Multi Objective Six Sigma Methodology: Application on Chromojet Printing

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Abstract

Using multi objective techniques within quality improvement methodologies open and enhance the link between operations research tools and techniques and quality improvement techniques. In this paper we propose a methodology that link between multi objective techniques and six sigma methodology which considered one of most important quality improvement strategy used in continuous quality improvement in manufacturing, services, and health care sectors through project basis frame work. Using the proposed methodology "multi objective six sigma" improve the current six sigma methodology to be able to deal with two or more critical process output simultaneously. Here we present this methodology and its main steps and techniques, and the application of the proposed methodology in Chromjet printing process. By developing two characteristic models that link between the main process input and two process output separately using Design of experiment technique (DOE) and then we formulate Multi-objective Mathematical model and solve the model using weighting method to get efficient solution satisfy and improve the two process output.

Keywords: Multi-objective, Six Sigma, Design of experiment, Chromjet printing

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1. Introduction:

Dealing with one process output in quality improvement is not enough in today's complex business environment. In most cases we deal with more than one requirement needed to be satisfied. In this paper we present the proposed methodology which improves the six sigma methodology based on the multi-objective techniques and Design of experiment.

Six sigma was launched by Motorola in 1987. It was the result of a series of changes in the quality area starting in the late 1970s, with ambitious ten-fold improvement drives. The top-level management along with CEO Robert Galvin developed a concept called Six Sigma. After some internal pilot implementations, Galvin, in 1987, formulated the goal of "achieving Six-Sigma capability by 1992" in a memo to all Motorola employees (Bhote, 1989). The results in terms of reduction in process variation were on-track and cost savings totaled US$13 billion and improvement in labor productivity achieved 204% increase over the period 1987–1997 (Losianowycz, 1999). Six sigma phases described as Define, Measure, Analyze, Improve, and Control (DMAIC). The proposed methodology is to dived the Improve phase in DMAIC to be Modeling, Optimize and implement, and back to control so the proposed methodology will be Define, Measure, Analyze, Modeling, Optimize, Implementation and Control (DMAMOIC) and application of modified methodology in chromojet printing process which used in carpet printing.

In section 2 we present an over view on the multi objective definition and techniques, in section 3 we present the six sigma definition and methodology, in section4 we present an over view on the design of experiments (DOE), in section 5 we present overview on chromojet printing, in section 6 we present the proposed methodology, in section 7 we present the application details in chromojet printing, section 8 discussion and conclusion.

2. Multi objective optimization

In this section we present the definition and mathematical model and solution technique of multi objective optimization problems.

Multi-objective problems are those problems where the goal is to optimize simultaneously k objective functions on the form of

$$\text{Minimize } \{f_1(x), f_2(x) \ldots f_k(x)\} \qquad 2.1$$

$$\text{Subject to } x \in S,$$

Where k ≥2 objective functions $f_i : R^n \rightarrow R$. the objective function

F(x) $= (f_1(x), f_2(x), \ldots, f_k(x))^T$. the decision variable vectors $x = (x_1, x_2, \ldots, x_n)^T$. Belong to the (nonempty) feasible region set (S), which is a subset of the decision variable space R^n. (Kaisia Miettinen, 1994),

Multi-objective problems (as a rule) present a possibly uncountable set of solutions. Two Euclidean spaces from R^n are considered in multi-objective problems.

- The n-dimensional space of the decision variables in which each coordinate axis corresponds to a component of vector x;

- The k-dimensional space of the objective functions in which each coordinate axis corresponds to a component vector $f_k(x)$.

The evaluation function of a multi-objective problem, F: Ω → Λ, maps the decision variables ($x = x1, . . . ,x_n$) to vectors ($y = a_1, . . . , a_k$). The set of solutions is found through the use of the Pareto Optimality Theory (M. Ehrgott, 2000).

2.1. Solution techniques:

The solving of multi-objective optimization problem helps the decision maker in finding the best solution that fits the specified preferences. The decision maker can be one or more experts in the problem domain with the main task of selecting one of the Pareto optimal solutions. Multi-objective optimization is a multi-disciplinary field which combines ideas from mathematical programming with multiple criteria decision making, glued together by the computer programming techniques. Multiple criteria decision making is the research domain which considers decision problems with multiple conflicting objectives (Branke et al., 2008; Hakanen, 2006; Miettinen, 1999; Rangaiah, 2009). Methods available for multi-objective optimization can be classified in different ways. In the classification adopted by Miettinen (1999), multi-objective optimization methods are split into two main groups: generating methods and preferences-based methods. Methods from the first class generate one or more Pareto-optimal solutions without any inputs from the decision maker. The solutions obtained are then provided to the decision maker for selection. The generating methods are divided into two subgroups: no-preference methods (in which additional preference information are not required from the decision maker) and a posterior methods (which use posterior information to select a solution from the generated Pareto front). Preference-based methods use the preferences specified by the decision maker at some stage in solving the multi-objective optimization problem. These have been divided in a priori methods (Pareto optimal solution is found using preference information given by the decision maker at the beginning of the process) and interactive methods. Interactive methods require multiple interactions with the decision maker during the optimization procedure. For each interaction, the decision maker analyzes the generated Pareto optimal solution(s) and specifies preferences. These preferences are used in formulating and solving the optimization problem during the next iteration. The main steps of an interactive method are (Branke et al., 2008; Rangaiah, 2009):

1. Initialization: calculating an ideal and/or nadir vector and presenting them to the decision maker;
2. Generation of a Pareto optimal starting point;
3. Requesting preference information from the decision maker;

4. Generation of a new Pareto optimal solution(s) based on specified preferences;

5. If several solutions were generated, the decision maker is asked to select the preferred one;

6. If the decision maker is satisfied with the obtained solution it comes to the end, else it goes to step3.

2.2. Weighting Method:

In the weighting method the idea is to associate each objective function with a weighting factor and minimize the weighted sum of objectives. In this way the multiple objective functions are transformed into single objective function. We suppose that weighting coefficients w_i are real numbers such that $w_i \geq 0$ for all $i = 1, \dots, k.$ it usually supposed to the weight are normalized, that is $\sum_{i=1}^{k} w_i = 1.$ and the multi objective optimization problem will modified to the following problem (Kaisia Miettinen, 1994).

$$minimize \sum_{i=1}^{k} w_i f_i(x) \qquad 2.2$$

Subject to x ϵ S

Where $w_i \geq 0$ for all $i = 1, \dots, k.$ and

$$\sum_{i=1}^{k} w_i = 1.$$

3. Six Sigma Methodology

In this section we present the definition of six sigma and main phases of six sigma methodology known as DMAIC and the main target of each phase.

Six Sigma is defined by Linderman et al.(2003) as “an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates.’’ Academic research, such as Zu et al (2008) and Schroeder et al (2008), has tried to determine which elements in Six Sigma make it effective. Besides its role structure and focus on metrics, Six Sigma’s structured improvement procedure is seen as a novel and effective contribution to quality management. This improvement procedure is generally known under the acronym DMAIC, standing for Define, Measure, Analyze, Improve and Control. DMAIC is similar in function as its predecessors in manufacturing problem solving, such as Plan-Do-Check-Act and the Seven Step method of Juran and Gryna (Balakrishnan et al., 1995).

3.1. Six Sigma's DMAIC method

The Six Sigma phenomenon does not refer to a single, clearly delineated method. Rather, it refers to a related collection of practices in organizations, De Koning and DeMast (2006) make a rational reconstruction of Six Sigma's as a system of prescriptions; they discern four classes of elements of the method:

- A model of the function and purpose for which the method applies.
- A stage model (DMAIC) providing a stepwise procedure.
- A collection of techniques.
- Concepts and classifications, such as Critical-to-Quality (CTQ) characteristics and the distinction between the vital few and the trivial many causes.

Based on an extensive analysis of descriptions of these elements in the practitioners' literature, De Koning and DeMast (2006) conclude that these various accounts have enough commonalities to consider them variations of a single method, thus claiming convergent validity for the method. From a large number of sources, the functions of the DMAIC stages and their steps and prescribed actions are reconstructed,

- Define: problem selection and benefit analysis

Identify and map relevant processes, Identify stakeholders, Determine and prioritize customer needs and requirements, and Make a business case for the project.

- Measure: translation of the problem into a measurable form, and measurement of the current situation; refined definition of objectives

Select one or more CTQs, Determine operational definitions for CTQs and requirements, Validate measurement systems of the CTQs, Assess the current process capability, and Define objectives.

- Analyze: identification of influence factors and causes that determine the CTQs' behavior
  Identify potential influence factors, and Select the vital few influence factors
- Improve: design and implementation of adjustments to the process to improve the performance of the CTQs

Quantify relationships between Xs and CTQs, Design actions to modify the process or settings of influence factors in such a way that the CTQs are optimized, and Conduct pilot test of improvement actions

- Control: empirical verification of the project's results and adjustment of the process management and control system in order that improvements are sustainable

4. Design Of experiments (DOE):

Design of Experiments provides the foundation for experimenters to systematically investigate hypotheses about systems and processes. By outlining a series of structured tests in which well thought out adjustments are made to the controllable inputs of a process or system, then the effects of these changes on a pre-defined output or response variable can be observed and their significance evaluated. The importance of applying such a structured method is found in its ability to minimize the number of factors influencing a system, maximize the responses deemed desirable in the system by manipulating the factors, and minimize the amount of experimentation required to effectively cover the design space characterized by the factors. It not only serves as a useful tool, but usually a necessary tool in cases where performing ’one change at a time’ masks the interaction effects of multiple, concurrent inputs on the system response. In comparison DOE plans for all of the possible combinations of input variables initially. It then imposes data requirements which enable the experimenter to determine the significance of that effect on the system response, and the independence of that effect from the influence of others (Ahmed Abdallah, 2008).

DOE can be used in a wide variety of circumstances. Typically though the most common uses of DOE are in the following situations (A. Dean and A. Voss, 1999):

• To help establish the main sources for variation in a measured response of a system,

• To uncover the conditions or sets of factor levels which create a maximum or minimum in the response?

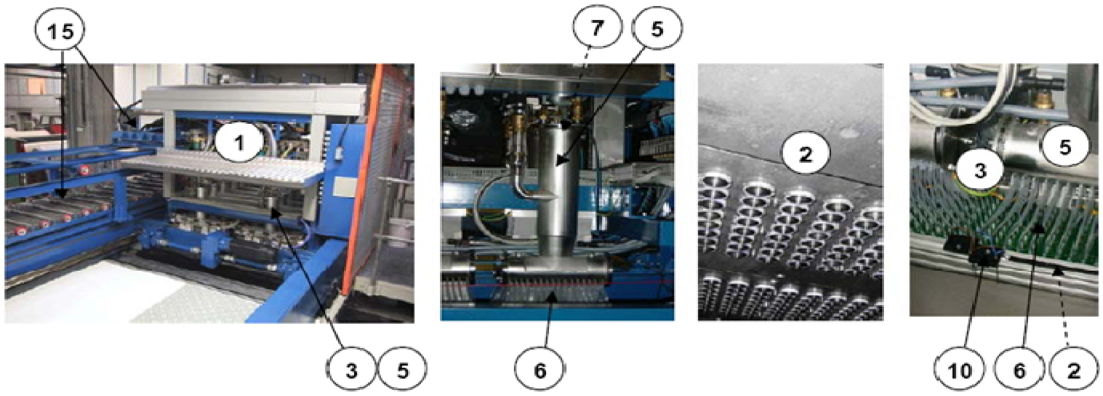
• To compare the effect which different levels of controllable variables have on the response?

• And to derive a mathematical model enabling the prediction or estimation of future responses.

These methods are well established and have been widely used in other fields of engineering. Their application fields are widely varied and include manufacturing, industry, fabrication, IC design and process calibration, biological science, social science, medicine, marketing, and even software engineering.

5. Chromjet printing

Chromo jet is a computer-controlled design system, which applies the air-pressurized printing dye point by point by means of high speed valves (jets) to the material to be printed. The open / close control of the jets is performed by the machine computer (PC) connected using the stored color information (= pattern). An intensity control is not available. To apply the printing dye according to the pattern stored in the PC in a point-precise way onto the material, jets are used to control the dye which is under air pressure. To obtain a precise switching on and cutting off of the dye streams, the jets must operate very exactly and with high frequency. All jets are located on a jet carriage, which is movable across the transport direction of the material. To reach every point on the surface of the material, which appears in the pattern, the jet carriage is moved crosswise across the material. At the same time the position of the carriage is determined. The accuracy of the measurement corresponds to the particular resolution or point size of the pattern. The position of the carriage is compared in the PC with the stored pattern information by the accompanying program. The result of this comparison is, which jets of which color for this position of the carriage are opened or closed. After each stroke of the carriage the material is moved by the transport or feeding device by a specified distance in production direction, and the carriage carries out its movement in the opposite direction see figure 1[10].



Main component of chromojet printing machine

1: jet Carriage, 2: Nozzles, 3: Machine color segment, 5: composition container 6: color distribution, 7: Level sensor, 10: the sensor, 15: Energy chain.

Figure 1: Main component of chromojet line.

6. The proposed Multi objective six sigma methodology

In Multi Objective Six Sigma Methodology (MOSS) we use first three phases from DMAIC process as the same in normal methodology and split the improve phase to modeling , optimize, and implementation then we back to the control phase from DMAIC methodology as shown in the figure2.

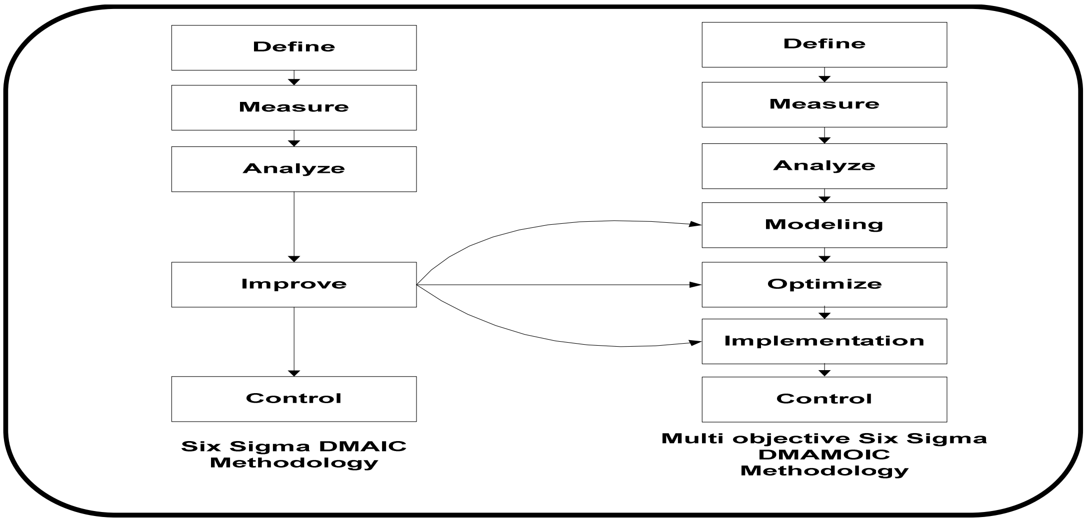


Figure 2: The deference between six sigma and multi objective six sigma methodology.

The separation of improve phase to Modeling, Optimization, and Implementation enable us to deal with process improvement and optimization for two or more process output simultaneously. In modeling phase we ling key process outputs with the key process inputs mathematically using design of experiment (DOE) for one or several responses (outputs) see Figure 3.

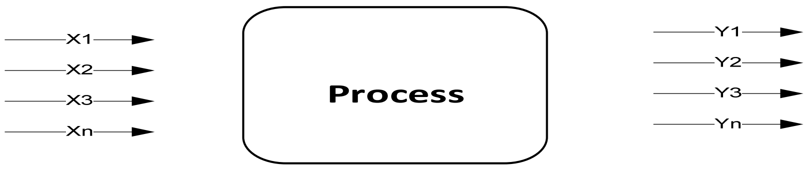


Figure 3: Process illustration of inputs and outputs.

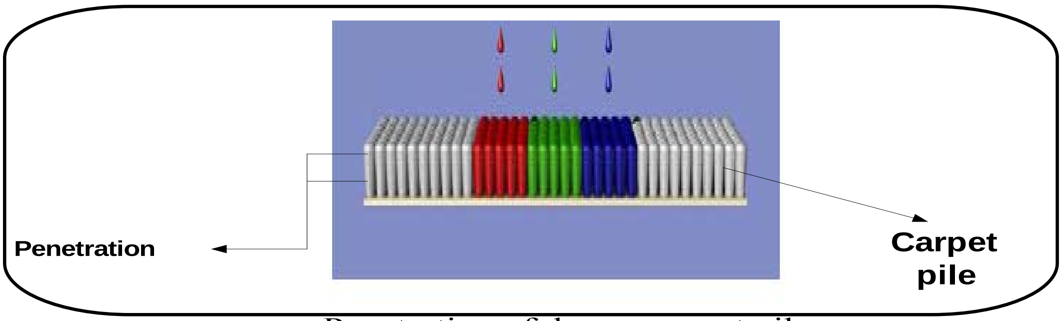
In optimization we formulate the multi objective mathematical model and solving the model using multi objective optimization technique to get efficient solution. In implementation phase we implement the solution get from the optimization phase and evaluate the results and validate the benefit from the solutions.

7. Application:

We implement the proposed Multi-Objective Six Sigma Methodology for improving the chromojet carpet printing process using DMAMOIC phases to minimize the quantity of printing paste and maximize the penetration of the colors into pile of the carpet.

7.1. Define phase

In define phase as shown in table 1 we need to identify the objective for improvement In the chromojet printing process we have two important process output one of them is the quantity of dye paste using in carpet printing which affect the cost of printing process and the cost of waste water treatment in case of excess color used and the second is the penetration of dye on carpet pile see figure 4 , which needed to be full covered with dye solution in order to prevent the effect on the printed design. So we need to minimize the quantity of the printing dye with keeping the full penetration of the dye on carpet pile. In six sigma methodology we cannot deal with those two outputs simultaneously.



Penetration of dye on carpet pile

Figure 4

7.2. Measure

In measure phase we need to define the details application and the how we will measure the defined two process output. We will print on the white carpet and measure the quantity of dye get out from the jet and the penetration on the carpet pile. We used in this application

The carpet specification as:

Styrene butadiene rubber backed BCF nylon carpet with weight of 855gm/m2, pile height of 10.5 mm, and gage 1/10.

Printing paste specification:

Acid dye low viscosity poly acrelate solution yellow, blue and gray colors.

Measurement and equipments:

Chromo jet machine sample printing Zimmer CHR P27 TH, 4jet per color

Rion viscotester VT03F

Balance 3 digits sensitivity OHAUS GT480

Electronic caliber

7.3. Analyze :

In analyze phase we need to get the details of the machine setting and the condition of the printing process will be used and the most effective factors affecting the two defined process output.

From the application and machine constraint we define the detailed application and machine setting as the following. Color solution with viscosity vary from 50 - 300 mPa.s And the color pump pressure vary from 0.9 -2.2 bar and the speed of printing carriage vary from 0.556 – 0.926 m/s.

7.4. Modeling:

In modeling phase we need to link the defined key process output and most affecting factor s in mathematical model. So the model layout begin to be clear we have two responses Y_1 (Quantity of printing paste) and Y_2 (Penetration of the color on the pile), and three factors X_1(Speed of jet carriage), X_2(Viscosity of printing paste), and X_3(Pressure of the pump) see Figure 5.

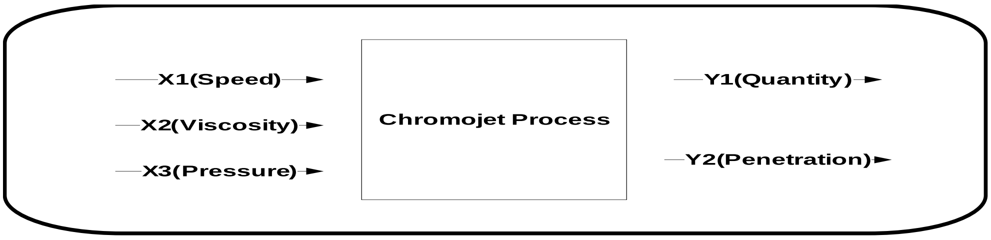


Figure 5: Key Chromojet process inputs and outputs.

By using DOE (Design Of Experiments) technique with full factorial design 3 factors 2 levels the no of trails per one run L^F, where L= the number of levels, F= the no of factors so we have 2^3 =8 runs, we will perform two replicate with three central points with three replicates so the total no of runs is 19 runs. The details of runs and the details of the factors change seen in the Table (1).

We will apply the 19 runs illustrate in table (1) and for each run we measure the quantity of dye solution come out of one jet in one struck in gram by collecting the dye in cretin container and determine the weight difference between empty and full container and measure the penetration of the dye solution on the pile in millimeter as and the detailed run results in table (2).

Table (1): the DOE run details

Run Order	Speed (m/s)	Viscosity (mPa.s)	Pressure(bar)
1	0.556	300	2.2
2	0.764	190	1.55
3	0.764	190	1.55
4	0.556	80	0.9
5	0.926	300	2.2
6	0.926	300	2.2
7	0.556	300	0.9
8	0.926	80	0.9
9	0.926	300	0.9
10	0.556	300	0.9

Run Order	Speed (m/s)	Viscosity (mPa.s)	Pressure(bar)
11	0.926	80	2.2
12	0.764	190	1.55
13	0.926	80	0.9
14	0.556	80	2.2
15	0.556	80	0.9
16	0.556	80	2.2
17	0.926	80	2.2
18	0.556	300	2.2
19	0.926	300	0.9

Table (2): The results of the trail runs

Run Order	S	V	P	Qty/1 jet(gm)	Penetration (mm)
1	0.556	300	2.2	1.0342	4.64
2	0.764	190	1.55	0.7654	5.58
3	0.764	190	1.55	0.7241	5.24
4	0.556	80	0.9	0.7938	6.19
5	0.926	300	2.2	0.6188	5.29
6	0.926	300	2.2	0.5628	4.86
7	0.556	300	0.9	0.61	5.96
8	0.926	80	0.9	0.4355	5.38
9	0.926	300	0.9	0.2229	3.39
10	0.556	300	0.9	0.3754	4.53

Run Order	S	V	P	Qty/1 jet(gm)	Penetration (mm)
11	0.926	80	2.2	0.9352	6.67
12	0.764	190	1.55	0.7352	4.85
13	0.926	80	0.9	0.459	5.9
14	0.556	80	2.2	1.513	9.47
15	0.556	80	0.9	0.926	5.73
16	0.556	80	2.2	1.7416	8.98
17	0.926	80	2.2	0.8523	6
18	0.556	300	2.2	1.2284	6.46
19	0.926	300	0.9	0.2191	4.26

S: Speed, V: Viscosity, and P: pressure

By using the Minitab 14 in analysis of the data got from DOE. We can conclude that for the response Y_1 (Quantity of the printing paste) we will take in consideration the Main effects of factors speed, Viscosity, and Pressure, and the neglect the other effects, For response Y_2 (Penetration of dye on pile) we will take in consideration the main effects of Factors speed, Viscosity, and Pressure, and neglect the other effects. To get the characteristic equation of response Y_1 we should use the Factorial Fit: Qty versus Speed, Viscosity, and Pressure and Analysis of Variance for Qty see Figure 6 (Session window of Minitab 14).

Estimated Coefficients for Qty

Term	Coefficient.
Constant	0.773283
Speed	-0.617911
Viscosity	-0.00198016
Pressure	1.01917
Speed*Viscosity	0.00128846
Speed*Pressure	-0.706539
Viscosity*Pressure	-0.00072409

Estimated Coefficients for Penetration

Term	Coefficient.
Constant	-0.90916
Speed	7.41656
Viscosity	0.0301999
Pressure	7.78772
Speed*Viscosity	-0.0434086
Speed*Pressure	-8.00038
Viscosity*Pressure	-0.0288182
Speed*Viscosity*Pressure	0.0332168

Figure 6: Minitab session of estimates coefficients of quantity and penetration.

From the previous figure we can now get the equation

$$Y_1=1.01917\, X_3 - 0.00198016\, X_2 - 0.617911\, X_1 + 0.773283 \qquad 7.1$$

$$Y_2=7.41656X_1 + 0.0301999X_2 + 7.78772X_1 -0.90916 \qquad 7.2$$

Where Y_2: the penetration of dye on pile (mm), X_1: Speed of head carriage (m/s), X_2: Viscosity of printing paste (mPa.s), X_3: pressure of the pump (bar).

Now the Multi-objective Model can be formulated to minimize the Quantity of the paste and maximize the penetration simultaneously.

$$\text{Min: } Y_1=1.01917\, X_3 - 0.00198016\, X_2 - 0.617911\, X_1 + 0.773283$$

$$\text{Max: } Y_2=7.41656X_3 + 0.0301999X_2 + 7.78772X_1 -0.90916$$

$$\text{Subject to: } 0.926 \geq X_1 \geq 0.556$$

$$300 \geq X_2 \geq 80$$

$$2.2 \geq X_3 \geq 0.9$$

$$X_1, X_2, X_3 \geq 0$$

No we will solve the previous model to get the value of the decision variables to X_1, X_2, and X_3 to get effective solution of the model.

7.5. Optimization:

In optimization phase we need to solve the previous model to get the value of Xi which satisfy the constraint and achieve acceptable solution for the objective functions (efficient solution). We use in solving this model the weighting method with W=0.7 for Y_1 and 0.3 for Y_2 (1-W).

The Model will be:

$$\text{Min: } Y_1 = 1.01917\, X_3 - 0.00198016\, X_2 - 0.617911\, X_1 + 0.773283$$

$$\text{Min: } -Y_2 = -7.41656 X_3 - 0.0301999 X_2 - 7.78772 X_1 + 0.90916$$

$$\text{Subject to: } 0.926 \geq X_1 \geq 0.556$$

$$300 \geq X_2 \geq 80$$

$$2.2 \geq X_3 \geq 0.9$$

$$X_1, X_2, X_3 \geq 0$$

We transfer the objective function of Y_2 to Minimize by multiplying in by -1 the two side of the function.

The Model will be:

$$\text{Min: } Q = -2.76885\, X_1 - 0.01045\, X_2 - 1.51155\, X_3 + 0.814046$$

$$\text{Subject To: } 0.926 \geq X_1 \geq 0.556$$

$$300 \geq X_2 \geq 80$$

$$2.2 \geq X_3 \geq 0.9$$

$$X_1, X_2, X_3 \geq 0$$

We will neglect the fixed no added to the equation in mathematical model then we will add it to the final solution value of objective function.

So the model will be:

$$\text{Min: } Q = -2.76885\, X_1 - 0.01045\, X_2 - 1.51155\, X_3$$

$$\text{Subject To: } 0.926 \geq X_1 \geq 0.556$$

$$300 \geq X_2 \geq 80$$

$$2.2 \geq X_3 \geq 0.9$$

$$X_1, X_2, X_3 \geq 0$$

The solution of the using WINQSB See Figure 7

	13:13:40		Thursday	February	28	2013		
	Decision Variable	Solution Value	Unit Cost or Profit c(j)	Total Contribution	Reduced Cost	Basis Status	Allowable Min. c(j)	Allowable Max. c(j)
1	X1	0.9260	-1.5115	-1.3997	0	basic	-M	0
2	X2	300.0000	-0.0104	-3.1338	0	basic	-M	0
3	X3	2.2000	-2.7689	-6.0915	0	basic	-M	0
	Objective	Function	(Min.) =	-10.6250				
	Constraint	Left Hand Side	Direction	Right Hand Side	Slack or Surplus	Shadow Price	Allowable Min. RHS	Allowable Max. RHS
1	C1	0.9260	>=	0.5560	0.3700	0	-M	0.9260
2	C2	0.9260	<=	0.9260	0	-1.5115	0.5560	M
3	C3	300.0000	>=	80.0000	220.0000	0	-M	300.0000
4	C4	300.0000	<=	300.0000	0	-0.0104	80.0000	M
5	C5	2.2000	>=	0.9000	1.3000	0	-M	2.2000
6	C6	2.2000	<=	2.2000	0	-2.7689	0.9000	M

Figure 7: WINQSB solution results.

From the previous Figure the efficient solution will be at X_1=0.926, X_2= 300, X_3 =2.2.

7.6. Implementation & Control

In implementation phase we use the value of X_1, X_2, and X_3 from optimization phase in the chromo jet printing setting and follow up and evaluate the effect on the two process outputs Y_1 and Y_2. In control phase we develop and implement control plan that maintain and sustain the results we got from the previous phases such that written procedure, written work instruction, written, and machine setup.

8. Discussion and conclusion:

In this paper, we develop a new methodology for using multi objective optimization technique within six sigma methodology for improve quality to modify DMAIC methodology to DMAMOIC and implement the modified methodology in Chromjet printing process to improve two key process output (responses) simultaneously quantity of printing past and penetration of printing paste on carpet as application and validation of the methodology. The results indicates that the integration between six sigma as continuous quality improvement methodology classified as professional methodology and operations research technique can add and enhance the methodology and add new dimensions to it which can use in process improvement and optimization in many sectors such as manufacturing ,services, and health care. Also we can use the same methodology for more than two key process output (used in this paper) according to the complicity of the process under investigation. The challenge now how to merge the operations research tools and techniques in the quality improvement methodologies to be easy to use for non academic teams.

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