^2) /n\right]$

Y: Response for given factor level n: number of responses in the factor level
$\bar{Y}$: mean of responses for factor level σ: standard deviation
Assign the weight to each S/N ratio of four responses and sum the weighted S/N ratio for computing the performance measurement of multi response as follows:

$$The\ overall \frac{S}{N_0} = w_1\left(\frac{S}{N_1}\right) + w_2\left(\frac{S}{N_2}\right) + \cdots + w_i(S/N_i) \qquad (3)$$

Where i: number of quality characteristics or response
w_i: the weight of i^{th} response

Step 5: Evaluation of each treatment effect
Evaluate the effect of each treatment for each responses as follows:
- Assume a process factor l is assigned at s levels. Let m_{jls} be the sum of η_j for the experiment at level s of factor l and let m_{ils} be the average of η_{ils}
- m_{ils} is calculated for each factor level using the following formula:

$$m_{ils} = \frac{1}{n}\sum_{i=1}^{n}\eta_i \qquad (4)$$

where n: number of factor level

Step 6: Analysis of results using ANOVA
ANOVA partition the variation in response measurement into components that correspond to different source of variation; portion due to random error and another portion due to changes in the values of the independent variables. The aim is to explain which factors and their associated levels have most effect on the variation in the response variable.
In ANOVA table, the p-value represents the probability of error involved in accepting the observed results. The sequential sum of square (Seq. SS) and adjusted sum of square (Adj. SS) indicate the relative importance of each factor with response. F value is a tool which helps to determine if the variance between the means is significantly different. The larger F value with $P< 0.05$ confirms the significance of a factor. The R-Sq. indicates how well the model fits the data.

5. Experimental results

5.1 Color variation results

A full factorial design is used where the columns represent factors to be investigated, while the rows denote individual experiments.

In our case study, all responses are NTB response type. The S/N ratio is calculated as follows:

$$\eta = -10log(\sigma^2) \qquad (5)$$

Where σ is the standard deviation

The weights of the four colours for each experiment are shown in Table 4. S/N ratios calculated from the experimental data of color variation are listed in Table 5.

From the color weight value listed in Table 4, the overall S/N ratio of the sixteen experiments can be calculated as follows:

For Exp.1:

$$\eta_{overall} = [(-4.4871 * 0.5682) + (2.0066 * 0.0227) + (0.5061 * 0.1364) + (2.7572 * 0.2727)] = -1.683$$

Similarly, the overall S/N ratio is computed for the 16 experiments and the results are listed in Table 6.

The effect of factor level for color variation is calculated for each color according to its weight and the results are listed in table 7. Figure 2 represents the main effects plot for S/N ratio of factor levels for color variation (K, C, M and Y).

Table 4: Color weight according to proposed formula

Exp.	**K** (%)	**C** (%)	**M** (%)	**Y** (%)
1	56.82	2.27	13.64	27.27
2	61.9	11.9	2.38	23.82
3	42.86	36.73	2.04	18.37
4	2.04	34.7	34.7	28.56
5	4.35	52.17	2.18	41.3
6	2.86	42.86	5.71	48.57
7	33.33	16.67	33.33	16.67
8	33.33	16.67	33.33	16.67
9	0.74	28.15	25.19	45.92
10	0.95	26.67	31.43	40.95
11	0.6	35.12	19.05	45.23
12	0.55	18.58	29.5	51.37
13	0.85	56.41	23.08	19.66
14	0.8	37.6	37.6	24
15	0.51	34.87	28.21	36.41
16	0.89	30.36	41.07	27.68

Table 5: S/N ratio for color variation values

Exp. No.	Factor			S/N ratios			
	A	B	H	η_K	η_C	η_M	η_Y
1	1	1	1	-4.4871	2.0066	0.5061	2.7572
2	1	1	2	-1.7898	-6.3649	3.8722	-3.2838
3	1	2	1	-10.1703	1.2494	-0.6819	-3.7475
4	1	2	2	-15.7634	-6.8215	-6.6745	-12.4304
5	2	1	1	40	-2.9226	5.8503	-1.8184
6	2	1	2	40	-7.1933	-9.1275	-2.1484
7	2	2	1	40	-0.0432	40	5.8503
8	2	2	2	40	6.9897	7.2125	6.0206
9	3	1	1	-13.8561	-22.0303	-6.9810	-15.4283
10	3	1	2	-18.0956	-10.7004	-11.5534	-17.2099
11	3	2	1	-3.1175	-12.3779	40	-16.9373
12	3	2	2	-15.9988	2.0066	-13.9094	-13.4439
13	4	1	1	4.3180	3.4679	-0.5690	-0.3342
14	4	1	2	2.2915	-7.0757	-9.2531	3.3724
15	4	2	1	1.6115	3.3724	0.4096	-1.0721
16	4	2	2	-0.8636	-13.3244	-7.4036	-6.3849

* For experiment where the response Y equal to 0, it is assumed to be 0.0001 in order to calculate the effect of treatments.

Table 6: Overall S/N ratio of color variation

Exp. No.	Factors			Overall S/N ratio ($\eta_{overall}$)
	A	B	H	
1	1	1	1	-1.683
2	1	1	2	-2.555
3	1	2	1	-4.602
4	1	2	2	-8.555
5	2	1	1	-0.408
6	2	1	2	-3.504
7	2	2	1	27.632
8	2	2	2	17.9047
9	3	1	1	-15.147
10	3	1	2	-13.704
11	3	2	1	-4.4066
12	3	2	2	-10.7246
13	4	1	1	1.7959
14	4	1	2	-5.3119
15	4	2	1	1.01
16	4	2	2	-8.861

Table 7: Effect of factor level according to color weights

Responses	Factor / level	A	B	H
Overall Responses	1	-4.3488	-5.065	**0.5239***
	2	**10.406***	**1.175***	-4.4139
	3	-10.996		
	4	-2.8418		

*Preferable levels

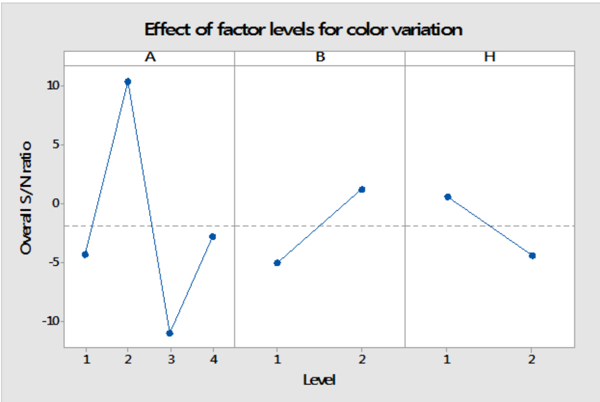

Figure 2: Main effect plot of overall S/N ratio for color variation

From Table 7 and Figure 2, the optimal factor level is $A_2B_2H_1$ (paper category 2, large batch and without human intervention).

5.2 Results of colour mis-registration

The experiment was designed to minimize defects caused by colour mis-registration. Colour mis –registration was graded as "Good, Accepted and Bad", where only the Bad was unacceptable to the customer. Hence, the objective is to maximize "Good and Accepted "grade. The response type is smaller-the-better (STB) and the formula used to compute S/N ratio is as follows:

$$^{S}/_{N} = -10log[\sum(Y^2)/n] \qquad (6)$$

The S/N ratios of all treatments for colour mis-registration are listed in Table 8. Also, the effect of each treatment is calculated and listed in Table 9. And, Figure 3 represents the main effects plot for S/N ratio of treatments for quality characteristic: colour mis-registration.

Table 8: S/N ratio for colour mis-registration

Exp.	S/N	Exp.	S/N	Exp.	S/N	Exp.	S/N
1	62.55	5	62.55	9	62.55	13	62.55
2	62.55	6	62.55	10	19.54	14	62.55
3	62.55	7	22.55	11	12.14	15	19.54
4	62.55	8	62.55	12	12.14	16	62.55

*For experiment where the response Y equal to 0, it is assumed to be 0.0001 in order to calculate the effect of treatments

Table 9: Effect of treatments for colour mis-registration

Responses	Factor / level	A	B	H
Colour mis-registration	1	**62.55***	**57.17***	45.87
	2	52.55	39.57	**50.87***
	3	26.59		
	4	51.8		

*Preferable levels

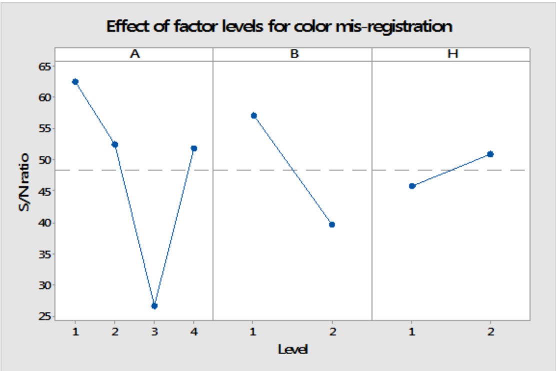

Figure 3: Effect of treatments for color mis-registration

From Table 9 and Figure 3, the optimal treatment is $A_1B_1H_2$ (paper category 1, small batch and with human intervention).

5.3 Results of paper waste

One of the important pamameter affected the cost of printed product is the cost of quality which is calculated according to the cost of paper waste as the price of paper constituted a large percentage of the operating cost. For this reason, the minimize of paper waste reduce the printed product cost. Percentage of paper waste for each treatment is listed in Table 10.

Table 10: Paper waste data

Exp.	A	B	H	P_{w1}	P_{w2}	Q_{QC}	Q_{MR}	Q_S	Q_{PW}	% T_{PW}
1	1	1	1	0	0	0	60	140	200	10%
2	1	1	2	0	0	0	50	100	150	10%
3	1	2	1	0	0	0	60	640	700	5%
4	1	2	2	10	0	10000	180	1820	12000	12%
5	2	1	1	0	0	0	60	140	200	10%
6	2	1	2	0	0	0	60	140	200	10%
7	2	2	1	0	0.56	560	180	1820	2560	2.56%
8	2	2	2	0	0	0	180	1820	2000	2%

9	3	1	1	10	0	60	50	40	150	25%
10	3	1	2	6.67	1.11	117	50	100	267	17.8%
11	3	2	1	33.33	6.11	3944	60	440	4444	44.44%
12	3	2	2	16.67	6.11	2278	60	440	2778	27.78%
13	4	1	1	0	0	0	60	60	120	15%
14	4	1	2	0	0	0	60	90	150	10%
15	4	2	1	0	1.11	111	60	440	611	6.11%
16	4	2	2	3.33	0	333	60	440	833	8.33%

P_{w1}: Percentage of paper rejected due to color variation
P_{w2}: Percentage of paper rejected due to colour mis-registration
Q_{QC}: Quantity of paper rejected due to quality control (color variation and colour mis-registration)
Q_{MR}: Quantity of paper used in make-ready
Q_{S}: Quantity of paper spoiled during machine run length
Q_{PW}: Total quantity of paper waste
% T_{PW}: percentage of total paper waste

S/N ratio is calculated to investigate the effect of factor levels and to determine the optimal factor levels. For paper waste, the response type is smaller-the-better (STB) and the formula used to calculate S/N ratio is as follows:

$$S/N = -10log[\sum(Y^2)/n] \quad (7)$$

The S/N ratio of all factors at all levels for total paper waste, are listed in Table 11. Then, the effect of each factor level is calculated and listed in Table 12.

Table 11: S/N for total paper waste

Exp.	S/N	Exp.	S/N	Exp.	S/N	Exp.	S/N
1	10	5	10	9	6.02	13	8.24
2	10	6	10	10	7.5	14	10
3	13.01	7	15.92	11	3.52	15	2.14
4	9.21	8	16.99	12	5.56	16	0.79

Table 12: Effect of investigated factor levels on total paper waste

Responses	**Factor / level**	**A**	**B**	**H**
Paper waste	1	10.56	**8.97***	8.61
	2	**13.23***	8.39	**8.76***
	3	5.65		
	4	5.29		

*Preferable levels

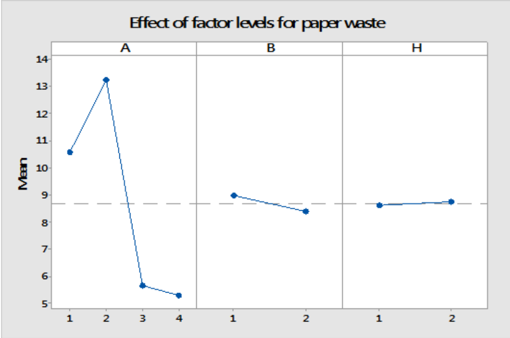

Figure 4: S/N ratio for paper waste

From Table 12 and Figure 4, the optimal factor level for total paper waste is $\mathbf{A_2B_1H_2}$ (Paper category 2, small batch and with human intervention).

ANOVA is computed for quantity of paper waste in order to obtain the relative significance and percentage contributions of investigated factors. The results are listed in Table 13.

Table 13: ANOVA of paper waste versus A, B, H factors

Source	DoF	Adj SS	Adj MS	F	P-Value	Contribution (%)
Main effects	5	0.455559	0.091112	-	-	
A	3	0.349315	0.116438	**19.08**	**0.019**	44.88
B	1	0.106243	0.106243	17.41	**0.025**	13.65
H	1	0	0	0	0.995	0
2-way interactions	7	0.304504	0.043501	-	-	
A*B	3	0.277989	0.092663	15.18	**0.026**	35.71
A*H	3	0.022861	0.00762	1.25	0.43	2.94
B*H	1	0.003654	0.003654	0.6	0.495	0.47
Error	3	0.018312	0.006104	-	-	
Total	15	0.778375				100
S = 0.0781279		R-Sq = 97.65%		R-Sq (Adj.) = 88.24%		

From Table 13, for paper waste the significant factors are A, B and the interaction A*B as the P-value is below α value of 0.05. Factor A (paper category) had highest Adj. SS of 0.349315 which indicates its greatest impact in model, then interaction A*B has Adj. SS of 0.277989 and factor B (batch size) has Adj. SS of 0.106243. Also, the relatively higher F-statistic values for paper waste show that factors A, B and interaction A*B, have the paramount influence on paper waste. The higher percentage of coefficient of determination (R- Sq.) indicates that 97.65% of the variability could be explained by the model.

6. Conclusion

In this paper, the authors implement engineering weight to solve the multi response problem of quality characteristics of paper printed on sheet-fed offset press in order to minimize printed paper wasted due to quality control and consequently reduce the cost. The experimental research was carried out in real production conditions.

The effect of paper category, batch size and human intervention are experimentally investigated on quality characteristics: color variation and colour mis-registration for the four colours (CMYK) of the printed product. A full factorial design was applied and the experimental data was analysed using S/N ratio. First the responses are standardized to minimize the scaling effect. The S/N ratio of each response is calculated and the weighted S/N ratio is obtained. Then, the average S/N ratio for each factor level from all responses is estimated and used to obtain the optimal levels for all process factors.

Based on the results of this study, the following conclusions are drawn:

- The optimal factor level for the multi response of color variation (ΔE) is $A_2B_2H_1$. In other words the optimal combination for color variation is the paper of category 2 (Security paper of weight $90g/m^2$) printed on large batch size without human intervention.
- The optimal factor level for colour mis-registration is $A_1B_1H_2$. In other words the optimal combination for colour mis-registration is the paper of category 1 (uncoated paper of weight $80g/m^2$) printed on small batch size with human intervention.
- It was confirmed that paper waste is minimized when using paper of category 2 (Security paper of weight $90g/m^2$) printed in small batch size with human intervention. The optimal factor level is $A_2B_1H_2$ which gives the best print quality results for investigated quality characteristics and consequently minimize the paper waste rejected due to quality control.
- The analysis for paper waste reveals significance of factor A (paper category) with contribution 44.88%, factor B (batch size) with contribution 13.65% and interaction A*B (interaction between paper category and batch size) with contribution 35.71%.
- The ANOVA results showed higher than 97% for R-Sq and higher than 88% for R-Sq adjusted which assure the ability of the model to explain variability and make efficient prediction for new observations.

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