CHAPTER 4

PRELIMINARY EXPERIMENT

This chapter aims to quantify factors affecting to image printing defects in the image printing process. Initially an improvement team is set to brainstorming session. Next the team has selected potential affecting factors to do preliminary experiment and analysis results.

4.1 Factor-affecting Selection

There are many factors affecting image printing defects in the image printing process, so an improvement team is established to brainstorm and arrange these factors. This team consists of production personnel, process engineer, supervisors, production manager and QA engineer as a researcher who conduct the meeting, plan for the experiment, collect data to analyse by used statistical technique and also include summary and suggestion for this quality improvement. Meetings and discussions will be set many times to find many causes as possible, which are considered to be affecting the image printing defects.

In image printing process, the image printing defects can occur in many forms such as uneven thickness distribution on substrate, skip print along the line edge, poor printed pattern registration and poor dimensional printed surface, etc. The image printing defects, in fact, could have been caused by either insufficient or excess ink thickness. However, from the manufacturing standpoint, the optimum condition should be the condition that required minimum ink thickness that sufficient for producing good quality printing without the image printing defects.

According to the improvement team brainstorming, they divided the possible causes into 4 main different factors including man, machine, material, and method. In addition, individual factors can be detailed into many sub-factors followed by applying a cause and effect diagram in figure 4.1

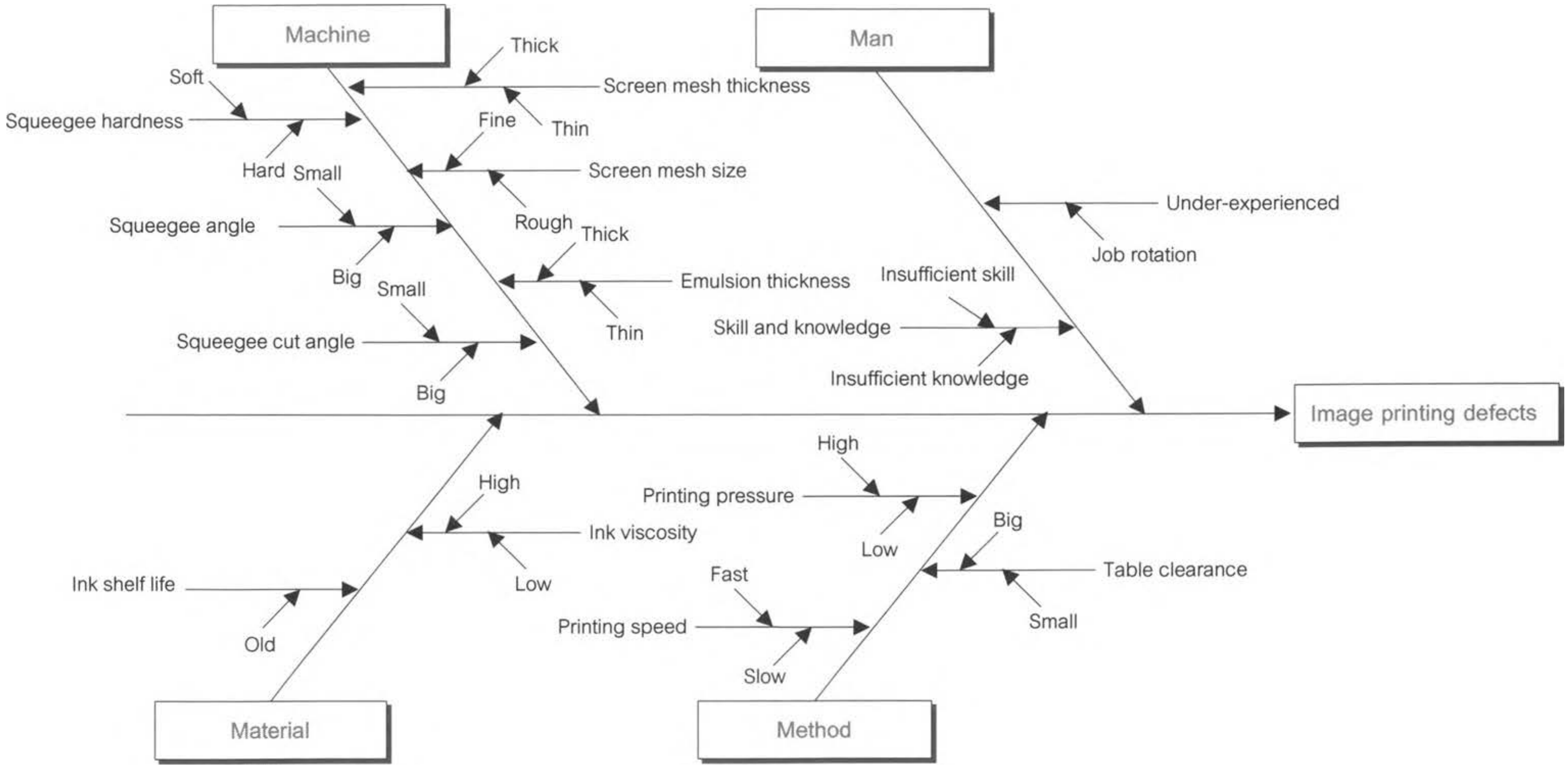

Figure 4.1 Cause and effect diagram of the image printing defects

Refer to figure 4.1, the cause and effect diagram defined and linked the relationships of the possible causes to effect as follows:

4.1.1 Man

The different in man will cause the problem of:

- ☆ Workmanship error from under-experienced caused by job rotation
- ☆ Workmanship error from insufficient skill and knowledge

4.1.2 Machine

The different in machine will cause the problem of:

- ☆ Improper squeegee hardness
- ☆ Improper squeegee angle
- ☆ Improper squeegee cut angle
- ☆ Improper screen mesh thickness
- ☆ Improper screen mesh size
- ☆ Improper emulsion thickness

4.1.3 Material

The different in material will cause the problem of:

- ☆ Unsuitable ink viscosity
- ☆ Old ink (shelf life exceed)

4.1.4 Method

The different in method will cause the problem of:

- ☆ Improper printing pressure
- ☆ Improper printing speed
- ☆ Unsuitable table clearance

It can be seen that the cause and effect diagram has illustrated the various factors affecting the image printing defects. Most factors are emphasized on machine and method element. Next, the team will search for additional information and will get as many ideas from participants to select important affecting factors.

4.2 Selected Affecting Factors

According to the cause and effect diagram in figure 4.1, there are many influencing factors affecting thickness of ink in image printing process. It can be seen that the team could not do testing for all factors, so they have decided on some potential factors to experiment with. They are:

4.2.1 Squeegee hardness

4.2.2 Squeegee angle

4.2.3 Squeegee cut angle

4.2.4 Emulsion thickness

4.2.5 Printing pressure

4.2.6 Printing speed

4.2.7 Table clearance

The company technical information and the old technical experiment are determined when selecting the potential factors. At this time, the team has chosen these potential factors from the following reasons.

☆ There are controllable factors with minimal incurring additional production costs.

☆ There are able to reach a result in reducing the image printing defects in image printing process.

☆ There are small effect to cycle time.

☆ There is low effect on the whole quality of product.

☆ For man factor, the team will choose skilled operator to perform experiment to reduce any errors so it can be set as control factor.

☆ For measurement and testing equipment, the team will choose calibrated measurement and testing equipment actors to do experiment also.

For non-chosen factors, we have reasons as follows.

Factor	Reason for non-chosen factor	Method to control
1. Workmanship error	1. Under-experienced operator 2. Insufficient skill and knowledge operator	Trained and set skilled operator to response the experiment
2. Improper screen mesh size	The company has fixed to use only one size of screen mesh.	-
3. Improper screen mesh thickness	The company has fixed to use only screen mesh thickness 12 microns.	-
4. Unsuitable ink viscosity	Ink viscosity is too high or too low.	Adjust viscosity per suppliers recommendation in data sheet
5. Old ink (Shelf life exceed)	High volume orders, which result in high volumes of ink not being used.	Set shelf life control of ink by computerized min-max stock

Table 4.1 Non-chosen factors

4.3 Selected the Experiment

The team used a cause and effect diagram as a problem solving technique, helping to form the quality improvement process. However, the diagram does not rank causes according to their importance. Consequently the team cannot identify rank of factors that will significantly improve the quality of this process. So the team will set a meeting to find suitable method for factor screen experiment. The team set the condition for performing the experiments as below.

Initially, the team has investigated and selected seven influencing factors. Normally, testing all combinations of factor levels becomes too expensive and time-consuming with five or more factors. Then the team will find methods to reduce the total number of runs required when the number of potential factors is relatively large.

In addition, the team has concluded to perform experiments on each factor with 3 factor levels in each run because they want to test more than the maximum and minimum factor level, which has been recommended by the well-trained statistical technique production manager.

Since the seven potential factors were selected, the team has considered performing the experiment from these experiment design and statistical techniques.

4.3.1 Three-level full factorial design

The three-level full factorial design is one with all input factors set at three levels each. These are referred to as low, intermediate and high levels, numerically expressed as 0, 1, and 2. If there are k factors, each at 3 levels, the three-level full factorial design has 3k runs. Then the number of trials required for this three-level full factorial design is $3^K = 3^7 = 2{,}187$ runs. It can be seen that the number of runs required for the three-level factorial becomes unacceptable because the team could not perform all the experiment in limited time.

4.3.2 Fractional factorial design

The fractional factorial design is prescribed as subset of a full factorial design. The fractional factorial is useful when the number of potential factors is relatively large because it will reduce the total number of runs required. If there are k factors, each at 3 levels, the fractional factorial design has 3^{k-1}runs. Then the number of trials required for this fractional factorial design is $3^{K-1} = 3^{6} = 729$ runs. It can be seen that the number of runs required for the fractional factorial becomes larger than the team to perform all the experiments.

4.3.3 Orthogonal array

The orthogonal array is a statistical method corresponded to levels and parameters. It can assist in determining how many trials are necessary, and the factor levels for each variable in each trial. While there are many standard orthogonal arrays available, each of the arrays is meant for a specific number of design variables and levels. If there are 7 factors with each factor having 3 set levels, then an L_{18} orthogonal array would be selected. Consequently, the number of trials required for the orthogonal array is 18 runs.

Comparing number of runs for each technique, the orthogonal array is required the smallest number of trials required as 18 runs. While the fractional functional and the three-level factorial design had required to perform 729 and 2,187 runs, respectively. Finally, the orthogonal array L_{18} (2^{1} x 3^{6}) was chosen to conduct the experiments due to it is very expensive to conducting a full production scale-experiment. Moreover, it is useful when the number of potential factors is relatively large because they reduce the total number of runs required including able to create an adequate equivalency.

4.4 Conducting the Experiment

Once the orthogonal array is selected, it is necessary to conduct the experiments as per the level combinations. The main factors are described and represented as follows.

4.4.1 Squeegee hardness

The squeegee is used to press the screen into line contact and push paste down into the stencil and onto the copper surface. The squeegees are available in a two range of hardness, normally in the range of 70 to 80 B. Very soft squeegees conform well with uneven surfaces but collapse under applied pressure, very hard ones behave conversely. The squeegee hardness is exhibited in figure 4.2.

Figure 4.2 Squeegee hardness

This is represented by factor A, where

Level 1 is squeegee hardness 70 B.

Level 2 is squeegee hardness 80 B.

4.4.2 Squeegee angle

This refers to the angle of attack at the squeegee tip. Much bigger angles give the thick coating, much smaller angles give the thin coating. The squeegee angle is exhibited in figure 4.3.

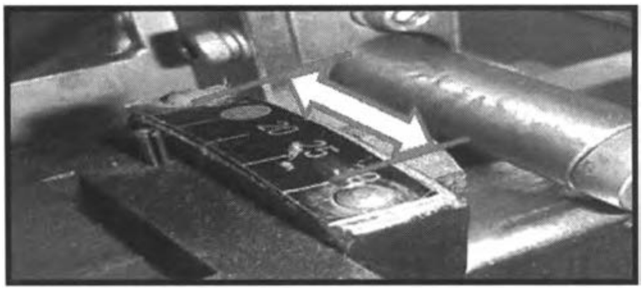

Figure 4.3 Squeegee angle

This is represented by factor B, where

Level 1 is squeegee angle 10 degrees.

Level 2 is squeegee angle 20 degrees.

Level 3 is squeegee angle 30 degrees.

4.4.3 Squeegee cut angle

This refers to the cut angle applied to adjust squeegee tip. The squeegee cut angle is exhibited in figure 4.4.

Figure 4.4 Squeegee cut angle

This is represented by factor C, where

Level 1 is squeegee cut angle 0 degree.

Level 2 is squeegee cut angle 30 degrees.

Level 3 is squeegee cut angle 60 degrees.

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4.4.4 Emulsion thickness

The emulsion is coated under printing screen. The emulsion thickness is exhibited in figure 4.5.

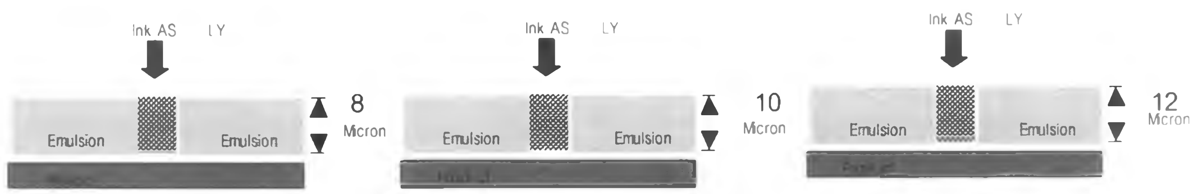

Figure 4.5 Emulsion thickness

This is represented by factor D, where

Level 1 is Emulsion thickness 8 micron.

Level 2 is Emulsion thickness 10 micron.

Level 3 is Emulsion thickness 12 micron.

4.4.5 Printing pressure

This refers to pressure attack at the squeegee. The printing pressure can be adjusted as figure 4.6.

Figure 4.6 Printing pressure

This is represented by factor E, where

Level 1 is printing pressure 16 Kgf/cm^2.

Level 2 is printing pressure 20 $Kgf/\ cm^2$.

Level 3 is printing pressure 24 $Kgf/\ cm^2$.

4.4.6 Printing speed

This refers to speed of squeegee used to press the screen into line contact. The printing speed can be adjusted as figure 4.7.

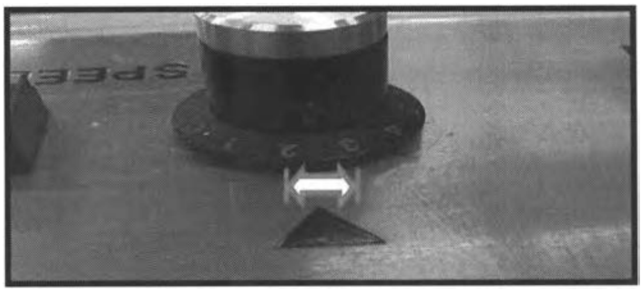

Figure 4.7 Printing speed

This is represented by factor F, where

Level 1 is printing speed 2.0 m/min.

Level 2 is printing speed 2.5 m/min.

Level 3 is printing speed 3.0 m/min.

4.4.7 Table clearance

This refers to the gap between screen and product. The table clearance can be adjusted as figure 4.8.

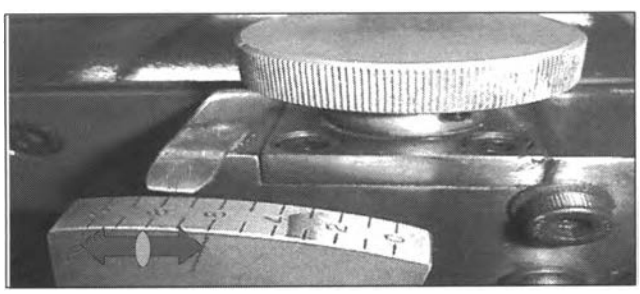

Figure 4.8 Table clearance

This is represented by factor G, where

Level 1 is table clearance 6 mm.

Level 2 is table clearance 8 mm.

Level 3 is table clearance 10 mm.

These seven main factors and levels are shown in table 4.2.

Controllable factors	Level 1	Level 2	Level 3	Specification
1. Squeegee hardness (A)	70	80	-	70B and 80B
2. Squeegee angle (B)	10	20	30	0-30 degrees
3. Squeegee cut angle (C)	0	30	60	0-90 degrees
4. Emulsion thickness (D)	8	10	12	No specification
5. Printing pressure (E)	16	20	24	0-32 Kgf/ cm^2
6. Printing speed (F)	2.0	2.5	3.0	1-5 m/min
7. Table clearance (G)	6	8	10	0-10 mm.

Table 4.2 The main factors and levels

According to the main factors and levels in table 4.2, the team had set value levels for each variable by adjusted current image printing condition. Due to machine settings not being able to be adjusted easily, it will certainly effect several changes in production output. Consequently, the value levels for some factors are not tested to cover the whole scope of specification e.g. printing pressure, printing speed.

Next the L_{18} orthogonal array will be used to analyse the data to determine which level is suitable for each parameter. The two different ink's thicknesses are shown as output, Y1 and Y2. The layout sheet of the experiment is shown in table 4.3.

Experiment No.	Factors							Output	
	A	B	C	D	E	F	G	Y1	Y2
1	1	1	1	1	1	1	1		
2	1	1	2	2	2	2	2		
3	1	1	3	3	3	3	3		
4	1	2	1	1	2	2	3		
5	1	2	2	2	3	3	1		
6	1	2	3	3	1	1	2		
7	1	3	1	2	1	3	2		
8	1	3	2	3	2	1	3		
9	1	3	3	1	3	2	1		
10	2	1	1	3	3	2	2		
11	2	1	2	1	1	3	3		
12	2	1	3	2	2	1	1		
13	2	2	1	2	3	1	3		
14	2	2	2	3	1	2	1		
15	2	2	3	1	2	3	2		
16	2	3	1	3	2	3	1		
17	2	3	2	1	3	1	2		
18	2	3	3	2	1	2	3		

Table 4.3 The layout sheet of the experiment

4.5 Collected Data

The collected data from the experiment are shown in table 4.4.

Experiment No.	Factors							Output	
	A	B	C	D	E	F	G	Y1	Y2
1	1	1	1	1	1	1	1	9.8	11.8
2	1	1	2	2	2	2	2	10.6	9.5
3	1	1	3	3	3	3	3	13.3	15.4
4	1	2	1	1	2	2	3	12.3	10.2
5	1	2	2	2	3	3	1	13.1	11.8
6	1	2	3	3	1	1	2	18.2	16.5
7	1	3	1	2	1	3	2	10.0	11.0
8	1	3	2	3	2	1	3	17.5	16.2
9	1	3	3	1	3	2	1	13.0	13.0
10	2	1	1	3	3	2	2	11.3	9.9
11	2	1	2	1	1	3	3	9.8	10.8
12	2	1	3	2	2	1	1	16.6	15.3
13	2	2	1	2	3	1	3	12.3	11.8
14	2	2	2	3	1	2	1	11.5	11.1
15	2	2	3	1	2	3	2	11.1	11.6
16	2	3	1	3	2	3	1	17.0	16.0
17	2	3	2	1	3	1	2	12.5	11.8
18	2	3	3	2	1	2	3	10.8	10.1

Table 4.4 The data of the experiment

4.6 Data Analysis of Experiment

According to the experiment, all runs are needed to test 7 factors indicated by the number 1, 2, or 3 under the column header A, B, C, D, E, F, or G. After the results' columns are obtained, the mean effects are calculated by combining the simulation results in each factor-level combination and shown as below.

Level	A	B	C	D	E	F	G
1	12.7	12.0	11.2	11.5	12.3	13.6	12.7
2	12.0	12.6	11.2	12.6	12.5	11.2	12.2
3	-	12.6	14.3	13.3	12.6	12.1	12.0
Different	0.7	0.6	3.2	1.9	0.3	2.4	0.7

Table 4.5 The mean effects of the influencing factors

The ranges of mean effects are illustrated in figure 4.9.

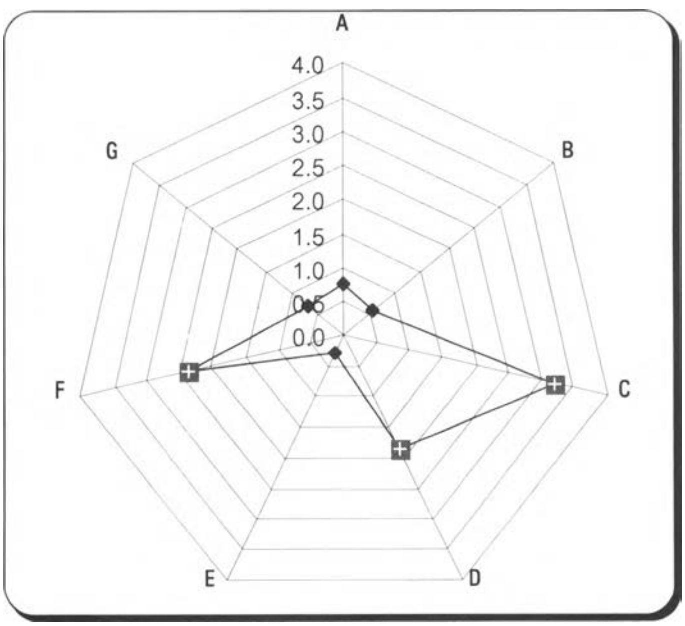

Figure 4.9 The range of mean effects of the influencing factors

Next, the mean effects with respect to each factor are illustrated in figure 4.10.

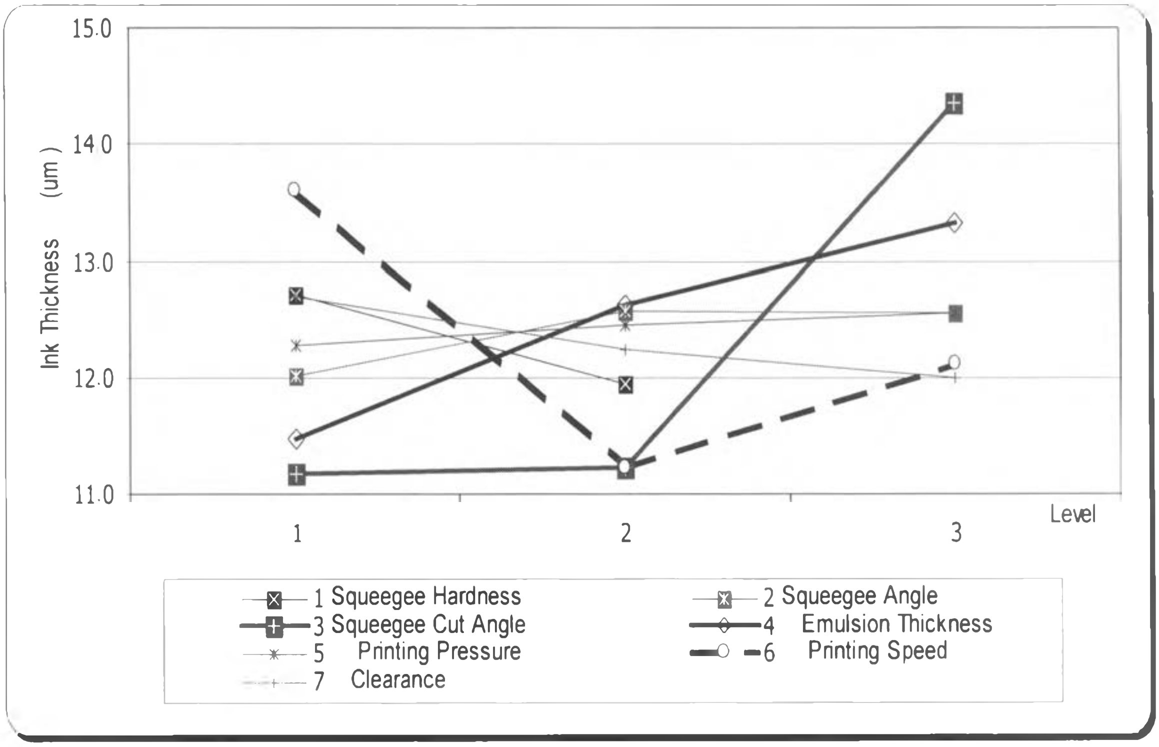

Figure 4.10 The mean effects of the influencing factors

In addition, the analysed results grouped by machine and method factor are shown as below.

4.6.1 Analysed result and trend of machine factor

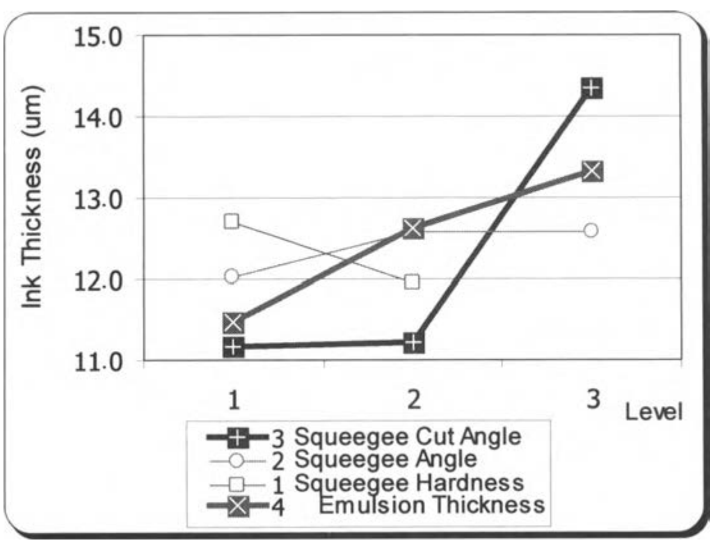

Figure 4.11 The mean effects of the machine factor

Refer to figure 4.11, this includes the analysed result of squeegee hardness, squeegee angle, squeegee cut angle, and emulsion thickness.

☆ Squeegee hardness

The optimal setting for the squeegee hardness is level 2, or its hardness 80 B.

☆ Squeegee angle

The optimal setting for the squeegee angle is level 1, or its cut angle 10 degrees. Although the machine specifications range from 0 to 30 degree, the machine could not be adjusted to an angle to be less than 10 degrees. Consequently, the minimum squeegee angle is determined to be 10 degrees.

☆ Squeegee cut angle

The optimal setting for the squeegee cut angle is level 1 as well as level 2, or its cut angle 0 and 30 degrees. When the cut angle is changed, the squeegee tip needs to be cut manually, so the team had chosen a squeegee cut angle of 0 degree to minimise additional cost and time.

☆ Emulsion thickness

The optimal setting for the emulsion thickness is level 1, or its thickness 8 microns. However, there are no specifications that can be adjusted. The team aims to reduce the emulsion thickness to minimise the ink thickness.

4.6.2 Analysed result and trend of method factor

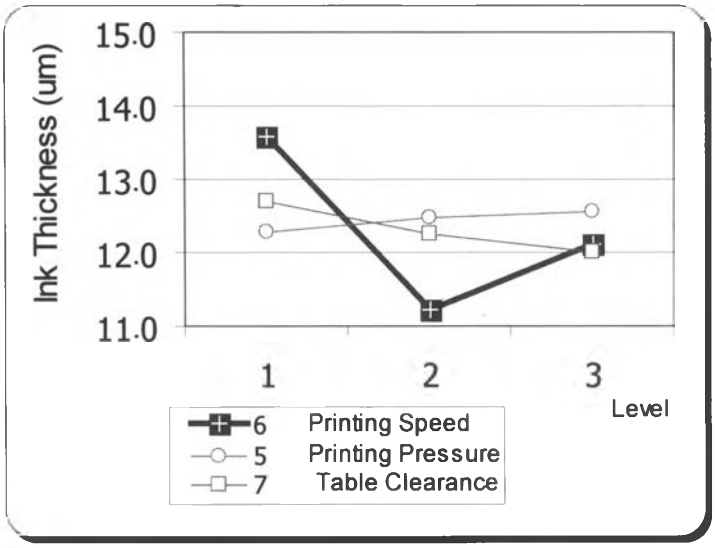

Figure 4.12 The mean effects of the method factor

Refer to figure 4.12, this includes the analysed result of printing pressure, printing speed, and table clearance.

☆ Printing pressure

The optimal setting for the printing pressure is level 1, or its pressure 16 kgf/cm^2. However, the machine specifications range from 0 to 32 kgf/cm^2. This factor is required to have additional experiment to cover its specification range to minimise ink thickness.

☆ Printing speed

The optimal setting for the printing speed is level 2, or its speed 2.5 m/min. However, the machine specifications range from 0 to 5 m/min. This factor is required to have additional experiment to cover its specification range to minimise ink thickness as well as increase productivity.

☆ Table clearance

The optimal setting for the table clearance is level 3, or its clearance 10 mm. Because this is the maximum setting value of the table clearance, so the machine could not be adjusted to the table clearance more than 10 mm.

According to the analysed results, the optimum levels were determined to be squeegee hardness of 80 B, squeegee angle of 10 degree, squeegee cut angle of 0 degree, and table clearance of 10 mm. However, the other setting levels, which were determined to be printing speed of 4 m/s, printing pressure of 28 Kgf/cm^2, and emulsion thickness of 8 microns, are needed to have additional analyse for the appropriate condition which cover its specification range and other constraints including their high range of mean effects of the influencing factors.

In next chapter, the appropriate condition for controlling the image printing defects in image printing process will be determined.