Parameter Design for Analyzing Factors Affecting the Production of Printed Slotted-Type Corrugated Boxes

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Abstract

The main problem of the case study company is erratically printed colors on the surface finish of the printed image on slotted-type corrugated boxes, resulting in a high defect rate of 17.58%. This research was carried out to firstly, identify the factors that are causing the erratically printed colors, specifically from the flexographic printing process, secondly, to identify appropriate parameters to be used in the printing process, and lastly, to reduce the rate of defective printed colors to an acceptable level of no more than 10%. Experiments were conducted to investigate the influence and interaction of various parameters on the surface finish of the printed image. The results showed that the interaction between four parameters had a significant impact on the surface finish of the printed image. These were the distance between the anilox roller and the printing plate, the printing temperature, printing speed and the drying time and the viscosity of the ink used during the printing process. The appropriate level of each parameter was identified and, when those parameter values were instituted, the printing defective rate was reduced to 7.5%.

Keywords: Full factorial design, slotted-type corrugated board, printed image, flexography, print quality

Introduction

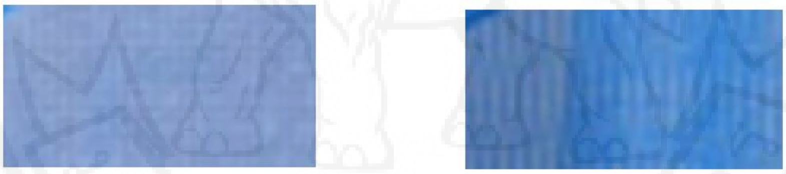
Raising awareness among consumers of environmentally-friendly products has resulted in a higher demand for corrugated board packaging (Tomašegović, Pibernik, Poljaček, & Madžar, 2021; Garbowski, Gajewski, & Grabski, 2021). More than 69 countries around the world, including China, France, Italy, Taiwan and India, have passed some sort of full or partial ban on plastic bags (Buchholz, 2020). Thailand has also had a plastic bag ban since 2020 to reduce the pollution of waste and garbage in the sea (Chankaew, 2020). In this atmosphere of environment, the packaging industry, especially corrugated board production, plays an important role in the modern world (Tomašegović et al., 2021; Garbowski et al., 2021). The advantages of corrugated boxes are that they are lightweight, relatively cheap and can be recycled (Pereira et al., 2020; Khadzhynova & Havenko, 2020). Corrugated boxes have been used in various industries, but mainly for storage, and transportation of products. However, prior research (Garbowski et al., 2021; Khadzhynova & Havenko, 2020) has indicated that there are some specific properties of corrugated boards that are a challenge to production and printing, especially with its liner, and surface roughness and smoothness.

Different types of printing techniques are used to print on packaging. Digital printing, such as flexo and gravure printing systems, has become very popular and is a more cost-effective process for small runs (Zhong et al., 2020; Galton 2004; Khadzhynova & Havenko, 2020). The flexographic printing process is used to produce higher print quality than is achieved with the traditional offset printing process. When using a flexographic printing machine for the printing process, higher print quality is achieved and the printing ink dries quickly (Khadzhynova & Havenko, 2020; Pereira et al., 2020). However, the optimal parameters in each technical process, including ink density, speed, temperature, and types of screens, must be considered carefully to gain a high level of print quality than was previously achievable for various products (Kurt et al., 2018; Havenko et al., 2020).

This study is case-based, using a medium-sized Thai manufacturing company that supplies various types of corrugated board packaging, including slotted-type corrugated and die-cut corrugated board boxes. The issues faced by the case-study company are related to a high defective rate in the production process of slotted-type corrugated boxes. More specifically, the color of the surface finish of the printed image on the corrugated board boxes was erratically printed. Data gathered between July and December 2020 indicated an average defective rate of 17.58% as shown in Table 1. Figure 1(a) represents an acceptable printed color of the surface finish of the printed image on slotted-type corrugated boxes and Figure 1 (b) shows the defect caused by the erratically printed color of the surface finish. This situation has negatively impacted the quality of the printed images which has resulted in higher production costs of an average of about 375,283 Baht per month (given the cost per defective product of 230 baht).

Table 1 Type of defect in the production process of slotted-type corrugated boxes

Type of defect	Number of defects (Pieces)	Percentage of defects	Cost of defects (Baht/month)
An erratically printed color of the surface finish	4,895	17.58	375,283.33
The print has not adhered to the surface	1,291	4.64	98,976.67
Paper peel off	1,768	6.35	135,546.67
Total number of products: 27,840 pieces			
Total number of defects: 7,954 pieces			



(a) Acceptable (b) Defective

Figure 1 Acceptable and defective printed color of the surface finish of the printed board sheets

A solution to this expensive defect situation was urgently needed, which gave rise to this research, with the objectives of (1) to identify the factors that are causing the erratically printed color of the surface finish, (2) to identify appropriate parameters to be used in the printing process of slotted-type corrugated boxes, and (3) to reduce this defect rate to an acceptable level, stated by the case study company as no more than 10%.

Methods and Materials

The case study company's production process of slotted-type corrugated boxes is illustrated in Figure 2. The production process starts when the flat board sheets are inserted into the feeder. These are corrugated, and the corrugated board sheets are cut into required sizes which are then transferred to the printing section to have required labels or images printed on them. After printing, the product is moved to the creaser machine to perform longitudinal creases, then to the slotter machine to make 5 mm grooves on the corrugated board. The slotter machine processes approximately 3,000 sheets per hour (Rudawska, Čuboňova, Pomarańska, Stančeková, & Gola, 2016). It is equipped with a set of blades, which can be adjusted as per requirements (Rudawska et al., 2016).

The corrugated boards are then stapled by using a stitching machine. Finally, the print quality inspection takes place to examine if there has been any paper peel off, if the print has not adhered to the surface, or if there has been an erratically printed color of the surface finish of the printed image. The finished products are then stacked on pallets and sent to the finished goods warehouse.

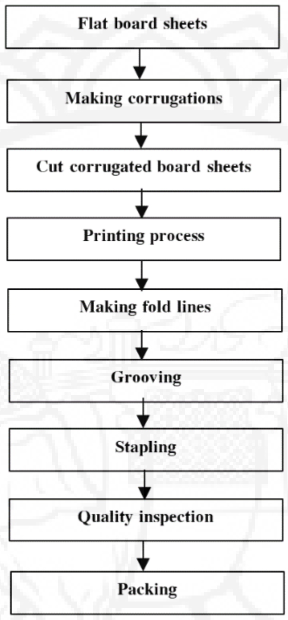


Figure 2 The production process for slotted-type corrugated boxes

The flexographic printing technique, using a Flexo printing machine, is used in the printing process. Flexographic printing is a well-known and long-standing printing technique in graphic printing and the packaging industries (Maddipatla, Narakathu, & Atashbar, 2020; Khan et al., 2012; Berardinis, 2005). Flexography can be used to print onto almost any type of substrate such as paper, corrugated board, plastic, film, multi-wall bags and aluminium foil (Khan et al., 2012; Zhong, Eea, Chenb, & Shan, 2020; Bates, Zjakic, & Budimir, 2015; Zolek- Tryznowska, Rombel, Petriaszwili, Dedijer, & Kašikoví, 2020; Johnson, 2008; Tomašegovi´c, Polja˘cek, Jakovljevi´c, & Urbas, 2020).

However, there are some disadvantages of flexographic printing, including where the printed features can be distorted by plate deformation and ink spreading, or the surface topology of printed features can be non-uniform, or not uniformly thick over the full printed area (Khan et al., 2012). Other problems are related to the correct reproduction of elements in the image with different patterns, and obtaining high-quality prints (Valdec, Zjakić, & Milković, 2013).

Identifying the causes of the problem

A cause and effect diagram, shown in Figure 3, was applied to identify the causes of the problem. At first, there was a brainstorming session with three experienced engineers in the case-study company, as they had a deep knowledge of the production process, and were chosen because they had worked in the company for over five years.

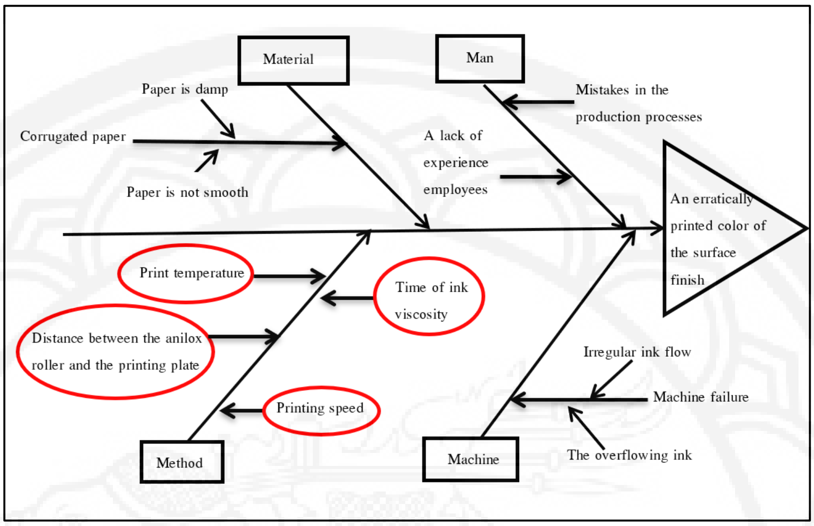


Figure 3 Cause and Effect Diagram

The causes of the problem were then identified as follows:

Man: employees have to follow the steps in the working process. However, due to a turnover of employees, there is a lack of experienced employees, resulting in many mistakes in the production process.

Machine: the machine usually works continuously throughout an operational day. This might cause irregular ink flow: print density is a measurement of how much ink is transferred to the substrate and its appearance. Research by Olsson, Yang, van Stam, and Lestelius (2007) asserted that a higher temperature results in drastic ink transference while a too low print density leads to the print looking dull; and the overflowing ink leads to smudges on the printing.

Prior studies by Johnson (2008) Joshi and Bandyopadhyay (2015) indicated that the ink transfer is influenced by parameters such as printing speed, pressure, the nature of substrate and ink viscosity. Hence, decreasing printing speed, as well as increasing the printing pressure, will lead to an expansion of the total ink assigned to the substrate. Additionally, a low viscosity printing ink can also cause the flooding of dots (Zolek-Tryznowsk et al., 2020). Other research by Zhong et al. (2020) and Johnson (2008) suggested that the amount of ink transferred is related to the amount of ink picked up by the anilox roller; for example, at a lower speed, more ink is picked up by the anilox roller because it allows more time for the ink to enter the anilox cells. Then, with more ink on the anilox cells, more ink will be transferred to the printing plate, which can lead to the surface finish of the printing image being ruined due to more ink spreading over the surface.

Material: it is well known in the printing industry that material plays an important role in the adhesion of ink to the substrate (Izdebska-Podsiadły & Podsiadło, 2016). The properties of the printing paper, including surface roughness, porosity and water absorbency are important (Johnson, 2008; Valdec, Miljkovic, & Augustin, 2017; Tomašegović et al., 2020; Tomašegović, Beynon, Claypole, & Poljacˑek, 2016). Printing success factors include:

1. the smoothness of the cardboard surface is directly related to ink spreading on the surface of the print (Tomašegović et al., 2021; Valdec et al., 2017). On a smooth paper, printing ink spreads mostly on the surface. The surface roughness of the substrate influences the ink transfer so that a rougher surface accepts more ink because printing ink can freely sink into the pores of the paper (Tomašegović et al., 2021). However, when the surface gets too rough the contact is reduced, which also reduces the ink transfer (Olsson et al., 2007);

2. when the paper is damp, resulting in humidity, which is an important material property, then this has an impact on the box strength (Garbowski et al., 2021). This leads to wetting of the printing surface by the ink, which is detrimental to the process.

Method: the method that the company applied in their production process might have been the cause of the problem of an erratically printed color of the surface finish. Problematic aspects of that production process included:

1. The distance between the anilox roller and the printing plate must be at an appropriate distance (Zhong et al., 2020; Gajadhur & Regulska, 2020). Hence, if the distance between the anilox roller and the printing plate is too close, this may cause a large volume of printing ink, leading to printing smears. However, when the distance between the anilox roller and the printing plate is too far, the ink might spread causing smudges and contaminating the paper blocks;

2. The printing temperature is one of the causes of an erratically printed colour of the surface finish of the printed image. During printing, the temperature in the flexographic printing process increases as a consequence of friction between the doctor blade and the anilox roll, pumping the ink and friction in the different nips between the cylinders in the printing press which affects the ink performance and the print quality (Olsson et al., 2007). Increasing the temperature may speed up the drying of ink on the prints; however, this can cause the print to deteriorate, leading to a large amount of the ink coming out of the print head (Havenko, Ohirko, Ryvak, & Kotmalova, 2020). This causes colored ink smears on the paper. Additionally, increasing the temperature of the ink affects the ink properties such as viscosity and surface tension (Olsson et al., 2007). In contrast, a low temperature has a high viscosity, resulting in the printed colors sticking together;

3. Printing speed is the speed of color screen printing on a block of paper. A lower printing speed creates a wider printed line width because more ink is transferred onto the substrate when the contact time is longer (Berardinis, 2005; Zhong et al., 2020). In contrast, a high printing speed, where less ink is transferred from the anilox roller onto the printing plate, due to shear thinning of the ink, results in less ink spreading and a smaller line is transferred onto the printing plate (Zhong et al., 2020);

4. Time of ink viscosity (viscosity and drying time of the ink used in the printing process). Adjusting the ink viscosity is especially important to ensure the high quality of a print (Havenko et al., 2020). In this respect, ink should not be extruded over the boundaries of the printed image. We defined the time of ink viscosity as the

time setting of the ink viscosity used to print the color screen onto the substrate. Also, it affects the amount of ink that can be transferred to the surface. The ink viscosity is also affected by temperature. An increase in temperature leads to a decrease in viscosity (Zolek-Tryznowsk et al., 2020; Olsson et al., 2007). Hence, a shorter time of ink viscosity setting leads to an increase in ink transfer, and an increase in print speed and pressure (Olsson et al., 2007). This forces more ink into the substrate as well as a longer time of ink viscosity during the printing process which reduces ink transfer.

Of the problems described here, the parameters of the distance between the anilox roller and the printing plate and the printing temperature have been considered as the main cause of this problem. Primary analysis by using Two-way ANOVA was utilized for variables of the printing speed (at 180, 210, 230 piece/minute) and the time of ink viscosity used in the printing process (at 35, 37, 39, 40 seconds) to statistically test whether these two factors have an impact on the erratic print color on the surface. This is to ensure that the variables were not just randomly selected. The primary experiment was randomly selected and run separately by using 20 slotted-type corrugated boxes. These were inspected based on visual experience, checking for the print color on the surface so that it was smooth and not smeared on the printed image. Then, the proportion of the erratically printed color of the surface finish of the printed image was recorded (response; Y). Then data were analyzed by using Statistical Program Minitab 17.

The ANOVA results, shown in Figure 4, can be explained by the printing speed (p=0.002) and the time of ink viscosity used in the printing process (p-value = 0.044) having a significant impact on the proportion of the surface finish of the printed image having an erratically printed color, at a significance level of 0.05. Therefore, four potential parameters related to the methods of setting up the machine have been selected to conduct the experiments for this study, these are:

1. The distance between the anilox roller and the printing plate,
2. The printing temperature,
3. The printing speed, and
4. The time of ink viscosity used in the printing process.

Experimental Design

The design of the experiment was based on Full Factorial Design with two replicates. The Full Factorial Design encompasses several factors with each factor having a different possible number of levels (Montgomery & Runger, 2018). As well, it allows appropriate settings to minimise the defects of the surface finish of the printed image, to be identified. The design levels of each factor have a certain range based on the operations manual of the flexographic printing machine. Each factor consists of two or more levels. The experimental levels of each factor were chosen based on practical experience as well as studies of prior research (See Section "Identifying causes of the problem"). The levels of each parameter used for this research were identified as follows:

The distance between the anilox roller and the printing plate is currently set up at 2.2 millimetres which is considered to be too far and leads to an erratically printed color of the surface finish of the printed image. However, prior research (e.g., Zhong et al., 2020; Gajadhur & Regulska, 2020) asserted that the position of the anilox roller and the printing plate has to be precised. Therefore, this research considered 3 factorial levels of: 1.5 millimetres (low), 1.8 millimetres (medium) and 2.0 millimetres (high).

General Linear Model: Y versus Print speed, Time of ink viscosity

Factor Information

Factor	Type	Levels	Values
Print speed	Fixed	3	180, 210, 230
Time of ink viscosity	Fixed	4	35, 37, 39, 40

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Print speed	**2**	**0.39563**	**0.197813**	**9.53**	**0.002**
Time of ink viscosity	**3**	**0.20583**	**0.068611**	**3.31**	**0.044**
Error	18	0.37354	0.020752		
Lack-of-Fit	6	0.36104	0.060174	57.77	0.000
Pure Error	12	0.01250	0.001042		
Total	23	0.97500			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.144057	61.69%	51.05%	31.89%

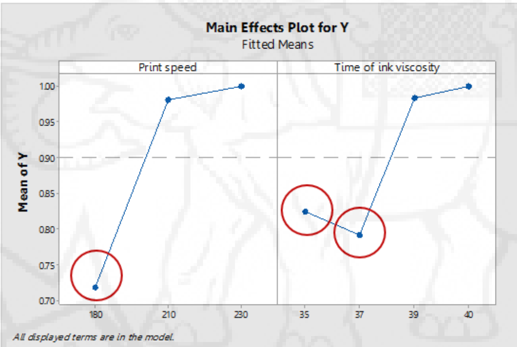


Figure 4 Primary analysis by using the Two-way ANOVA method

The printing temperature is normally set at 22°C. Previous studies (e.g., Olsson et al., 2007; Havenko et al., 2020) also claimed that printing temperature is one of the main factors that have an impact on the ink performance and the quality of the printed surface finish. Therefore, this study ran the experiment with the print temperature at 3 levels: 21°C (low), 22°C (medium) and 23°C (high).

The printing speed is generally set at 180 pieces per minute. The selection of this number was based on the primary analysis and the main effect plot shown in Figure 4. A low level of print speed created a low proportion of the erratically printed colour of the surface finish, so 2 levels of the print speed were used: 180 pieces per minute (low) and 190 pieces per minute (high).

The time of ink viscosity used in the printing process is normally set at 35 seconds. Based on the primary analysis results, shown in Figure 4, the time of ink viscosity at 35 and 37 seconds created a lower proportion of the erratically printed colour of the surface finish. Therefore, this research ran this experiment at 2 levels of time of ink viscosity used in the printing process: 35 and 37 seconds. Therefore, the levels of each parameter can be summarized, as shown in Table 2.

Table 2 Parameters and levels of slotted type corrugated board boxes production processes

Parameters	Set up range	Current level	Experiment level		
			Low	Medium	High
The distance between the anilox roller and the printing plate (A)	0.5-2.2 Millimetres	2.2	1.5	1.8	2.0
Printing temperature (B)	20-25°C	22	21	22	23
Printing speed (C)	180-230 Piece/minute	180	180	-	190
Time of ink viscosity used in the printing process (D)	30-40 Seconds	35	35	-	37

In total, this research completed 72 experiments (3^2 x 2^2 x 2). The experiments were carried out in industrial conditions of the slotted-type corrugated box production processes, not in the laboratory, using parameters and levels that are shown in Table 2. Each experiment was randomly selected and run separately by using 20 pieces of the product (slotted-type corrugated boxes). The printed products were inspected based on an overall visual experience; examining the products and checking the print colour on the surface for smoothness and smearing of the printed image. Then, the proportion of the erratically printed colour of the surface finish of the printed image was recorded (response; Y). The data were analyzed by using Statistical Programme Minitab 17 and followed the steps of Full Factorial analysis suggested by (Montgomery & Runger, 2018) as shown in Figure 5.

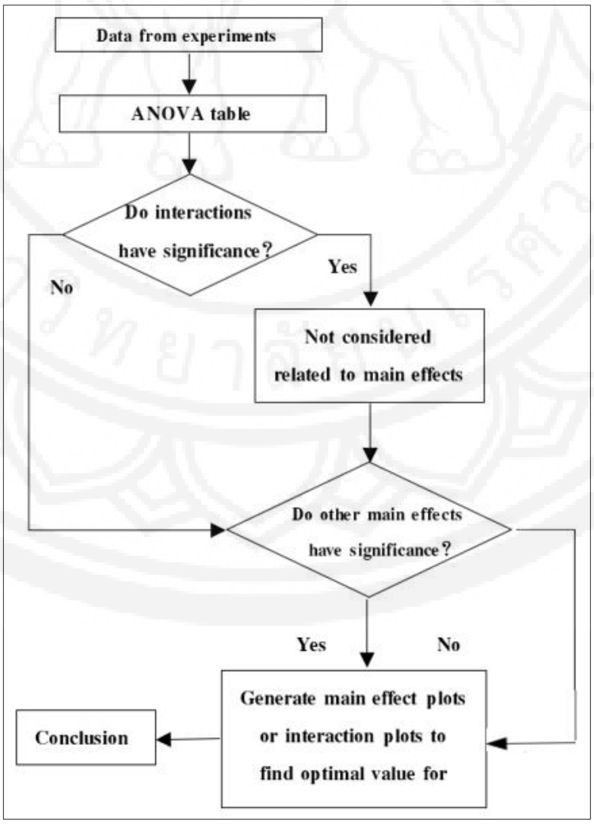


Figure 5 Steps for main and interaction effects analysis

Results and Discussion

The analysis started by checking the residual plots to investigate the model accuracy, as shown in Figure 6. The results indicated that;

From a normal probability plot, residuals tended to be in a straight line, indicating that the residuals had normal distribution; the graph 'versus fits' and 'versus order' represented that,

1. The residuals were independent;
2. The stability value of the residual's variances; and
3. The residuals had a mean of zero.

Therefore, the residuals did not exhibit any violation of the assumptions of normality, independence, and constant variance. Hence, the experimental model and data are accurate and acceptable (Montgomery & Runger, 2018) with the ε_i ~NID $(0, \sigma^2)$.

Then, the results of the analysis of variance (ANOVA) and the model summary were examined as represented in Table 3.

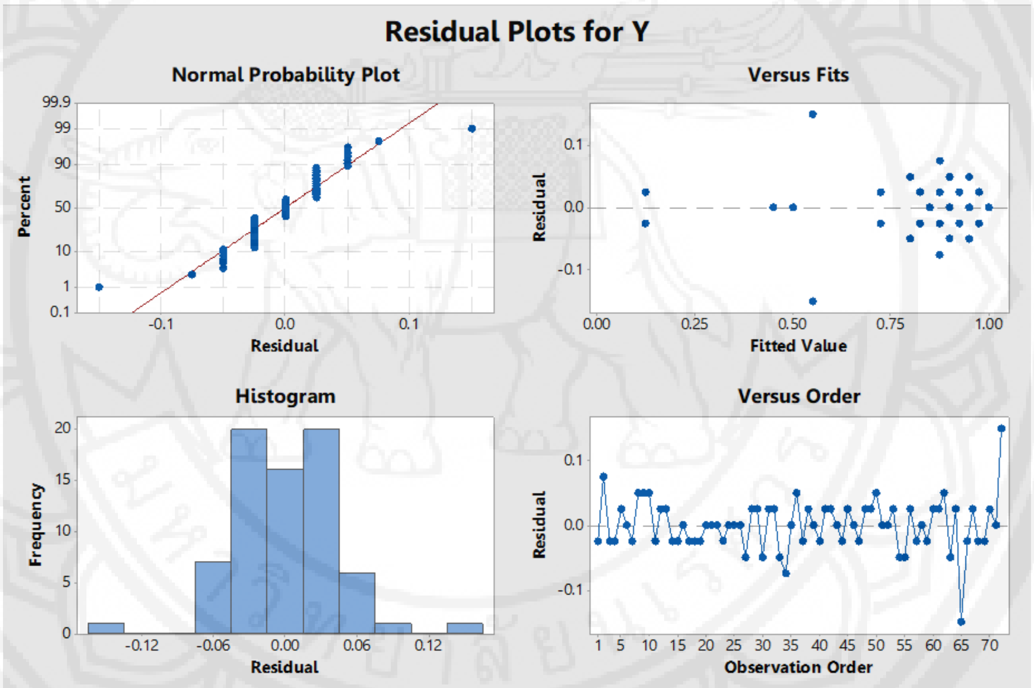


Figure 6 Residual plots for Y

The R^2 adjusted showed that the model explains 91.19% of the variability in the measurement of an erratically printed colour of the surface finish. This means that the design parameters are appropriate and acceptable for an erratically printed colour of the surface finish of the printed image (Montgomery & Runger, 2018). The ANOVA results also showed that the four-factor interactions between the distance between the anilox roller and the printing plate, printing temperature, printing speed, and time of ink viscosity used during the printing process (A*B*C*D) had a significant impact (p=0.000) on the proportion of an erratically printed colour of the surface finish of the printed image, at a significance level of 0.05.

Table 3 Analysis of the variance (ANOVA) of the parameters affecting the proportion of an erratically printed colour of the surface finish of the printed image

General Factorial Regression

Factor Information

Factor	Levels	Values
The distance between the anilox roller and the printing plate (A)	3	1.5, 1.8, 2.0
Printing temperature (B)	3	21, 22, 23
Printing speed (C)	2	180, 190
Time of ink viscosity used in the printing process (D)	2	35, 37

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	35	2.37844	0.067955	21.99	0.000
Linear	6	1.26833	0.211389	68.40	0.000
A	2	0.32688	0.163438	52.89	0.000
B	2	0.16583	0.082917	26.83	0.000
C	1	0.75031	0.750313	242.80	0.000
D	1	0.02531	0.025313	8.19	0.007
2-Way Interactions	13	0.58441	0.044955	14.55	0.000
A*B	4	0.22604	0.056510	18.29	0.000
A*C	2	0.14021	0.070104	22.69	0.000
A*D	2	0.03062	0.015312	4.96	0.013
B*C	2	0.15250	0.076250	24.67	0.000
B*D	2	0.03083	0.015417	4.99	0.012
C*D	1	0.00420	0.004201	1.36	0.251
3-Way Interactions	12	0.36701	0.030584	9.90	0.000
A*B*C	4	0.21979	0.054948	17.78	0.000
A*B*D	4	0.06604	0.016510	5.34	0.002
A*C*D	2	0.05924	0.029618	9.58	0.000
B*C*D	2	0.02194	0.010972	3.55	0.039
4-Way Interactions	4	0.15868	0.039670	12.84	0.000
A*B*C*D	**4**	**0.15868**	**0.039670**	**12.84**	**0.000**
Error	36	0.11125	0.003090		
Total	71	2.48969			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0555903	95.53%	91.19%	82.13%

Table 4 shows the means of the interactions of the four factors. Therefore, to achieve the smallest proportion of erratically printed colour of the surface finish of the printed image, the appropriate value of each parameter can be identified as the distance between the anilox roller and the printing plate (A) is 1.8 millimetre, printing temperature (B) should be set at 23°C, the appropriate level of printing speed (C) is 180 pieces per minute, and the time of ink viscosity used during the printing process (D) should be set at 37 seconds.

To confirm the results, each factor was adjusted according to the appropriate level that was obtained from the data analysis above, and these were then used in the production process. A total of 600 pieces of the products were tested, and it was found that there were 45 pieces of defective products with the erratically printed color of the surface finish of the printed image. Therefore, the proportion of the defect can be calculated as 0.075 or 7.5%.

Table 4 The means of four factors' interactions

Means

Term A*B*C*D	Fitted Mean	SE Mean
1.5 21 180 35	0.8250	0.0393
1.5 21 180 37	0.8750	0.0393
1.5 21 190 35	1.0000	0.0393
1.5 21 190 37	0.9500	0.0393
1.5 22 180 35	0.8750	0.0393
1.5 22 180 37	0.8750	0.0393
1.5 22 190 35	0.9750	0.0393
1.5 22 190 37	0.9500	0.0393
1.5 23 180 35	0.8750	0.0393
1.5 23 180 37	0.9000	0.0393
1.5 23 190 35	0.9500	0.0393
1.5 23 190 37	0.9000	0.0393
1.8 21 180 35	0.8000	0.0393
1.8 21 180 37	0.8250	0.0393
1.8 21 190 35	0.9250	0.0393
1.8 21 190 37	0.9000	0.0393
1.8 22 180 35	0.8250	0.0393
1.8 22 180 37	0.8250	0.0393
1.8 22 190 35	0.9750	0.0393
1.8 22 190 37	0.9500	0.0393
1.8 23 180 35	0.7250	0.0393
1.8 23 180 37	**0.1250**	**0.0393**
1.8 23 190 35	0.8750	0.0393
1.8 23 190 37	0.9250	0.0393
2.0 21 180 35	0.8500	0.0393
2.0 21 180 37	0.8250	0.0393
2.0 21 190 35	0.8750	0.0393
2.0 21 190 37	0.8750	0.0393
2.0 22 180 35	0.5000	0.0393
2.0 22 180 37	0.4500	0.0393
2.0 22 190 35	0.8750	0.0393
2.0 22 190 37	0.9000	0.0393
2.0 23 180 35	0.4500	0.0393
2.0 23 180 37	0.5500	0.0393
2.0 23 190 35	0.9750	0.0393
2.0 23 190 37	0.8750	0.0393

The hypothesis was then tested to see if the erratically printed colour of the surface finish of the printed image was no more than 10% based on the goal of the company case study. The hypotheses were set as follows:

H_0: The proportion of defective products based on an erratically printed colour of the surface finish of the printed image is no more than 0.10 ($p \leq 0.10$).

H_1: The proportion of defective products based on an erratically printed colour of the surface finish of the printed image is more than 0.10 ($p > 0.10$).

The results are shown in Table 5. The results affirmed that the proportion of an erratically printed colour of the surface finish of the printed image was no more than 10% (p-value = 0.979) at a significance level of 0.05 which is acceptable for the case-study company.

Table 5 The confirmation of the results

Test and CI for One Proportion

Test of p = 0.1 vs p > 0.1

Sample	X	N	Sample p	95% Lower Bound	Z-Value	P-Value
1	45	600	0.075000	0.057313	-2.04	0.979

Using the normal approximation.

Table 6 represents a comparison of before and after applying the parameter values. Therefore, after applying the appropriate values of each parameter, the proportion of an erratically printed color on the surface finish was reduced to 7.5%, and the cost of the defective products was reduced to 160,080 baht per month (or 1,920,960 baht per year). The distance between the anilox roller and the printing plate should be set at 1.8 millimetres, which is shorter than the set-up value before the experiments. Our results are consistent with suggestions by (Zhong et al., 2020; Gajadhur & Regulska, 2020) who indicated that the distance between the anilox roller and the printing plate has to be set at an appropriate length, as too long a distance leads to a spread of ink and contamination of the paper blocks (See section 2.2.4). Our results suggested an appropriate printing temperature of 23°C and time of ink viscosity at 37 seconds which are higher than the levels that the company used before the experiments, while our results suggested using the same level of printing speed as were used before the experiments. Our results are similar to the research by (Zolek-Tryznowsk et al., 2020; Olsson et al., 2007) who concluded that printing temperature, printing speed and time of ink viscosity provided a significant impact on the production process.

Table 6 Comparison before and after applying the parameter values

Topic	Before	After
The distance between the anilox roller and the printing plate (millimetres)	2.2	1.8
Printing temperature (°C)	22	23
Printing speed (pieces per minute)	180	180
The time of ink viscosity (seconds)	35	37
Percentage of defects	17.58%	7.5%
Cost of defects (baht per month)	375,283.33	160,080

Conclusion and Suggestions

The objectives of this research were to identify factors causing an erratically printed colour of the surface finish of the printed image in the production process of slotted corrugated boxes, and, to identify appropriate parameters to be used in the printing process, thus reducing the defective rate. The results of the Full Factorial design with two replicates showed that there were interactions between four factors: distance between the anilox roller and the printing plate, printing temperature, printing speed, and time of ink viscosity used in the printing process at a significance level of 0.05. The results also showed that the appropriate values for each parameter should be; a 1.8 mm distance between the anilox roller and the printing plate, 23°C printing temperature, 180 pieces per minute printing throughput, and the time of ink viscosity used in the printing process of 37 seconds. Having applied the most appropriate level for each parameter in the production process, the results confirmed that the defective rate of erratically printed colors of the surface finish was reduced to 7.5% which was acceptable for the case-study company. Importantly, the cost of the defective products was reduced to 160,080 baht per month (or 1,920,960 baht per year).

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