DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEVELOPMENT OF A SOFTWARE FRAMEWORK FOR EXPERIMENTAL DESIGN IN THE CHEMICAL INDUSTRY

by
Pınar AZİMLİ

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İZMİR

DEVELOPMENT OF A SOFTWARE FRAMEWORK FOR EXPERIMENTAL DESIGN IN THE CHEMICAL INDUSTRY

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"DEVELOPMENT OF A SOFTWARE FRAMEWORK FOR EXPERIMENTAL DESIGN IN THE CHEMICAL INDUSTRY"** completed by **PINAR AZİMLİ** under supervision of **ASST. PROF. DR. DERYA BİRANT** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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DEVELOPMENT OF A SOFTWARE FRAMEWORK FOR EXPERIMENTAL DESIGN IN THE CHEMICAL INDUSTRY

ABSTRACT

Cost reduction is very important for the companies as competition increases in the market. Experimental Design Methods are used in various units of enterprises are a major factor for businesses in this direction and provide a way to reach the most accurate desired results by using shortest path with a minimum cost.

In this thesis, a new framework for experimental design and a system, called DOExpert, is proposed and implemented to use at several industries. In particular, we provide several tasks (a) designing a model with Unified Modeling Language (UML) and creating a database (b) implementation of the framework and DOExpert system (c) applying experimental works at chemical industry. Proposed framework contains two Design of Experiment (DOE) approaches: Taguchi Method and Regression Analysis.

In this study, we provide the following new contributions: (i) supporting several DOE methods at the same time, (ii) calculating more than one response values at the same time, (iii) ordering main factors and the effects of their interactions and (iv) finding optimum values of factors for one response variable and (v) finding optimum values of the factors for more than one response variables.

In this thesis, experimental studies were applied at chemical industry. Taguchi experimental method and regression analysis were used to set optimum windows profiles color levels or values during product recipe preparation to reach the desired results. These experimental design methods can be also used for different purposes in different industries.

Experimental results obtained at chemical industry show the effectiveness of the proposed framework. The results show that our framework has a good performance in time and cost. Results obtained in this study shows that approximately 75 percent process recovery can be provided by using experimental design methods.

Keywords: Design of experiment, Taguchi method, regression analysis, chemical industry

KİMYA ENDÜSTRİSİNDE DENEY TASARIMI İÇİN BİR YAZILIM ÇERÇEVESİNİN GELİŞTİRİLMESİ

ÖZ

Pazardaki rekabetin artması ile birlikte maliyetlerin azaltılması şirketler için çok önemlidir. Bu yönde, oldukça önemli bir faktör olan Deney Tasarım Yöntemleri kuruluşlara en kısa yoldan en az maliyet ile istenilen doğru sonuca ulaşmak için yol göstermektedir.

Bu tezde, çeşitli endüstrilerde kullanmak için DOExpert adında yeni bir deney tasarım yapısı önerilmiş ve geliştirilmiştir. Gerçekleştirilen başlıca çalışmalar (a) Birleşik Modelleme Dili (UML) ile bir model tasarlanması ve bir veritabanı oluşturulması (b) yazılım çerçevesinin ve DOExpert sisteminin geliştirilmesi (c) deneysel çalışmaların kimya endüstrisinde uygulanmasıdır. Önerilen yazılım çerçevesi; Taguchi Metodu ve Regresyon Analizi olmak üzere iki tür Deney Tasarımı (DOE) yaklaşımı içermektedir.

Bu çalışmada sağladığımız yeni katkılar: (i) birkaç DOE metodunun aynı anda desteklenmesi, (ii) birden fazla yanıt değişken değerlerinin aynı anda hesaplatılabilmesi, (iii) ana faktörlerin ve faktörlerin ilişki etkilerinin sıralanabilmesi, (iv) birden fazla yanıt değişkeni için faktörlerin optimum değerlerinin bulunmasıdır.

Bu tezde, deneysel çalışmalar kimya endüstrisinde uygulanmıştır. Taguchi yöntemi ve regresyon analizi, istenilen sonuca ulaşmak için pencere profillerinin optimum değerlerinin ayarlanması ve ürün reçetesi hazırlanması aşamasında kullanılmıştır. Bu deneysel tasarım metotları, farklı amaçlar için farklı endüstrilerde de kullanılabilir.

Kimya endüstrisinde elde edilen deneysel sonuçlar, önerilen yazılım çerçevesinin etkinliğini göstermektedir. Sonuçlar göstermiştir ki, oluşturduğumuz yazılım

çerçevesi, zaman ve maliyet yönünden iyi bir performans sağlamaktadır. Çalışmada elde edilen sonuçlar göstermektedir ki, deneysel tasarım yöntemleri kullanılarak yaklaşık yüzde 75 iyileştirme sağlanabilmektedir.

Anahtar sözcükler: Deney tasarımı, Taguchi metodu, regresyon analizi, kimya sektörü

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CHAPTER ONE
INTRODUCTION

1.1 General

Experiment is a product / process development, an idea or learning something in order to prove the accuracy of the observations (Taylan, 2009). The term experiment is defined as a systematic procedure in order to discover an unknown effect, to test or establish a hypothesis, or to illustrate a known effect.

During a process, experiments are needed to define the input's impact on the output to get desired result. Experiments are collected and designed as a model to guide to reach desired results. DOE is used to design experiments. Many input factors which effect on output (alone and together) may be discovered and modeled by using DOE techniques.

Firstly, the objectives of the experiment should be discovered. Input factors are reviewed and main factors are found. By using optimum values of main factors for an experiment, desired result can be achieved. An *Experimental Design* guides us to make a detailed experimental plan to do the experiment. So that necessary effort can be reduced and trials number can be decreased in this way.

1.2 Purpose

In this thesis, we propose a new *Design of Experiment* system, called DOExpert, to provide new contributions over current systems. Differently from the previous works, our system supports several DOE methods at the same time, calculates more than one response values at the same time, orders main factors and the effects of their interactions and finds optimum values of the factors for more than one response variables. DOExpert contains two DOE approaches: Taguchi Method and Regression Analysis.

In this thesis, DOE methods were applied on chemical data to show the benefits of the methods. Experimental results show that our framework has a good performance in time and cost. In order to compare the results, same chemical data is analyzed with other DOE methods by using Minitab program.

1.3 Organization of the Thesis

This thesis includes eight chapters and the remaining of this thesis is organized as follows.

In Chapter 2, general information about *Design of Experiment*, review of the literature at chemical industry and other industries, and the differences of our work from previous works are given.

In Chapter 3, *Design of Experiment* fundamentals and DOE methods like Taguchi, Regression Analysis, Factorial Design, Response Surface are explained.

In Chapter 4, innovations of DOExpert system are explained in detail, flowcharts are shown, and pseudo codes of main functions of our study are explained.

In Chapter 5, database design (E/R diagram) and UML diagrams (use case and class diagram) of DOExpert system, main functions and procedures are given.

In Chapter 6, general usage of DOExpert system is explained with screenshots, and the technologies used like components, developing environment, relational database system detail are explained.

In Chapter 7, experimental work details about color measurement fundamentals, programming logic about analyzing color data values, analysis results and The success rate is discussed in terms of cost, time and labor.

Finally in Chapter 8, the conclusion remarks and future works are given.

CHAPTER TWO
RELATED WORK

The use of experimental design methods at the chemical industry and other fields are increasing day by day. The benefits of these methods are known by experts more than before. In this chapter, some studies about this subject are reviewed. The literature review is given and previous works at the chemical industry and other industries are explained.

2.1 Literature Review

Design of Experiment methods are used at different industries. For example: Taguchi algorithm has been proposed for different areas such as the software testing (Kuhn 2002), the healthcare (Matthews 2008), ecological modeling (Scheiner & Gurevitch 2001), and the financial sector (Libby 2002).

Taylan (2009) deals with the problem of destruction of *A, B, C* materials (occur after production) without harm to natural environment. The work was done by burning of these materials in a static oven by loading different amount and feed rates. However, the base and medium temperature of oven are affected from materials under different amount and the different feeding rate. For this reason, the furnace temperature may vary depending on the conditions. For example, after putting a mixture with very high-calorie degree into oven, base temperature of oven can increase. If the temperature reaches 950C, oven stops automatically and does not start before cool down. In addition to this, heat change of oven base reduces the life of the oven. The goal of this study is to increase the life of this oven and burning amount of *A, B, C* materials under best working conditions. In this study, controlled and uncontrolled variables were reviewed and four important factors were found. Each factor has three levels as low, medium, high. Normally, it was needed to done 81 experiments for this study. The results were reached by using Taguchi method via only 9 experiments.

Taguchi method was used to optimize the steel welding metal's (Gökçe, Talaş & Taşgetiren, 2012). Experimental design and optimization technique was used for optimization. After applying Taguchi method, the results were studied according to tensile strength, yield stress and elongation percentage. Carbon equivalent formula was used for parameter selection. The optimized parameters that give highest values were discovered after studying the results of this work.

Orthodontics is a form of science on dental treatment for applying a force on the tooth by using a wire or special tires. According to direction of force, movement of tooth is obtained. The most common materials used at orthodontic applications are stainless steel, titanium alloys and cobalt-chromium. Beside of mechanical properties of materials, corrosion-resistant property is very important. The usage of orthodontic wire applications needs high corrosion resistance of wire for fluorine-containing toothpastes, acid-containing foods and beverages. The corrosion behavior of orthodontic wires by using classical methods was studied by Taguchi method (Baynal, Altuğ & Ünal, 2012). The classical experimental design method, *3k* multi-factorial experimental design was used. Over time, the pitting corrosion was occurred on the wire's surface. This is a result of the interaction of the chemical solution, the metallic surface of dissolution has occurred. The results of hypothesis test showed that wire type and solution interactions have main effect on corrosion behavior of wires. Minitab interactions graphs showed that the most weight loss is obtained under *Fusuyama* solution and β-Titanyum composite wire.

Öztop (2007) showed industrial applicability of Taguchi experimental design method. Aluminum extrusion process uses circular cross-section aluminum raw materials. The effects of some parameters before the extrusion process were investigated. These parameters are billet temperature, extrusion speed, die shape and extrusion rate. In addition, the effects of the parameters on mold surface temperature, temperature profile were investigated. Taguchi L8 and L16 tables were used to examine the effects of the main and interactions of factors. Taguchi method with L16 tables was used. The results showed that the effects of interactions are minimum so that aluminum extrusion interactions can be omitted. The results of 24 and 16 trials showed a parallel effect so it was understood that Taguchi method can be used for interactions effects. It was decided to use Taguchi method at many industrial applications for the company.

Durmaz (2008) used Taguchi experimental design to ensure product quality at design phase and minimum cost. Taguchi method was applied to prevent quality loses at Rubber process. After giving any shape to a rubber material, it is not possible to use this material again. The goal was to find optimal values of factors to obtain a maximum strength of product on manufacturing phase. Desired resistance type can be changed according to customer request. Some strength types are gas, fire and temperature resistance. The errors that cause breakage of strength were determined (air, inaccurate, incorrect hardness, raw, roasted, etc.). The factors that cause the errors were found. Controlled and uncontrolled factors were determined (e.g. environment temperature, moisture). Taguchi table L16 orthogonal array was used with 9 degrees of freedom. The results were showed that there are 7 controlled factors. So that L16 orthogonal array assignments were made. Instead of doing 9 X37=512 trials, analysis was done by using L16 orthogonal array with 5 repeat. The faulty product was 60% decreased.

Şanyılmaz (2006) studied on quality improvement activities for Taguchi method of experimental design and the implementation of quality improvement activities. Kaleporselen electronic company produces HRC00 blade fuse. Some cracks occur on the surface of blade fuse. The purpose was to apply Taguchi experimental design method to eliminate cracks. Instead of using imported raw material, a domestic raw material was started to use because of the cost. After using domestic raw material, the cracks were increased on the fuse surface. So that controlled and uncontrolled factors and interactions were determined and suitable orthogonal tables were chosen. The firm was used design of experimental results, so that product quality was increased.

2.2 Related Works in Chemical Industry

DOE methods are used at several chemical sectors. This section explains the usage of these methods at the field of chemistry.

Karabaş (2012) studied for biodiesel production from crude acorn kernel oil. Acorn kernel oil with high free fatty acid content is used as raw material to produce biodiesel. The biodiesel production process parameters are the alcohol: oil molar ratio, catalyst concentration, reaction temperature and reaction time (the Acorn Kernel Oil Methyl Ester (AKOME) sample). Each factor has three levels as shown below. For process parameter optimization Taguchi method with L9 orthogonal array was used to analyze factor effects and find optimum values of each factor.

Table 2.1 AKOME factors and levels (Karabaş, 2012)

Design experiments with four three-level parameters for AKOME production.

Parameters	Levels		
	1	2	3
(*A*) Catalyst concentration (wt%)	0.5	0.7	1
(*B*) Alcohol:oil molar ratio	6:1	8:1	10:1
(*C*) Reaction time (min)	40	60	80
(*D*) Reaction temperature (°C)	50	60	55

Signal-to-noise ratio (often abbreviated SNR or S/N) was used to identify the optimum values of parameters. A larger S/N ratio means a better quality. Instead of doing 3^4=81 trials for this experiment, using orthogonal array L9, 9 trials was enough to find optimum values of factors.

These are: *A* (reaction time) at level 1, *B* (alcohol: oil molar ratio) at level 2, *C* (reaction temperature) at level 1 and *D* (catalyst concentration) at level 2. Under these conditions, the AKOME yield in the confirmation experiment is 90%.

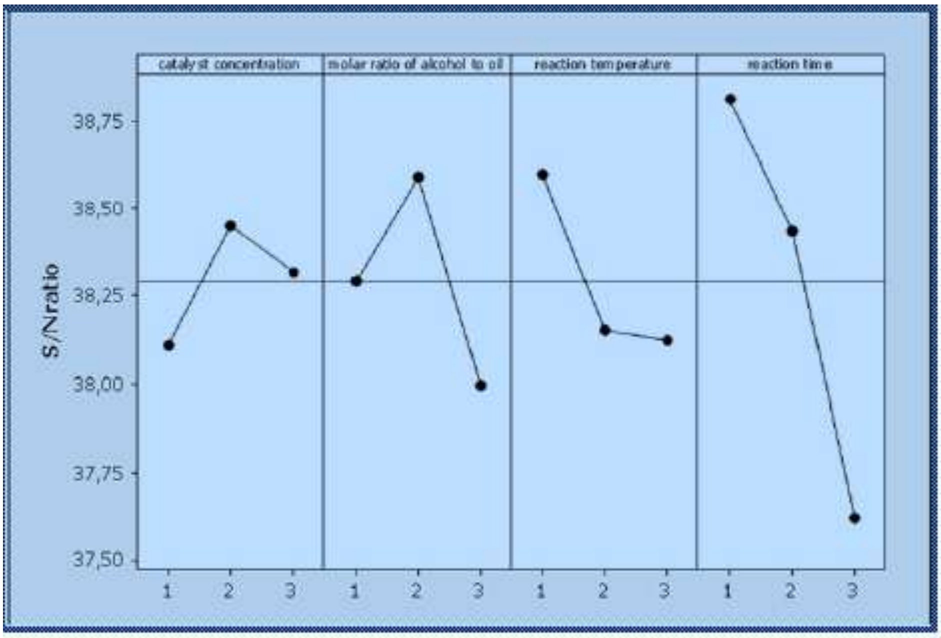

Figure 2.1 AKOME factors effects results graph (Karabaş, 2012)

Madaeni & Koocheki (2006) applied Taguchi method for the optimization of wastewater treatment by using spiral-wound reverse osmosis element. A pilot study for wastewater treatment was conducted using a Reverse Osmosis (RO) system. RO system is the most acceptable method to get very high quality water with the capacity of 14.38 3/d. Before starting to analyze, the flux of water at pilot system was scaled and found about 58 l/m^2h. Trials were done under different conditions like pressures, temperature and concentration.

Three factors (pressure, temperature and concentration) with three levels were analyzed with Taguchi L9 orthogonal array. Before applying Taguchi method, each factor level value was set as shown below. Three factors were named as *A, B, C* (temperature, pressures, concentration) and levels were named as 1, 2 and 3. The interactions between factors are omitted. Analysis of this data was done at QUALITEK-4 (QT4) Version 4.75 software.

Table 2.2 L_9 orthogonal array

Run#	Factor Levels		
	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Deionized water permeability for Filmtec TW30HP-4641 element vs. transmembrane pressure (25 ◦C) figure is shown in Figure 2.2 (Madaeni & Koocheki, 2006).

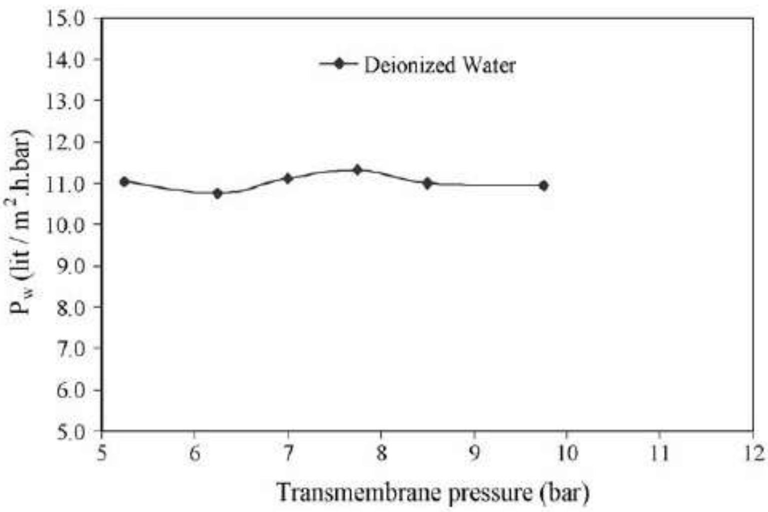

Figure 2.2 Deionized water permeability figure (Madaeni & Koocheki, 2006)

Analysis of the experiments showed that the temperature of feed solution and transmembrane pressure have the most effect in water flux. More pressure causes more flux of water. In addition to this it is shown that the concentration of feed solution has main effect. After applying Taguchi method, controlled factors are set to better level, so that the flux of water was increased to about to 69 l/m^2 h. For this case study, Taguchi method success is about 99.9 % rate of optimization.

Joseph (2007) studied the robust parameter design of a chemical process. The problem is to increase one element amount at a chemical reaction step.
Chemical reaction is described at Formula 2.1 as follows:

$$A \rightarrow^{k_1} B \rightarrow^{k_2} C, \tag{2.1}$$

This means *A* is an initial chemical and converts to *B* at a reaction rate *k1*. *B* converts to another chemical *C* at a reaction rate *k2*. If *B* is a desired chemical and *C* is an unwanted chemical.

In this process there are many control factors like reaction time, temperature, pressure, cooling rate, and stirring rate in the reaction tank. The purpose was to maximize the concentration of *B* by using advised levels of the factors. To do this, experiment is designed so that only one of the factors is changed at the same time, the others remain fixed. It was supposed that *Y1, Y2, Y3* stands for *A, B, C* chemicals respectively. *X* is the pressure. Chemical and experimental data is shown in Figure 2.3 (Fowlkes & Creveling, 1995).

Run	x	Y_1	Y_2	Y_3
1	10	0.3	0.6	0.1
2	15	0.2	0.6	0.2
3	20	0.1	0.6	0.3

Figure 2.3 Chemical and experimental data (Fowlkes & Creveling, 1995)

Plot of the concentrations of the chemicals *A, B,* and *C* against time are shown in Figure 2.4 (Joseph 2007).

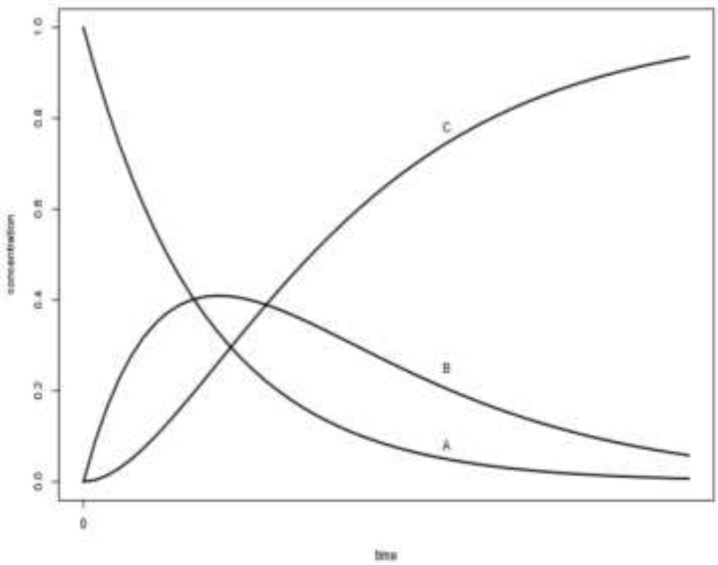

Figure 2.4 Plot of the chemicals and time (Joseph, 1995)

To find *S/N* ratio, some transformations were made as follows:

u1 = Y1, u2 = Y1+Y2, and u3 = Y1+Y2+Y3. Set initial value u3=1

To maximize *Y2*, *u1* needs to minimized, means Smaller-the-better (STB), *u2* needs to be maximized, means Larger-the-better (LTB). For a fraction defective variable (p), Taguchi defined the S/N ratio as

$$SN = -10 \log \frac{p}{1-p}. \tag{2.2}$$

(Phadke, 1989, p.113)

The S/N ratio for *u1* and *u2* is written as follows:

$$SN_1 = -10 \log \frac{u_1}{1-u_1} \text{ and } SN_2 = 10 \log \frac{u_2}{1-u_2}. \tag{2.3}$$

It is obvious that maximizing the S/N ratios will minimize *u1* and maximize *u2*. S/N ratio of this process can be formulated as follows:

S/N Ratio= SN ratio of STB+ S/N ratio of LTB

$$SN \quad = \quad SN_1 + SN_2 \tag{2.4}$$

$$
\begin{aligned}
&= 10\log\left\{\frac{u_2(1-u_1)}{u_1(1-u_2)}\right\} \\
&= 10\log\left\{\frac{(Y_1+Y_2)(1-Y_1)}{Y_1(1-Y_1-Y_2)}\right\}.
\end{aligned} \tag{2.5}
$$

For x=10, 15, 20, the three S/N ratios are 13.2, 12, and 13.2 according to the S/N ratio the setting x = 15 is bad, whereas x = 10 and x = 20 are equally good. If S/N ratios are reviewed, it is shown that x = 15 is bad, but x = 10 and x = 20 are equally good. At x = 15, Y1 = Y3, there is not much scope for improvement. At x = 10, the process can be run so that more of *A* can be converted to *B* and *B*'s concentration increases. The reaction time can be decreased at x = 20 to increase the concentration of *B*. So that S/N ratio is a measure which increase the performance of the process independent of the adjustment. A better performance measure can be derived using chemical kinetics.

As a result of robust parameter design investigation of adjustment factor for an experiment is very important. Because adjustment of factors can be used to simplify experiment by using fixed adjustment factors at fixed value.

2.2 Innovation

Several literatures were reviewed at different areas but there are not found any work about DOE framework developed in Turkey. A new framework which has more features is needed to enable an opportunity to analyze experimental data easily. Before starting to develop a framework, some current DOE programs like Echip, Minitab were analyzed, they were applied on sample data and the results of the programs were examined.

In this study, a new system, called DOExpert, was developed for DOE. This system contains the following new innovations: (i) it analyzes the project trials for several methods like Mean Value, S/N at the same time, so user can reach the result in a short time, (ii) it provides a way for analyzing the all response variables at the same time and project trial may have more than one response variables like pressure, time etc. (iii) it allows users to show the Taguchi tables in detail by ordering of main and interaction affects so that user can learn the effects order without looking Analysis of Variance (ANOVA) table results which are very complex, (iv) it advices an optimum value for the factors for one response variable, (v) it finds the optimum values of factors for more than one response variables.

CHAPTER THREE
DESIGN OF EXPERIMENT

3.1 Description of the Experiment

An experiment is a product / process development, an idea or learning something in order to prove the accuracy of the observations (Taylan, 2009). The term experiment is defined as the systematic procedure in order to discover an unknown effect, to test or establish a hypothesis, or to illustrate a known effect.

3.2 Design of the Experiments

The impact of input factors on response variable should be investigated for experimental results. Experiments are collected and then a model is designed using the experiments. This model guides to achieve the desired result. In this way DOE methods are used to design experiments. These methods give an opportunity to investigate the input factor effects on output (alone or together).

Several statistical design methods are used to reach desired results. Firstly, the objectives of the experiment should be discovered. After that important factors which have main effect on result should be reviewed. An *Experimental Design* guides us detailed experimental plan to do the experiment so needed effort can be reduced and trials number can be decreased to achieve the result.

The following sections present general information about the fundamentals, process model, history and basic principles of DOE.

3.2.1 Process Model for DOE

The components of *Experimental Design* are: (Figure 3.1)

- *Factors*, inputs of process. Factor can be controllable or uncontrollable variables.

- *Levels*, factor settings
- *Response*, experiment outputs

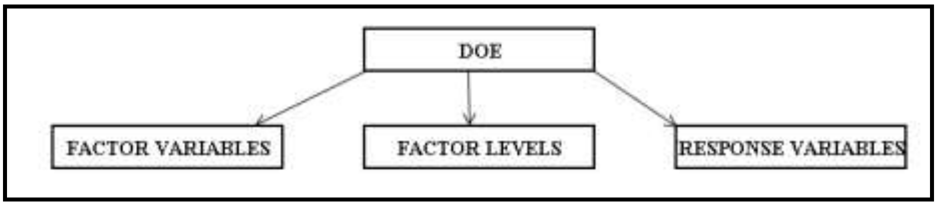

Figure 3.1 Components of experimental design

DOE can be considered as a black box that has input factors and output(s). As shown in Figure 3.2, it produces desired results using input parameters under external factors. The goal is to achieve result with minimum trials. Another goal is to minimize the effects of external sources and uncontrolled variables at result.

This methodology makes it possible the optimization of a system. After optimization the best input combinations can be created and also productivity can be increased.

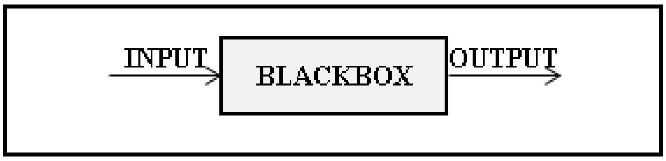

Figure 3.2 Scheme of a black box

3.2.2 History of DOE

Design of experiments was invented by Ronald A. Fisher in the 1920s and 1930s. Firstly, this method was used at agricultural research to reach desired result under nature events like temperature, soil conditions, and rain fall. After using in an agricultural context, the method was started to use at military and industry since the 1940s.

Experimental design was used to find the cause of bad sources at a naval shipyard during World War II. George Box is a main developer of experimental design processes. He was employed by Imperial Chemical Industries. These processes enable to optimize a chemical process. At the beginning of 1950's, W. Edwards Deming taught statistical methods, including experimental design. The most well-known Japanese scientist is Genichi Taguchi. Quality improvement methods were developed by him.

Toyota is one of the companies that use Taguchi methods to improve quality. Since the late 1970s, U.S. industry started to use Taguchi methods at their programs named as "Total Quality" and "Six sigma" to improve their quality.

3.2.3 Basic Principles of DOE

3.2.3.1 Randomization

Randomization is a critical step at any experiment if experiment has at least two treatments, every treatment should be assigned randomly.

3.2.3.2 Replication

At replication step, experiment conditions are repeated. Experimental error can be estimated easily. Accuracy of an experiment increases with replication. The uncertainty of the results of an experiment can be controlled.

3.2.3.3 Blocking

Experimental units are divided into homogeneous blocks. After that any treatment comparison is made on blocks that contain similar units. Experimental errors can be decreased and precision of an experiment can be increased.

3.2.3.4 Multi-Factor Designs

During an experiment, there may be more than one factor. If one of these factors changed while the others remain fixed, it will be difficult to get the desired result in a short time. Firstly, main factors should be determined and more than one factor should be changed at the same time. In this case, an effective result can be reached in a short time.

3.2.4 The Usage of Experimental Design

a) Discovering Interactions between Factors.

There is a need for discovering the effects of combined factors. The interactions of factors may be more significant effect than main factor effects. So this step is very important process of DOE.

b) Screening many factors

A process consists of input variables (raw materials), condition factor (temperature) levels and outputs. A computer simulation program which is developed to model this process can show importance of any factors on outputs.

c) Establishing and maintaining quality control

Quality control offers a chance to produce perfect products to satisfy customer needs. DOE methods provide a chance to do this.

d) Optimizing a process

Optimization is an iterative process that determines an optimal region for a process.

e) Designing robust and reliable products in an effective way

After defining factor effects and finding and optimum values of the factors, reliable products can be produced with minimum cost at a short time.

3.2.5 Experimental Design Process

3.2.5.1 Experimental Design Steps

A *Design Process* begins with the definition of the problem and ends with a solution. D.T. gathered the steps under the hood (Anagün, 2000). The steps of design process are presented in Figure 3.3.

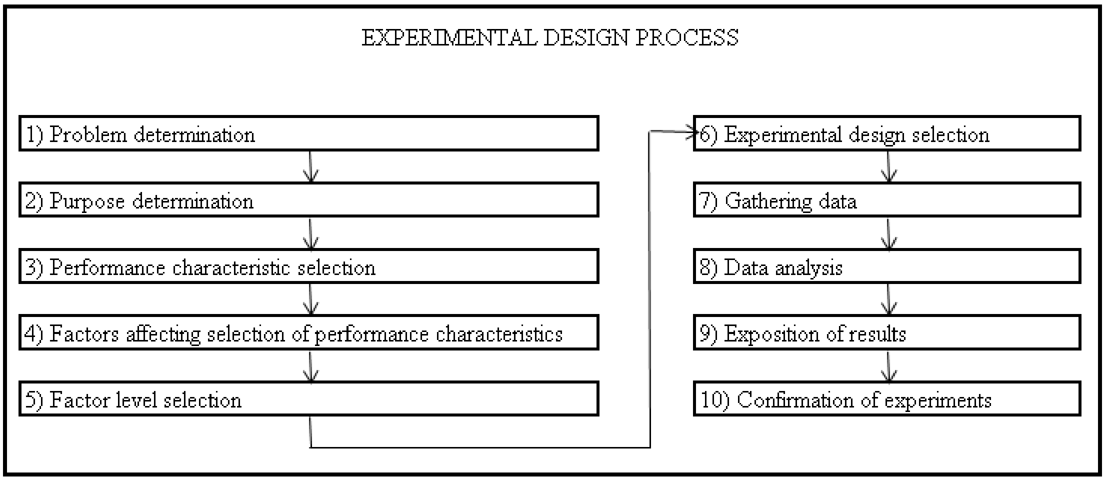

Figure 3.3 Design of experiments (DOE)

3.3 DOE Methods

3.3.1 Experimental Design with Classic Design Methodology

An experiment consists of several factors with different affects. With classical method, one of these factors is changed and the experiment results effect are observed. The impact of the changed parameter can be shown with this method. In this method, the interaction between the parameters will be ignored. It is obvious that the interactions may be more significant than main factors. Classical method causes waste of time and cost and omits interaction effects.

3.3.2 Experimental Design with Statistical Design Methodology

The lack of some points of classical methods led to develop statistical design methods. The interactions among factors can be defined as statistically. During experiment some uncontrolled factors can be modeled and controlled. In this case, experiment errors can be minimized. The interactions between the variables are determined with statistical methods. After doing the estimation of real variance, some predictions can be made using these variance variables.

3.3.3 Factorial Design

Factorial Design is a popular design method that was advised by Fisher and Yates. Factor main effects and interactions effects can be researched at the same time with this method. The number of factors can be two or more. Instead of researching one factor at a unit time, more than one factor can be researched at the same time so that this method is more useful than classical methods.

3.3.3.1 Full Factorial Design

The factors of an experiment may have two or more levels. Each factor has levels as `high' and `low' or `+1' and `-1', respectively.

Table 3.1 Full factorial design

Number of factors	**Number of runs**
2	4
3	8
4	16
...	...
7	128

Table 3.1 shows the combination of two levels for each factor, if factor number is more than 5, the number of combination of these factor grow. If there are *k* factors,

each at 2 levels, a full factorial design has *2k* runs. In this case, an experiment is done in an inefficient way.

Table 3.2 shows an example of 2 factors, 2 levels as -1,+1.

Full factorial design has each combination of these levels so that for this example there are 4 trials.

Table 3.2. Full factorial design example (2 factors, 2 levels)

A	B
-1	-1
-1	1
1	1
1	-1

Figure 3.4 shows the 3 factors x1, x2, x3 and 2 levels full factorial design at a cube.

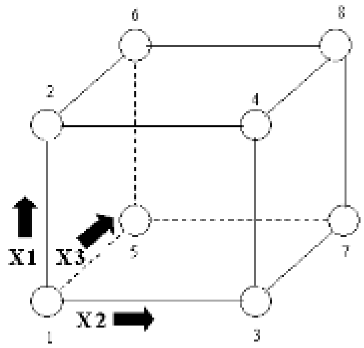

Figure 3.4 Full factorial design (3 factors, 2 levels, 8 points). (Croarkin, Guthrie & Others, 2003)

3.3.3.2 Fractional Factorial Design

If the number of factors is *k* and each factor has two levels, according to full factorial design, the number of trials will be *2k*. More trial number means more cost, time and inefficiency. It is needed to discover center point trials, to reach result in a short time. The solution to this problem is to use only a fraction of the trials of full factorial design. In general, a fraction such as ½, ¼, etc of the trials are used.

For example, $2^7 = 128$ full factorial design contains 128 trials.

For full factorial design, a block contains 128 trials can be used.

1 block*128 trial=128

For ½ factorial design, one of the two blocks can be used (each block has 64 trials).

2 block *64 trial =128

For ¼ factorial design, one of the four blocks can be used (each block has 32 trials).

4 block *32 trial =128

3.3.4 Taguchi Method

The purpose of Taguchi method is to produce high quality product at low cost. The Taguchi method was developed by Dr. Genichi Taguchi. Taguchi uses orthogonal arrays to organize the main parameters and their levels. The number of experimentation can be decreased by determining of main factors. Time and cost saving are done by using this method.

3.3.4.1 Philosophy of the Taguchi Method

a) Quality should be designed into a product. This process is designed as system design, parameter design, and tolerance design. At parameter design, the main process parameters that affect the product are determined.

b) Quality has same meaning with the minimizing the deviation from a target. An uncontrollable environmental factors affects should be minimized. Shortly, the signal (product quality) to noise (uncontrollable factors) ratio should be high.

c) The concept of loss function is the cost of quality should be measured as a function of deviation from the standard and the losses should be measured system wide. The goal of the Taguchi method is to reduce costs to the manufacturer and to society from variability in manufacturing processes.

Figure 3.5 shows the graph of Taguchi loss function. In this function, *T* is the target value of quality characteristic, *L* is the lower specification limit of quality characteristic, *U* is upper specification limit of quality characteristic, c is loss associated with a unit produced at the specification limits, assuming the loss at the target is zero.

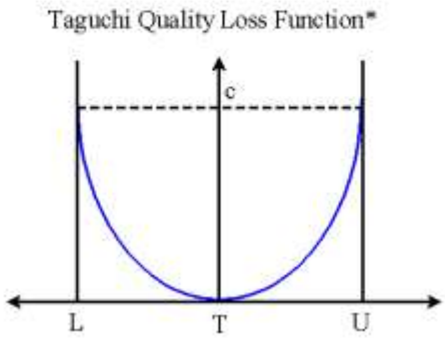

Figure 3.5 Taguchi quality loss function (Kim & Liao, 1994)

3.3.4.2 Taguchi Method Steps

Taguchi method has five steps which are explained in detail below. The purpose of any experimental work should investigated by interviewing with experts and examining input and output factors to reach desired result in an effective way. Taguchi orthogonal arrays provide a way to reach desired result by doing minimum experiment. After explaining the steps of Taguchi method, it is well understood the benefits of this method for minimizing experiments number (Fraley & Others, 2012).

1. Define the process objective, a target value for a performance measure of the process.

2. Determine the design parameters affecting the process. Parameters should be easily controlled within the process such as temperatures, pressures. Parameter levels should be determined as a level. When the number of levels is increased, the number of experiments will increase in a linear way.

3. For each experiment orthogonal arrays are created for the parameter design indicating the number of any conditions. Orthogonal array selection is based on the number of parameters and their levels.

4. Do experiments specified in the orthogonal array to find data on the effect on the performance measure.

5. Data analysis is done to determine the effect of the different parameters on the performance measure.

3.3.4.3 Determining Parameter Design Orthogonal Array

The proper orthogonal array can be selected by knowing the number of parameters and the number of levels. Array selector table is used to find appropriate orthogonal array by looking the column and row intersection. As column corresponds to the number of parameters, row corresponds to the number of levels. Taguchi orthogonal array selector is shown in Figure 3.6.

	Number of Parameters (P)														
Number of Levels	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32						
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50				

	Number of Parameters (P)														
Number of Levels	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L36	L36	L36	L36	L36	L36	L36								
4															
5															

Figure 3.6 Orthogonal array selector (Roy, 2001)

There is an example experiment table below with 3 parameters each have 2 levels. A proper array table for these combinations is named as L4 orthogonal table, shown in Figure 3.7.

Experiment	P1	P2	P3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Figure 3.7 L4 design, combinations of factors levels

3.3.5 Response Surface Methodology

Response surface methodology, "Test-optimal conditions Reach" with the name defined in 1951 and developed by Box and Wilson. The method was first applied to the chemical industry. Myers & Montgomery describes this method as statistical and mathematical functions to optimize a response variable.

This method has 3 stages: (i) screening experiments, (ii) regional research and (iii) the optimal operation point. Response can be shown via three dimensional space graphics or contour plots. First of all this method finds the relationship between input variables and applies method on experiments by using low order polynomials.

A second-order model can be constructed efficiently with central composite designs (CCD) (Montgomery, 1997). Figure 3.8 shows the response surface methodology at a cube.

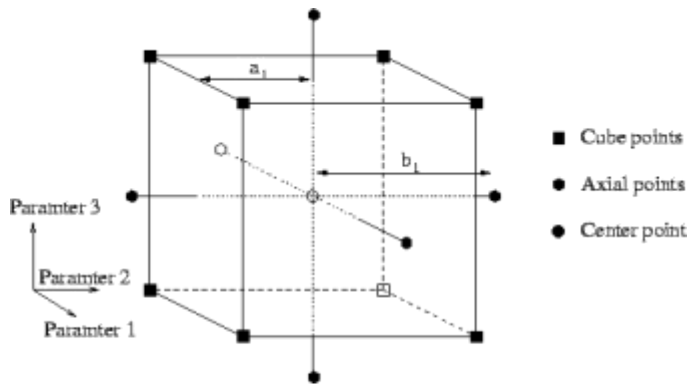

Figure 3.8 The example points of a CCD with three input parameters. (Montgomery, 1997)

The above design involves 2N factorial points, 2N axial points and 1 central point. N:number of parameters

Two important models are commonly used in RSM. These are special cases of model (1) and include the first-degree at Formula 3.1 model and second-degree model at Formula 3.2.

$$y = b_0 + b_1x_1 + b_2x_2 + e \tag{3.1}$$

$$y = b_0 + b_1x_1 + b_2x_2 + b_{11}x_{11}^2 + b_{22}x_{22}^2 + b_{12}x_1x_2 + e \tag{3.2}$$

In Formula 3.1 and Formula 3.2, y is the dependent variable, x1, x_2, x_{11}, x_{22}, x_1x_2 are independent variable, e is the error item, b_o is intercept item, b_1, b_2, b_{11}, b_{22}, b_{12} are the coefficients.

Model parameters are found with regression analysis, regression coefficients are found with least square method. After finding regression model, predictions are made to test this model and optimization is done by using regression equation.

3.3.6 Regression Analysis

Regression Analysis is used to find the relationship between two or more than two variables. Regression Analysis's method name is defined according to count of the variables that are used.

Simple regression is used for one independent variable, multiple regression analysis is used for more than one independent variable. Regression problem is solved by using dependent and independent variables. Dependent variable is shown as *Y*, independent variables are shown as *X*. The relationship between variables can be linear or nonlinear.

Regression equation is written as shown Formula 3.3 below:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_n X_n + \varepsilon \tag{3.3}$$

In Formula 3.3, Y is the dependent variable, X_n are the independent variable, β_0 is the intercept item, β_n are the n coefficients for independent variables, Ɛ is the error item.

The questions that can be answered with Regression Analysis are:

- find relationship between dependent and independent factors.
- find the power and kind of correlation of this relationship

- make prediction.

As shown below, *x* and *y* values are market at *X*, *Y* scatter diagram as *x* and *y* axis. After that regression line which intercepts these values is drawn. The purpose is to minimize the distance between predicted and real values.

Figure 3.9 shows a typical regression line graphic.

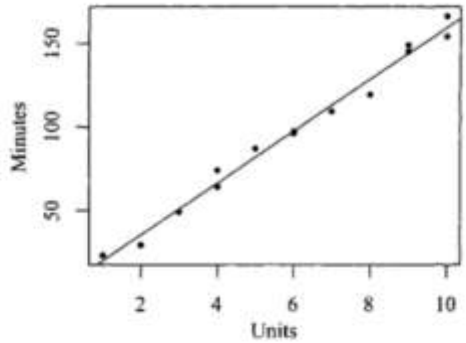

Figure 3.9 Least Squares Method sample (Cheng, 2006)

Multivariate regression estimation for the regression coefficient, such as the two-variable regression is done by the method of least squares. This means that the shortcut will be used to minimize the sum of squares of the residuals will be revealed.

In other words, the difference between real and predicted values should be minimum. The error between real and predicted value is shown in Formula 3.4.
The difference can be expressed as:

$$\sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \tag{3.4}$$

y_i (x) : real, $\hat{y}_i$ (x) : predicted value , e_i : error between real and predicted value

Regression equation formula shown in Formula 3.5.

$$b_0 = \bar{y} - b_1\bar{x} \qquad b_1 = \frac{\sum_{i=1}^{n} x_i y_i - (n\,\bar{x}\,\bar{y})}{\sum_{i=1}^{n} x_i^2 - (n\,\bar{x}^2)} \tag{3.5}$$

CHAPTER FOUR
PROPOSED APPROACH

4.1 Innovation Details

Before developing a new system, the following tasks were done:

- *Design of Experiment* subject was studied and also literature review was done.
- Interviews were done with experts who work on a chemical company.
- A chemical company laboratory works were investigated for the applicable of DOE methods in an effective way. In this chemical company, lots of product types are produced according to customer request.
- Some DOE programs were investigated in detail but there are not found any domestic software framework for this purpose.

All these tasks showed that it is needed to develop a new framework to analyze laboratory works and to reach the optimum results. So, DOExpert system was developed with the innovations that are explained in detail below.

4.1.1 Supporting Several Methods

Experimental work can be analyzed by using several calculation methods. These are Mean Value, Signal/Noise ratio (S/N) value or logarithmic calculations. Mean value is the average of experiment trials result for the same combinations of input factors. S/N values are estimated because maximum S/N ratio indicates the success of the model. In this work, some calculation methods were developed and the number of methods can be increased by writing new functions into DOExpert software database package.

4.1.2 Supporting Several Response Variables

After applying DOE methods on some chemical data, it was shown that there may be more than one response variable for same input factors. Experts should find the optimum level or values of the factors that supply more than one response variable.

Project trials can be done with a high cost. When experimental methods are applied, more than one result value can be entered into the system so that more than one response value can be calculated and observed at the same time. A temperature and pressure can be analyzed at the same time with this framework as an example. So expert analyze time can be reduced. All these features were supported with our DOExpert system.

4.1.3 Supporting Interaction Tables

Current DOE programs don't provide the details of Taguchi method estimation table. The only way to understand and interpret the results it is needed to use ANOVA table which is very complex for the expert who has not an expert on statistical calculations. Main factor and main factor interactions affect can be ordered at these programs. For example Minitab program, with Taguchi method can order only main factor and factor interactions. Our work shows the results and effect values as a table. In addition, the order of the main and interaction effects can be monitored by using DOExpert software.

4.1.4 Supporting Optimum Factor Values for One Response Variable

DOExpert system saves the analysis results of project trials so that personnel can use these results to find the optimum factor values for one response variable.

4.1.5 Supporting Optimum Factor Values for Multiple Response Variables

This innovation is done because, in some works, there is more than one equation and experts want to find the optimum values for more than one response values. Our system contains some methods to achieve this result

4.2 DOExpert System Flowcharts

DOExpert system needs a valid user name and password for authorization. A user should have a valid user name and password to use this software. If not, system administrator should define a user name and password for each user. The flowchart in Figure 4.1 shows the *User Configuration* part of DOExpert system.

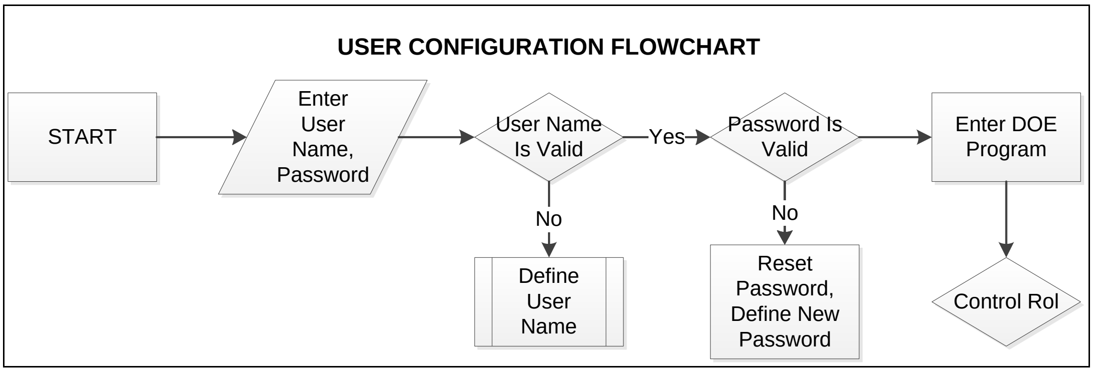

Figure 4.1 User configuration

Figure 4.2 shows the *Menu Definition* part of DOExpert system. An authorized user can define menu items. If the menu item is defined before routine stops, if not, user enters menu item and saves the data into the database.

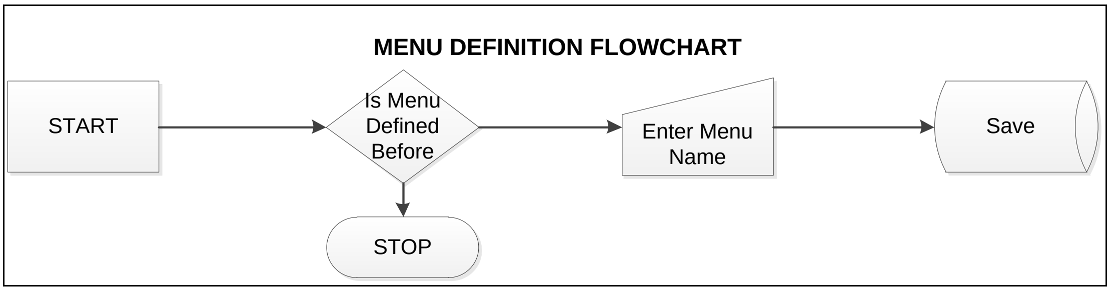

Figure 4.2 Menu definition

User Authorization Control part of DOExpert system is shown in Figure 4.3. It contains menu definition, user definition, Taguchi table definition, experimental project definition and project trial entrance and experimental analysis roles.

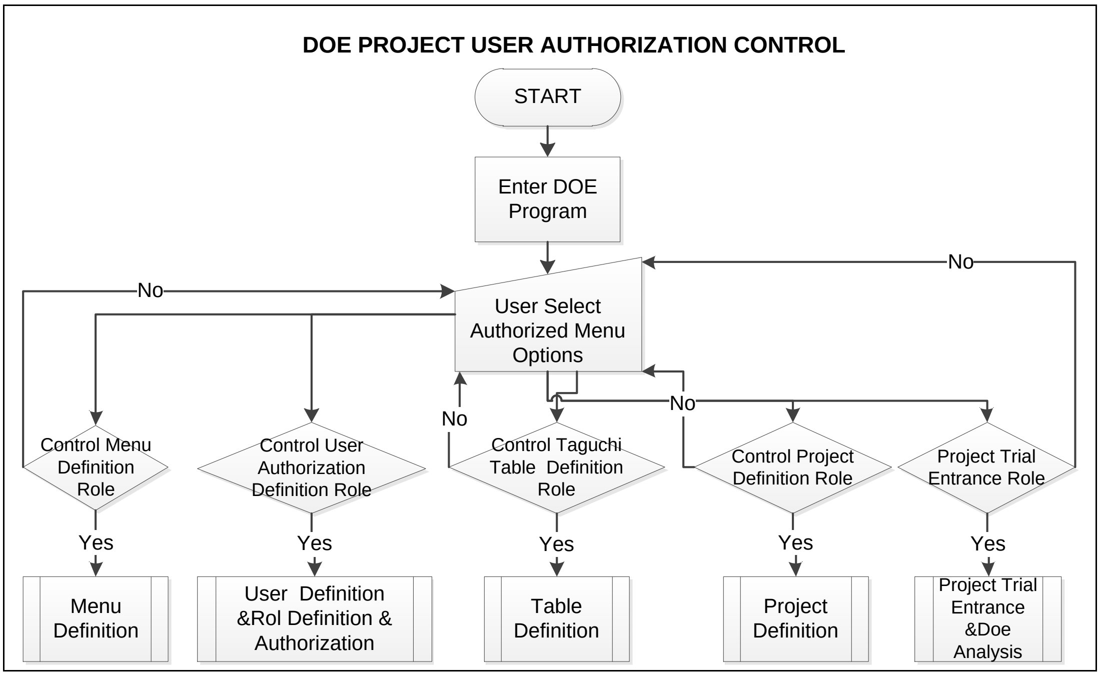

Figure 4.3 User authorization control

Figure 4.4 shows *Role Definition* part of the system. An authorized user can define roles for user by selecting roles. If a role does not exist, authorized user defines a role by giving a role name and selecting menu items for this role. If a desired menu item does not exist, routine stops, menu definition routine should be run to define new menu item. If the desired menu item exists then user selects menu item for this role and saves data into the database.

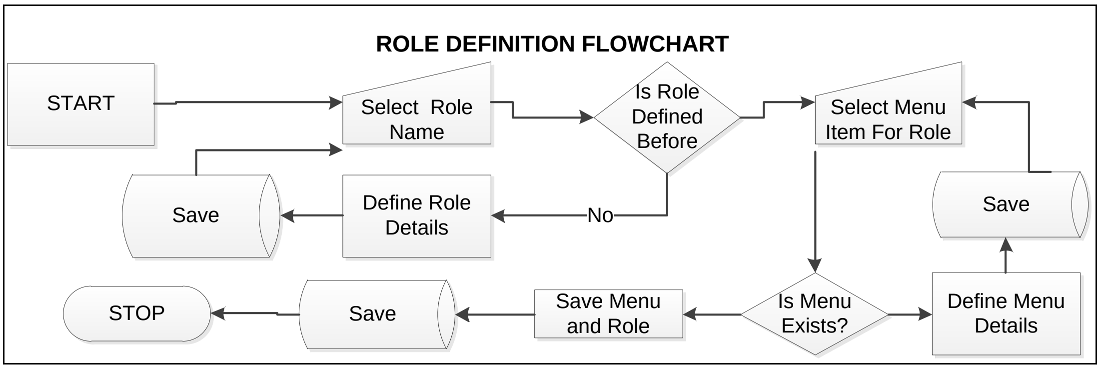

Figure 4.4 Role definition

The flowchart in Figure 4.5 shows the *Taguchi Table Definition* part of the system. An authorized user defines table structures of Taguchi tables like L8, L16, L32 and defines the table interactions and estimation table structures. Taguchi table definition part of the system creates a framework for DOE analysis. This framework can be defined by a system user or copied from database tables by using Oracle PL/SQL scripts or import from an Excel file.

.

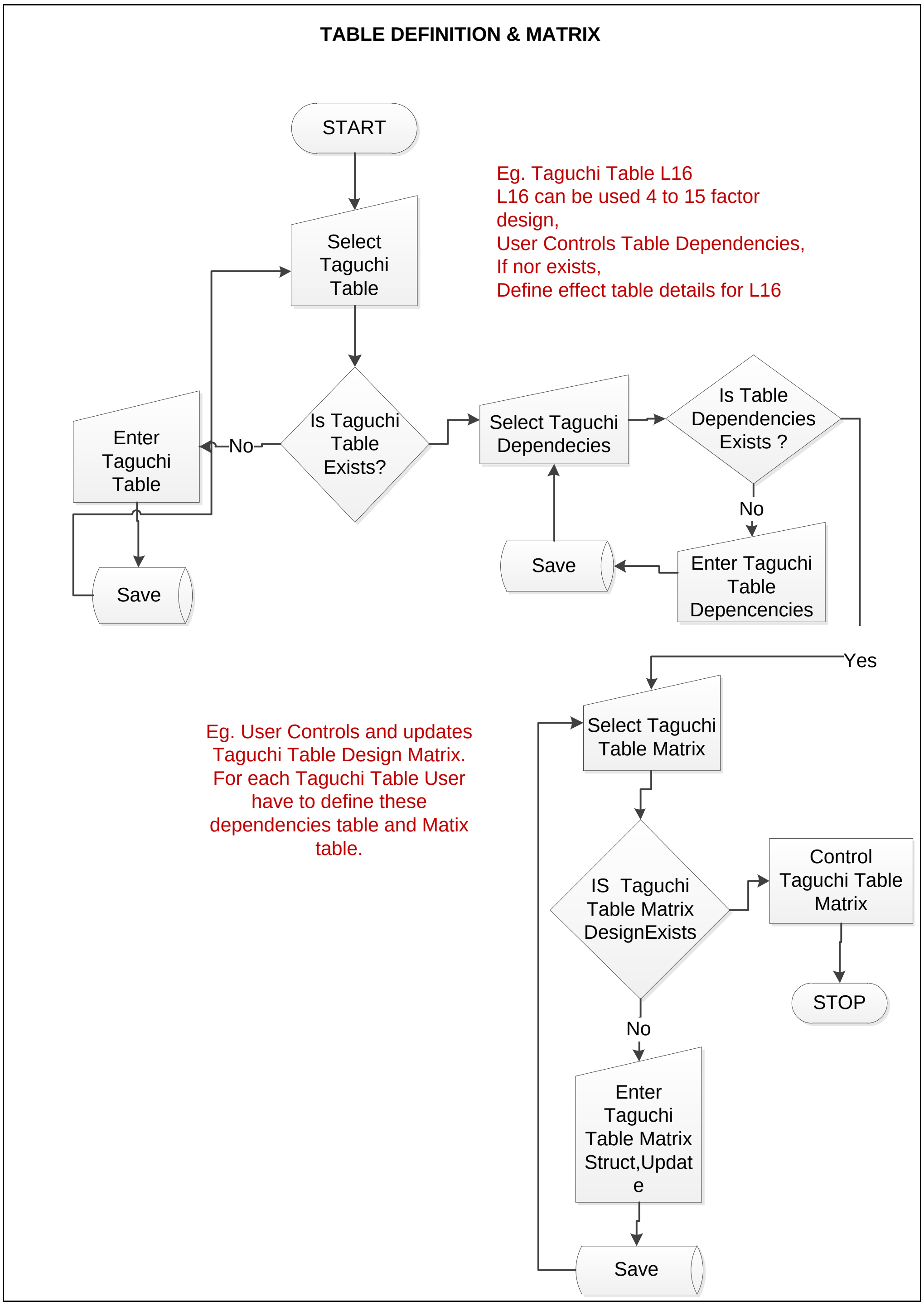

Figure 4.5 Taguchi table definition

Figure 4.6 shows *Project Definition* part of the system. An authorized user can define experimental projects. If a project exists, routine stops. If a project does not exist, user enters project name and detail like factor count level count. After pressing generate button, table structure is created automatically. User enters factor's name, level's values and units of the factors and saves data into the database.

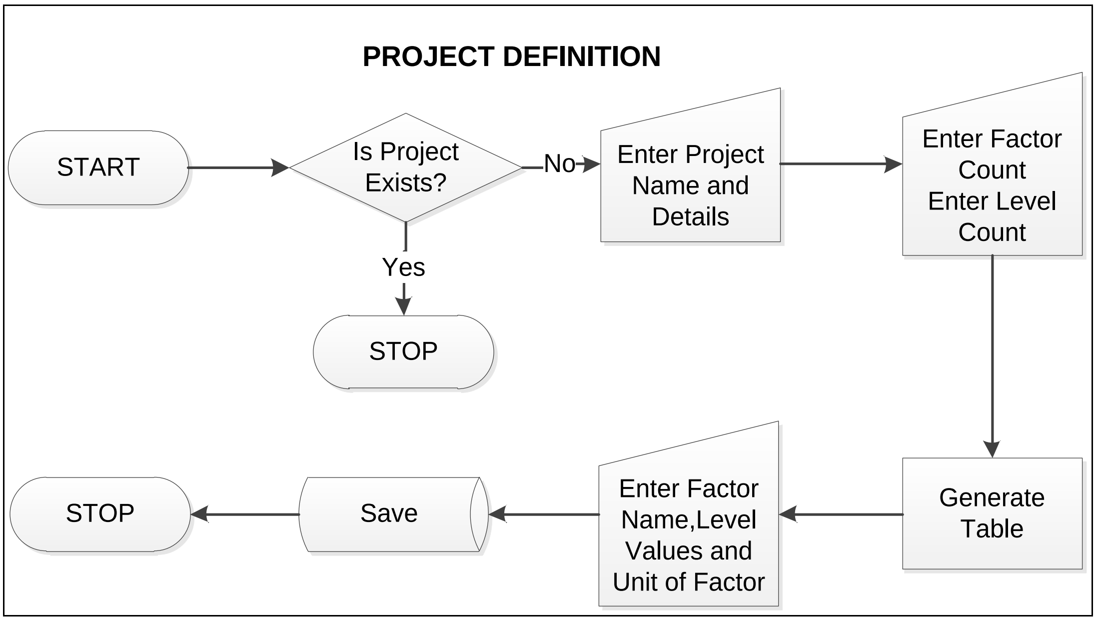

Figure 4.6 Project definition

Figure 4.7 shows the *Project trial prediction* part of the system. This system allows user to predict result with a selected method and response results. User selects factors and factor's levels. Afterwards, system shows prediction result on the screen.

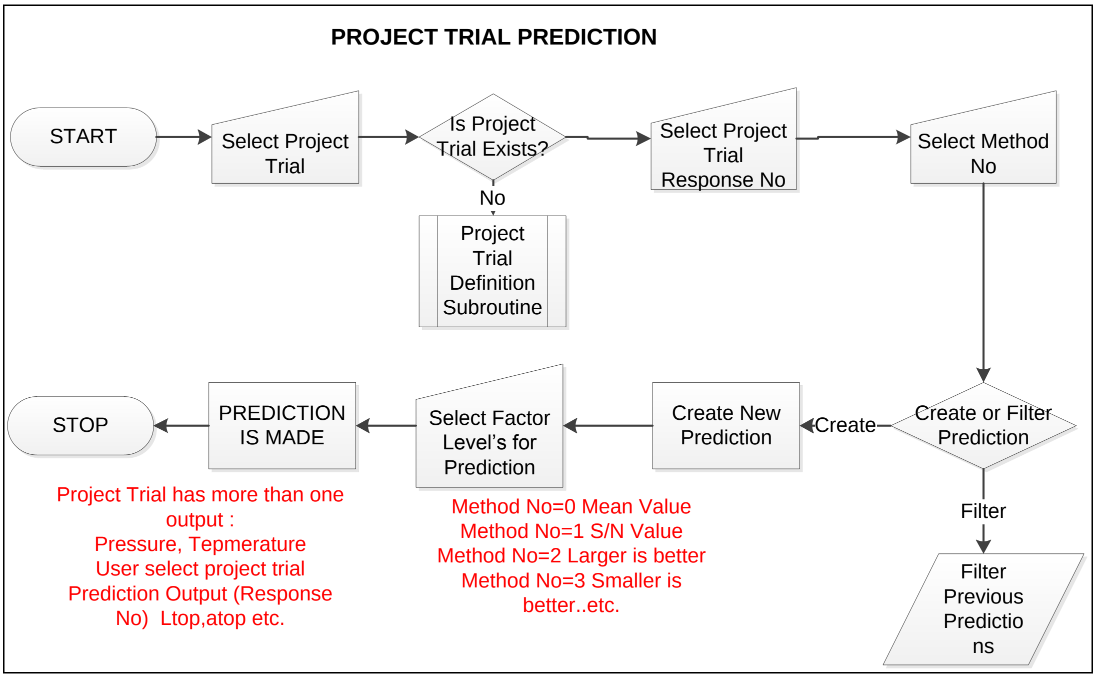

Figure 4.7 Project trial prediction

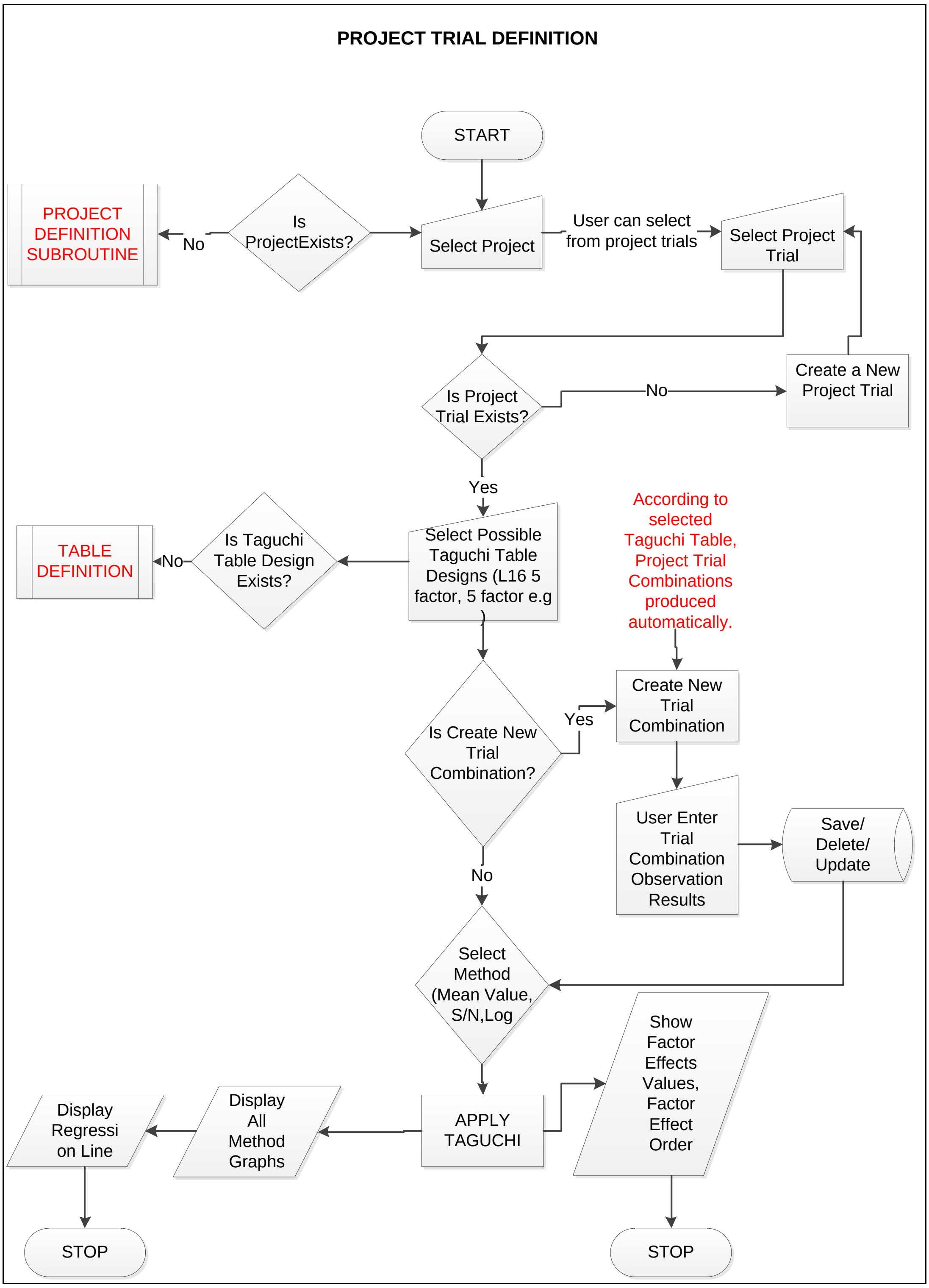

Figure 4.8 Project Trial Definition

Figure 4.8 shows the *Project Trial Definition* part of the system. User selects a Project and enters a trial for a project. In order to analyze a trial, user selects Taguchi table that is defined on the system. DOExpert system shows the suitable tables for a trial. If a suitable table exists, trial combinations are created by the system. User enters the response values and applies Taguchi method to analyze the results. Afterwards, system gives the effects of the factors and factors interactions on the screen.

4.3 Presudocode

4.3.1 Create Project Table

This function shown in Table 4.1 creates project table, column, column levels, cells according to suitable Taguchi estimation table structure for a project trial.

Table 4.1 Create project table

```
FUNCTION  CREATEPROJECTTABLE (pProjectNo :integer, pTrialNo:integer)
Return integer
DECLARE integer vtablo
DECLARE integer  vrowno
BEGIN
   #Taguchi Table structs
OPEN "tg_table_column" FOR Input As TableColumn
OPEN "tg_table_column_detail" FOR Input As TableColumnDetail
OPEN "tg_project_parameter" FOR Input As ProjectParameter
OPEN "tg_table_column_level" FOR Input As TableColumnLevel
 #Project Tabl's
OPEN "tg_project_table_column" FOR Output As ProjectTableColumn
OPEN "tg_project_table_column_param" FOR Output As ProjectTableColumnParam
OPEN "tg_project_table_column_level" FOR Output As ProjectTableColumnLevel
OPEN "tg_project_table_value" FOR Delete As ProjectTableValue
 #find Project trial Table_no and TrialNo
    SET  vtablo:=READ Table_No FROM  Project_ Trial FOR Project_No=pProjectNo AND
trial=pTrialNo)
    SET  vrowno:=READ Row_No FROM  Project_ Trial   FOR Project_No=pProjectNo AND
trial=pTrialNo)
#construct Project table values,column,column levels
DELETE FROM ProjectTableValue  FOR Project_No=pProjectNo
DELETE FROM ProjectTableColumnLevel FOR Project_No=pProjectNo
DELETE FROM ProjectTableColumnParam FOR Project_No=pProjectNo
DELETE FROM ProjectTableColumn FOR Project_No=pProjectNo
#construct Project table columns for main factors
WHILE (NOT EOF(TableColumn) AND Table_No= vtablo)
READ TableColumn, param_no as column_no
READ  ProjectParameter, param_name as column_name FOR ProjectNo=pProjectNo
WRITE ProjectTableColumn, project_no, trial_no, column_no,column_name
END WHILE
#construct Project table columns for Taguchi table interactions
WHILE (NOT EOF(TableColumnDetail AND Table_no= vtablo  AND Row_no= vrowno))
READ TableColumnDetail, column_no, column_name
WRITE ProjectTableColumn, project_no, trial_no, column_no,column_name
```

Table 4.1 Create project table

```
END WHILE
#Construct Table Column Parameters
WHILE (NOT EOF(ProjectParameter) AND Project_no= pprojectno)
READ ProjectParameter, column_no ,column_no as parameter_no, column_name
WRITE ProjectTableColumnParam, project_no, trial_no, column_no,param_no
END WHILE
#Construct Project Table Column Levels
WHILE (NOT EOF(TableColumnLevel) AND Project_no= pprojectno)
READ TableColumnLevel, column_no ,level_no
WRITE ProjectTableColumnLevel, project_no, trial_no, column_no,level_no
END WHILE
#Close  Tables
CLOSE TableColumnDetail
CLOSE TableColumn
CLOSE ProjectParameter
CLOSE TableColumnLevel
# Close Project Tables
CLOSE projecttablecolumn
CLOSE projecttablecolumnparam
CLOSE projecttablecolumnlevel

END FUNCTION
```

4.3.2 Creating Project Table Result Function

This function shown in Table 4.2 runs after CreateProjectTable function. According to Taguchi table, the sum, average, effects of project table cells are calculated, main and interactions of factors effects are ordered with this function.

Table 4.2 Create project table result

```
{This function creates Taguchi matrix table cell values.}
FUNCTION  CREATEPROJECTTABLERESULT (pProjectNo :integer,
pTable:integer,pTrialNo:integer,pYontem integer,pResponse integer) Return integer

DECLARE integer vtablo
DECLARE integer  vrowno
DECLARE integer vresult,vrealobsno
DECLARE integer vtvaluecount,vrealvaluecount, vtvaluesay, vrealvaluesay
DECLARE real vtvaluetop,vrealvalueTOP,vtvaluesay,vrealvaluesay,vgenelorttvalue,vgenelortrvalue

        BEGIN
 #Project Tabl's
OPEN "tg_project_table" FOR Output As ProjectTable
OPEN "tg_project_table_value" FOR Output As ProjectTableValue
OPEN "tg_project_table_matrix" FOR Input As ProjectTableMatrix

 #find Project trial Table_no and TrialNo
        SET  vtablo:=READ Table_No FROM  Project_ Trial FOR Project_No=pProjectNo AND
trial=pTrialNo)
```

Table 4.2 Create project table result

```
    SET vrowno:=READ Row_No FROM Project_ Trial FOR Project_No=pProjectNo AND
trial=pTrialNo)

#delete ProjectTable and ProjectTableValue
DELETE FROM ProjectTable FOR Project_No=pProjectNo AND Trial_no= pTrialNo
AND method_no=pyontem AND response_no= pResponse
DELETE FROM ProjectTableValue FOR Project_No=pProjectNo AND Trial_no=pTrialNo
   AND method_no=pyontem AND response_no= pResponse

#insert estimation table matrix into Project Table matrix
WHILE (NOT EOF(TableMatrix) AND Table_No= vtablo)
READ TableMatrix, observation_no
WRITE ProjectTable, pProjectNo, pTrialNo, observation_no, tvalue =0,
   result_no= 1, method_no =pyontem,response_no=presponse
END WHILE

#insert estimation table matrix into Project Table Value matrix
WHILE (NOT EOF(TableMatrix) AND Table_No= vtablo)
READ TableMatrix, column_no, level_no, observation_no,status
IF status='A' THEN vresult:=1
Else vresult:=0
WRITE ProjectTableValue,
         ProjectNo= pProjectNo ,TrialNo= pTrialNo, ColumnNo= column_no, LevelNo= level_no,
         ObservationNo=observation_no, TValue= vresult, ResultNo=1, MethodNo= pyontem,
                 response_no=presponseno
END WHILE

#read table matrix
/*********************************************************************************
**/
WHILE (NOT EOF(TableMatrix) AND Table_No= vtablo)
READ TableMatrix, observation_no

 STORE vrealobsno=CALL GetTaguchiMatrixRow(pProjectNo,
pTrialNo,ptableno,observation_no,4)

   READ ProjectTrialObservation, result as vrealresult
    FOR project_no = pprojectno   AND trial_no = ptrialno   AND observation_no = vrealobsno
    AND response_no = presponseno;
{Taguchi Methods are:   Larger is better: -10log10((1/y2)/n)    Smaller is better: -10log10(y2)/n)}
  IF(pyontem=1) THEN
                 COMPUTE  vdeger:=vrealresult;      #real value
  ELSIF(pyontem=2) THEN                             #-S/N larger is better
                 STORE  vdeger=vrealresult;
                  STORE  vdeger:=power(vdeger,2);    #square
                  STORE  vdeger:=log(10,(1/vdeger)); #logarithm(vdeger)
                  COMPUTE  vdeger:=vdeger*-10;       #multiply with 10
  ELSIF(pyontem=3) THEN                             #-S/N smaller is better
                 STORE  vdeger=vrealresult;
                  STORE  vdeger:=power(vdeger,2);    #square
                  STORE  vdeger:=log(10,(vdeger));   #logarithm(vdeger)
                  COMPUTE  vdeger:=vdeger*-10;       #multiply with 10
  ELSIF(pyontem=4) then
                STORE  vdeger:=vrealresult;          #logarithm(vdeger)
                COMPUTE  vdeger:=log(10,vdeger);
```

Table 4.2 Create project table result

```
  ENDIF;

 #write project tble matrix real values and estimated values.
  UPDATE ProjectTableValue,
               tvalue= vdeger,  matrix_order_no = vrealobsno,    real_value = vrealresult
                FOR project_no = pprojectno   AND trial_no = ptrialno   AND observation_no =
xobservation_no
                AND tvalue <> -1   AND method_no = pyontem    AND response_no = presponseno;
{response means one observation have more than one response value like temperature,pressure..
Analyze all response values at time same time.}

   UPDATE ProjectTable,
                tvalue = vdeger, matrix_order_no = vrealobsno, real_value = vrealresult
               FOR project_no = pprojectno  AND trial_no = ptrialno
              AND observation_no = observation_no    #Read from TableMatrix
                AND method_no = pyontem   AND response_no = presponseno;
END WHILE

{*******************************************************************************
********
#Write Sum,Count,Avegare of values to ProjectTable
#create sum column
*******************************************************************************
*******}
WHILE (NOT EOF(ProjectTableValue) AND project_no = pprojectno
AND trial_no = pTrialNo  AND column_no = 1   AND tvalue <> -1   AND result_no < 90   AND
method_no = pyontem)
READ ProjectTableValue, tvalue,realvalue
STORE vtvalue=vtvalue+tvalue
STORE vrealvalue= vrealvalue + realvalue
END WHILE

WRITE ProjectTable,project_no,trial_no,observation_no=90,
Tvalue=vtvalue,realvalue=vrealvalue,resultno=91,resultname="SUM",
Methodno=pmethod,response_no=presponse

#create count  column
WHILE (NOT EOF(ProjectTableValue) AND project_no = pprojectno
AND trial_no = pTrialNo  AND column_no = 1   AND tvalue <> -1   AND result_no < 90   AND
method_no = pyontem)
READ ProjectTableValue, tvalue,realvalue
STORE vtvaluecount= vtvaluecount +1
STORE vrealvaluecount= vrealvaluecount + 1
END WHILE
WRITE ProjectTable,project_no,trial_no,observation_no=92,
Tvalue=vtvalue,realvalue=vrealvalue,resultno=92,resultname="COUNT",
Methodno=pmethod,response_no=presponse

#create Average  column
READ ProjectTableValue, tvalue,realvalue FOR project_no = pprojectno
AND trial_no = pTrialNo  AND result_no=91   AND method_no = pyontem AND response_no=
presponseno)
STORE vtvaluetop=tvalue
STORE vrealvaluetop= realvalue
READ ProjectTableValue, tvalue,realvalue FOR project_no = pprojectno
```

Table 4.2 Create project table result

```
 AND trial_no = pTrialNo  AND result_no=92   AND method_no = pyontem AND response_no=
presponseno)

STORE vtvaluesay=tvalue
STORE vrealvaluesay= realvalue
COMPUTE vgenelorttvalue:=round(vtvaluetop/vtvaluesay ,5)        #calculate estimated value
average
COMPUTE vgenelortrvalue:=round(vrealvaluetop/vrealvaluesay,5) #calculate real  value average

WRITE ProjectTable,project_no,trial_no,observation_no=93,
Tvalue= vgenelorttvalue,realvalue= vgenelortrvalue,resultno=93,resultname=”AVERAGE”,
Methodno=pmethod,response_no=presponse
{***************************************************************************
*******}
#Write Sum,Count,Avegare of values to ProjectTableValue
#create sum column
WHILE (NOT EOF(ProjectTableValue) AND project_no = pprojectno
 AND trial_no = pTrialNo  AND tvalue <> -1   AND result_no < 90   AND method_no = pyontem)
READ ProjectTableValue, columnno,levelno,tvalue,realvalue
STORE vtvalue=vtvalue+tvalue
STORE vrealvalue= vrealvalue + realvalue
END WHILE
WRITE ProjectTableValue,project_no,trial_no,observation_no=90,
Column_no= columnno #read from ProjectTableValue table
Level_no=levelno #read from ProjectTableValue table
Tvalue=vtvalue,realvalue=vrealvalue,resultno=91,resultname=”SUM”,
Methodno=pmethod,response_no=presponse

#create count  column
WHILE (NOT EOF(ProjectTableValue) AND project_no = pprojectno
 AND trial_no = pTrialNo  AND tvalue <> -1   AND result_no < 90   AND method_no = pyontem)
READ ProjectTableValue, columnno,levelno,tvalue,realvalue

STORE vtvaluecount= vtvaluecount +1
STORE vrealvaluecount= vrealvaluecount + 1
END WHILE

WRITE ProjectTableValue,project_no,trial_no,observation_no=92,
Column_no= columnno #read from ProjectTableValue table
Level_no=levelno #read from ProjectTableValue table
Tvalue= vtvaluecount,realvalue= vrealvaluecount,resultno=92,resultname=”COUNT”,
Methodno=pmethod,response_no=presponse

WHILE (NOT EOF(ProjectTableValue) AND project_no = pprojectno
AND trial_no = pTrialNo AND result_no =91   AND method_no = pyontem)
READ ProjectTableValue, columnno as xcolumnno ,
          Levelno as xlevelno ,tvalue as xtoptvalue,
          Realvalue as xtoprealvalue
    WHILE (NOT EOF(ProjectTableValue) AND project_no = pprojectno
 AND trial_no = pTrialNo AND result_no =92   AND method_no = pyontem
AND columnno=xcolumno AND levelno=xlevelno  #read from ProjectTableValue)
READ ProjectTableValue, tvalue as xsaytvalue ,realvalue as xsayrealvalue
COMPUTE vgenelorttvalue:=round(xtoptvalue / xsaytvalue,5);
COMPUTE  vgenelortrvalue:=round(xtoprealvalue / xsayrealvalue,5) ;
WRITE ProjectTableValue,project_no,trial_no,observation_no=93,
Column_no= xcolumnno #read from ProjectTableValue table from Sum row
```

Table 4.2 Create project table result

```
Level_no=xlevelno #read from ProjectTableValue table from Sum row
Tvalue= vgenelorttvalue,realvalue= vgenelortrvalue,resultno=93,resultname="AVERAGE",
Methodno=pmethod,response_no=presponse
              END WHILE
STORE vtvaluecount= vtvaluecount +1
STORE vrealvaluecount= vrealvaluecount + 1
END WHILE
{*****************************************************************************
#Write dummy record into Projettable effects of columns
WRITE ProjectTable ,  PROJECT_NO = pprojectno   TRIAL_NO= ptrialno
OBSERVATION_NO=94,
  TVALUE=0, real_value=0, ,RESULT_NO=94, METHOD_NO=PYONTEM
RESULT_NAME='EFFECT', RESPONSE_NO= presponseno)
#Write dummy record into Projettable order of columns
WRITE ProjectTable ,  PROJECT_NO = pprojectno   TRIAL_NO= ptrialno
OBSERVATION_NO=95,
  TVALUE=0, real_value=0, ,RESULT_NO=95, METHOD_NO=PYONTEM
RESULT_NAME=ORDER, RESPONSE_NO= presponseno)
#Write record into ProjettableValue effects of columns
WHILE (NOT EOF(ProjectTableValue) AND project_no = pprojectno  AND trial_no = pTrialNo
AND result_no =93   AND method_no = pyontem
READ ProjectTableValue, columnno as xcolumnno , Levelno as xlevelno ,tvalue as xTvalue,
Realvalue as xrealvalue
IF (xlevelno=1) THEN            STORE  Vlevelcarp=1 ELSE  STORE Vlevelcarp=-1 END IF
COMPUTE vtvaluetop= vtvaluetop+xtvalue* Vlevelcarp
COMPUTE vrealvaluetop= vrealvaluetop +xtrealvalue* Vlevelcarp
WRITE ProjectTableValue,project_no,trial_no,observation_no=94,
Column_no= xcolumnno ,Level_no=1 ,Tvalue= vtvaluetop,realvalue=
             vrealvaluetop,resultno=94,resultname="EFFECT",
Methodno=pmethod,response_no=presponse
END WHILE
#Write record into ProjettableValue orders  of columns
WHILE (NOT EOF(ProjectTableValue) AND project_no = pprojectno
 AND trial_no = pTrialNo AND result_no =94   AND method_no = pyontem)
READ ProjectTableValue, columnno as xcolumnno ,
           tvalue as xTvalue,
           Realvalue as xrealvalue

STORE SIRA=SORT ABSOULTE(xTvalue)
WRITE ProjectTableValue,project_no,trial_no,observation_no=94,
Column_no= xcolumnno ,Level_no=1
Tvalue= sira ,realvalue= sira ,resultno=95,resultname="ORDER",
             Methodno=pmethod,response_no=presponse

WRITE ProjectTableValue,project_no,trial_no,observation_no=94,
Column_no= xcolumnno
Level_no=2
Tvalue= sira ,realvalue= sira ,resultno=95,resultname="ORDER",
            Methodno=pmethod,response_no=presponse
END WHILE
#Close  Tables
CLOSE ProjectTable
CLOSE ProjectTableValue
CLOSE ProjectTableMatrix
RETURN 0;
END;
```

4.4 Views

4.4.1 Formula Coefficients for Prediction

DOExpert Software uses some database views to make some operations in an easy way. Project trial analysis is done by using viw_tg_formula view that is shown below. This view combines the coefficients and formulas from the all project trial analysis results so that this software uses this view to analyze and to make a prediction. Some values of Taguchi analysis and project trial table is combined as a formula. This view is shown in Figure 4.9.

```
CREATE OR REPLACE FORCE VIEW CONFIDA40.VIW_TG_FORMULA
(project_no,trial_no,method_no,param_no,constant,tvalue, response_no,project_name,
trial_name,response_name)
As
  SELECT a.project_no, a.trial_no, a.method_no, a.param_no,
       a.constant, a.tvalue, a.response_no, p.project_name,
       pt.trial_name, response name
    FROM (SELECT t.project_no, t.trial_no, method_no, 0 param_no,
            'constant' constant, tvalue, response_no
            FROM tg_project_table t
            WHERE result_no = 93
            UNION ALL
            SELECT t.project_no, t.trial_no, method_no,
                   nvl (column_no, param_no) param_no,
                   nvl (param_name, column_name) param_name,
                   round ((t.tvalue / 2), 5) etki, response_no
            FROM viw_tg_result_table t
            WHERE result_no = 94) a,
       tg_project p,
       tg_project_trial pt,
       tg_project_response r
   WHERE a.project_no = p.project_no
    AND a.project_no = pt.project_no
    AND a.trial_no = pt.trial_no
    AND a.project_no = r.project_no
    AND a.response_no = r.response_no
```

Figure 4.9 Formula coefficients for prediction formula

4.4.2 Taguchi Analysis Result Table

DOExpert Software shows the total Taguchi estimation table via this viw_tg_result_table view as shown below. This view contains framework tables which are tg_project_table, tg_project_table_value and tg_project_table_column to show the Taguchi analysis results. This view is shown in Figure 4.10.

```
CREATE OR REPLACE FORCE VIEW CONFIDA40.VIW_TG_RESULT_TABLE
(satir_no, project_no, trial_no, column_no,level_no,observation_no,tvalue,column_name,
param_no,param_name,value_type,method_no,gozlemtvalue,matrix_order_no,result_no,
result_name,response_no                                            )
AS
  SELECT TO_CHAR (observation_no) satir_no, project_no, trial_no, column_no,
      level_no, observation_no, tvalue, column_name, param_no, param_name,
      value_type, method_no, gozlemtvalue, matrix_order_no, result_no,
      result_name, response_no
   FROM (SELECT a.*, pp.param_no, param_name, value_type
        FROM (SELECT v.method_no, t.project_no, t.trial_no, v.column_no,
                 v.level_no, t.observation_no, t.tvalue gozlemtvalue,
                 c.column_name, v.tvalue, v.real_value,
                 t.matrix_order_no, v.result_no, v.result_name,
                 v.response_no
              FROM tg_project_table t,
                 tg_project_table_value v,
                 tg_project_table_column c
             WHERE t.project_no = v.project_no
              AND t.trial_no = v.trial_no
              AND t.observation_no = v.observation_no(+)
              AND t.method_no = v.method_no(+)
              AND t.result_no = v.result_no(+)
              AND t.project_no = c.project_no
              AND t.trial_no = c.trial_no
              AND v.column_no = c.column_no
              AND t.response_no = v.response_no) a,
            tg_project_table_column_param cp,
            tg_project_parameter pp
        WHERE a.project_no = cp.project_no(+)
         AND a.trial_no = cp.trial_no(+)
         AND a.column_no = cp.column_no(+)
         AND cp.project_no = pp.project_no(+)
      AND cp.param_no = pp.param_no(+));
```

Figure 4.9 Taguchi analysis result table view

CHAPTER FIVE
SYSTEM DESIGN

This chapter explains the design of the system in detail. It presents UML diagrams such as Use Case Diagram and Class Diagrams, explains database in detail by giving Entity Relation Diagram (E/R) diagram, database tables, view list, package functions and procedures.

5.1 Use Case Diagram

DOExpert Use Case Diagrams is shown in Figure 5.1. This part of the software contains configuration operations. User, role definition and authorization can be done by administrator user.

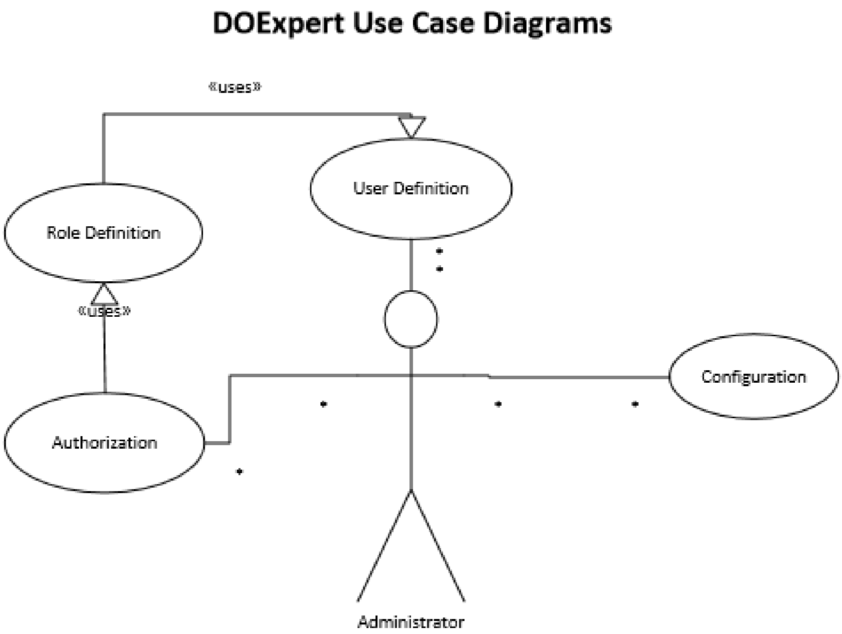

Figure 5.1 User definition use case diagram

Authorized user can make some operations like factor definition, project definition, observation entrance and other operations related with this main functions. Use case diagram of some of these operations are shown in Figure 5.2.

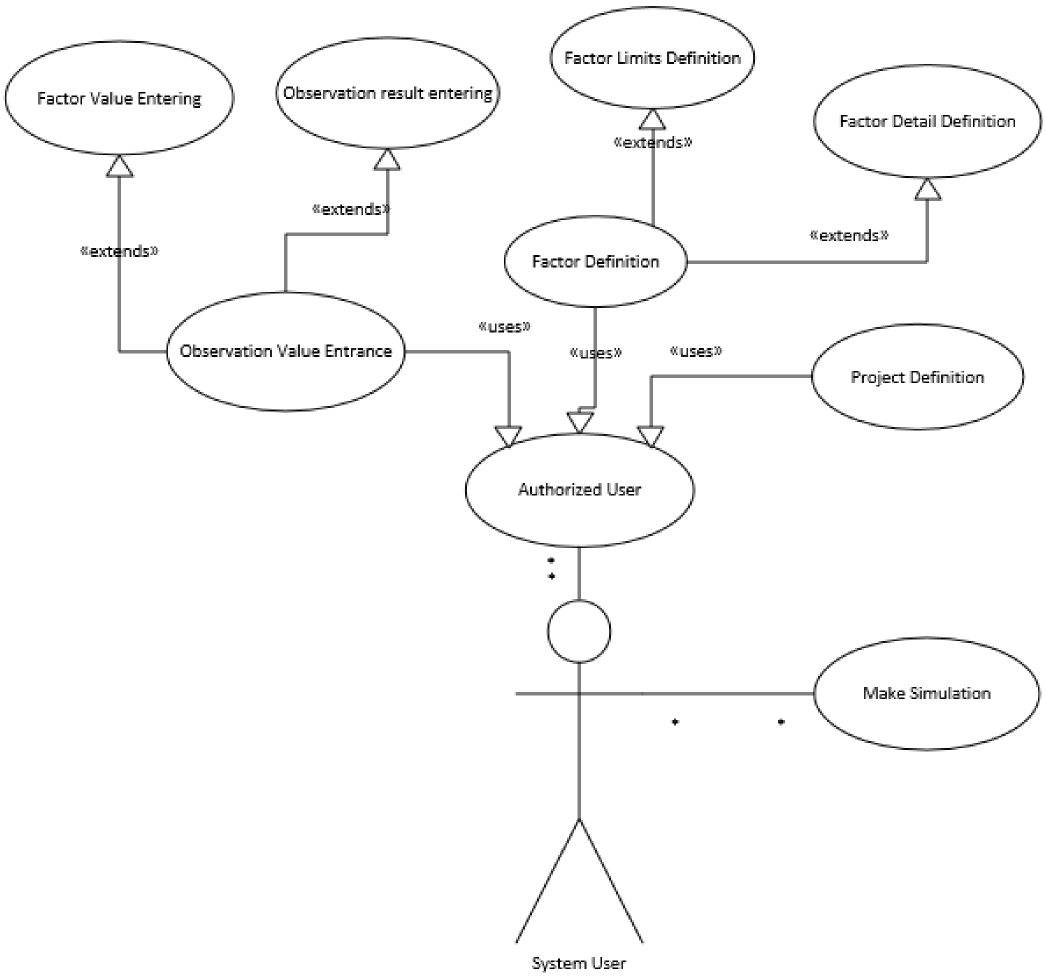

Figure 5.2 Authorized user operations

5.2 E/R Diagram

Project definitions can be made in detail by using this framework. Project definition and the columns and parameters of columns of a project can be defined. A project has more one trial for more than one response variable. By using this system design, project table definition and Taguchi table definition can be done on the system for configuration. After configuration of the system, project trials can be analyzed with an algorithm using Taguchi table structures. After analyzing of a project trial, the result values of analysis are stored as Taguchi table format.

Experimental project definition E/R diagram is shown in Figure 5.1. Project trial observation details and trial combinations data can also be stored in this framework.

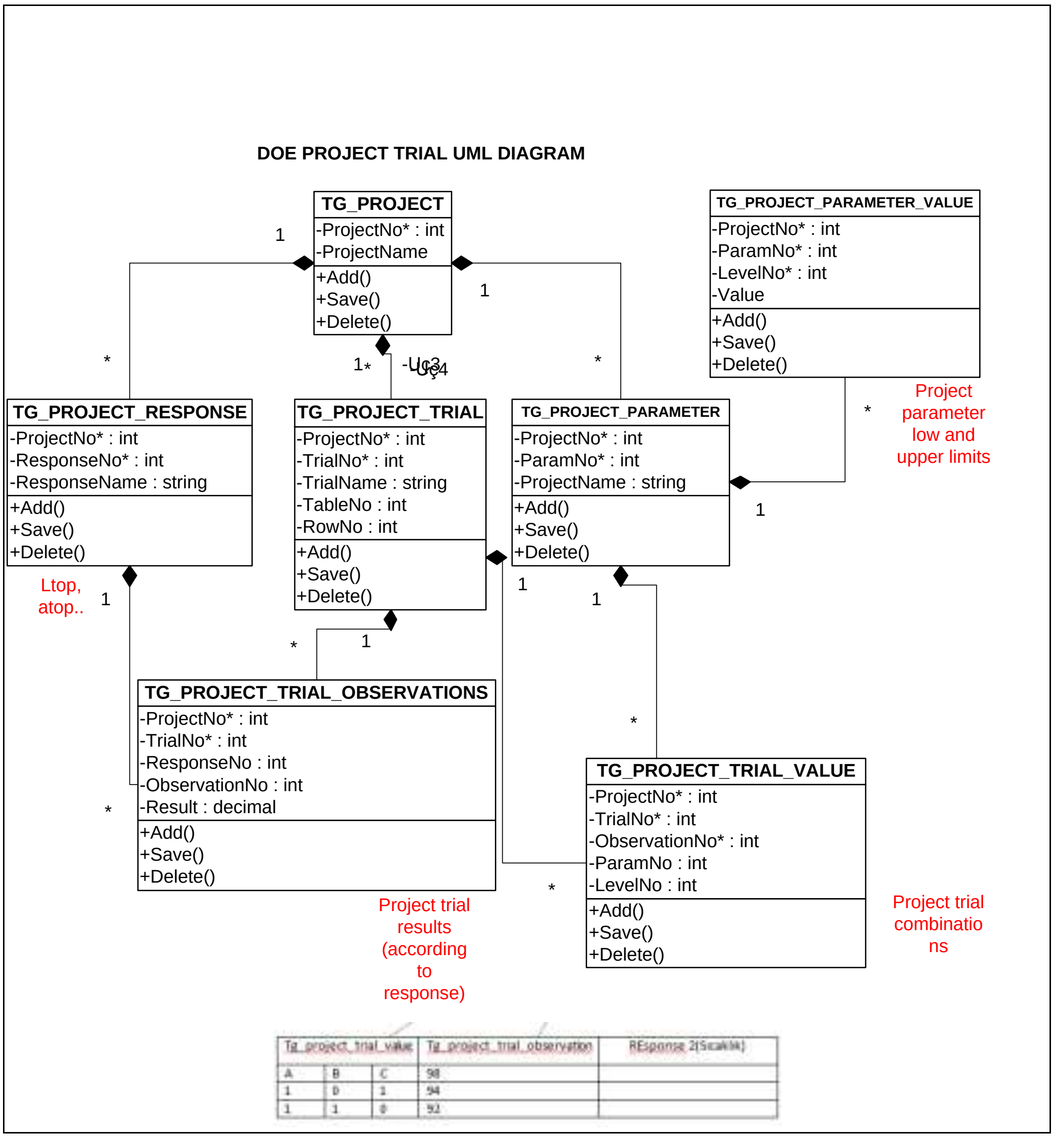

Figure 5.1 DOExpert Project trial design E/R diagram

The E/R diagram of a project trial Taguchi estimation table and project response tables is shown in Figure 5.2. Project can more than one response variable. At this experimental work color project has 6 response variables as *ltop*, *atop*, *btop*, *lbottom*, *abottom* and *bbottom*.

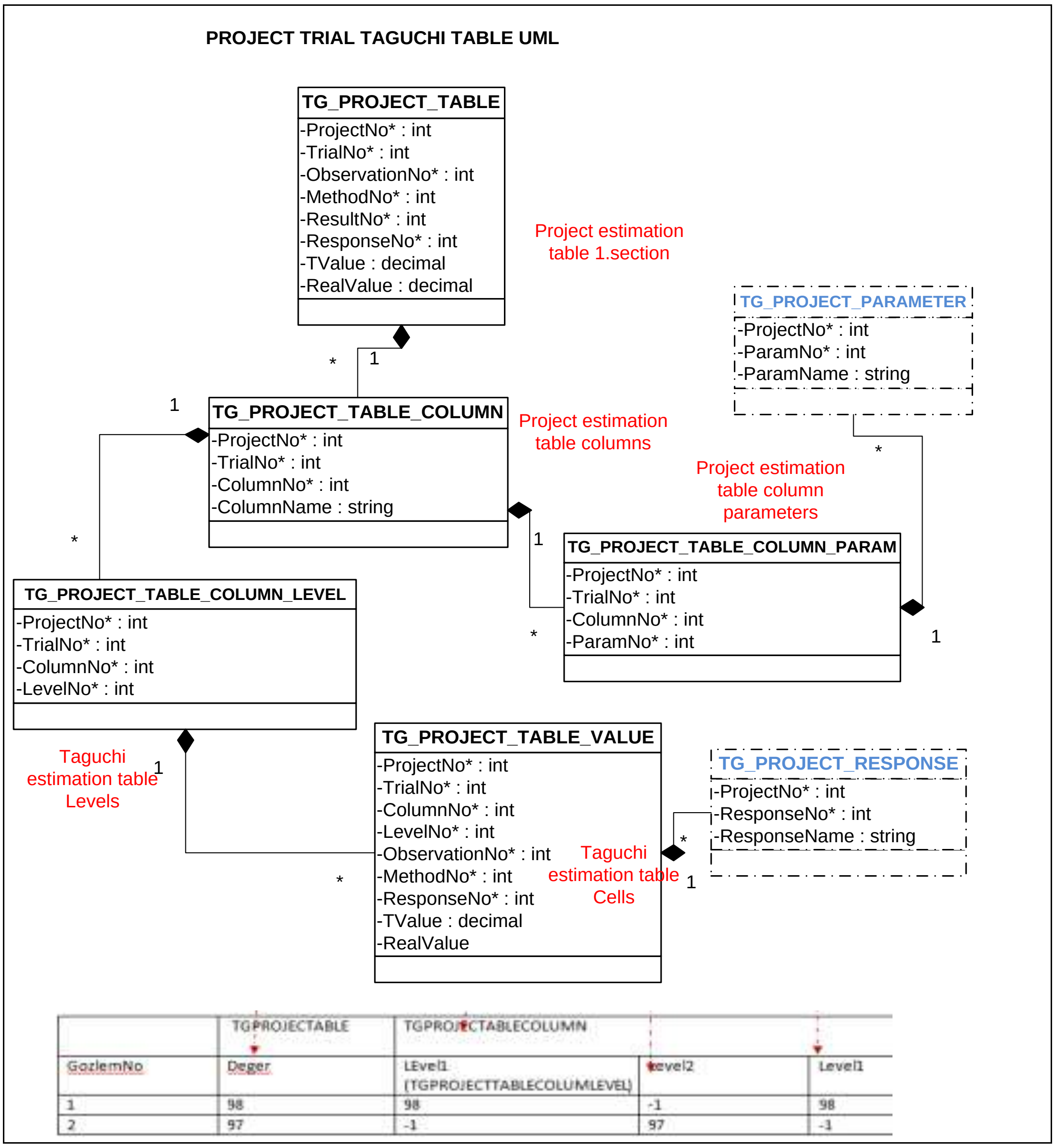

Figure 5.2 DOExpert Taguchi table design UML diagram

After analyzing a project trial, the result values of all response variables are stored in this database. The E/R diagram of project response tables is shown in Figure 5.3.

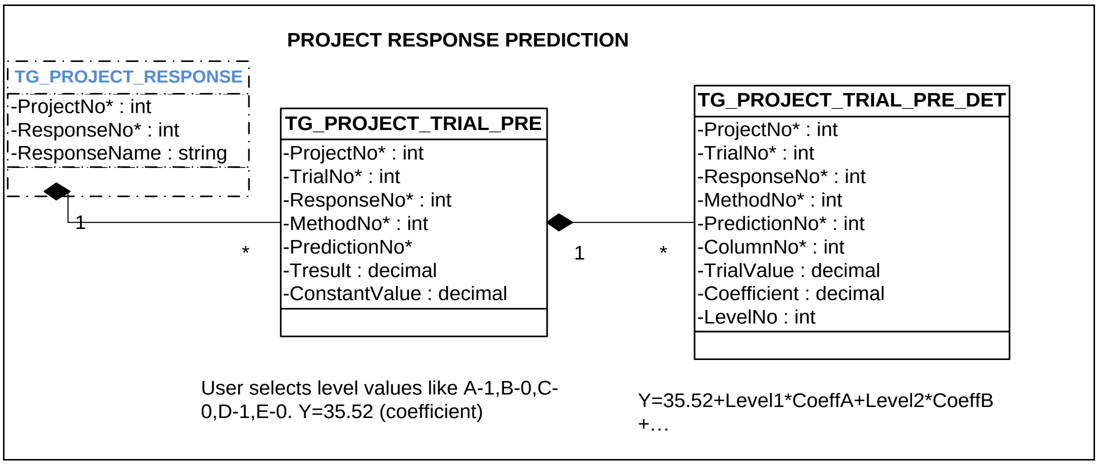

Figure 5.3 DOExpert project response prediction diagram

5.3 Class Diagram

DOExpert software contains database classes, windows form classes and classes for matrix operations. Database classes were created by Llblgen software contains database fields as properties, database functions as methods. Windows form classes are inherited from form class. DOExpert definition forms classes are shown in Figure 5.4, while project trial and graph form classes are shown in Figure 5.5, matrix functions class diagram is shown in Figure 5.6.

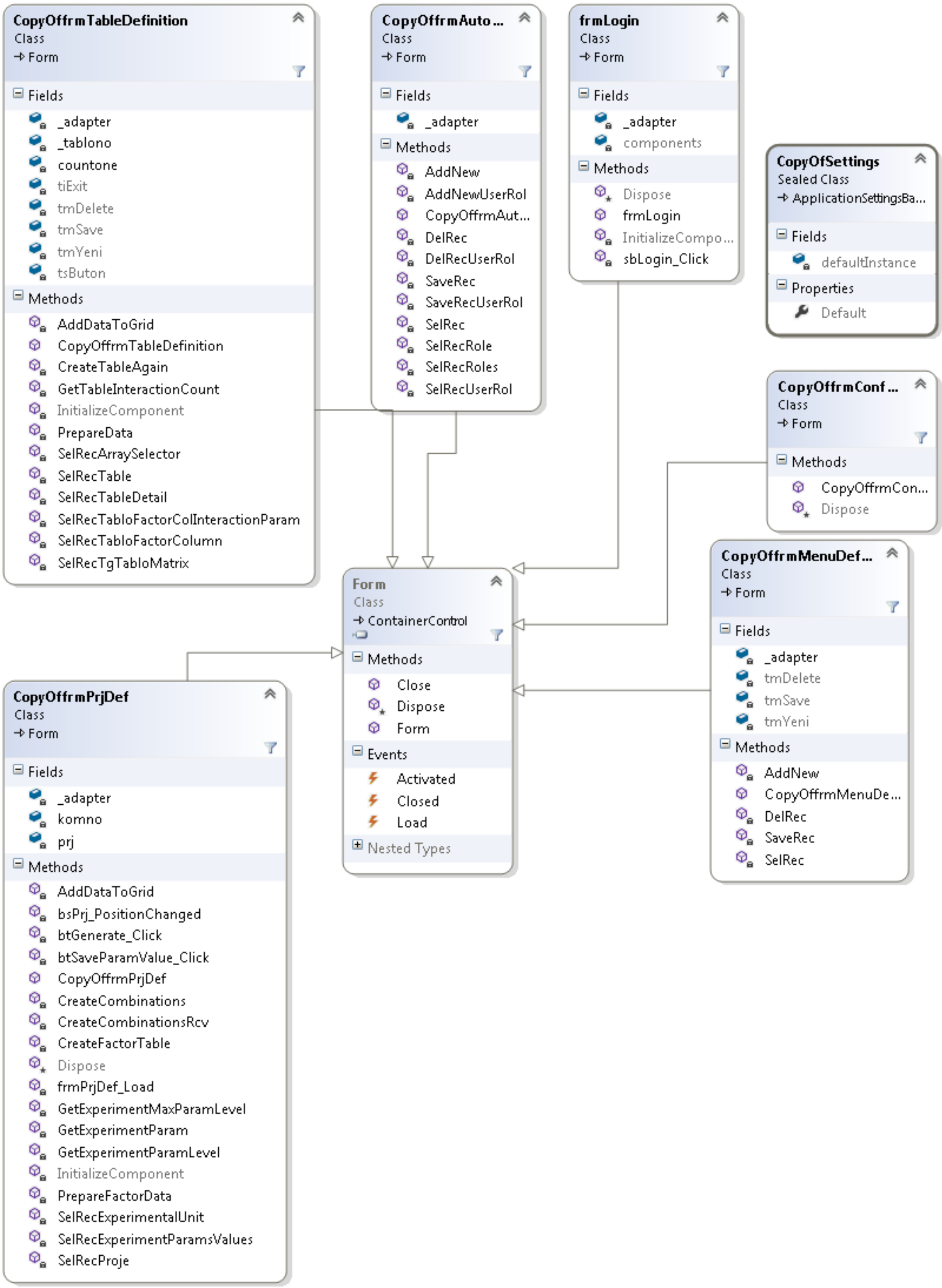

Figure 5.4 DOExpert definition forms classes

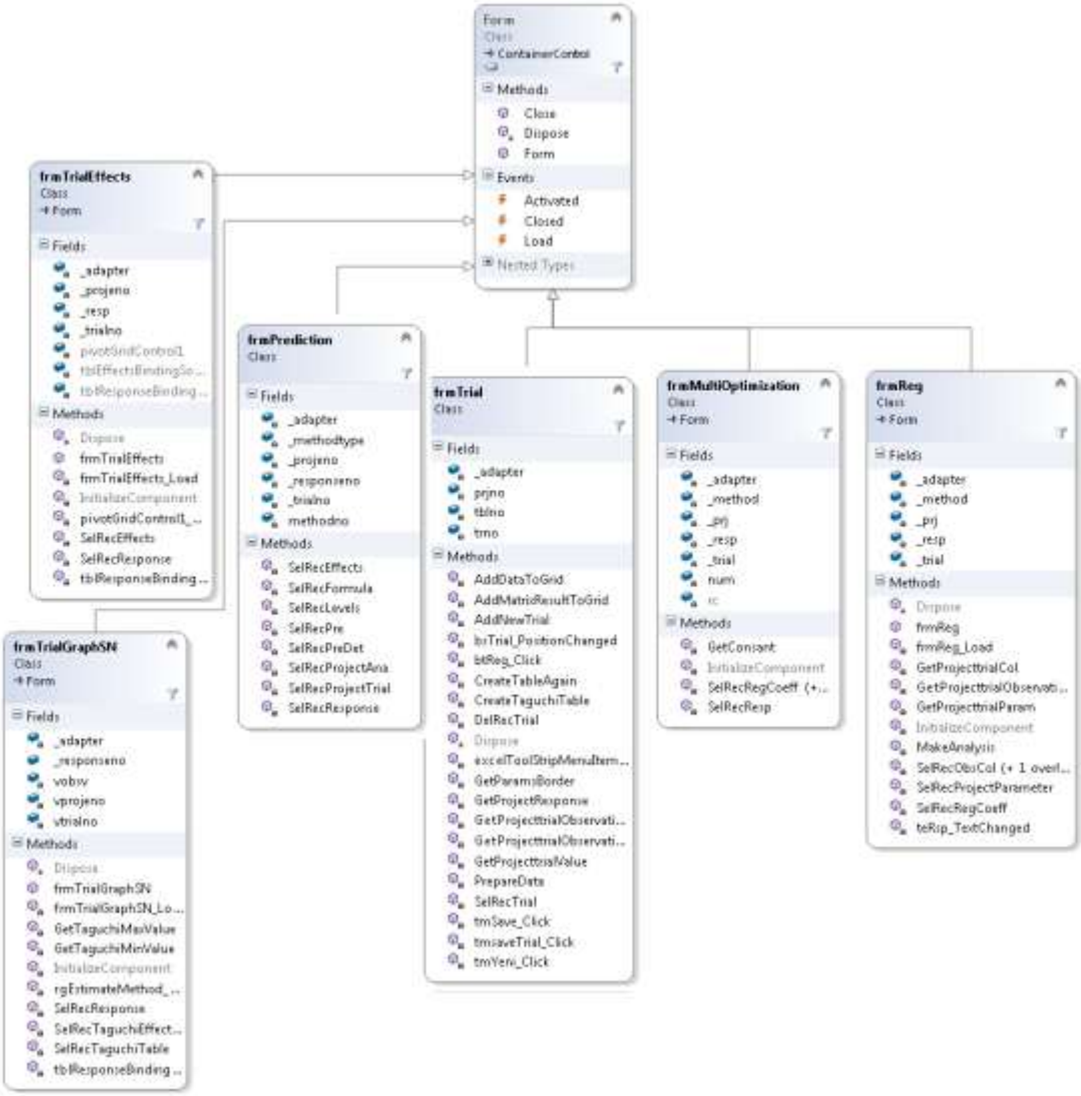

Figure 5.5 DOExpert project trial and graphs form classes

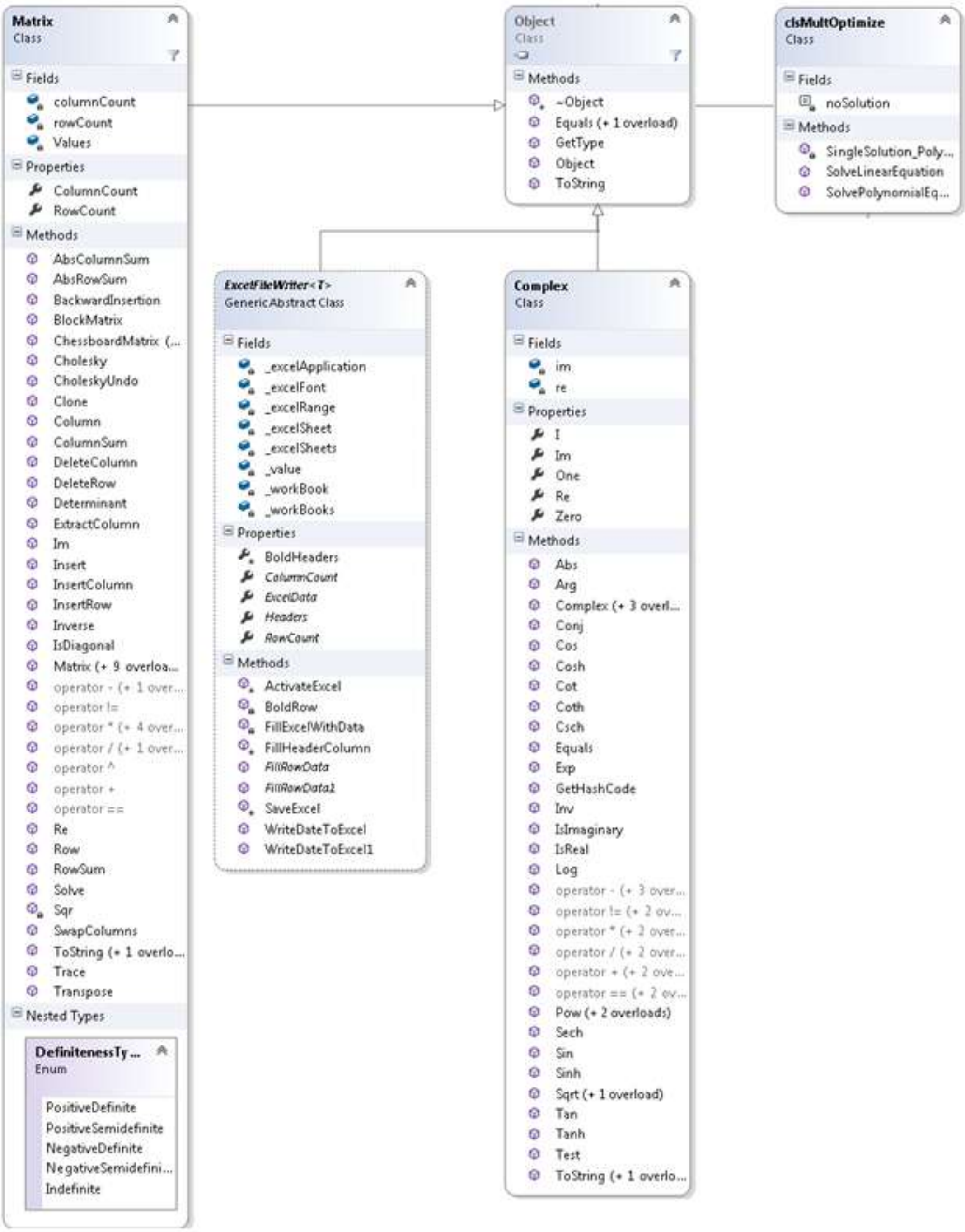

Figure 5.6 DOExpert classes for matrix operations

5.4 Database Tables

DOExpert software framework table list is shown in Table 5.1.

Table 5.1 DOExpert software framework table list

TABLE NAME	FIELDS	DESCRIPTION
USER TABLES		
TG_USER	User Code,User Name,Status	User definition
TG_ROLE	Role Code,Role name	Role Definition
TG_USER_ROLE	User Code,Role Code	User Role definition
TG_MENU	Menu Code,Menu Name	Menu Definitions
TG_ROLE_MENU	Role Code,Menu Code,Role Type	Role Menu detail
TAGUCHI TABLE DEFINITION		
TG_TABLE	Table No, TableName, ColumnCount	Taguchi Table Names and column counts eg. L4,L8..
TG_TABLE_COLUMN	Table No, ColumnNo, ColumnName	Taguchi Table Columns defined.
TG_TABLE_COLUMN_DETAIL	Table No, RowNo,ColumnNo, EffectNo,ParameterNo	Taguchi Table Columns Details defined. Eg. Suppose L16 Taguchi Table, This table contains possible column parameters, and also equivalent of parameters.
TG_TABLE_COLUMN_LEVEL	Table No,ColumnNo, LevelNo	Taguchi Table Column Levels are defined. Eg. For L16 estimation Table column levels
TG_TABLE_COMBINATION	Table No, RowNo,ColumnNo, ObservationNo, LevelNo	User constructs combinations according to desired factor count User make trials according to these combinations.
TG_TABLE_DETAIL	(Table No, RowNo, ParamNumber, LevelCount	Effected or noneffected Tables. Eg. For L16 These table can be as follows: (Row1:15 factors, Row2: 5 factors ,non-effected, Row3: 5 faktors non-effected…
TG_TABLE_MATRIX	Table No,ColumnNo, ObservationNo, LevelNo	The matrix desing of Taguchi Tables.active and passive cells records are here.
TG_TABLE_PARAMETER	(Table No, RowNo, ParameterNo, ParameterNAme	Taguchi Table Parameters. Eg.L16, 5 factors parameter
TG_TABLE_ROW	(Table No,ObservationNo	Taguchi Table Trials. Eg.L16 has 16 trials.
PROJECTS		
TG_PROJECT	(Project No,Name)	Project Definitions
TG_PROJECT_PARAMETER	(Project No, ParamNo, PAramName)	Project Parameters, parameter units are defined Blue,PS01
TG_PROJECT_PARAMETER_VALUE	(Project No,ParamNo,LevelNo,Value	Project Parameters Levels and Levels Values defined Project parameter Low and Upper Limits
TG_PROJECT_RESPONSE	(Project No,Response No,Response Name)	Project Response variables are defined. Eg. Ltop
PROJECT TRIALS		
TG_PROJECT_TRIAL	(Project No,Trial No,TrialNAme, TableNo,RowNo)	Project Trials
TG_PROJECT_TRIAL_OBSERVATION	(Project No,Trial No,Response No,ObservationNo,Result	Project Trials Response Values

Table 5.1 DOExpert software framework table list

TG_PROJECT_TRIAL_VALUE	Project No,Trial No,ObservationNo, Param_No,Level No)	Projects Trial Combinations
PROJE TRIALS TO TAGUCHI TABLES		
TG_PROJECT_TABLE	(Project No,Trial No,ObservationNo,MethodNo, ResultNo,ResponseNo, Tvalue,RealValue	First part of Estimation Table of Project
TG_PROJECT_TABLE_COLUMN	Project No,Trial No, ColumnNo, ColumnName	Project Estimation Table Columns
TG_PROJECT_TABLE_COLUMN_ LEVEL	Project No,Trial No,ColumnNo, LevelNo)	Project Estimation Table Column Levels
TG_PROJECT_TABLE_COLUMN_P ARAM	(Project No,Trial No,ColumnNo, LevelNo)	Project Estimation Table Column Parameters
TG_PROJECT_TABLE_VALUE	(Project No,Trial No,ColumnNo, LevelNo,ObservationNo,MethodNo , ResponseNo, TValue,Rvalue	Project Estimation Table Cells
MAKE PREDICTION		
TG_PROJECT_TRIAL_PRE	Project No,Trial No, ResponseNo,MethodNo, PredictionNo,Tresult,ConstantValue	Make Prediction according to coefficiens that found. User selects levels for factors like A-1,B-0,C-0,D-1,E-0. Program makes prediction according to these coefficients like Y=35.52
TG_PROJECT_TRIAL_PRE_DET	Project No,Trial No, ResponseNo, MethodNo, PredictionNo,ColumnNo, TrialValue, Coefficient,LevelNo	Y=35.52+ALevel*ACoeffient+B*Bcoefiient TrialValue=ALevel*ACoeffient ,A=column MethodNo=1,2,larger is best ,ResponseNo(like ltop) In shortly ,the eauation Y=35.52+ Level1*CoeffA+Level2*CoeffB+… stored here.

5.5 DOExpert Software Framework View List

DOExpert software framework view list and used tables is shown in Table 5.2.

Table 5.2 DOExpert software framework view list

VIEW NAME	**FIELDS**	**USED TABLES**	**DESCRIPTION**
VIW_TG_FORMULA	project_no, trial_no, method_no, param_no, constant, tvalue,response_no	tg_project_table, viw_tg_result_table	Used for prediction
VIW_TG_RESULT_ TABLE	satir_no, project_no, trial_no,column_no,level_no, observation_no, tvalue, column_name, param_no, param_name, value_type, method_no, gozlemtvalue, matrix_order_no, result_no, result_name, response_no	tg_project_table t, tg_project_table_value v, tg_project_table_column c, tg_project_table_column_param, tg_project_parameter	All of the Taguchi analysis results can be shown via this view

5.6 Package Functions & Procedures

DOExpert framework functions and procedures list is shown in Table 5.3.

Table 5.3 DOExpert software framework functions and procedures

PROCEDURE NAME	PARAMETERS	RETURN	DESCRIPTION
CreateProjectTable	pProjectNo in number, pTrialNo in number	Number	(TG_PROJECT_TABLE_VALUE) Constructs Project Estimation Table Cells (TG_PROJECT_TABLE_COLUMN_LEVEL column levels (TG_PROJECT_TABLE_COLUM_PARAM) Column parameters (TG_PROJECT_TABLE_COLUMN) Columns
CreateProjectTableResult	pProjectNo in number, pTableNo in number, pTrialNo in number, pMethod in number	No return	(TG_PROJECT_TABLE) Fisrt part of Estimation Table of Project (TG_PROJECT_TABLE_VALUE) Project estimation table cells
CreateProjectTrialResult	pProjectNo in number, pTableNo in number, pRowNo in number, pTrialNo in number, pResponse number	No return	A combination table is constructed for the Taguchi table selected by user. User makes project trials according to these combinations. TG_PROJECT_TRIAL_VALUE, TG_PROJECT_TRIAL_OBSERVATION constructed.
GetTaguchiMatrixRow	pProjectNo in number, pTrialNo in number, pTableNo in number, pObsNo in number, pColNo in number, presponse number	Number	Real observationno is found and called by CreateProjectTable function.
MakePrediction	pproject number, ptrial number,presponseno number, pmethodno number,ppredictionno number,pyontem varchar2	Number	Prediction is done. TG_PROJECT_TRIAL_PRE_DET and TG_PROJECT_TRIAL_PRE values are esimated by using VIW_TG_FORMULA view.

CHAPTER SIX
IMPLEMENTATION

In this thesis, several development and mapping tools and database system were used to develop DOExpert system. These are LLBLGEN Pro, Oracle Database, Microsoft Visual Studio, DevExpress Components and Microsoft Visio to draw diagrams.

6.1 LLBLGEN Pro

LLBLGEN Pro 2.6 is an ORM (Object Relational Mapping) tool which generates a class for each database object. These programs generate classes for tables and views. For example if we create a new table, ORM tool generates a new class for this table automatically. Instead of using this tool, a developer has to write *Update*, *Insert*, *Delete* and *Select* statements. ORM tool makes all these standard operations automatically. Apart from this, any stored procedure, function codes are generated by ORM tool. In addition, developer can write codes independent from the database.

6.2 Oracle Database

Oracle Database 10g is one of the best database systems to develop critical applications in business and technical areas. It has strong management and development tools such as Enterprise Manager and SQL Developer to develop an application which includes scripts, packages, procedures, triggers and functions.

6.3 Microsoft Visual Studio

Microsoft Visual Studio 2012 is an IDE (Integrated Development Environment) tool which was developed by Microsoft. It is supported by Microsoft Windows, Windows Mobile, Windows CE, NET Framework, NET Compact Framework and Microsoft Silverlight. It is used to develop web, mobile and desktop applications.

6.4 DevExpress Components

DevExpress is a .NET component for Windows Forms applications. DevExpress WinForm components offer many options both visually as well as functionality. Some of the supports of the DevExpress components are: Skin Care, Instrument Support, ProgressBar, Grid Support, Table Support (ChartControl), Navigation Bar Support.

6.5 Microsoft Visio

Microsoft Office Visio provides a platform to draw UML diagrams, flowcharts, maps, scheduling diagrams, detailed network diagram, industrial control systems and others systems diagrams. At this project UML diagrams, flowcharts are drawn by Microsoft Office Visio.

6.6 DOExpert Software

The implementation details and general usage information about our DOExpert software is explained in this section. Software contains 4 parts as follows:

a) User & Menu & Role Configuration
b) DOE Configuration for Taguchi Design
c) DOE Project Definition
d) Project Trials & Prediction & Graphs

6.6.1 Login Page

User enters the system by entering a valid username and password. After entering the system, configuration screen appears to select a menu item from the list.

6.6.2 DOExpert System Configuration Screen

DOExpert system configuration screen is shown in Figure 6.10. Menu definition, Role definition, User definition and authorization operations are done by using these menu items.

Figure 6.1 DOExpert system configuration screen

6.6.3 Menu Definition

Menu definition screen shows the menu items of this DOExpert system. Data Manipulation Language (DML) operations of menu items can be done from the screen shown in Figure 6.2.

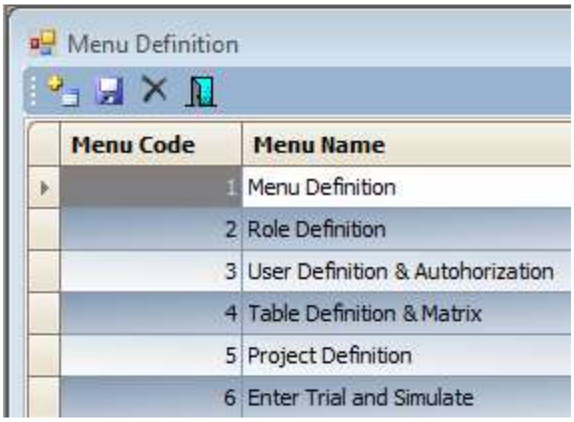

Figure 6.2 Menu definition

6.6.4 Role Definition

Role definition is an important part of DOExpert System. This system is an authorized system by assigning roles to users. There are three roles on the system as a default. A user is authorized to enter the menu options via this menu. Figure 6.3 shows role definition screen details.

Figure 6.3 Role definition

6.6.5 User Definition & Authorization

Each user has a role as shown in Figure 6.13. Administrator of the system can give an authority to a user via *User Authority* screen. Each user has a role and each role have menu item(s).

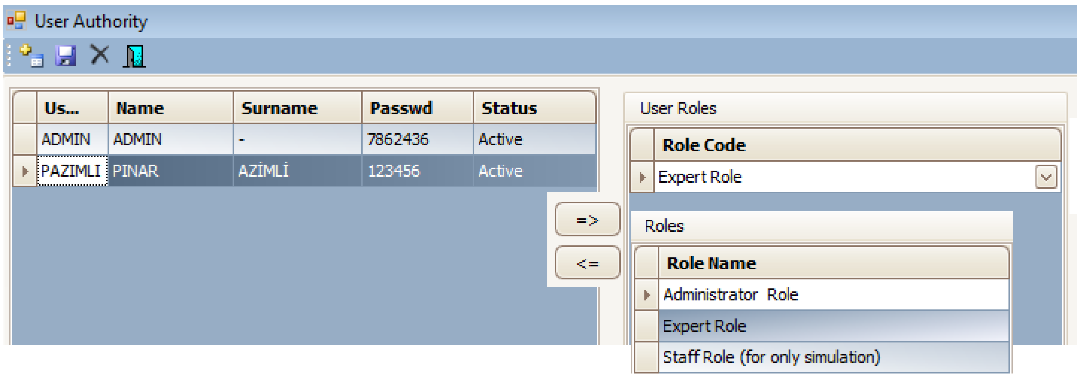

Figure 6.4 User definition & authorization screen

6.6.6 DOE Configuration for Taguchi

6.6.6.1 Table Definition & Matrix

DOExpert System allows user to analyze an experimental work by using Taguchi method. So it is needed to define Taguchi Tables framework on the system for later use. Figure 6.14 shows *Table Definition* screen to define Taguchi L16 orthogonal tables and the interactions of these tables according to factor numbers on the system.

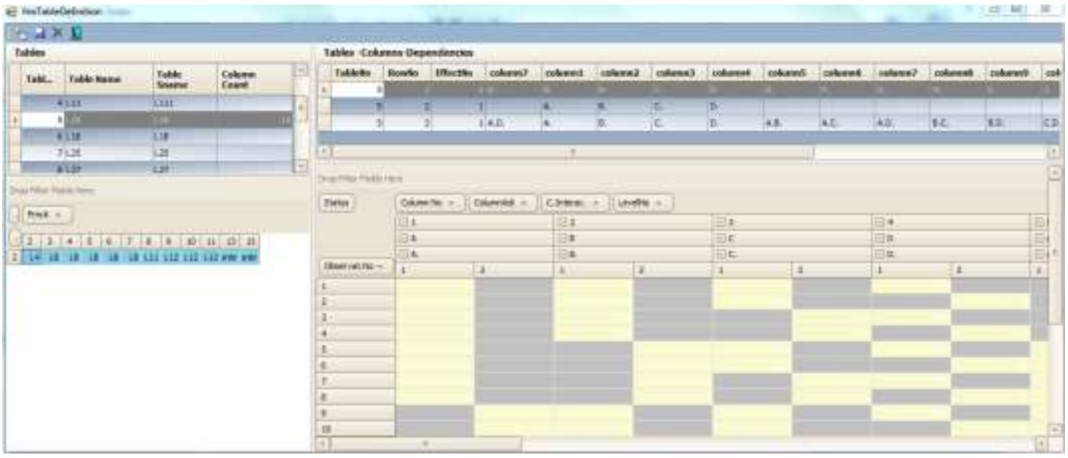

Figure 6.5 Table definition screen

6.6.7 DOExpert Projects

6.6.7.1 Project Definition

In order to analyze an experimental work, project definitions, project factors and factor levels must be defined on the system. This operation is important to construct the DOExpert framework. Color Project factors and levels on Project Definition screen are shown in Figure 6.6.

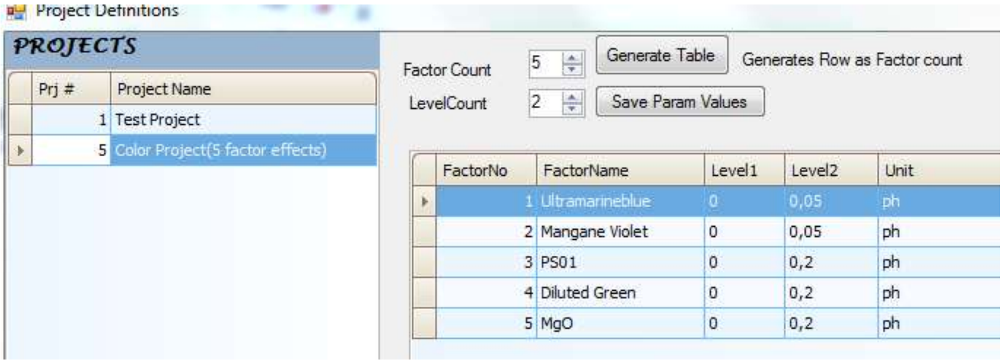

Figure 6.6 Project definition

6.6.8 Project Trials

6.6.8.1 Enter Trial & Simulate

Project Trials should be entered on the system to analyze the effects of the factors. User selects Taguchi table and creates a combination table to enter the response values for a trial. Figure 6.7 shows the Project Trial combination screen for this experimental work.

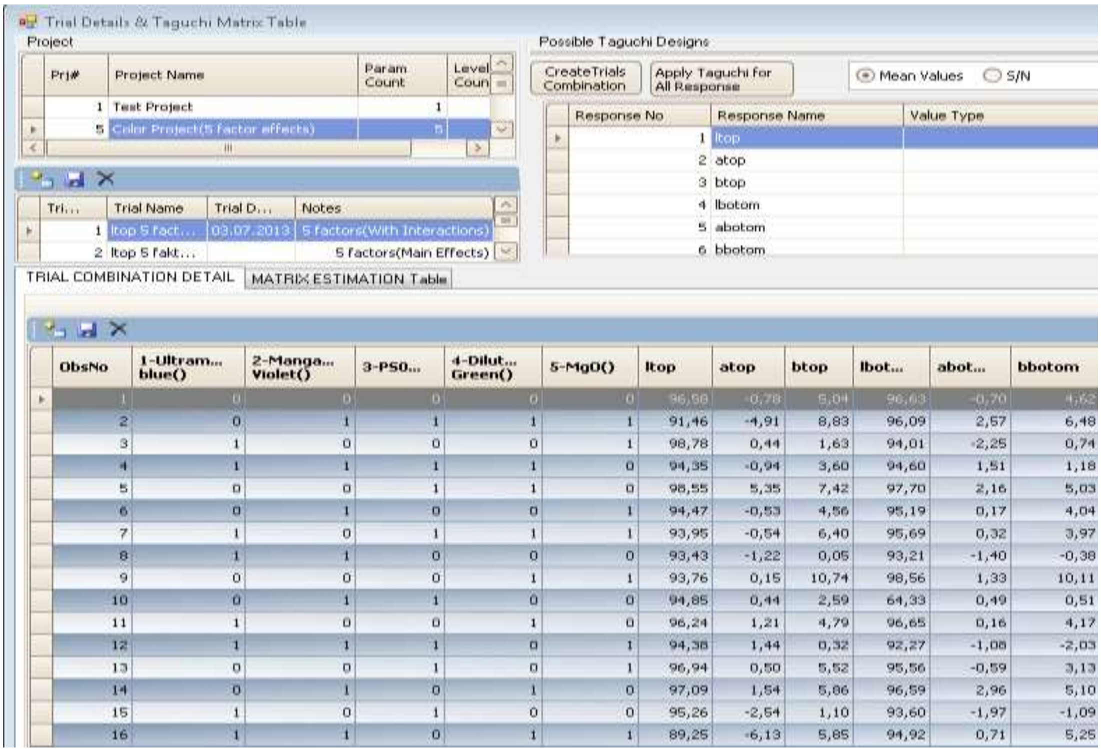

Figure 6.7 Trial details screen

CHAPTER SEVEN
EXPERIMENTAL WORK

In experimental works, after making several interviews with laboratory experts, it was decided to apply design of experiment methods on color work of windows profiles. Color study contains defining factor levels to find color amounts to reach customer request. Factors consist of five different paints. Desired results can be reached by setting amount of top and bottom color values for window profiles. In this study, Taguchi method and regression analysis were applied at color data's to find the effects and optimum values of color factors.

7.1 Color Measurement System

The color of a (white) window profile is characterized by CIELab (color) space. The CIE-L a b color space is a color-opponent space with dimension L (black-white direction) for lightness and a (green-red direction) and b (blue-yellow direction) for the color-opponent dimensions (Figure 7.1), based on nonlinearly compressed CIE XYZ color space coordinates.

The right color specification of a customer can sometimes be reached by the right addition of additives. However, sometimes the addition of tinting pigments (blue, violet, black, green and yellow) is necessary.

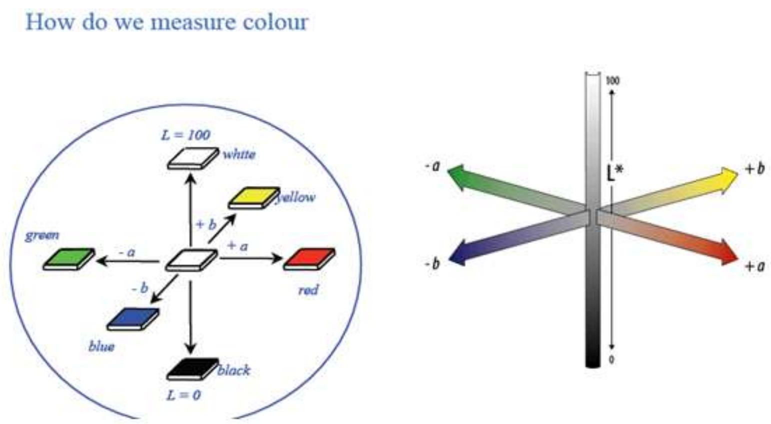

Figure 7.1 CIELab colour space (Dr. Schiller, 2013)

7.2 Project Detail

7.2.1 Color Pigments

The addition of the right tinting pigment in the right amount is needed a lot of experience or a lot of trials to be done. The 3rd option is a DOE in which the five tinting pigments were varied. The constant part of this DOE is a dryblend combination similar to that what a customer has been using without tinting pigment and a Clacium-Zinc based stabilizer:

100 phr PVC (k = 66 … 68)

6 phr coated Filler

5 phr Acrylic impact modifier

5 phr Titanium dioxide (Rutile, window grade)

7 phr commercially available Calcium-Zinc based window profile stabilizer without tinting pigment (commercially available for more than 5 years; produced on pilot production to avoid additional mistakes)

In this work there are 5 color pigment values, each have minimum and maximum level values as follows:

- defined and diluted blue pigment from 0.0 to 0.2 phr
- defined and diluted violet pigment from 0.0 to 0.2 phr
- defined and diluted black pigment from 0.0 to 0.1 phr
- defined and diluted green pigment from 0.0 to 0.1 phr
- defined non-diluted yellow pigment from 0.0 to 0.1 phr

Laboratory personnel made 21 trials based on a DOE Project according to Taguchi design. The design was changed by logical reasons to avoid many contradicting combinations e.g. violet combined with green. The dryblends were weighted (about 15 kg) and mixed on a hot-cool-mixer according standard conditions. The dryblends were extruded on a KM 35-25 L/D extruded with a window profile standard set up. Extrusion speed was about 1 m/min and about 30 kg/hr. Extrusion torques, pressures and temperatures were measured. Details are entered into a R&D Project from “Trial01” to “Trial21”. (Pressure, torque and mass temperature were going slightly down during extrusion. The influence on color is investigated.)

More important parts of this study were the color values *L, a, b* on the top and the bottom side of window profile. As shown in Figure 7.2 and Figure 7.3 windows profile section is produced and *ltop* and *lbottom* values are written.

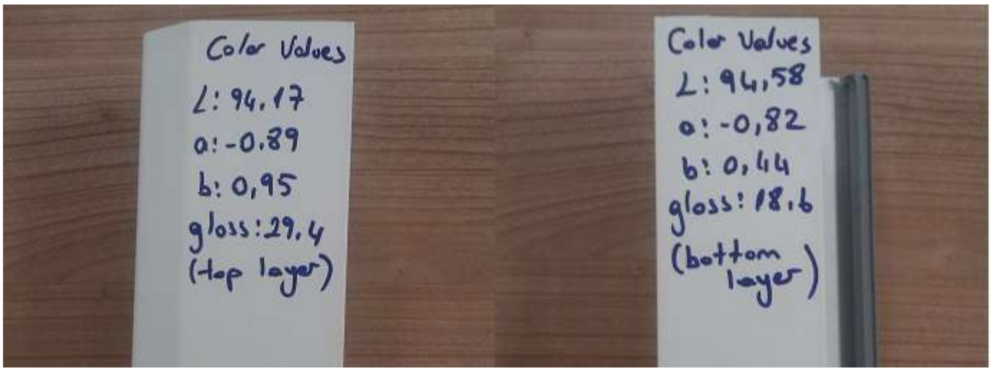

Figure 7.2 Window Profile top and bottom color values

Figure 7.3 Window Profile from different perspectives

7.2.2 Extrusion Process

Extrusion is a method that is used to give a shape to materials under some temperature and pressure. A plastic extrusion machine is shown in Figure 7.4.

7.2.2.1 Extrusion process stages

Extrusion process stages are as follows; Powder or granular is put in the hopper, goes to heating roller and is pushed forward by extrusion screw, as a result of this friction softens and melts.

After passing some cylinder part, it is forced to pass through from mold. After passing from mold, the product is in the shape of mold. Product goes to cooling system. After that product measurement is done and cut.

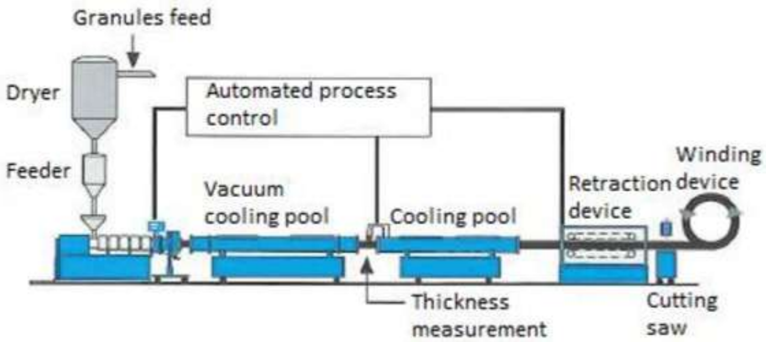

Figure 7.4 Plastic Extrusion Machine Line (Auvinen, 2013)

7.3 Benefits of DOExpert

7.3.1 Time to Make a Trial

For each color study, for one trial, plastic extrusion machine spends about 30 minute and 1 personnel job rotation. Personnel spend time to mix color pigments and make some preparation to make a trial.

After trial ends, some operations that should be done are:

- save information from extruder machine
- get sample
- measure color values of sample
- enter results Confida system
- create product receipt

7.3.2 Preparation of the Mixture Powder

Recipes are given to the lab. The materials are weighted at laboratory. Weighing material is put into the mixer. Weighing and Mixer takes 20 minutes to process a single trial.

7.3.3 Number of Work About Color Calibration at Laboratory

An average count of recipe (per month) is 25. For 25 recipes 75 trials should be done. DOExpert system reaches the truth result after doing 50 trials instead of 75 trials.

7.3.4 R&D Expert Time

Operations like getting results, evaluation, doing theoretical calculations for new experiments takes an average of 7 minutes.

7.3.5 Reology Work

Plastograph extrusion trials performed outside the machine (raw material plasticization time determination (plastograph) analysis is done for 6-7 minutes for the first trial is in progress.

7.3.6 Save Time

- Thermal stabilizer (strength) varies by product, takes an average of 50-60 minutes
- Personnel preparing time of sample takes 2 minutes
- Raw material gain, a wider basis of the inventory (from factory or outside.)
- The energy used in electric and nitrogen tube

7.4 DOExpert Software

DOExpert Software was designed to make an analysis of experimental design and applied to one of the chemical factory for color measurement system. This system proposes a framework that contains user controlled system, Taguchi table definition system to analyze data for optimum values. In this section every section of this software will be explained and windows profile top and bottom color measurement values will be analyzed by the system.

7.4.1 User & Role Administration

User roles consist of Administration Role, Expert Role, Staff Role. These were explained in detail.

7.4.1.1 Administration Role

Administration Role enables user to define the system tables, functions, roles to configure the system. Taguchi orthogonal table structures are defined by administrator. These operations can be done via a screen shown in Figure 7.5.

7.4.1.2 Expert Role

Each user who has expert role can create projects, trial combinations and enter observation values is used for experimental design of experiments into the system.

7.4.1.3 Staff role

Staff role is an unauthorized role. This role allows running prediction for projects. Predictions are done by using the coefficients found by Expert Role Experimental Design.

Figure 7.5 DOExpert user role definition screen

7.4.2 Table Definition & Matrix

Taguchi Tables definition and the structures of the tables can be defined by using Table Definition screen shown in Figure 7.6.

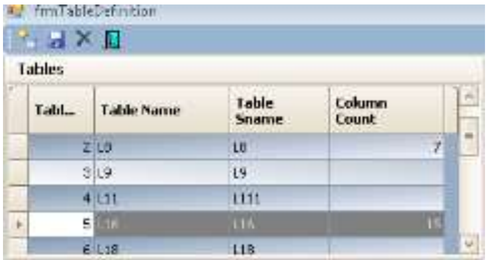

Figure 7.6 Taguchi tables

The combinations of Taguchi L16 table for 15 factors have 2 levels are shown in Figure 7.7. Taguchi orthogonal table details can be entered via a screen shown in Figure 7.8

Expe-riment	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	1	1	2	2	2	2	1	1	2	2	1	1
7	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1
8	1	2	2	2	2	1	1	2	2	1	1	1	1	2	2
9	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
10	2	1	2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	2	1	2	1
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	1	1	2	2	1	1	2	2	1
14	2	2	1	1	2	2	1	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	1	2	2	1	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	2	1	2	2	1

Figure 7.7 L16 estimation table

Taguchi table for 5 factors to 15 factors dependencies and estimation table structure is shown in Figure 7.8. This screen allows authorized user to add, delete or update a Taguchi table definition in detail. Gray cells show the passive cells of Taguchi table.

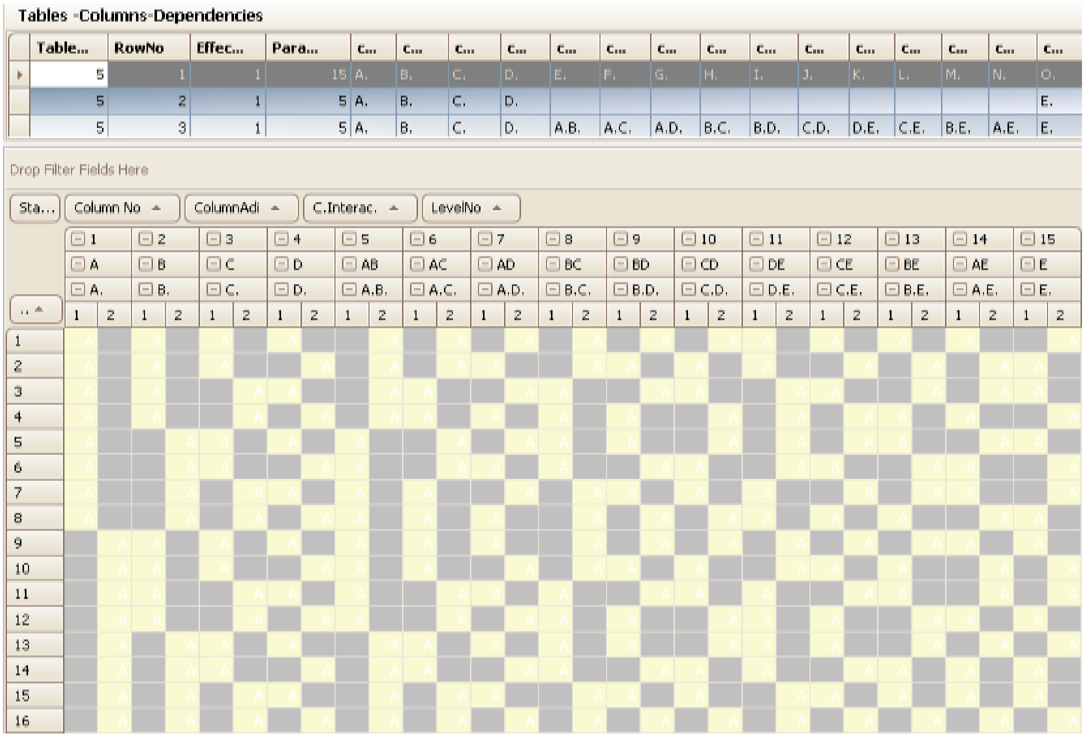

Figure 7.8 Taguchi table estimation table structure

7.4.3 Project Definition

Project definition screen is shown in Figure 7.9. In this work, 5 factors 2 levels color measurement values were analyzed. Before starting analyzing, color project and factors of the project are defined on the screen. The input factors of color projects are ultramarine blue, mangane violet, ps01, diluted green, mgo with two levels.

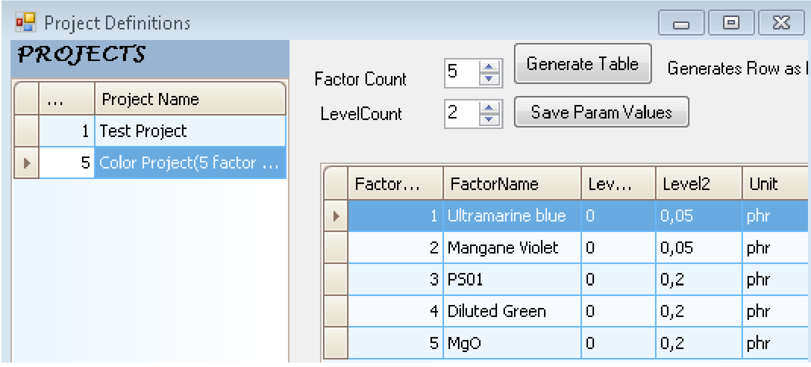

Figure 7.9 Project definition screen

Project definition section of this software enables to create a framework to analyze a project trial by using Taguchi or regression analysis method.

7.4.4 Project Trials

After defining project on the system, project trials response values should be entered into the system according to method of analysis. Figure 7.10 shows the possible Taguchi tables for a selected color project with 5 factors. User should choose one of the Taguchi tables to enter the response values of project trials.

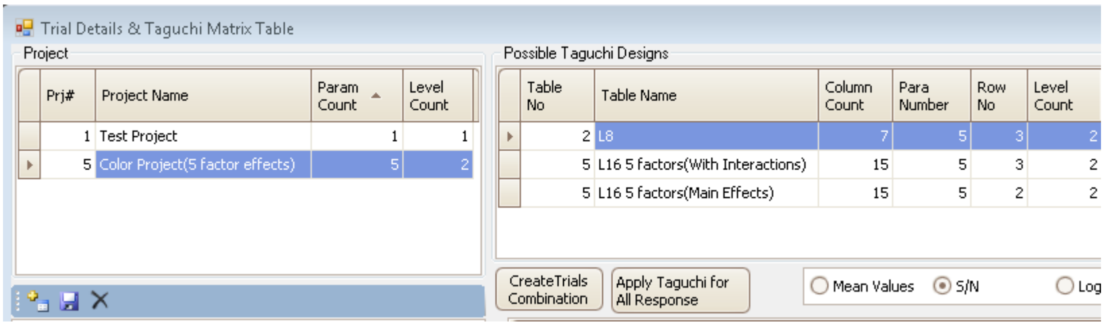

Figure 7.10 Project trial entry screen

As shown in Figure 7.10 project trial analysis may be done take into account main effects or main effects and interactions between factors. After choosing one of the suitable Taguchi table, user clicks on generate table button to create a combination table to enter the project trials response values. In shortly, after creating a combination for table L16, observation values can be entered to the system according to response number. All the columns are the same for all L16 combinations, so that

Taguchi columns are constructed for Project trials. Taguchi orthogonal array can be chose by user according to analyzing details. Two level Taguchi analyze is done at this Project. But the DOExpert framework is suitable to define other Taguchi tables. If Taguchi table is defined into DOExpert system, data can be analyzed using this Taguchi table structure Figure 7.11 shows the combinations for L16 design table structure, Figure 7.11 shows response variable values that can be entered on the system. This work contains color response variables as *ltop, btop, atop* and *lbotom, bbotom, abottom* as shown in Figure 7.11.

According to these combinations, experiments are done randomly and response results are entered into the system as respectively as shown in Figure 7.11.

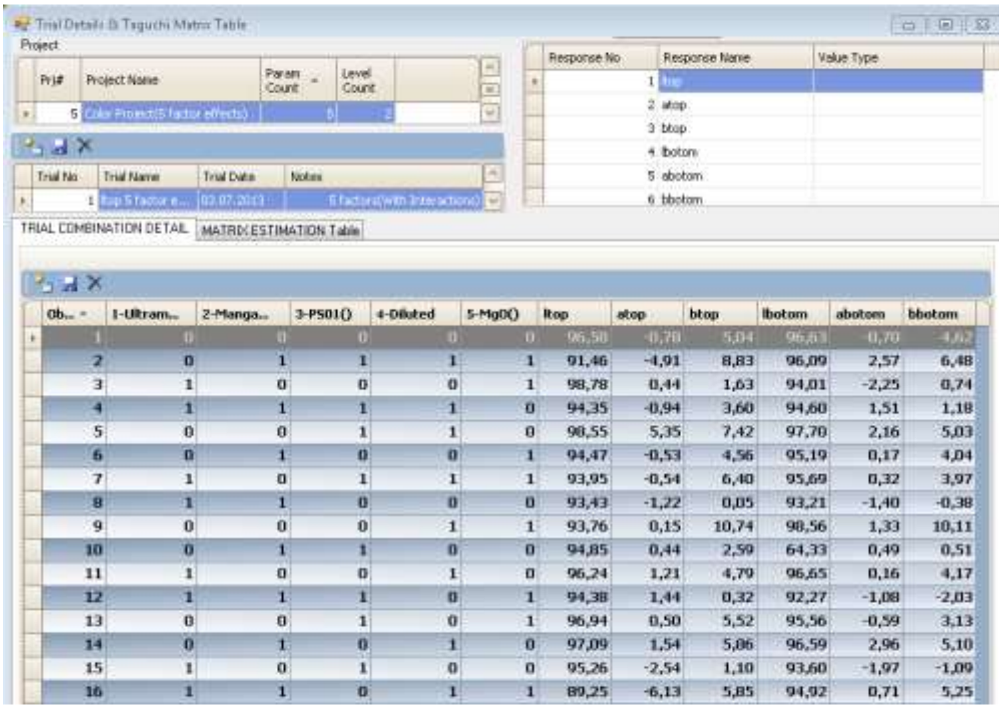

Figure 7.11 Project trial combinations and response variables screen

After entering response variables result values into the system, analysis method should be chosen by the user. After choosing one of the methods from “Mean”, S/N, “log10”, analysis can be done. This system can analyze the values for one or all of the methods at the same time. This means user can shows all results at the same time and compares the results so that an analysis can be done in an effective way. Project trial method and possible Taguchi table and response variable selection screen is shown in Figure 7.12.

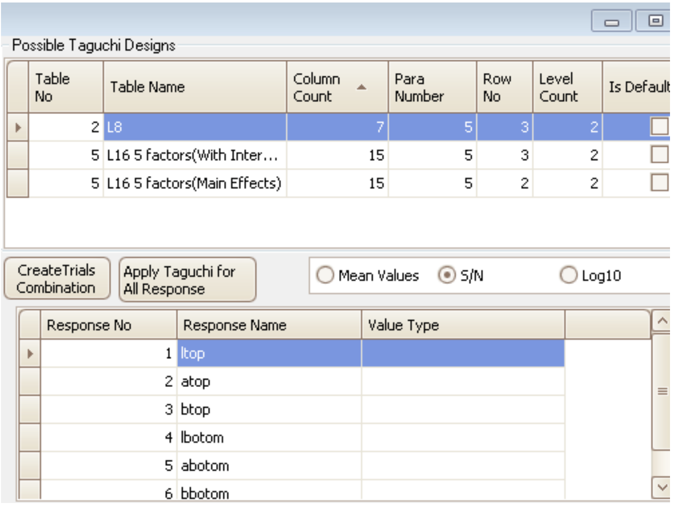

Figure 7.12 Project trial screen

7.4.5 Project Trial's Taguchi Analysis

After entering response variable values into the system, this system creates Taguchi estimation table which shows the effects of the factors in detail. This work analyzes *ltop*, *atop*, *btop*, *lbottom*, *abottom* and *bbotom* response values respectively according to mean of response values. In this work two analyses were done for 5 factors color project. First analysis is done for main factor effects. Second analysis is done for main factor effects with interactions. These are explained in detail below.

7.4.5.1 Main Effects Ltop

Windows profile *ltop* response values main effects table is shown in Figure 7.13. There are 5 color factors as input parameters. This table shows the effects as Mangane Violet=2.59, MgO=-1.67, Diluted Green =1.25, Ultramarine blue=1.00, PS01=-0.0175. The absolute values of the effects of the factors are ordered and can be shown in Figure 7.13.

TRIAL COMBINATION DETAIL | MATRIX ESTIMATION Table

Taguchi Table

SOr...	Res...	Ob...	U.B... L1	U.B... L2	M.V... L1	M.V... L2	PS01- L1	PS01- L2	D.G... L1	D.G... L2	MgO- L1	MgO- L2
1		96,58	96,58		96,58		96,58		96,58			96,58
2		93,76	93,76		93,76		93,76			93,76	93,76	
3		96,94	96,94		96,94			96,94	96,94		96,94	
4		98,55	98,55		98,55			98,55		98,55		98,55
5		94,47	94,47			94,47	94,47		94,47		94,47	
6		97,09	97,09			97,09	97,09			97,09		97,09
7		94,85	94,85			94,85		94,85	94,85			94,85
8		91,46	91,46			91,46		91,46		91,46	91,46	
9		98,78		98,78	98,78		98,78		98,78		98,78	
10		96,24		96,24	96,24		96,24			96,24		96,24
11		95,26		95,26	95,26			95,26	95,26			95,26
12		93,95		93,95	93,95			93,95		93,95	93,95	
13		93,43		93,43		93,43	93,43		93,43			93,43
14		89,25		89,25		89,25	89,25			89,25	89,25	
15		94,38		94,38		94,38		94,38	94,38		94,38	
16		94,35		94,35		94,35		94,35		94,35		94,35
90	SUM	1519,34	763,70	755,64	770,06	749,28	759,60	759,74	764,69	754,65	752,99	766,35
92	COUNT	16	8	8	8	8	8	8	8	8	8	8
93	AVG	94,95...	95,4625	94,4550	96,2575	93,66	94,95	94,9675	95,58...	94,33...	94,12...	95,79...
94	EFFECT	0	1,0075		2,5975		-0,0175		1,2550		-1,67	
95	ORDER	0	4	4	1	1	5	5	3	3	2	2

Figure 7.13 *Ltop* Taguchi L16 estimation table results

7.4.5.2 Main Effects Atop

Windows profile *atop* response values main effects table is shown in Figure 7.14. There are 5 color factors as input parameters. This table shows the effects as Mangane Violet=1.76, MgO=-1.58, Ultramarine blue=1.25, PS01=-0.51, Diluted Green=0.25. The absolute values of the effects of the factors are ordered and is shown in Figure 7.14.

TRIAL COMBINATION DETAIL | MATRIX ESTIMATION Table

Taguchi Table

SOr...	Res...	Ob...	U.B... L1	U.B... L2	M.V... L1	M.V... L2	PS01- L1	PS01- L2	D.G... L1	D.G... L2	MgO- L1	MgO- L2
1		-0,78	-0,78		-0,78		-0,78		-0,78			-0,78
2		0,15	0,15		0,15		0,15			0,15	0,15	
3		0,50	0,50		0,50			0,50	0,50		0,50	
4		5,35	5,35		5,35			5,35		5,35		5,35
5		-0,53	-0,53			-0,53	-0,53		-0,53		-0,53	
6		1,54	1,54			1,54	1,54			1,54		1,54
7		0,44	0,44			0,44		0,44	0,44			0,44
8		-4,91	-4,91			-4,91		-4,91		-4,91	-4,91	
9		0,44		0,44	0,44		0,44		0,44		0,44	
10		1,21		1,21	1,21		1,21			1,21		1,21
11		-2,54		-2,54	-2,54			-2,54	-2,54			-2,54
12		-0,54		-0,54	-0,54			-0,54		-0,54	-0,54	
13		-1,22		-1,22		-1,22	-1,22		-1,22			-1,22
14		-6,13		-6,13		-6,13	-6,13			-6,13	-6,13	
15		1,44		1,44		1,44		1,44	1,44		1,44	
16		-0,94		-0,94		-0,94		-0,94		-0,94		-0,94
90	SUM	1512,82	1,76	-8,28	3,79	-10,31	-5,32	-1,20	-2,25	-4,27	-9,58	3,06
92	COUNT	32	8	8	8	8	8	8	8	8	8	8
93	AVG	47,27...	0,22	-1,0350	0,473...	-1,288...	-0,6650	-0,15	-0,281...	-0,533...	-1,1975	0,3825
94	EFFECT	0	1,2550		1,7625		-0,5150		0,2525		-1,58	
95	ORDER	0	3	3	1	1	4	4	5	5	2	2

Figure 7.14 *Atop* Taguchi L16 estimation table results

7.4.5.3 Main Effects Btop

Windows profile *btop* response values main effects table is shown in Figure 7.15. There are 5 color factors as input parameters. This table shows the effects as Diluted Green=-4.08, Ultramarine blue=3.35, MgO=1.67, Mangane Violet=1.37, PS01=0.34 respectively. The absolute values of the effects of the factors are ordered and is shown in Figure 7.15.

TRIAL COMBINATION DETAIL | MATRIX ESTIMATION Table

Taguchi Table

SOr...	Res...	Ob...	U.B... L1	U.B... L2	M.V... L1	M.V... L2	PS01- L1	PS01- L2	D.G... L1	D.G... L2	MgO- L1	MgO- L2
1		5,04	5,04		5,04		5,04		5,04			5,04
2		10,74	10,74		10,74		10,74			10,74	10,74	
3		5,52	5,52		5,52			5,52	5,52		5,52	
4		7,42	7,42		7,42			7,42		7,42		7,42
5		4,56	4,56			4,56	4,56		4,56		4,56	
6		5,86	5,86			5,86	5,86			5,86		5,86
7		2,59	2,59			2,59		2,59	2,59			2,59
8		8,83	8,83			8,83		8,83		8,83	8,83	
9		1,63		1,63	1,63		1,63		1,63		1,63	
10		4,79		4,79	4,79		4,79			4,79		4,79
11		1,10		1,10	1,10			1,10	1,10			1,10
12		6,40		6,40	6,40			6,40		6,40	6,40	
13		0,05		0,05		0,05	0,05		0,05			0,05
14		5,85		5,85		5,85	5,85			5,85	5,85	
15		0,32		0,32		0,32		0,32	0,32		0,32	
16		3,60		3,60		3,60		3,60		3,60		3,60
90	SUM	1587,12	50,56	23,74	42,64	31,66	38,52	35,78	20,81	53,49	43,85	30,45
92	COUNT	48	8	8	8	8	8	8	8	8	8	8
93	AVG	33,0650	6,32	2,9675	5,33	3,9575	4,8150	4,4725	2,601...	6,686...	5,481...	3,806...
94	EFFECT	0	3,3525		1,3725		0,3425		-4,0850		1,6750	
95	ORDER	0	2	2	4	4	5	5	1	1	3	3

Figure 7.15 *Btop* Taguchi L16 estimation table results

7.4.5.4 Main Effects Lbottom

Windows profile *lbottom* response values main effects table is shown in Figure 7.16. There are 5 color factors as input parameters. This table shows the effects as Diluted Green=-5.75, Mangane Violet=5.15, PS01=4.49, MgO=3.62, Ultramarine blue=-1.78 respectively. The absolute values of the effects of the factors are ordered and is shown in Figure 7.16.

TRIAL COMBINATION DETAIL | MATRIX ESTIMATION Table

Taguchi Table

SOr...	Res...	Ob...	U.B... L1	U.B... L2	M.V... L1	M.V... L2	PS01- L1	PS01- L2	D.G... L1	D.G... L2	MgO- L1	MgO- L2
1		96,63	96,63		96,63		96,63		96,63			96,63
2		98,56	98,56		98,56		98,56			98,56	98,56	
3		95,56	95,56		95,56			95,56	95,56		95,56	
4		97,70	97,70		97,70			97,70		97,70		97,70
5		95,19	95,19			95,19	95,19		95,19		95,19	
6		96,59	96,59			96,59	96,59			96,59		96,59
7		64,33	64,33			64,33		64,33	64,33			64,33
8		96,09	96,09			96,09		96,09		96,09	96,09	
9		94,01		94,01	94,01		94,01		94,01		94,01	
10		96,65		96,65	96,65		96,65			96,65		96,65
11		93,60		93,60	93,60			93,60	93,60			93,60
12		95,69		95,69	95,69			95,69		95,69	95,69	
13		93,21		93,21		93,21	93,21		93,21			93,21
14		94,92		94,92		94,92	94,92			94,92	94,92	
15		92,27		92,27		92,27		92,27	92,27		92,27	
16		94,60		94,60		94,60		94,60		94,60		94,60
90	SUM	3082,72	740,65	754,95	768,40	727,20	765,76	729,84	724,80	770,80	762,29	733,31
92	COUNT	64	8	8	8	8	8	8	8	8	8	8
93	AVG	48,1675	92,58...	94,36...	96,05	90,90	95,72	91,23	90,60	96,35	95,28...	91,66...
94	EFFECT	0	-1,7875		5,15		4,49		-5,75		3,6225	
95	ORDER	0	5	5	2	2	3	3	1	1	4	4

Figure 7.16 *Lbottom* Taguchi L16 estimation table results

7.4.5.5 Main Effects Abottom

Windows profile *abottom* response values main effects table is shown in Figure 7.17. There are 5 color factors as input parameters. This table shows the effects as Diluted Green=-2.38, Ultramarine blue=1.54, Mangane Violet=-0.93, PS01=-0.30, MgO=-0.25 respectively. The absolute values of the effects of the factors are ordered and is shown in Figure 7.17.

TRIAL COMBINATION DETAIL | MATRIX ESTIMATION Table

Taguchi Table

SOr...	Res...	Ob...	U.B... L1	U.B... L2	M.V... L1	M.V... L2	PS01- L1	PS01- L2	D.G... L1	D.G... L2	MgO- L1	MgO- L2
1		-0,70	-0,70		-0,70		-0,70		-0,70			-0,70
2		1,33	1,33		1,33		1,33			1,33	1,33	
3		-0,59	-0,59		-0,59			-0,59	-0,59		-0,59	
4		2,16	2,16		2,16			2,16		2,16		2,16
5		0,17	0,17			0,17	0,17		0,17		0,17	
6		2,96	2,96			2,96	2,96			2,96		2,96
7		0,49	0,49			0,49		0,49	0,49			0,49
8		2,57	2,57			2,57		2,57		2,57	2,57	
9		-2,25		-2,25	-2,25		-2,25		-2,25		-2,25	
10		0,16		0,16	0,16		0,16			0,16		0,16
11		-1,97		-1,97	-1,97			-1,97	-1,97			-1,97
12		0,32		0,32	0,32			0,32		0,32	0,32	
13		-1,40		-1,40		-1,40	-1,40		-1,40			-1,40
14		0,71		0,71		0,71	0,71			0,71	0,71	
15		-1,08		-1,08		-1,08		-1,08	-1,08		-1,08	
16		1,51		1,51		1,51		1,51		1,51		1,51
90	SUM	3087,11	8,39	-4	-1,54	5,93	0,98	3,41	-7,33	11,72	1,18	3,21
92	COUNT	80	8	8	8	8	8	8	8	8	8	8
93	AVG	38,58...	1,048...	-0,50	-0,1925	0,741...	0,1225	0,426...	-0,916...	1,4650	0,1475	0,401...
94	EFFECT	0	1,548...		-0,933...		-0,303...		-2,381...		-0,253...	
95	ORDER	0	2	2	3	3	4	4	1	1	5	5

Figure 7.17 *Abottom* Taguchi L16 estimation table results

7.4.5.6 Main Effects Bbottom

Windows profile *bbottom* response values main effects table is shown in Figure 7.18. There are 5 color factors as input parameters. This table shows the effects as Diluted Green=-3.96, Ultramarine blue=3.40, PS01=2.058, MgO=1.56, Mangane Violet=1.31 respectively. The absolute values of the effects of the factors are ordered and is shown in Figure 7.18.

TRIAL COMBINATION DETAIL | MATRIX ESTIMATION Table

Taguchi Table

SOr...	Res...	Ob...	U.B... L1	U.B... L2	M.V... L1	M.V... L2	PS01-L1	PS01-L2	D.G... L1	D.G... L2	MgO-L1	MgO-L2
1		4,62	4,62		4,62		4,62		4,62			4,62
2		10,11	10,11		10,11		10,11			10,11	10,11	
3		3,13	3,13		3,13			3,13	3,13		3,13	
4		5,03	5,03		5,03			5,03		5,03		5,03
5		4,04	4,04			4,04	4,04		4,04		4,04	
6		5,10	5,10			5,10	5,10			5,10		5,10
7		0,51	0,51			0,51		0,51	0,51			0,51
8		6,48	6,48			6,48		6,48		6,48	6,48	
9		0,74		0,74	0,74		0,74		0,74		0,74	
10		4,17		4,17	4,17		4,17			4,17		4,17
11		-1,09		-1,09	-1,09			-1,09	-1,09			-1,09
12		3,97		3,97	3,97			3,97		3,97	3,97	
13		-0,38		-0,38		-0,38	-0,38		-0,38			-0,38
14		5,25		5,25		5,25	5,25			5,25	5,25	
15		-2,03		-2,03		-2,03		-2,03	-2,03		-2,03	
16		1,18		1,18		1,18		1,18		1,18		1,18
90	SUM	3137,94	39,02	11,81	30,68	20,15	33,65	17,18	9,54	41,29	31,69	19,14
92	COUNT	96	8	8	8	8	8	8	8	8	8	8
93	AVG	32,68...	4,8775	1,476...	3,8350	2,518...	4,206...	2,1475	1,1925	5,161...	3,961...	2,3925
94	EFFECT	0	3,401...		1,316...		2,058...		-3,968...		1,568...	
95	ORDER	0	2	2	5	5	3	3	1	1	4	4

Figure 7.18 *Bbottom* Taguchi L16 estimation table results

7.4.5.7 Main Effects and Interactions Ltop

Before starting the showing analysis results of this work including interaction effects a brief explanation will be done here.

After analyzing main factor effects, interactions of the factors for *ltop, atop, btop, lbottom, abottom, bbottom* response values should be analyzed. Because there may be a significant factors which has an important effect than main factor effect. Taguchi L16 table structure provides a way to analyze with interactions. Each factor is analyzed on the system and effects of main factors and their interactions are ordered respectively.

Table 7.1 Color factors and abbreviations

Main Factor Name	Abbreviation	Letter for factor
Ultramarine blue	U.B.	A

Table 7.1 Color factors and abbreviations

Main Factor Name	Abbreviation	Letter for factor
Mangane Violet	M.V	B
PS01	PS	C
Diluted Green	D.G.	D
MgO	M.O	E
Interactions	Abbreviation	Letter for factor
Ultramarine blue-Mangane Violet	A.B	A.B
Ultramarine blue- PS01	A.C	A.C
Ultramarine blue- Diluted Green	A.D	A.D
Mangane Violet- PS01	B.C	B.C
Mangane Violet- Diluted Green	B.D	B.D
PS01- Diluted Green	C.D	C.D
Diluted Green- MgO	D.E	D.E
PS01- MgO	C.E	C.E
Mangane Violet- MgO	B.E	B.E
Ultramarine blue- MgO	A.E.	A.E

Ltop, abtop, btop, lbottom, abottom and *bbotom* response values are analyzed via DOExpert software and each result is given at Taguchi L16 estimation table below.

Windows profile main effects and interactions order of color factors for *ltop* response value is shown in Figure 7.19 and table detail is shown in Figure 7.20.

FACTORS	DE-	M.V.	MgO	D.G	U.B.	AE	BE	AD	AB	CD	BC	CE	AC	PS	BD
EFFECT	-2,78	2,60	-1,67	1,26	1,01	0,94	-0,87	0,76	0,61	-0,48	-0,18	0,10	-0,04	-0,02	-0,01
ORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Figure 7.19 Ltop factors effects order

TRIAL COMBINATION DETAIL | MATRIX ESTIMATION Table

...	R...	O...	U...	U...	M...	M...	P...	P...	D...	D...	AB-	AB-	AC-	AC-	AD-	AD-	BC-	BC-	BD-	BD-	CD-	CD-	DE-	DE-	CE-	CE-	BE-	BE-	AE-	AE-	M...	M...
1		96,58	96,58		96,58		96,58		96,58			96,58		96,58		96,58		96,58		96,58		96,58	96,58		96,58		96,58		96,58			96,5
2		93,76	93,76		93,76		93,76			93,76		93,76		93,76	93,76			93,76	93,76		93,76		93,76			93,76		93,76		93,76	93,76	
3		96,94	96,94		96,94			96,94	96,94			96,94	96,94			96,94	96,94			96,94	96,94			96,94	96,94			96,94		96,94	96,94	
4		98,55	98,55		98,55			98,55		98,55		98,55	98,55		98,55		98,55		98,55			98,55		98,55		98,55	98,55		98,55			98,5
5		94,47	94,47			94,47	94,47		94,47		94,47			94,47		94,47	94,47		94,47			94,47		94,47		94,47	94,47			94,47	94,47	
6		97,09	97,09			97,09	97,09			97,09	97,09			97,09	97,09		97,09			97,09	97,09			97,09	97,09			97,09	97,09			97,0
7		94,85	94,85			94,85		94,85	94,85		94,85		94,85			94,85		94,85	94,85		94,85		94,85			94,85		94,85	94,85			94,8
8		91,46	91,46			91,46		91,46		91,46	91,46		91,46		91,46			91,46		91,46		91,46	91,46		91,46		91,46			91,46	91,46	
9		98,78		98,78	98,78		98,78		98,78		98,78		98,78		98,78			98,78		98,78		98,78		98,78		98,78		98,78	98,78		98,78	
10		96,24		96,24	96,24		96,24			96,24	96,24		96,24			96,24		96,24	96,24		96,24			96,24	96,24		96,24			96,24		96,2
11		95,26		95,26	95,26			95,26	95,26		95,26			95,26	95,26		95,26			95,26	95,26		95,26			95,26	95,26			95,26		95,2
12		93,95		93,95	93,95			93,95		93,95	93,95			93,95		93,95	93,95		93,95			93,95	93,95		93,95			93,95	93,95		93,95	
13		93,43		93,43		93,43	93,43		93,43			93,43	93,43		93,43		93,43		93,43			93,43	93,43		93,43			93,43		93,43		93,4
14		89,25		89,25		89,25	89,25			89,25		89,25	89,25			89,25	89,25			89,25	89,25		89,25			89,25	89,25		89,25		89,25	
15		94,38		94,38		94,38		94,38	94,38			94,38		94,38	94,38			94,38	94,38		94,38			94,38	94,38		94,38		94,38		94,38	
16		94,35		94,35		94,35		94,35		94,35		94,35		94,35		94,35		94,35		94,35		94,35		94,35		94,35		94,35		94,35		94,3
90	SUM	1519...	763,70	755,64	770,06	749,28	759,60	759,74	764,69	754,65	762,10	757,24	759,50	759,84	762,71	756,63	758,94	760,40	759,63	759,71	757,77	761,57	748,54	770,80	760,07	759,27	756,19	763,15	763,43	755,91	752,99	766,3
92	COU...	16	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
93	AVG	94,9...	95,4...	94,4...	96,2...	93,66	94,95	94,9...	95,5...	94,3...	95,2...	94,6...	94,9...	94,98	95,3...	94,5...	94,8...	95,05	94,9...	94,9...	94,7...	95,1...	93,5...	96,35	95,0...	94,9...	94,5...	95,3...	95,4...	94,4...	94,1...	95,7...
94	EFFE...	0	1,0075		2,5975		-0,01...		1,2550		0,6075		-0,04...		0,76		-0,18...		-0,01		-0,47...		-2,78...		0,10		-0,87		0,94		-1,67	
95	ORD...	0	5	5	2	2	14	14	4	4	9	9	13	13	8	8	11	11	15	15	10	10	1	1	12	12	7	7	6	6	3	3

Figure 7.20 *Ltop* Taguchi L16 estimation table results with interactions

7.4.5.8 Main Effects and Interactions Atop

Windows profile main effects and interactions order of color factors for *atop* response value is shown in Figure 7.21 and Figure 7.22.

FACTORS	DE	BD	M.V	MgO	AE	U.B	BE	AD	PS	AB	AC	D.G	CE	BC	CD
EFFECT	-3,07	2,39	1,763	-1,58	1,255	1,255	-0,91	0,878	-0,52	-0,41	-0,27	0,253	0,125	-0,08	-0,03
ORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Figure 7.21 Atop factors effects order

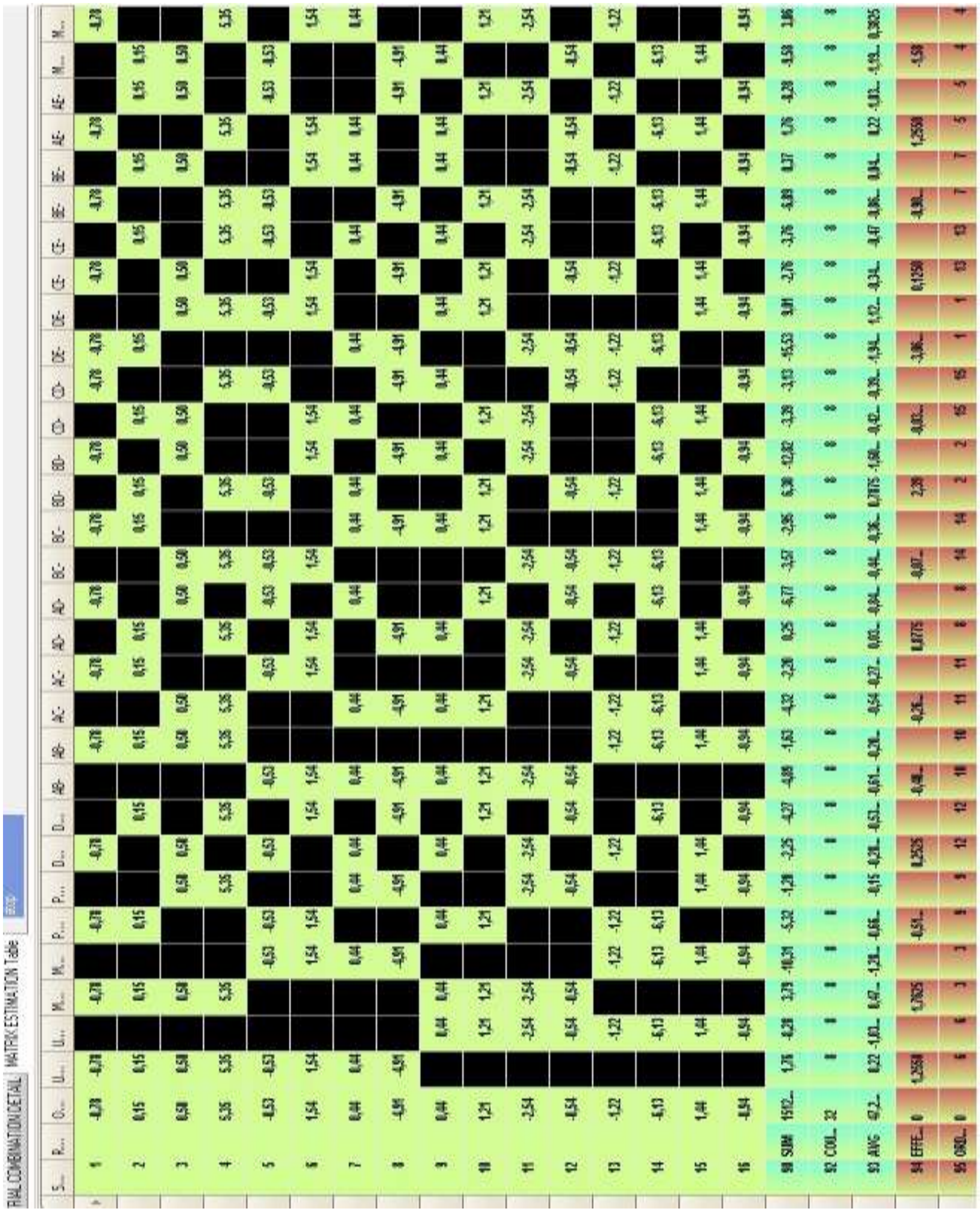

Figure 7.22 *Atop* Taguchi L16 estimation table results with interactions

7.4.5.9 Main Effects and Interactions Btop

Windows profile main effects and interactions order of color factors for *btop* response value is shown in Figure 7.23 and table detail is shown in Figure 7.24.

FACTORS	D.G	U.B.	MgO	M.V.	DE	AE	AB	PS	AD	BE	AC	BC	CD	CE	BD
EFFECT	-4,09	3,35	1,68	1,37	0,86	-0,51	-0,35	0,34	-0,30	0,19	-0,12	-0,10	-0,10	-0,09	-0,07
ORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Figure 7.23 Btop factors effects order

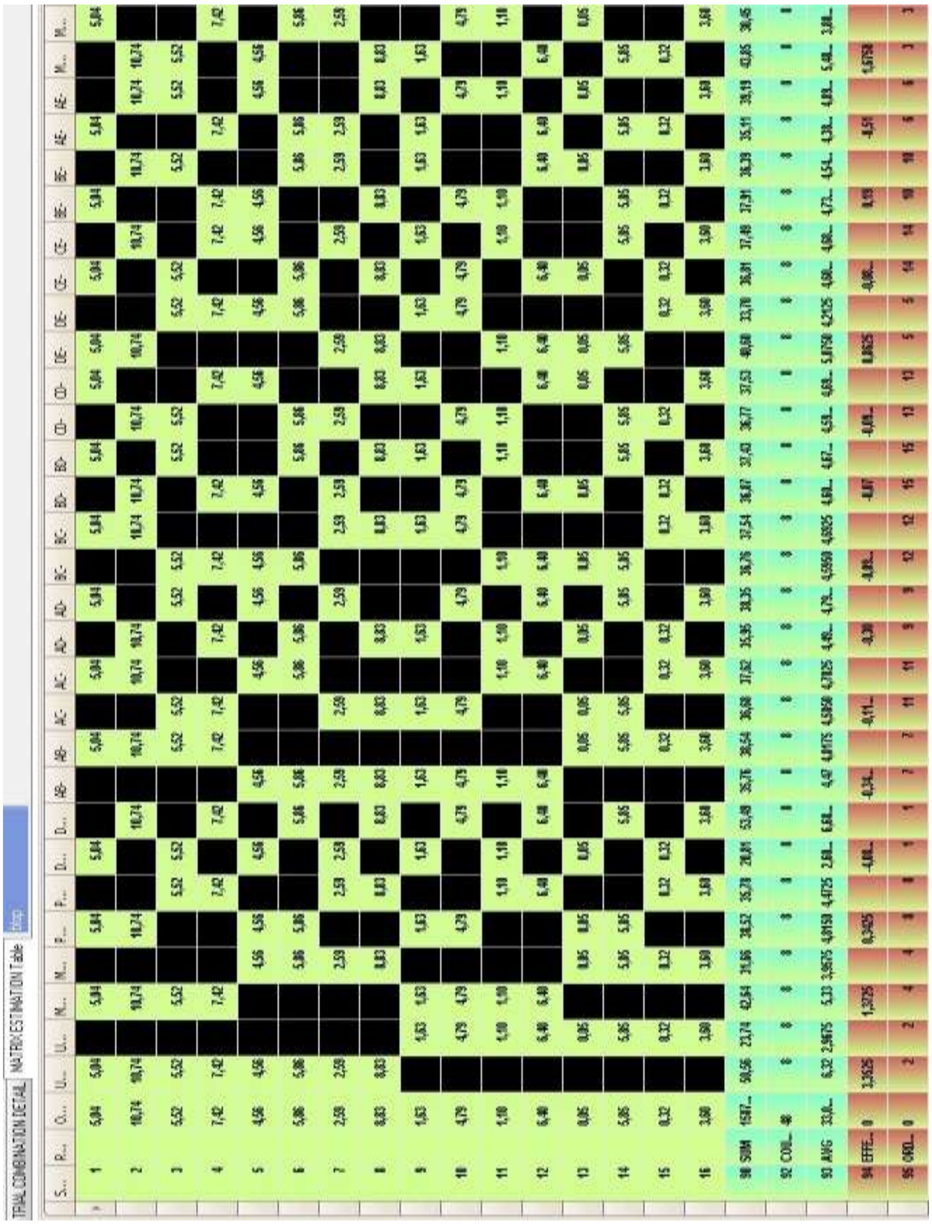

Figure 7.24 *Btop* Taguchi L16 estimation table results with interactions

7.4.5.10 Main Effects and Interactions Lbottom

The order of windows profile main effects and interactions for *lbottom* response value is shown in Figure 7.25 and table detail is shown in Figure 7.26.

FACTORS	D.G.	M.V	PS01	AE	AB	AC	CD	BE	CE	DE	BC	MgO	AD	BD	U.B.
EFFECT	-5,75	5,15	4,49	-3,92	-3,91	-3,83	-3,83	3,81	3,72	-3,69	3,67	3,62	3,56	-3,55	-1,79
ORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Figure 7.25 Lbottom factors effects order

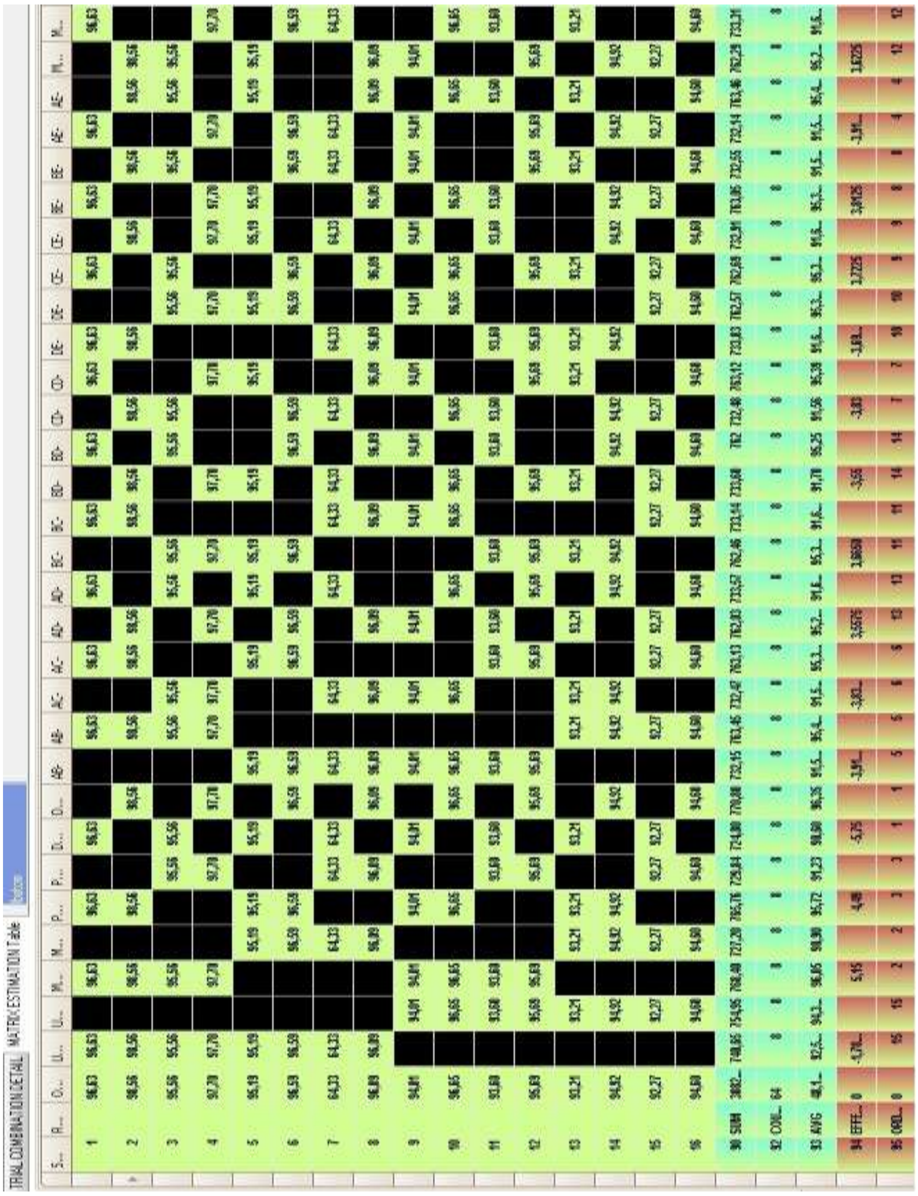

Figure 7.26 *Lbottom* Taguchi L16 estimation table results with interactions

7.4.5.11 Main Effects and Interactions Abottom

Windows profile main effects and interactions order of color factors for *abottom* response value is shown in Figure 7.27 and Figure 7.28.

FACTORS	D.G.	U.B.	M.V.	PS	MgO	DE	AE	AC	AB	CD	BE	BC	AD	CE	BD
EFFECT	-2,38	1,55	-0,93	-0,30	-0,25	-0,21	0,10	-0,09	0,06	-0,05	-0,04	0,04	0,03	0,01	-0,01
ORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Figure 7.27 Abottom factors effects order

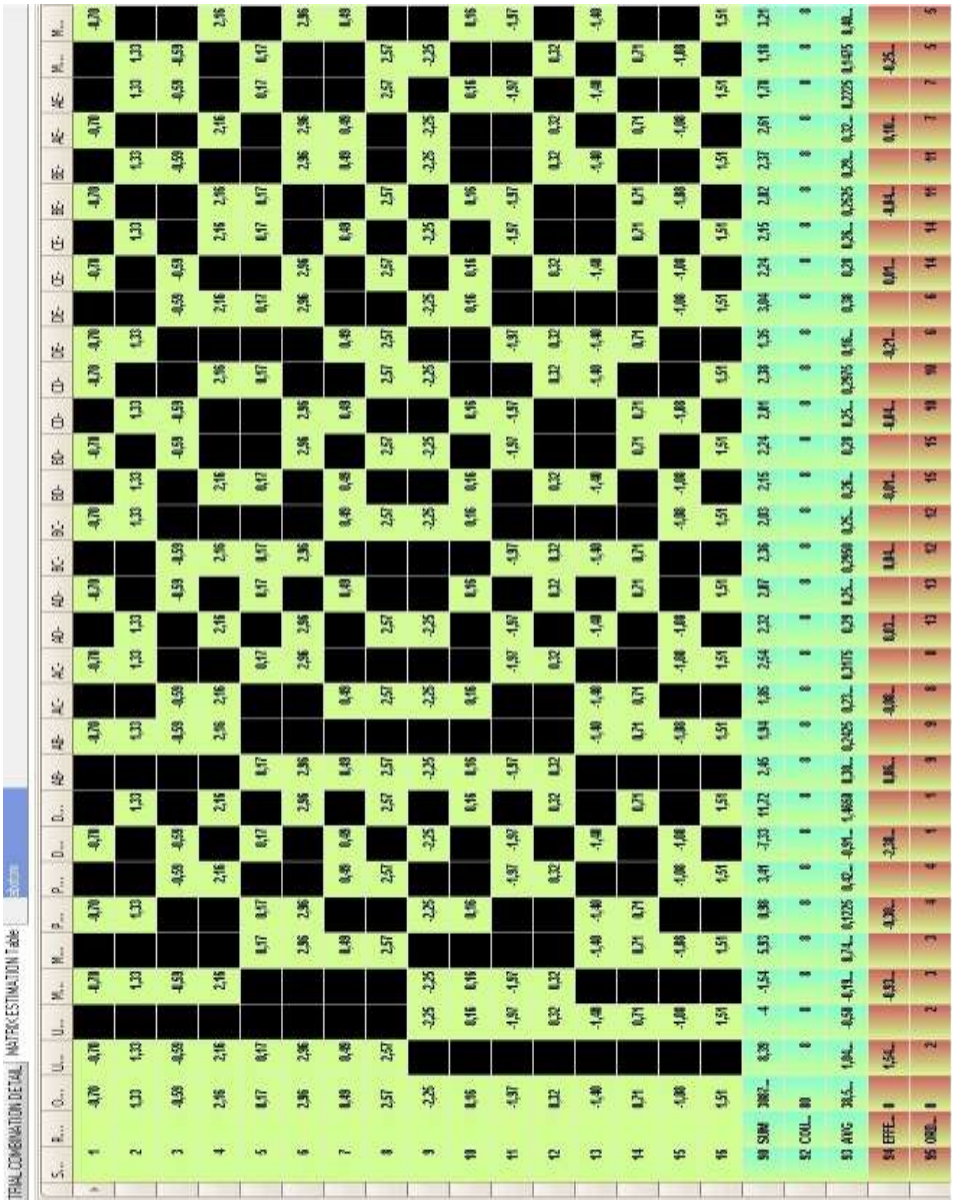

Figure 7.28 *Abottom* Taguchi L16 estimation table results with interactions

7.4.5.12 Main Effects and Interactions Bbottom

Windows profile main effects and interactions order of color factors for *bbottom* response value is shown in Figure 7.29 and Figure 7.30.

FACTORS	D.G.	U.B.	PS	MgO	M.V.	DE	AE	AB	AD	BE	AC	BC	CE	CD	BD
EFFECT	-3,97	3,40	2,06	1,57	1,32	1,01	-0,56	-0,37	-0,36	0,26	-0,12	-0,09	-0,09	-0,07	0,00
ORDER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Figure 7.29 Bbottom factors effects order

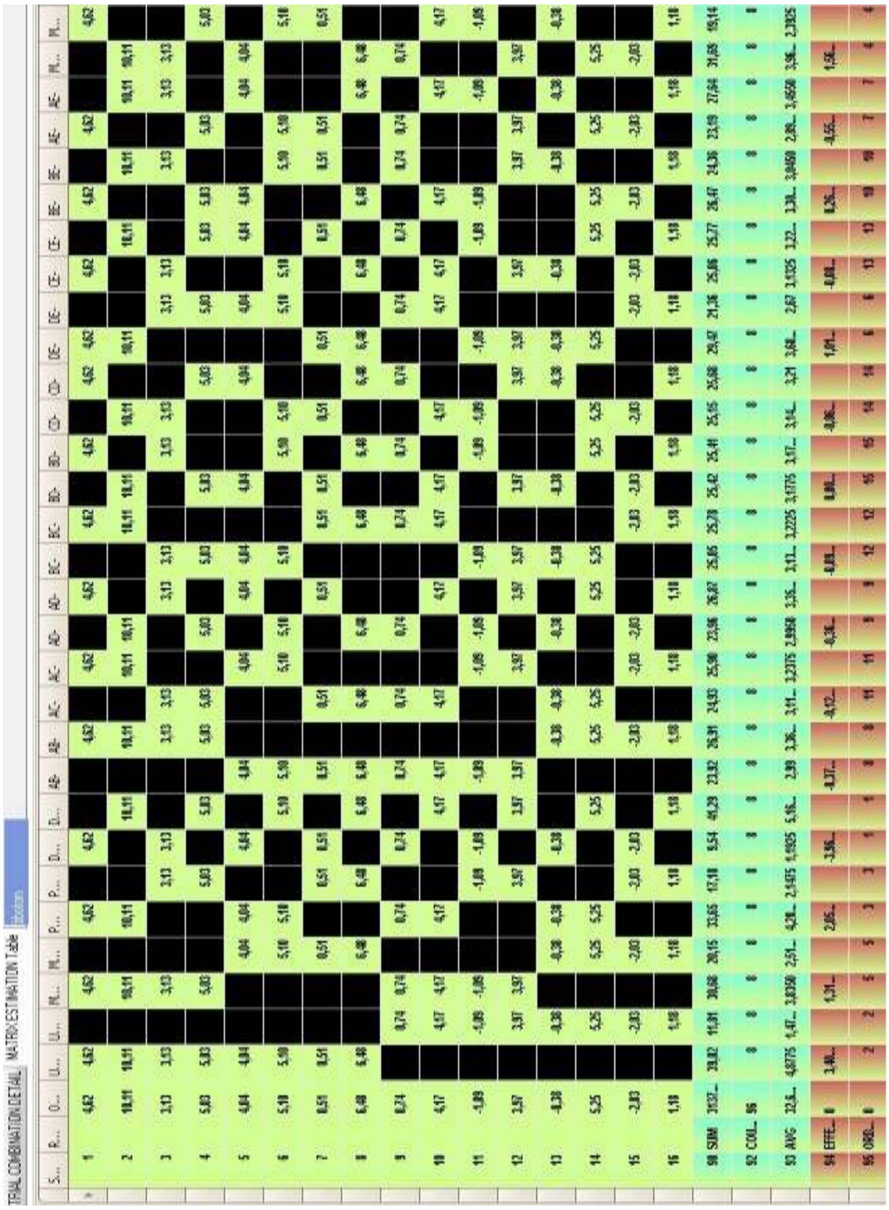

Figure 7.30 *Bbottom* Taguchi L16 estimation table results with interactions

7.4.6 Project Trial Regression Analysis

In this work, other experimental design method named regression analysis method was applied on color project data. *Regression Analysis* is a common statistical method for design of experiment. DOExpert Software includes the project parameter definition screen as shown in Figure 7.31. After choosing an experimental project, project parameters are shown on the screen. At the right hand of the screen, user enter the interactions with * (star character) between them. There are 8 interactions and 5 main factors as shown in Figure 7.31.

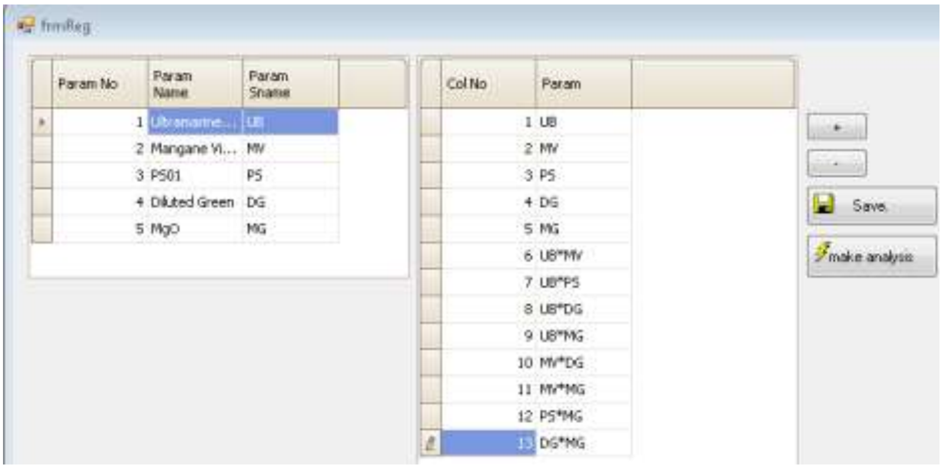

Figure 7.31 Project parameters and interactions entry screen

After entering the interactions on the screen, data saved into database to make a regression analysis. Combination table with interactions are constructed as shown in Figure 7.32. There are 13 columns contains main factors and interactions of the factors. After doing regression analysis, results are shown in Figure 7.33.

Drop Filter Fields Here

Trial Value | Column No | ColumnName

Observati...	1 UB	2 MV	3 PS	4 DG	5 MG	6 UB*MV	7 UB*PS	8 UB*DG	9 UB*MG	10 MV*DG	11 MV*MG	12 PS*MG	13 DG*MG
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	2	2	2	2	2	2	2	2	4	4	4	4
3	2	1	1	1	2	2	2	2	4	1	2	2	2
4	2	2	2	2	1	4	4	4	2	4	2	2	2
5	1	1	2	2	1	1	2	2	1	2	1	2	2
6	1	2	1	1	2	2	1	1	2	2	4	2	2
7	2	1	2	2	2	2	4	4	4	2	2	4	4
8	2	2	1	1	1	4	2	2	2	2	2	1	1
9	1	1	1	2	2	1	1	2	2	2	2	2	4
10	1	2	2	1	1	2	2	1	1	2	2	2	1
11	2	1	1	2	1	2	2	4	2	2	1	1	2
12	2	2	2	1	2	4	4	2	4	2	4	4	2
13	1	1	2	1	2	1	2	1	2	1	2	4	2
14	1	2	1	2	1	2	1	2	1	4	2	1	2
15	2	1	2	1	1	2	4	2	2	1	1	2	1
16	2	2	1	2	2	4	2	4	4	4	4	2	4

Figure 7.32 Project combinations for *ltop* response variable

Column No	Column Name	Reg Coeff
0	Constant	87,05375
1	UB	0,1475
2	MV	1,805
3	PS	-0,41
4	DG	9,3425
5	MG	6,1675
6	UB*MV	-1,215
7	UB*PS	0,085
8	UB*DG	-1,52
9	UB*MG	1,88
10	MV*DG	0,02
11	MV*MG	-1,74
12	PS*MG	0,2
13	DG*MG	-5,565

Figure 7.33 Project regression analysis results for *ltop* response variable

7.4.7 Taguchi and Regression Analysis Prediction

DOExpert software makes a prediction by using previous project trial results. User selects a project trial from the list shown in Figure 7.34. After selecting a project trial, project factors and response variables are shown on the screen.

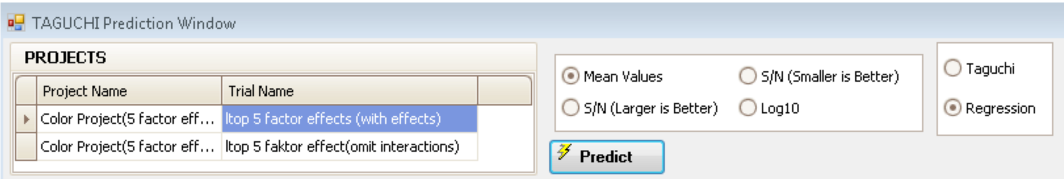

Figure 7.34 Project trials for prediction

Factor levels are chosen by user via Taguchi prediction window shown in Figure 7.35. For Taguchi analysis, one of the factor levels should be chosen to analyze. At the right hand of the screen, coefficients of factors are shown.

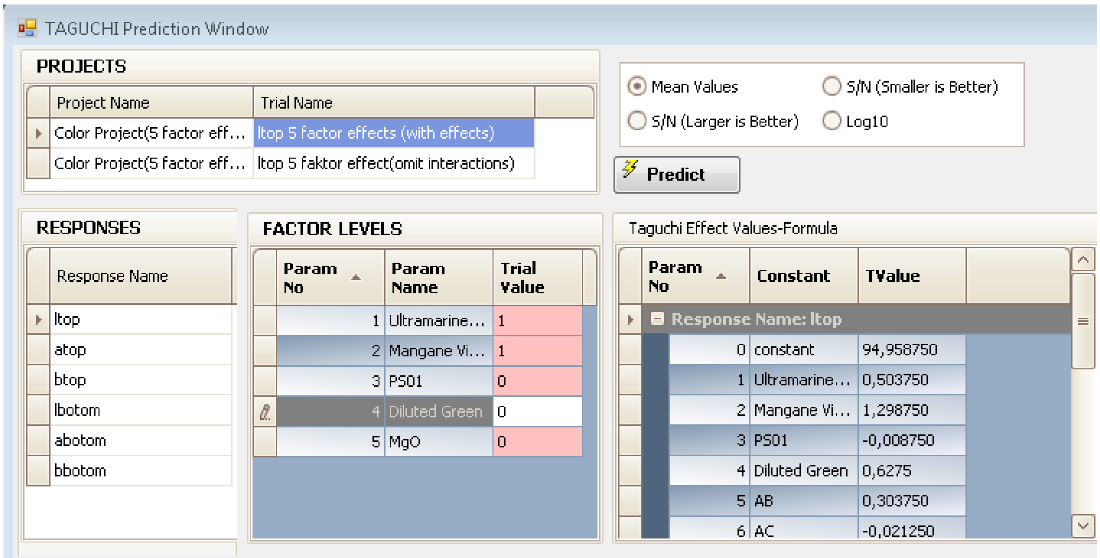

Figure 7.35 Project trials mean value coefficients

After entering trial values for prediction, DOExpert software finds a predicted response value for mean values is shown in Figure 7.36.

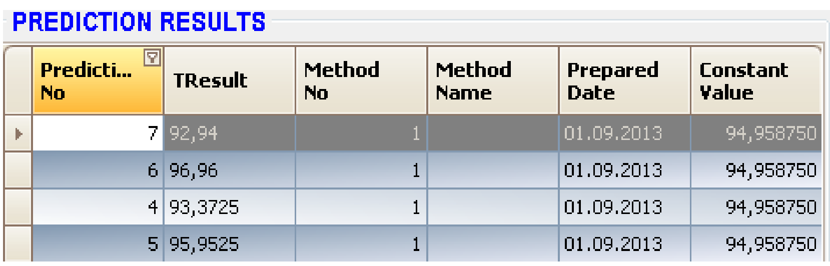

Figure 7.36 Project prediction results mean value coefficients

And also, this framework allows user to analyze an experimental project with regression analysis. Regression analysis equation of *ltop* response variable is shown in Figure 7.37.

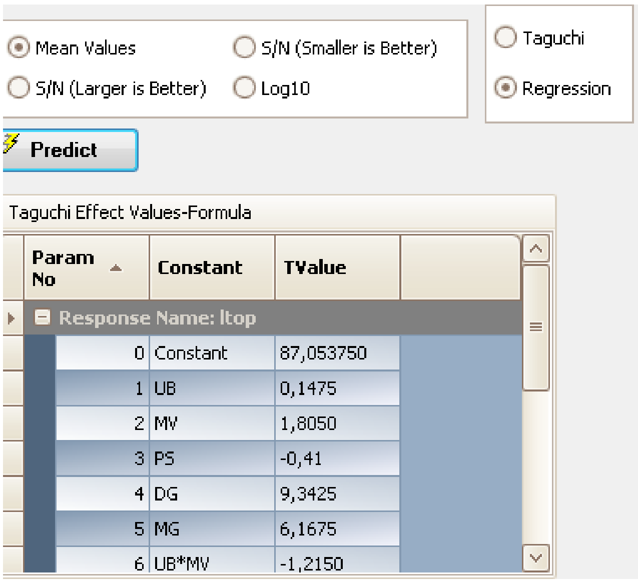

Figure 7.37 Project regression equation coefficients

7.4.8 DOExpert Project for Finding Optimum Values for Multiple Regression Equation

DOExpert project enables an opportunity to find the optimum values of the factors by using more than one equation. Regression equations are shown at the left hand side of the screen (Figure 7.38). By using the five of the equations and entering the target values, system finds the optimum values for the target. While the optimum values found by matrix elimination method is shown in Figure 7.38; optimum values found by *Least Square Method* are shown in Figure 7.39.

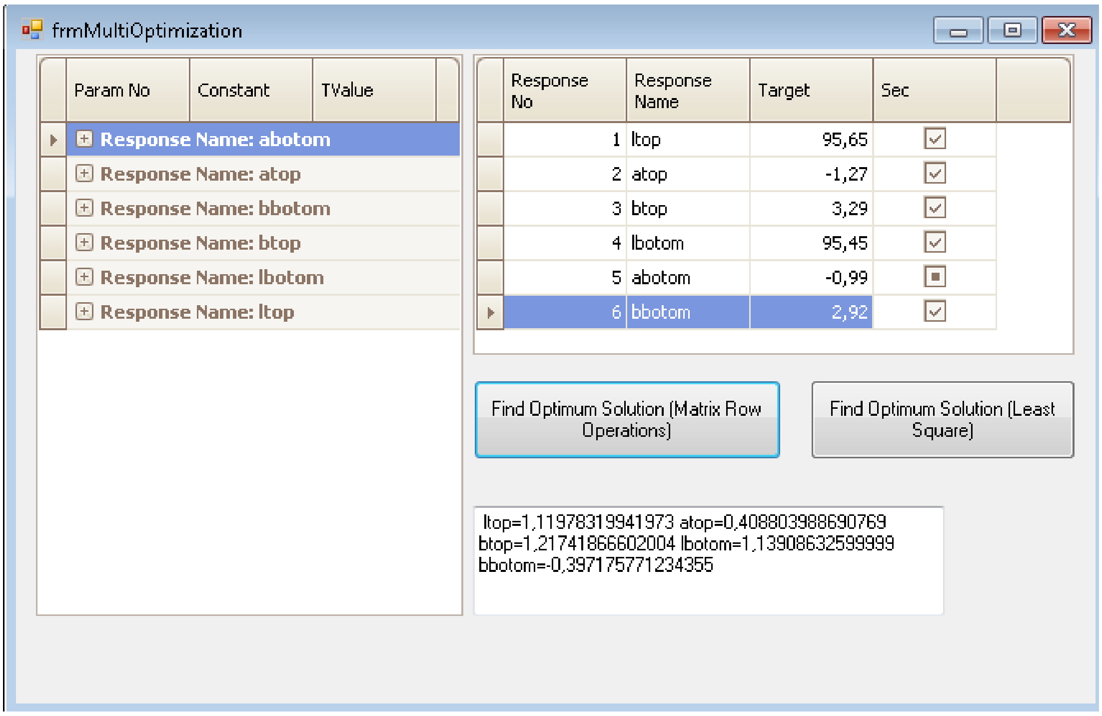

Figure 7.38 Project factor's optimum values by matrix elimination method

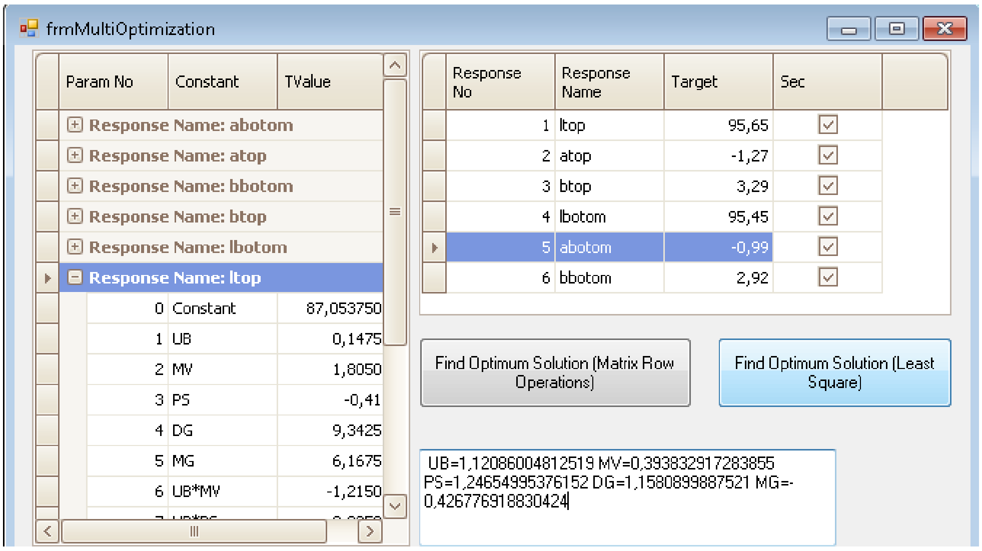

Figure 7.39 Project optimum values by Least Square Method

7.4.9 Ltop Comparing Methods

Project Trials can be analyzed with several methods. These are Mean value, S/N graph, log10 graph. All of the main effects and interactions are shown in Figure 7.40 for mean value, Figure 7.41 for S/N value, Figure 7.42 for log10 value.

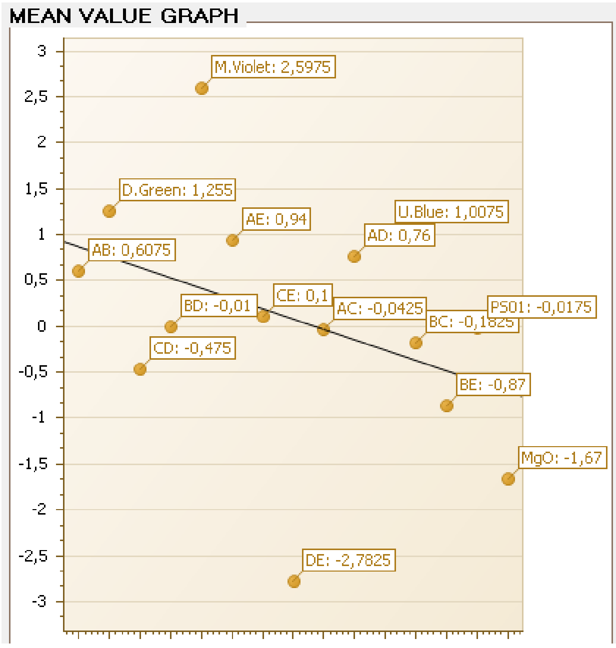

Figure 7.40 Mean value effect graph for *ltop*

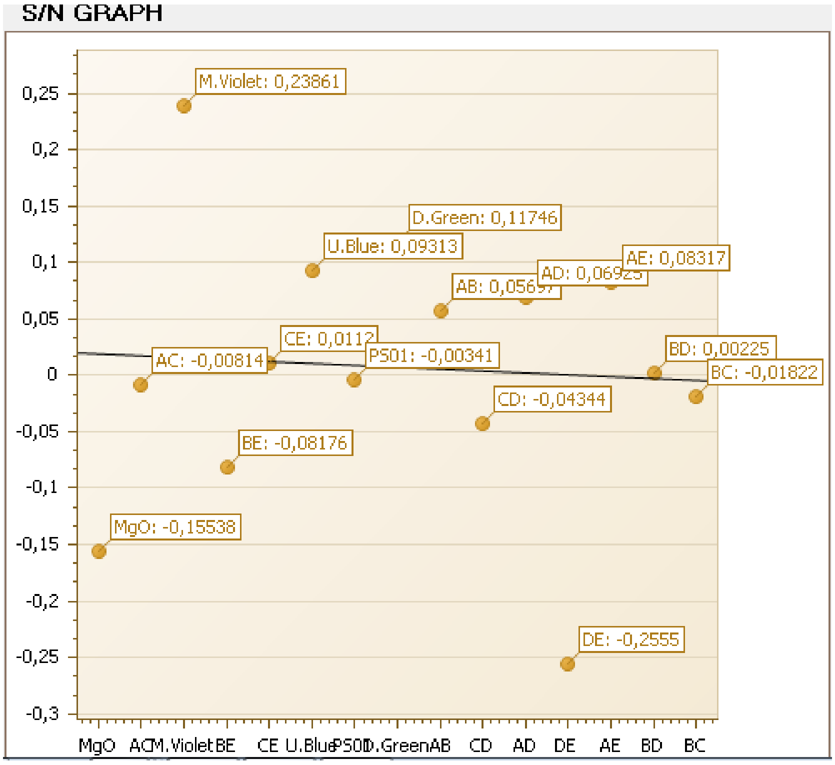

Figure 7.41 S/N value effect graph for *ltop*

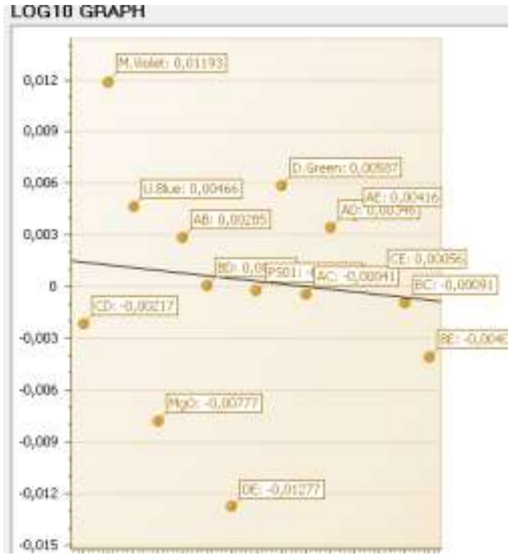

Figure 7.42 Log10 value effect graph for *ltop*

7.5 DOExpert Software Forms

DOExpert software consists of 13 windows forms and 3 classes as shown below. DOExpert Software solution explorer in Table 7.2 shows the forms, classes and references.

Table 7.2 DOExpert software windows forms and classes

PROJECT NAME	**DOExpert Software**
FORMS	**DESCRIPTION**
frmAuthorization	User Authorization Form
frmConfigurationMain.cs	DOExpert Configuration Screen
frmLogin.cs	Login Screen
frmMenuDefinition.cs	Menu definition screen
frmPrediction.cs	Prediction Screen
frmPrjDef.cs	Project Definition Screen
frmRegressionAnalysis.cs	Regression Analysis Screen
frmRoleDefinition.cs	Role Definition Screen
frmTableDefinition.cs	Table Definition Screen
frmTrial.cs	Project Trial Add/Remove Scren
frmTrialEffects.cs	Trial Effects Comparision Screen
frmTrialGraphSN.cs	Trial Effects Graphs Screen
frmMultiOptimization	Taguchi and Regression Multioptimization
CLASSES	**DESCRIPTION**
ExcelFileWrite.cs	Export Grid values into an Excel file
Matrix.cs	Matrix class for matrix operations
Complex.cs	Contains rows of matrix as elements.

7.6 Comparing Methods

This part of the work contains the comparable values for *ltop* values using Minitab 16 statistical software. *Ltop* values were analyzed with Taguchi L16 table, ½ fractional factorial design, full factorial design, Taguchi l32 table and regression analysis.

7.6.1 Taguchi Analysis L16

Ltop values for 16 observations and 5 factors combinations are entered into the Minitab 16 program as shown in Figure 7.43. Design table structure is the form of L16 table. Analysis was done and the results are shown below. Figure A shows the *ltop* real values and prediction results.

A	B	C	D	E	Y	MEAN1	FITS
-1	-1	-1	-1	-1	96.6	96.58	96.3
-1	-1	-1	1	1	93.8	93.76	94
-1	-1	1	-1	1	96.9	96.94	97.2
-1	-1	1	1	-1	98.6	98.55	98.3
-1	1	-1	-1	1	94.5	94.47	94.2
-1	1	-1	1	-1	97.1	97.09	97.3
-1	1	1	-1	-1	94.9	94.85	95.1
-1	1	1	1	1	91.5	91.46	91.2
1	-1	-1	-1	1	98.8	98.78	98.5
1	-1	-1	1	-1	96.2	96.24	96.5
1	-1	1	-1	-1	95.3	95.26	95.5
1	-1	1	1	1	94	93.95	93.7
1	1	-1	-1	-1	93.4	93.43	93.2
1	1	-1	1	1	89.3	89.25	89.5
1	1	1	-1	1	94.4	94.38	94.6
1	1	1	1	-1	94.4	94.35	94.1

Figure 7.43 *Ltop* real response values versus predicted values

Figure 7.44 shows the analysis results Taguchi L16 table. As shown below D*E and B are the significant factors. % 95 confidence interval, the results are S = 0.95 R-Sq = 99.0% R-Sq(adj) = 85.1%. This results are given by the program for larger is better response values.

Term	Constant	D*E	B	E	D	A	A*E	B*E	A*D	A*B	B*C	C*E	A*C	C	B*D
Y	94.9587	-1.39	1.30	0.84	0.63	0.50	0.47	-0.44	-0.38	-0.30	0.09	0.05	0.02	-0.01	0.01
Pre Y	94.9587	1.39	1.30	0.84	0.63	0.50	0.47	0.44	0.38	0.30	0.09	0.05	0.02	0.01	0.01

Figure 7.44 Interactions and main factors effects and order

Minitab orders the main factor effect shown in Figure 7.45.

Response Table for Means

Level	A	B	C	D	E
1	95,46	96,26	94,95	95,59	95,79
2	94,45	93,66	94,97	94,33	94,12
Delta	1,01	2,60	0,02	1,25	1,67
Rank	4	1	5	3	2

Figure 7.45 The order of the main effects of the factors in terms of levels

Figure 7.46 shows the detailed ANOVA table of Taguchi L16 design table.

Taguchi Analysis: Y versus A; B; C; D; E

Linear Model Analysis: Means versus A; B; C; D; E

Estimated Model Coefficients for Means

Term	Coef	SE Coef	T	P
Constant	94,9587	0,2375	399,826	0,002
A -1	0,5037	0,2375	2,121	0,280
B -1	1,2988	0,2375	5,468	0,115
C -1	-0,0087	0,2375	-0,037	0,977
D -1	0,6275	0,2375	2,642	0,230
E -1	0,8350	0,2375	3,516	0,176
A*B -1 -1	-0,3037	0,2375	-1,279	0,422
A*C -1 -1	0,0213	0,2375	0,089	0,943
A*D -1 -1	-0,3800	0,2375	-1,600	0,356
A*E -1 -1	0,4700	0,2375	1,979	0,298
B*C -1 -1	0,0912	0,2375	0,384	0,766
B*D -1 -1	0,0050	0,2375	0,021	0,987
B*E -1 -1	-0,4350	0,2375	-1,832	0,318
C*E -1 -1	0,0500	0,2375	0,211	0,868
D*E -1 -1	-1,3912	0,2375	-5,858	0,108

S = 0,95   R-Sq = 99,0%   R-Sq(adj) = 85,1%

Figure 7.46 Taguchi analysis ANOVA table and coefficients

Figure 7.47 shows the regression line of predicted *Y* values.

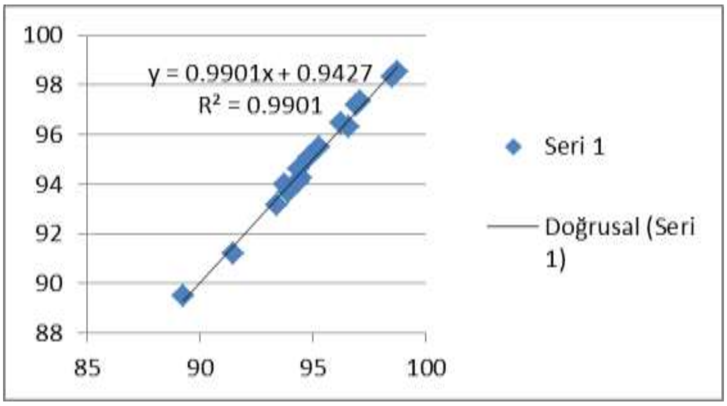

Figure 7.47 Response *ltop* variable regression line

As shown in Figure 7.48, predicted *Y* value is between *limit1* and *limit2*, this system is confidence.

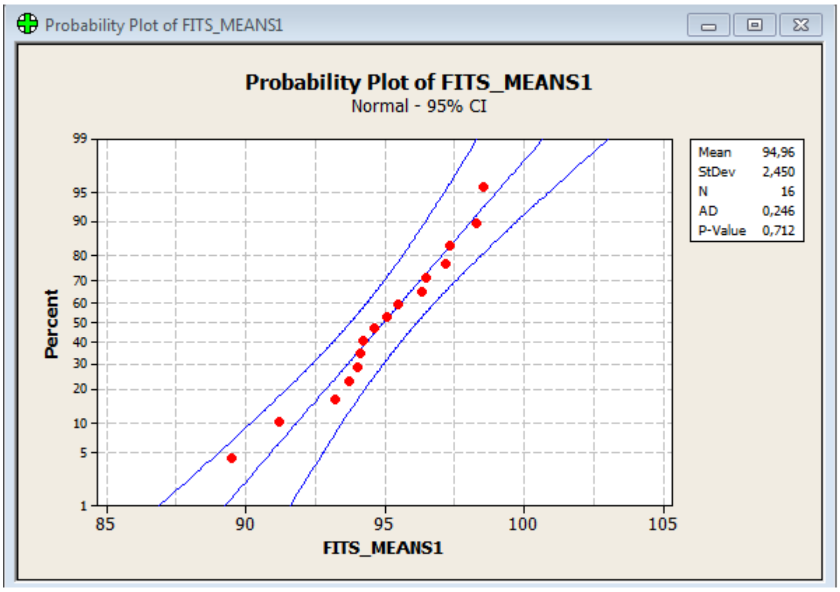

Figure 7.48 Probability plot of *ltop* prediction values.

Figure 7.49 shows the main effects separately.-1 is low limit, +1 is high limit.

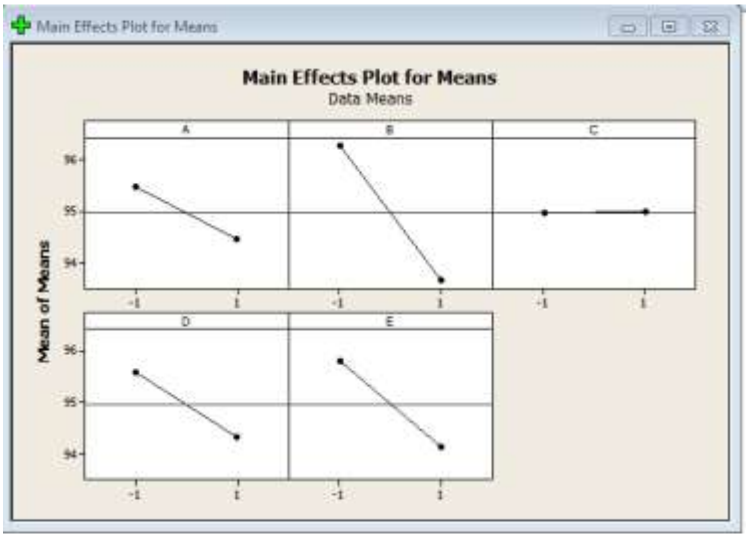

Figure 7.49 Main effects plot for Means.

7.6.2 Fractional Factoriyel ½

Ltop response values are analyzed by the method of Fractional factorial ½. This means when there are 5 factors with two levels each, there are 2^5=32 combinations by full factorial. ½ fractional factorial method uses only the half of the full factorial combinations.

After analyzing *ltop* response values for means, the effects of main factors and interactions is shown in Figure 7.50. *R2* value is 98% (Figure 7.51).

Term	Constant	D*E	B	E	D	A	A*E	B*E	A*D	A*B	C*E	A*C	C	B*D
Effect	94.959	-2.782	-2.598	-1.67	-1.255	-1.007	0.94	-0.87	-0.76	-0.608	0.1	0.043	0.017	0.01
Coef	0.1799	-1.391	-1.299	-0.835	-0.628	-0.504	0.47	-0.435	-0.38	-0.304	0.05	0.021	0.009	0.005
	0.1799	1.391	1.299	0.835	0.628	0.504	0.47	0.435	0.38	0.304	0.05	0.021	0.009	0.005

Figure 7.50 *Ltop* ½ fractional factorial analysis results

```
S = 0,719627     PRESS = 66,2864
R-Sq = 98,86%    R-Sq(pred) = 27,08%    R-Sq(adj) = 91,46%
```

Figure 7.51 Analysis results with 95% confidence interval

After analyzing with this method, system makes prediction and writes the combinations result as shown in Figure 7.52.

Y	96.58	93.76	96.94	98.55	94.47	97.09	94.85	91.46	98.78	96.24	95.26	93.95	93.43	89.25	94.38	94.35
Pre Y	96.25	93.91	97.27	98.40	94.32	97.42	95.00	91.13	98.45	96.39	95.59	93.80	93.28	89.58	94.53	94.02

Figure 7.52 Ltop real values and prediction values.

Figure 7.53 shows the predicted *ltop* response values, regression line and *R2* value.

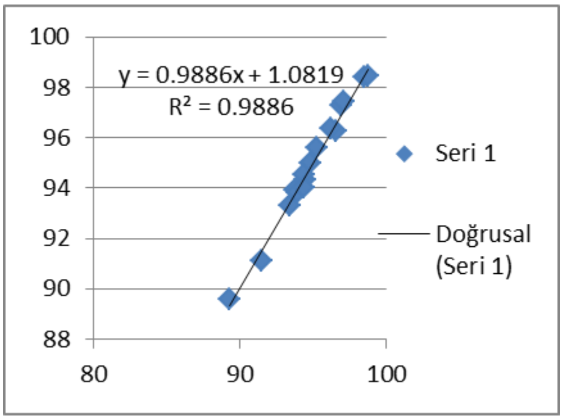

Figure 7.53 *Ltop* predicted *Y* response values and regression line.

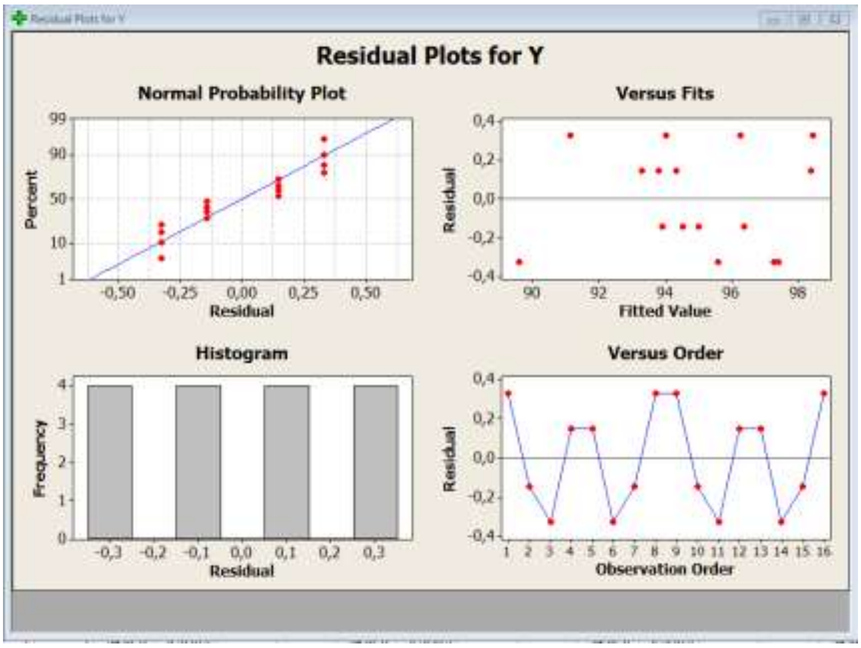

Figure 7.54 Graphs for *ltop* ½ fractional factorial analysis results.

Figure 7.54 contains 4 different graphs as follows:

- Normal probability plot: Sorts the residuals so that probability scale is constructed. All of the residuals should be at this trend. Residual value is the difference between real and predicted response values.
- Histogram: Distribution of residuals. Residuals should be at interval band.
- Residuals versus fits: Predicted Y values versus residuals distribution. Residuals not show a trend and should be from top –bottom or side by side.
- Versus order: Residuals in observation order

Double interaction graphs and Pareto graph are shown in Figure 7.55 and Figure 7.56 respectively. All factors and their interaction effects are shown as Figure 7.57. In this figure, red points indicate the significant factors.

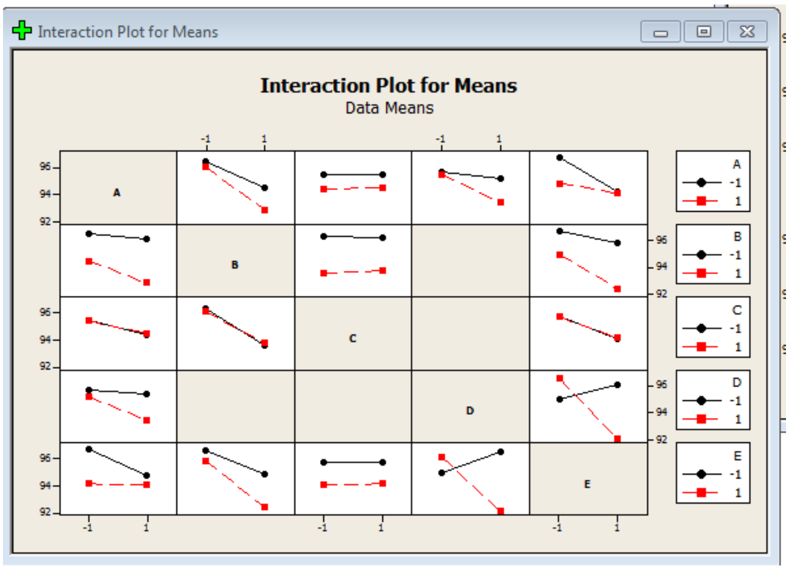

Figure 7.55 Double interactions graphs

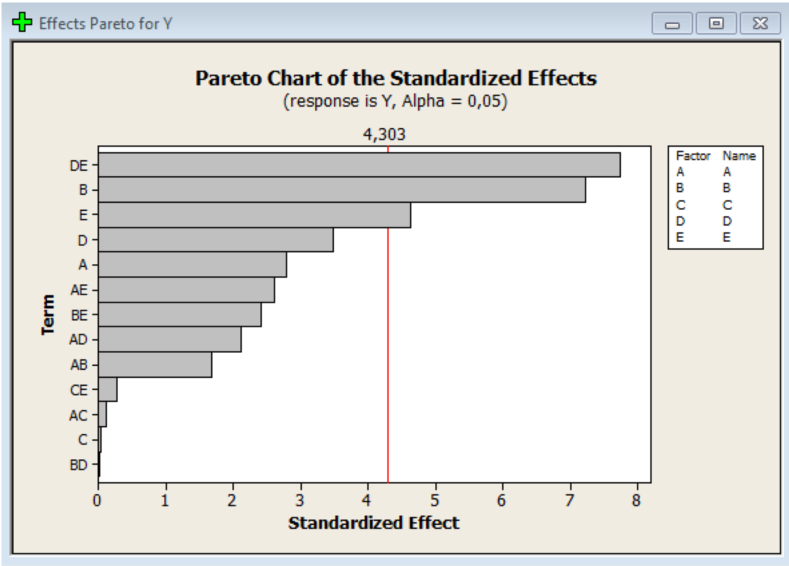

Figure 7.56 Pareto graph shows the effects.

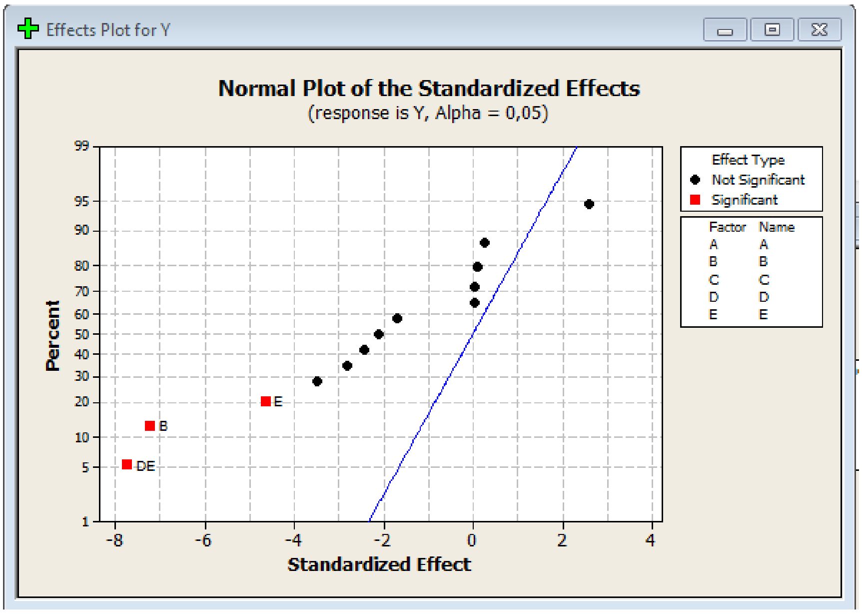

Figure 7.57 The effects of all factors, red points are significant

7.6.3 Regression Analysis

The results of *ltop* regression analysis and ANOVA table are shown in Figure 7.58.

General Regression Analysis: Y versus A; B; C; D; E

```
Regression Equation

Y  =  94,9588 - 0,50375 A - 1,29875 B + 0,00875 C - 0,6275 D - 0,835 E -
      0,30375 A*B + 0,02125 A*C - 0,38 A*D + 0,47 A*E + 0,005 B*D - 0,435 B*E +
      0,05 C*E - 1,39125 D*E
```

Coefficients

Term	Coef	SE Coef	T	P
Constant	94,9588	0,179907	527,822	0,000
A	-0,5037	0,179907	-2,800	0,107
B	-1,2988	0,179907	-7,219	0,019
C	0,0087	0,179907	0,049	0,966
D	-0,6275	0,179907	-3,488	0,073
E	-0,8350	0,179907	-4,641	0,043
A*B	-0,3037	0,179907	-1,688	0,233
A*C	0,0213	0,179907	0,118	0,917
A*D	-0,3800	0,179907	-2,112	0,169
A*E	0,4700	0,179907	2,612	0,121
B*D	0,0050	0,179907	0,028	0,980
B*E	-0,4350	0,179907	-2,418	0,137
C*E	0,0500	0,179907	0,278	0,807
D*E	-1,3912	0,179907	-7,733	0,016

```
Summary of Model

S = 0,719627      R-Sq = 98,86%        R-Sq(adj) = 91,46%
PRESS = 66,2864   R-Sq(pred) = 27,08%
```

Figure 7.58 Regression analysis results

Figure 7.59 shows the prediction of the results with the real values and regression line.

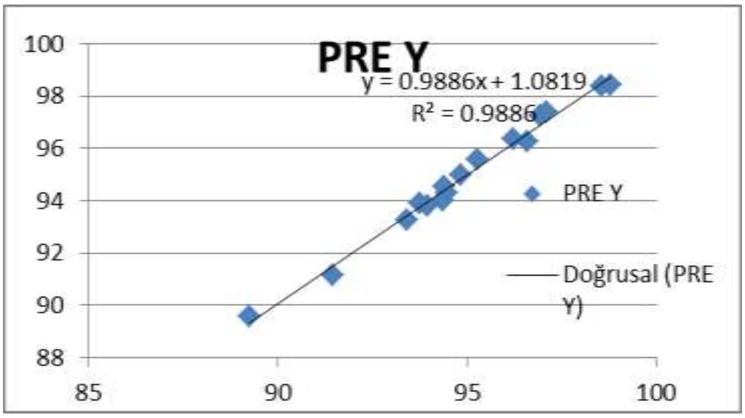

Figure 7.59 Ltop regression line.

Figure 7.60 shows the graphs for this analysis. And also probability plot graphs is shown in Figure 7.61. All of the red points are between the limits, this system is confident at 95% confidence interval.

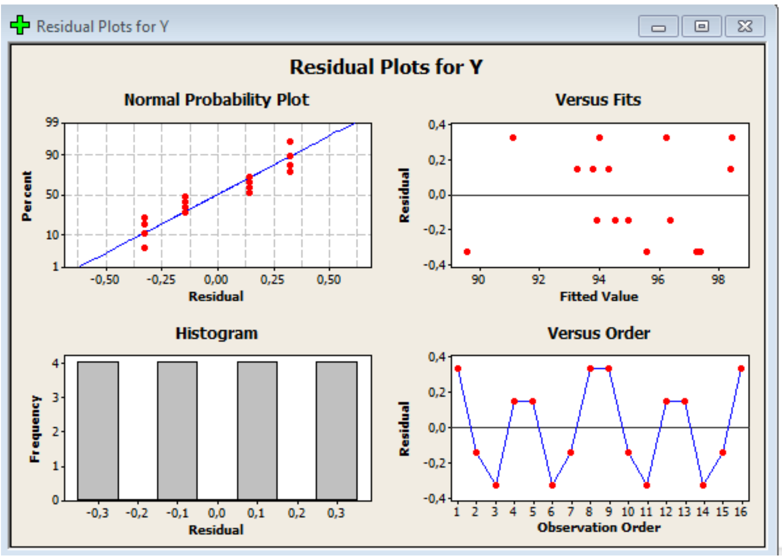

Figure 7.60 Regression analysis result graphs.

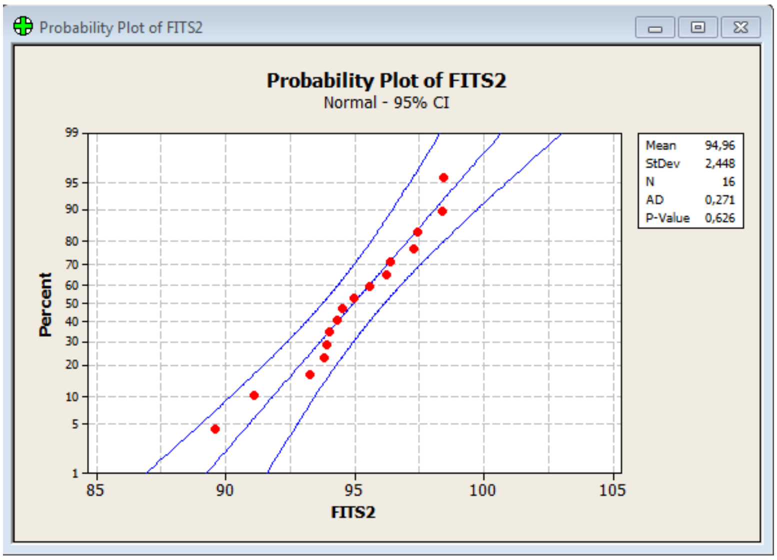

Figure 7.61 Probability plot of ltop values.

7.6.4. Full Factorial

In order to compare all methods, full factorial method was applied at this work. The ANOVA table of *ltop* response variable is shown in Figure 7.62. The effects and coefficients are shown in this table.

Factorial Fit: Y versus A; B; C; D; E

Estimated Effects and Coefficients for Y (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		94,422	0,3501	269,70	0,000
A	-1,159	-0,580	0,3501	-1,66	0,149
B	-2,051	-1,025	0,3501	-2,93	0,026
C	-0,917	-0,458	0,3501	-1,31	0,238
D	-1,123	-0,562	0,3501	-1,60	0,160
E	-0,912	-0,456	0,3501	-1,30	0,241
A*B	-0,466	-0,233	0,3501	-0,66	0,531
A*C	0,161	0,080	0,3501	0,23	0,826
A*D	-0,561	-0,280	0,3501	-0,80	0,454
A*E	1,193	0,597	0,3501	1,70	0,139
B*C	0,152	0,076	0,3501	0,22	0,835
B*D	0,871	0,435	0,3501	1,24	0,260
B*E	-0,431	-0,215	0,3501	-0,62	0,561
C*D	0,292	0,146	0,3501	0,42	0,691
C*E	0,126	0,063	0,3501	0,18	0,864
D*E	-1,451	-0,725	0,3501	-2,07	0,084
A*B*C	1,332	0,666	0,3501	1,90	0,106
A*B*D	0,026	0,013	0,3501	0,04	0,972
A*B*E	-0,183	-0,092	0,3501	-0,26	0,802
A*C*D	0,439	0,220	0,3501	0,63	0,553
A*C*E	0,861	0,430	0,3501	1,23	0,265
A*D*E	-0,031	-0,015	0,3501	-0,04	0,967
B*C*D	0,253	0,127	0,3501	0,36	0,730
B*C*E	0,199	0,100	0,3501	0,28	0,785
B*D*E	0,118	0,059	0,3501	0,17	0,872
C*D*E	0,142	0,071	0,3501	0,20	0,846

S = 1,98044 PRESS = 669,352
R-Sq = 84,88% R-Sq(pred) = 0,00% R-Sq(adj) = 21,89%

Figure 7.62 ANOVA table result for full factorial

Figure 7.63 shows the normal plot of the effects for *ltop*.

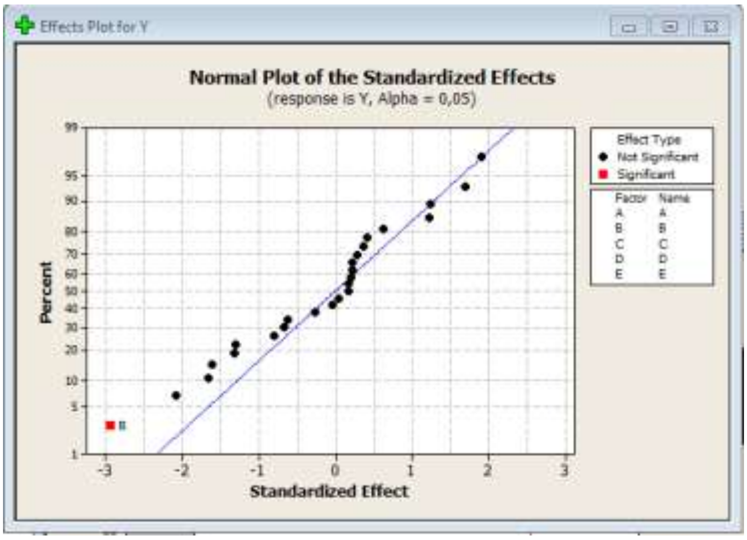

Figure 7.63 Normal plot of effect for *ltop*

Figure 7.64 shows the regression line for prediction of *ltop* response values.

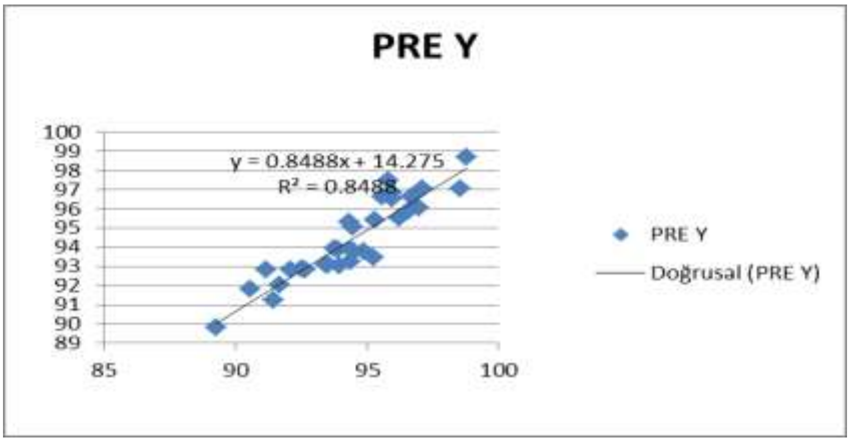

Figure 7.64 *Ltop* real values versus predicted *ltop* values and regression line

Figure 7.65 shows analysis results of *ltop* response value with full factorial.

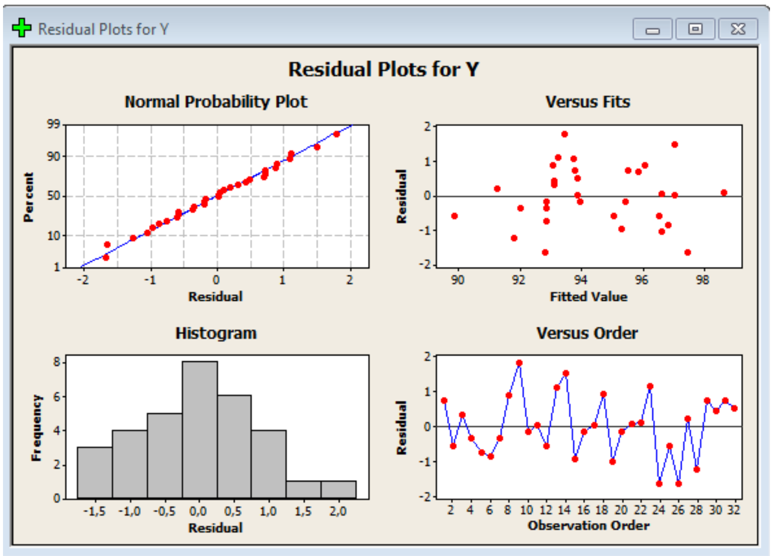

Figure 7.65 Analysis results of *ltop* response value with full factorial

7.6.5 Taguchi L32

Taguchi L32 method needs 32 trials to make an analysis. After entering 32 observations into the system, the interactions are chosen according to degrees of freedom. The ANOVA table is shown in Figure 7.66.

Factorial Fit: Y versus A; B; C; D; E

Estimated Effects and Coefficients for Y (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		94,422	0,3501	269,70	0,000
A	-1,159	-0,580	0,3501	-1,66	0,149
B	-2,051	-1,025	0,3501	-2,93	0,026
C	-0,917	-0,458	0,3501	-1,31	0,238
D	-1,123	-0,562	0,3501	-1,60	0,160
E	-0,912	-0,456	0,3501	-1,30	0,241
A*B	-0,466	-0,233	0,3501	-0,66	0,531
A*C	0,161	0,080	0,3501	0,23	0,826
A*D	-0,561	-0,280	0,3501	-0,80	0,454
A*E	1,193	0,597	0,3501	1,70	0,139
B*C	0,152	0,076	0,3501	0,22	0,835
B*D	0,871	0,435	0,3501	1,24	0,260
B*E	-0,431	-0,215	0,3501	-0,62	0,561
C*D	0,292	0,146	0,3501	0,42	0,691
C*E	0,126	0,063	0,3501	0,18	0,864
D*E	-1,451	-0,725	0,3501	-2,07	0,084
A*B*C	1,332	0,666	0,3501	1,90	0,106
A*B*D	0,026	0,013	0,3501	0,04	0,972
A*B*E	-0,183	-0,092	0,3501	-0,26	0,802
A*C*D	0,439	0,220	0,3501	0,63	0,553
A*C*E	0,861	0,430	0,3501	1,23	0,265
A*D*E	-0,031	-0,015	0,3501	-0,04	0,967
B*C*D	0,253	0,127	0,3501	0,36	0,730
B*C*E	0,199	0,100	0,3501	0,28	0,785
B*D*E	0,118	0,059	0,3501	0,17	0,872
C*D*E	0,142	0,071	0,3501	0,20	0,846

S = 1,98044 PRESS = 669,382
R-Sq = 84,88% R-Sq(pred) = 0,00% R-Sq(adj) = 21,89%

Figure 7.66 *Ltop* response variable ANOVA table

Figure 7.67 shows the real and predicted *ltop* value graph with regression line and equation.

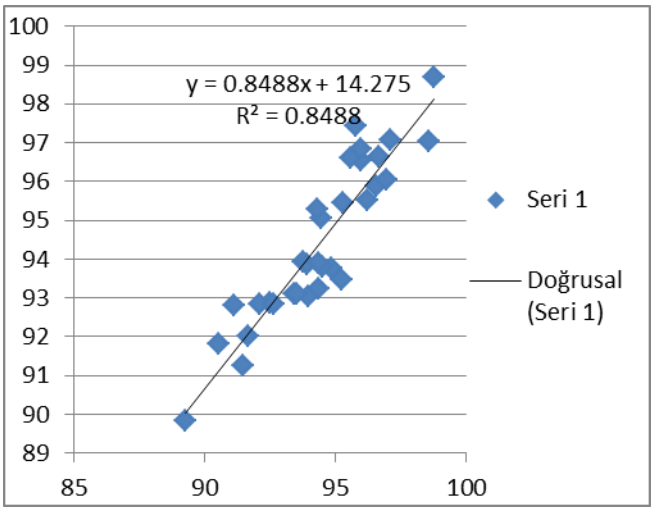

Figure 7.67 *Ltop* regression line

While Figure 7.68 shows the main effects, Figure 7.69 shows the interactions plots in means of SN values.

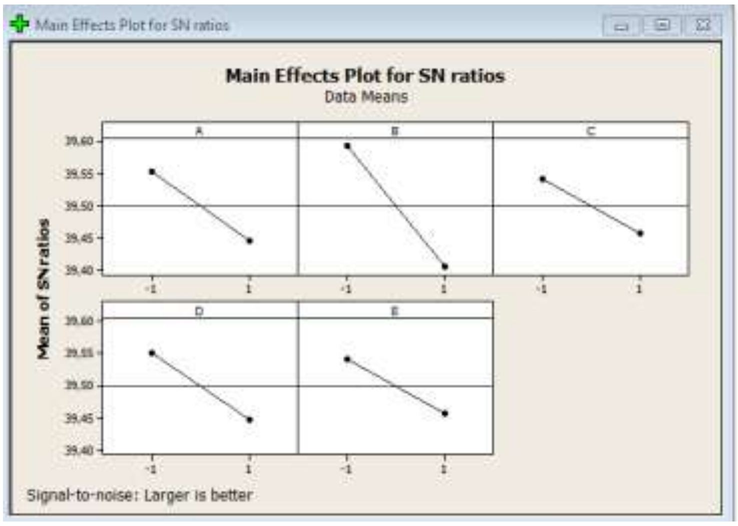

Figure 7.68 Main effects plot of *ltop* values in terms of means.

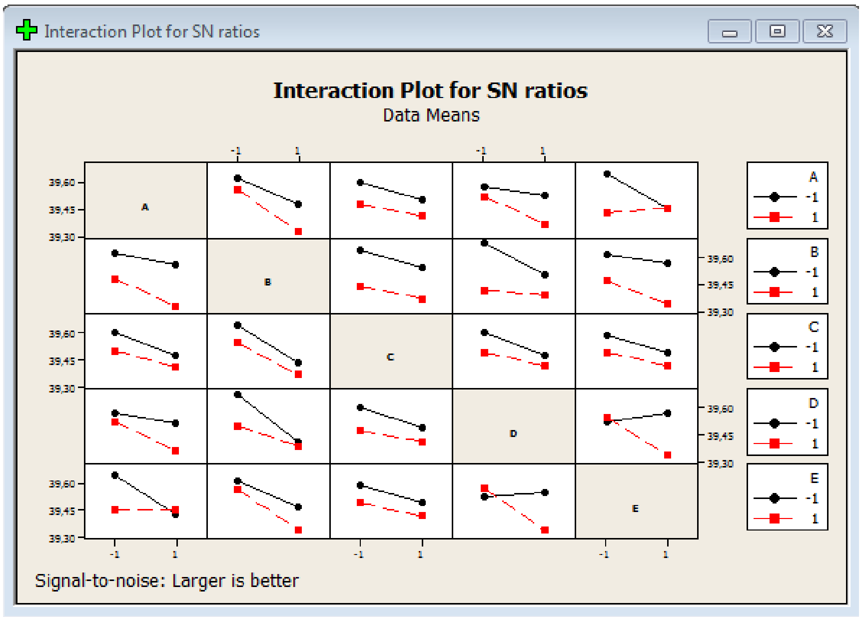

Figure 7.69 Interactions plot for SN ratios.

After analysis, result graphs are shown in Figure 7.70.

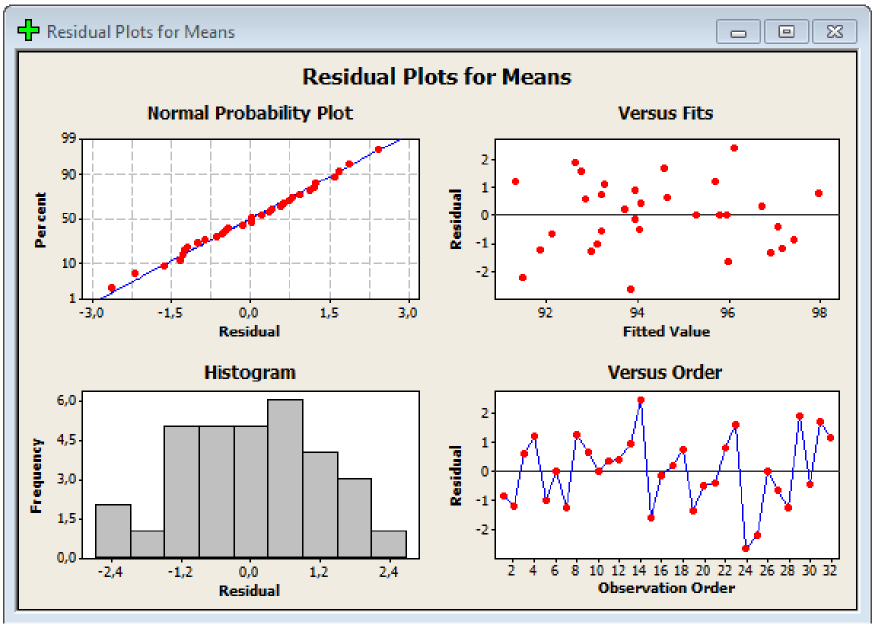

Figure 7.70 Graphs for analysis results.

7.7 Experimental Results

After applying these methods to color data, project trial results were discussed with laboratory experts. An average amount of product recipes done at chemical laboratory is 25 for a month. One recipe is accepted with approximately 75 trials. As we take into account extrusion machine spends 30 minutes for the process for windows profile to produce a sample. Beside of this, powder mixture is prepared by laboratory staff in about 20 minutes. At the end of producing a sample, experts spend approximately 7 minutes to make some calculations after getting the measurement results to reach conclusion. After we multiply recipe number with trial number, it was shown that trial numbers are increased. In this case process improvement is provided by using experimental methods. These results are explained in detail in Table 7.3.

Table 7.3 Cost saving with DOExpert system

PROCESS NAME	COST	DESCRIPTION
Extrusion machine time	**30 minutes/trial**	extruder time to produce sample +recording data values from extruder, measuring pvc top and bottom color values, results
Drybrand+mixer time	**20 minutes/trial**	recipe is given to the lab. Materials are weighed at the lab. Weighed material is put the mixer. Weighing and Mixer takes 20 minutes to process a single trial.
R&D expert analyze time	**7 minute/trial**	results, evaluation, new experiments to theoretical calculations, takes an average of 7 min.
Recipe number per month	**25 per month**	recipe numbers at laboratory
Trial number per recipe	**75 trial/recipe**	for every recipe, 75 trials have to made
Personnel cost	**1 staff shift/trial**	staff costs+time
Materials time for raw material	**6-7 minute/trial**	except from extruder, the other materials like raw material (not colors), another machine named plastograph analyzes material about 6-7 minutes for one trial.
Raw materials profit	**materials cost**	raw material from factory or outside
PROCESS NAME	**COST**	**DESCRIPTION**
Arranging inventory	**personel time+cost**	arranging of the inventory
Stock control	**personel time+cost**	raw materials stocks are checked periodically.
Energry	**electricity**	energy cost
laboratory material cost	**nitrogen tube**	spend at laboratory
termal stabilization	**50-60 minutes**	Thermal stability (strength) changes according to the product ,average it takes 50-60 minutes.
manuel iteration for optimum	**7 times/target**	

Ltop color data was analyzed with four methods. After applying all of the methods, the results of these methods are explained in detail in Table 7.4.

Table 7.4 Comparison of different methods

	TAGUCHI (L16)	FRACTIONAL FACTORIAL(1/2)	REGRESSION	FULL FACTORIAL	TAGUCHİ (L32)
Trial number for color work	16	16	16	32	32
R-Sq	99%	98.86%	98.86%	84.88%	84%
Recipe number/month	75				
Spend Time/ trial	30+27=57 min	30+27=57 min	30+27=57 min	30+27=57 min	30+27=57 min
Total Time for 75 trial (per recipe)	57 min.X75 trial	57 min.X75 trial	57 min.X75 trial	57 min.X75 trial	57 min.X75 trial
Recovery from trial number	80%	80%	76%	82%	82%
Trial rate reduced (per recipe)	80%	80%	76%	82%	82%
Recovery for finding optimum value	88%	88%	88%	92%	93%
Average success	87%	87%	85%	85%	85%
Cost profit	75%	75%	75%	75%	75%

CHAPTER EIGHT
CONCLUSION & FUTURE WORK

8.1 Conclusion

In this thesis, Experimental Design methods and the usage of these methods were studied and analyzed. A new design of experiment system, called DOExpert, was modeled and developed to provide new features over current studies. In addition, statistical methods were examined and applied by using several statistical analysis programs.

DOExpert system was developed to analyze each response values for factor effects. Factor effects can be analyzed by using main factors or main factors with their interactions. Analysis results are used to predict a response value. DOExpert system has been developed for general purpose use, so it can be able to use in different industries.

In this study, experimental works were done for color measurement system when producing windows profiles at chemical industry. DOE methods like Taguchi method and regression analysis were applied at windows profiles response variables. A window profile has six color values, called *ltop, atop, btop, lbottom, abottom,* and *bbotom*. These values are response variables and consist of five color pigments. A critical part of this study is to find optimum values of pigments that give the desired windows profile response values. However, it is seen that it is difficult to find optimum values without experience. In order to overcome this difficulty, our system analyzed these response values and found an equation for each of them. After analyzing response variables, it is possible to know the effects of all factor variables. In addition, our system can find an optimum value for these six response variables to help users in their works. In other words, the proposed method does not require expert knowledge and reduces the need for expert to find the factors and effects of factors.

Several experiments has been performed and presented to assess the success of our proposed method. A product recipe can be done by making approximately 75 trials. One trial spends approximately 30 minutes to make and analyze. When we look at from this point, product cost will be decreased by reducing number of trials, if our system (DOExpert) is used. Our color management study for windows profiles is only an example to show the benefits of DOE methods. In this case, factory cost was decreased about 75% and market share was increased. It is also possible to use our system at other different chemical studies, even at different industries, to find factor effects and eliminate the insignificant factors.

8.2 Future Work

Several test methods may be used in conjunction operation with DOExpert Software. Taguchi experimental results of the analysis to be made in the number or other methods, such as a blocked design or response surface design, may be used in addition to Taguchi method.

In future studies, it is possible to use the following nine factors and two-level analysis of the values of Extruder.

Table 8.1 Extruder Setup

EXTRUDER SETUP		**SET VALUES**	**REAL VALUES**
Feeding Screw Speed,rpm (nD1)		**50**	**50**
Extruder Screw Speed,rpm (ns)		**34**	**34**
ZONE TEMPERATURES	**Zone 1-TZ1**	**180**	**180**
	Zone 2-TZ1	**185**	**185**
	Zone 3-TZ1	**190**	**190**
	Zone 4-TZ1	**180**	**180**
	Zone 5-TZ1	**180**	**180**
	Adapter (TA1)	**187**	**187**
DIE	**TW1 // TW2**	**198**	**198**

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