DEVELOPMENT OF DESIGN OF EXPERIMENT SOFTWARE FOR TWO-FACTOR FACTORIAL DESIGN

Oleh

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Disertasi ini dikemukakan kepada
UNIVERSITI SAINS MALAYSIA

Sebagai memenuhi sebahagian daripada syarat keperluan
untuk ijazah dengan kepujian

SARJANA MUDA KEJURUTERAAN (KEJURUTERAAN MEKATRONIK)

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ABSTRAK

Merujuk kepada tajuk projek, **“Pembangunan Sebuah Perisian Rekabentuk dan Analisis Ujikaji (DOE) Bagi kes Dua Faktor Melalui Teknik Rekabentuk Faktorial (FD)”**, projek ini dilaksanakan bertujuan untuk membina sebuah perisian mudah yang berupaya menganalisa sesuatu ujikaji melibatkan hanya dua faktor yang kini ujikaji sedemikian banyak dijalankan di sektor-sektor perindustrian. Oleh kerana itu, pengetahuan asas mengenai kaedah FD ini adalah amat penting kepada pelajar-pelajar kejuruteraan khususnya bagi mereka yang banyak didedahkan dengan ujikaji-ujikaji untuk digunakan dalam penyelesaian masalah penganalisaan ujikaji.. Kepentingan DOE telah terbukti di seluruh dunia seperti di Malaysia sendiri, kebanyakan industri telah menggalakkan penganalisa dan penguji mereka untuk mengaplikasikan salah satu kaedah DOE ini dalam kajian dan ujikaji mereka. Kesannya boleh dilihat di mana beberapa syarikat gergasi seperti Motorola, Hewlett-Packett, Petronas dan lain-lain syarikat yang berjaya mengawal tahap kualiti mereka melalui kaedah DOE ini. Melalui pengasingan dan penyingkiran faktor-faktor yang sukar dikesan. Faktor-faktor ini boleh mengganggu proses penghasilan produk dan pengeluaran sesebuah syarikat seperti syarikat pembuatan. Kesan yang paling ketara adalah apabila faktor berikut turut mempengaruhi tahap kualiti barangan yang dihasilkan. Oleh itu, sebagai persediaan sebelum melangkah ke alam industri projek ini ingin membantu para pelajar kejuruteraan mempelajari kegunaan rekabentuk FD. Di samping itu, projek ini mendedahkan para pelajar kejuruteraan kepada penggunaan perisian komputer dalam menganalisa data ujikaji. Pembangunan perisian ini dijalankan dengan tujuan agar para pelajar dapat menguasai kemahiran menggunakan komputer dan boleh menganalisa data ujikaji dengan cepat dan berkesan.

ABSTRACT

Regarding to the title, **"Development Of A Design Of Experiment (DOE) Software For the case Two-Factor Factorial Designs (FD)"**, this project is intended as to develop a simple software which will be able to analyze any experiment that involving only two factors as for this kind of experiment is being used widely by an industrial sectors. Therefore, the basic knowledge of FD technique is very important to engineering students especially whom involved in many experiments as to use it in solving an analysis problem. The essential of the DOE technique have been proven in the world as in Malaysia itself, many industries have supported their analyzer and the experimenter to apply one of this DOE technique in their researches and experiments. The effect reflected by seen that the several major companies such as Motorola, Hewlett-Packet, Petronas and other companies succeeding in controlling their quality level by this DOE technique. By isolating and removing the undetected factors. Those factors interrupt the product production process of several companies such as the manufacturing company. The most considerable effect is when those factors also affecting the quality level of a product produced. Therefore, as the preparation before entering the industry world, this project wants to help engineering students learning the effectiveness of this FD technique. Besides that, this project revealing the use of computer software to engineering students in analyzing an experiment. The development of this software is being constructed with a reason for students will be able to coup the computer skills and able to analyze any experiment data fast and effectively.

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TABLE OF CONTENTS

	Page
ABSTRAK	**ii**
ABSTRACT	**iii**
ACKNOWLEDGMENT	**iv**
TABLE OF CONTENTS	**v-vii**
LIST OF FIGURES	**viii - xi**
REFERENCES	**xi - xiii**
PREFACE	**xiv**
CHAPTER 1: INTRODUCTION	
1.1 – Introduction	1
1.2 – Objective	2
1.3 – Scope of Research	3
1.3.1 – The research of 2FFD	3
1.3.2 – The research of software development	3
1.4 – Research Methodology: Flowchart	4
1.5 – Gantt Chart of Project	11
1.6 – Keywords	12
1.7 – Terminology	12
1.8 – Structure of Thesis	13
CHAPTER 2: LITERATURE REVIEW	
2.1 – Introduction	14
2.2 – Design of Experiment (DOE)	15
2.3 – The Two-Factor Factorial Designs (FD)	16
2.3.1 – Basic Definition and Principal of Factorial Designs	16
2.3.2 – The Advantage of Factorial Designs	20

2.3.3 – The Example of MiniTab Usage 21
2.3.4 – The Example of Excel Usage 35
2.3.4.1 – ANOVA Program 35
2.3.4.2 – Regression Program 40
2.4 – Software Development Process 44
2.4.1 – The Background and Definition 44
2.4.2 – The Activities and Steps 45
2.4.3 – The Process Models 47
2.4.4 – The Summary 49
2.5 – Unified Modeling Language (UML) 50
2.5.1 – Description of UML 50
2.5.2 – UML Diagrams 50
2.5.2.1 – Sequence Diagrams 50
2.5.2.2 – Collaboration Diagrams 51
2.6 – Programming Language: Borland C++ Builder 52
2.7 – Conclusion 53

CHAPTER 3: SOFTWARE DESIGN

3.1 – Introduction 54
3.2 – Software Design Development 55
3.2.1 – User Interface Design 56
3.2.1.1 – User Interface: Initial Design 56
3.2.1.2 – User Interface: Complete Design 64
3.2.3 – Programming Design 86
3.3 – Conclusion 87

CHAPTER 4: SOFTWARE TESTING

4.1 – Introduction 88
4.2 – Unit Testing 89
4.3 – Usability Testing 91

4.3.1 – Software Usability Measurement Inventory (SUMI) 92
4.3.2 – Pre-Testing of Questionnaires 94
4.3.3 – Complete List of Questionnaires 95
4.3.4 – Questionnaires Evaluations 96
4.3.5 – Modification of Questionnaires 97
4.3.6 – Target Respondent 97
4.4 – Conclusion 98

CHAPTER 5: OUTPUTS/RESULTS OF PROJECT
5.1 – Introduction 99
5.2 – Review of Questionnaires 100
5.3 – Results and Analysis 101
5.3.1 – Check Sheet 101
5.3.2 – Histogram 102
5.3.3 – Pareto Chart 104
5.4 – Discussions 105
5.4.1 – Brainstorming 106
5.4.2 – Cause and Effect Diagram: Fishbone 106
5.5 – Conclusion 107

CHAPTER 6 CONCLUSIONS
6.1 – Introduction 108
6.2 – Summary of Project 108
6.3 – Recommendations 109
6.4 – Conclusion 110

LIST OF FIGURES

#

Figure 2.1: A two-factor factorial experiment, with the response (y) shown at the corners.

Figure 2.2: A two-factor factorial experiment with interaction.

Figure 2.3: A factorial experiment without interaction.

Figure 2.4: A factorial experiment with interaction.

Figure 2.5: A one-factor-at-a-time experiment

Figure 2.6: Relative efficiency of a factorial design to a one-factor-at-a-time experiment (two factor levels).

Figure 2.7: Main window Minitab.

Figure 2.8: Create Factorial Design.

Figure 2.9: Display available designs.

Figure 2.10: Type of design.

Figure 2.11: Designs window.

Figure 2.12: Factors window.

Figure 2.13: Options window.

Figure 2.14: Results window.

Figure 2.15: A full factorial design is being created.

Figure 2.16: Key in response data in column C7.

Figure 2.17: To analyze the factorial design.

Figure 2.18: Analyze Factorial design window.

Figure 2.19: Choosing the graph options.

Figure 2-20: Normal Probability Plot in Minitab.

Figure 2-21: Terms window.

Figure 2-22: Pareto chart in Minitab.

Figure 2-23: Residual Plots for data response.

Figure 2-24: The example of the analysis in Session window.

Figure 2-25: To plot the factorial design.

Figure 2-26: Factorial Plots window.

Figure 2-27: Select the factors that available to get the main effect plot.
Figure 2-28: Main Effect Plot in Minitab.
Figure 2-29: Tutorials in Minitab.
Figure 2.30: Key in data in the Excel's table.
Figure 2.31: Microsoft Excel Help window.
Figure 2.32: Click to the data analysis in tools menu.
Figure 2.33: The data analysis consists of many analysis tools.
Figure 2.34: Highlight the data range.
Figure 2.35: Set the number of rows.
Figure 2.36: The analysis of variance for two factors.
Figure 2.37: Key in data again in Excel's table.
Figure 2.38: Click the regression analysis tool.
Figure 2.39: Pick the two type of data range. Input X and Y.
Figure 2.40: The regression setting window.
Figure 2.41: The summary output of **Regression**.
Figure 2.42: The Waterfall Model.
Figure 2.43: The Sequence Diagram.
Figure 2.44: The Collaboration Diagram.

#
Figure 3.1: Main Window.
Figure 3.2: One-Way ANOVA Window.
Figure 3.3: Two-Way ANOVA window.
Figure 3.4: Main Effect Estimation Window.
Figure 3.5: Interaction Plots Window.
Figure 3.6: General Arrangement Window.
Figure 3.7: The Regression Model Window.
Figure 3.8: Model Adequacy Checking Window.
Figure 3.9: The complete Main Window.
Figure 3.10: Click the Two-Way ANOVA on Menu Bar.

Figure 3.11: The **Two-Way ANOVA** window.
Figure 3.12: Inserting the level of the factors.
Figure 3.13: Key in the data in Design Worksheet's table.
Figure 3.14: Click the **Calculate** button.
Figure 3.15: Click the **Calculate2** button to finish the analysis.
Figure 3.16: Click **OK** button to close the **ANOVA** window.
Figure 3.17: The **ANOVA** Table window.
Figure 3.18: Click the **MAC** at Menu Bar.
Figure 3.19: The **MAC** window.
Figure 3.20: The **Residual Plots** window.
Figure 3.21: Click the **Main Effect Estimation** at Menu Bar.
Figure 3.22: The **MEE** window.
Figure 3.23: The Factors window.
Figure 3.24: The Table has been set according to the factors setting.
Figure 3.25: The Responses window.
Figure 3.26: Column E till H has been added.
Figure 3.27: Key in the data in the table.
Figure 3.28: After click OK button on MEE window.
Figure 3.29: The Option window.
Figure 3.30: The Interaction Plots window.
Figure 3.31: The Interaction Plots on Average Response versus Factor B.
Figure 3.32: Click on the **regression model** at Menu Bar.
Figure 3.33: The **Regression Model** window.
Figure 3.34: The result of **regression model** calculation.
Figure 3.35: The **Tutorial** window.
Figure 3.36: The **About** window.

#
Figure 4.1: Checklist of Pre-Testing of questionnaires
Figure 4.2: The complete list from Pre-Testing activities.

#
Figure 5.1: Check Sheet of the SUMI.
Figure 5.2: The histogram of SUMI's questionnaires.
Figure 5.3: The Pareto chart of SUMI's questionnaires.
Figure 5.4: The **Fishbone Diagram** of 2F-Design.

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PREFACE

This Design Of Experiments (DOE) software which calls 2F-Design is alternative software to the current statistical software such as Minitab and Design-Expert. 2F-Design is capable in analyzing any experiments that involve only two factors by using the Factorial Designs (FD). 2F-Design is specifically design to do all the calculation in FD technique. Besides, this software will follow the entire rule in constructing the factorial designs and 2F-Design's interpretation will help any particular engineering students who want to do such experiments. In the meantime, this project is focusing on to assist Mechatronic students in the School of Electrical and Electronic Engineering, USM in their studies of DOE subject especially for the FD cases. From the knowledge of DOE, FD is quite useful to assist experimenter in both design and analysis of the effect of the factors involved. The development of 2F-Design is based on knowledge of software engineering and the statistical analysis method by using the computer. As the benefit of using statistical software, students will get the result without need to analyze it manually and this will help in saving time and minimal cost involved.

CHAPTER 1: INTRODUCTION

1.1 – Introduction

This is the project which title, **"Development of a DOE Software for Two-Factor Factorial Designs Experiment (FD)"**, purposing on to help engineering students especially Mechatronic in learning the one of DOE experimental strategy tool. The objective of this chapter is to give an introduction to the students about the project, the research of Design and Analysis of Experiments (DOE) and introduction to the Factorial Designs (FD). In this chapter, it containing about the objective of project, the scope of research, the research methodology, the Gantt chart of project, keywords and its terminology and also the structure of thesis.

The objective of this project is to create a statistical software that is use to calculate and to analyze an experiment consist two factors only. The objective of this project will be explained in details later. The scope of research is focusing on the factorial designs experiments use only two factors. More on the scope research will be explain later in this chapter.

This chapter represents the research methodology in flowchart diagram. The software development process will be represents in Gantt chart diagram. All the steps in developing the particular software will be explain in those diagrams. Then in this thesis contain several terms and keywords, so in this chapter also will be explain the terminology for easier way the reader to understand.

Lastly, the structure of thesis will explain thoroughly all the chapter includes in this thesis. Every chapter will have their own introduction and also the conclusion of each chapter except for chapter one.

1.2 – The Objective of Project

The objective of this project is to develop a new statistical software which will be use to analyze an experiment. The experiments only involve two factors. The Two-Factors Factorial Designs (FD) will be use in this kind of experiment. So, this project is about to create one kind of DOE software which will be able to compute and do the analysis. Other objectives of this project are,

- To develop statistical software that should be simple, reliable and easy to use as it will be a statistical tool for students.
- To make a data analysis software that will produce an accurate result and effectively.
- To help enlarge the usage of computer in doing the analysis.
- To give an explanation to students about the advantage of using the FD rather than using the one-variable-at-a-time (OVAT) method.
- To show all the steps in FD for experimenter or any researcher who involve in the particular area to gain more information and tips.
- To develop a statistical software that also able to represent the statistical data in a diagram such an interaction plot and the residual plot.

1.3 – The Scope of Research

The Two-Factor Factorial Designs (2FFD) is the scope of research which is interested to be discussing in this project. The scope of research is dividing into two categories of research which are the research of 2FFD and the research of software development.

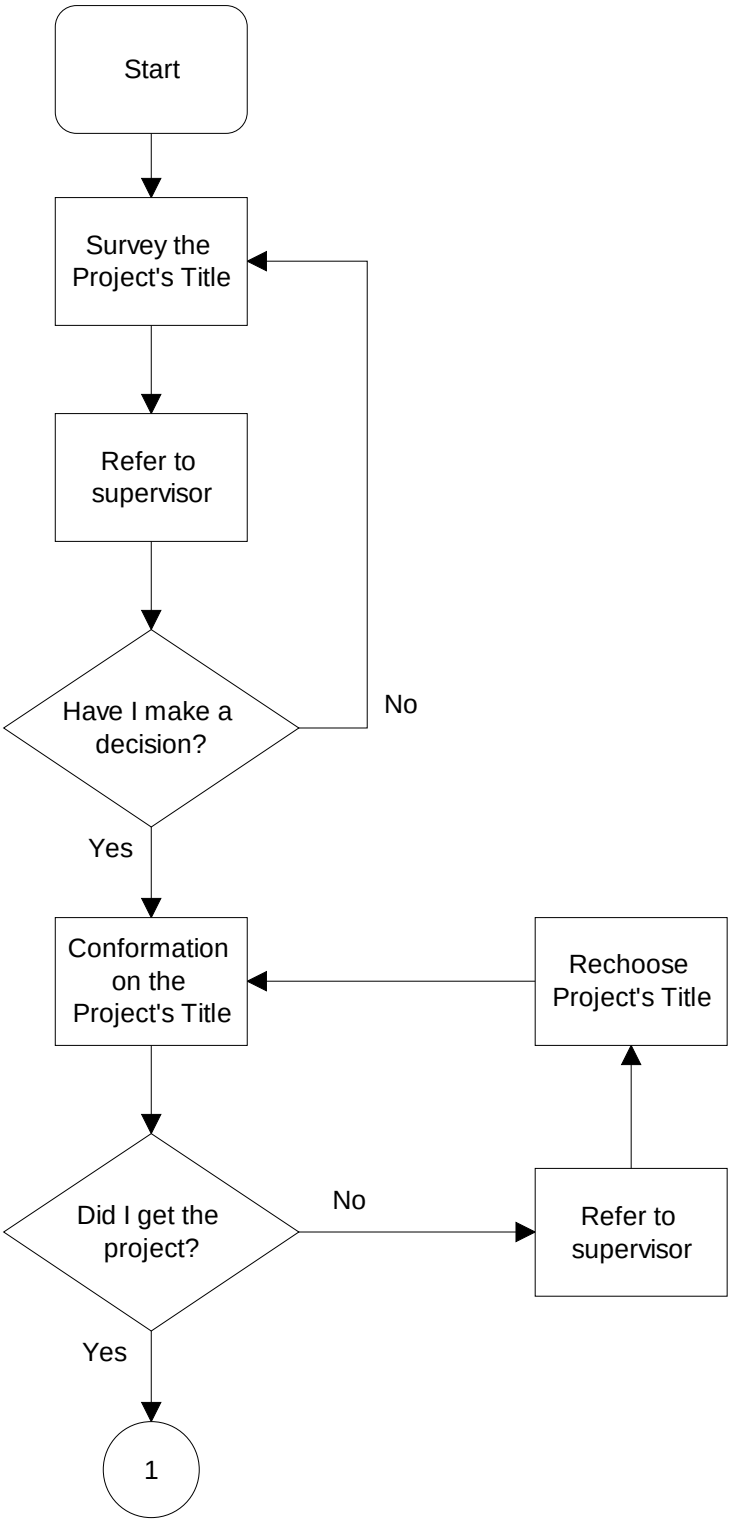
1.3.1 – The research of 2FFD

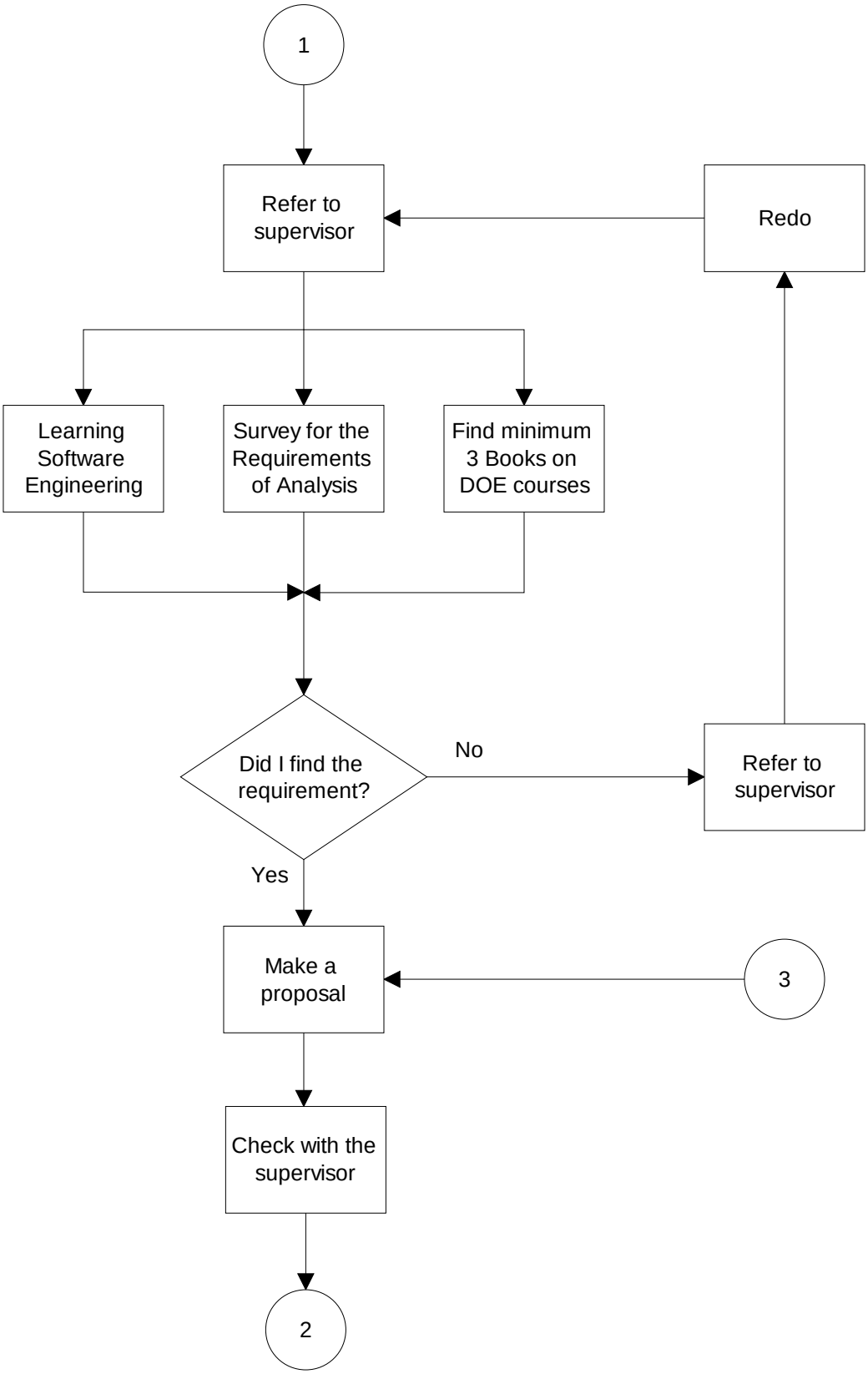
This research is about the basic definition of 2FFD, the principle and methodology of 2FFD, the advantage of 2FFD, and the output of the analysis by using the 2FFD techniques. In this research project, the analysis is considering only to the treatments that have been specifically chose by students or the user of this software. So, their hypotheses and the conclusions will apply only to the factor levels considered in the analysis. Therefore, this research only use fixed factor, and the statistical model that been used is the Fixed Effect Model (FEM).

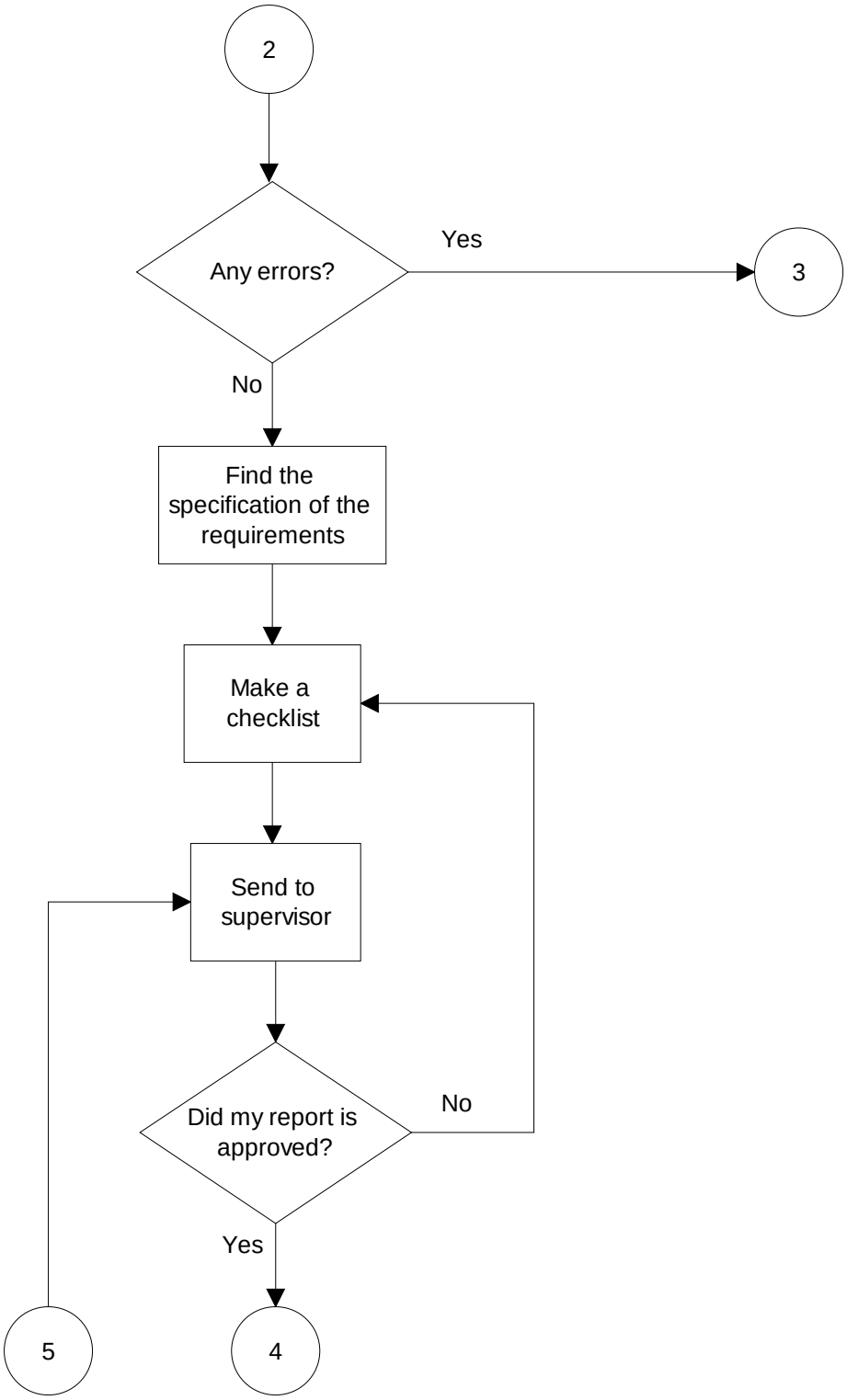
1.3.2 – The research of software development

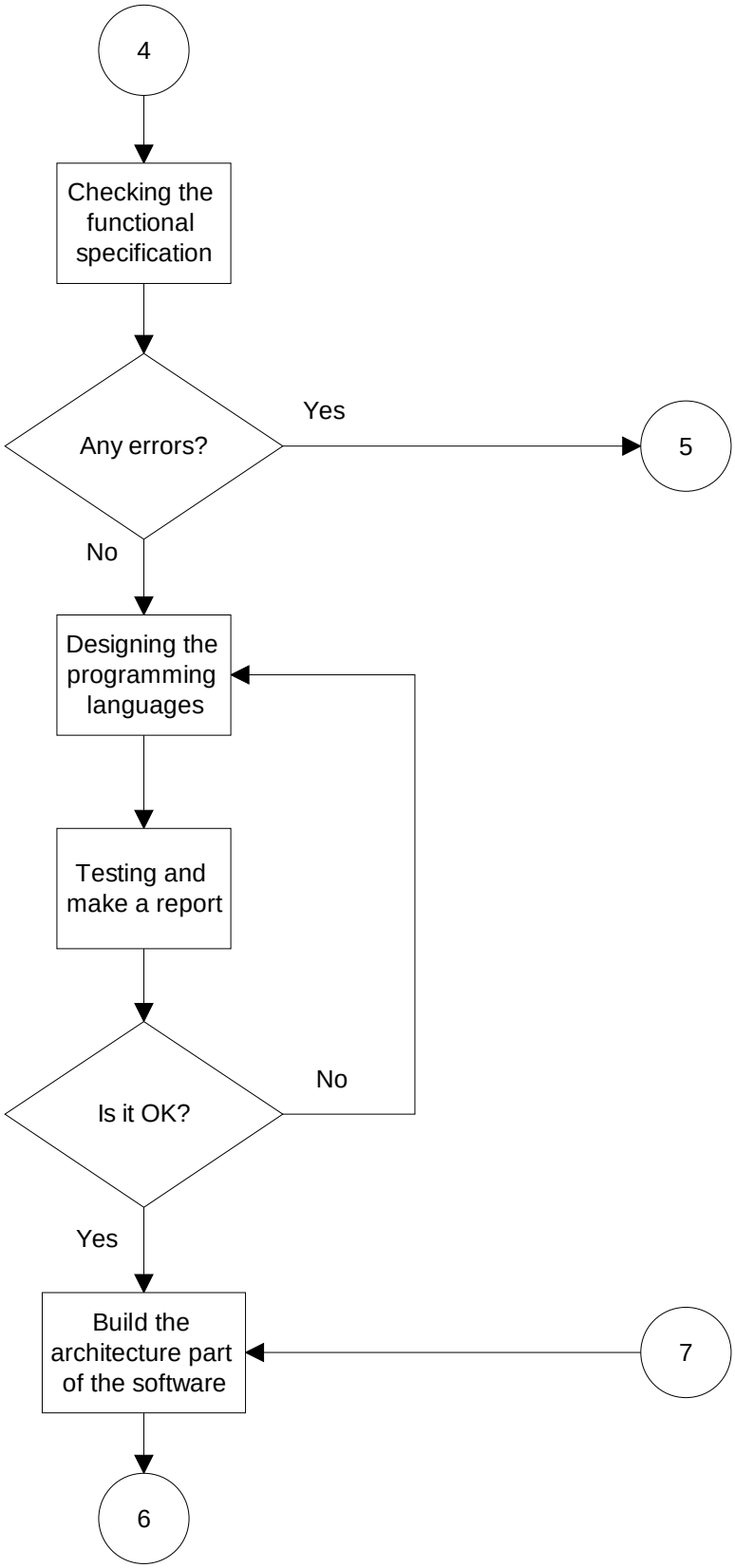
This research is about software development process, the software development process model and the Unified Modeling Language (UML) diagrams. This project is successfully developed until the validation activities in the software development process. No maintaining process involved and no prototype is produced. In this research project, waterfall model is been chosen to be the project's software development process. The advantage of the waterfall model is it shows an analogy to engineering practice and it is a simple management model. In UML, there are two specialized diagram that will be use in this research project to do the design program.

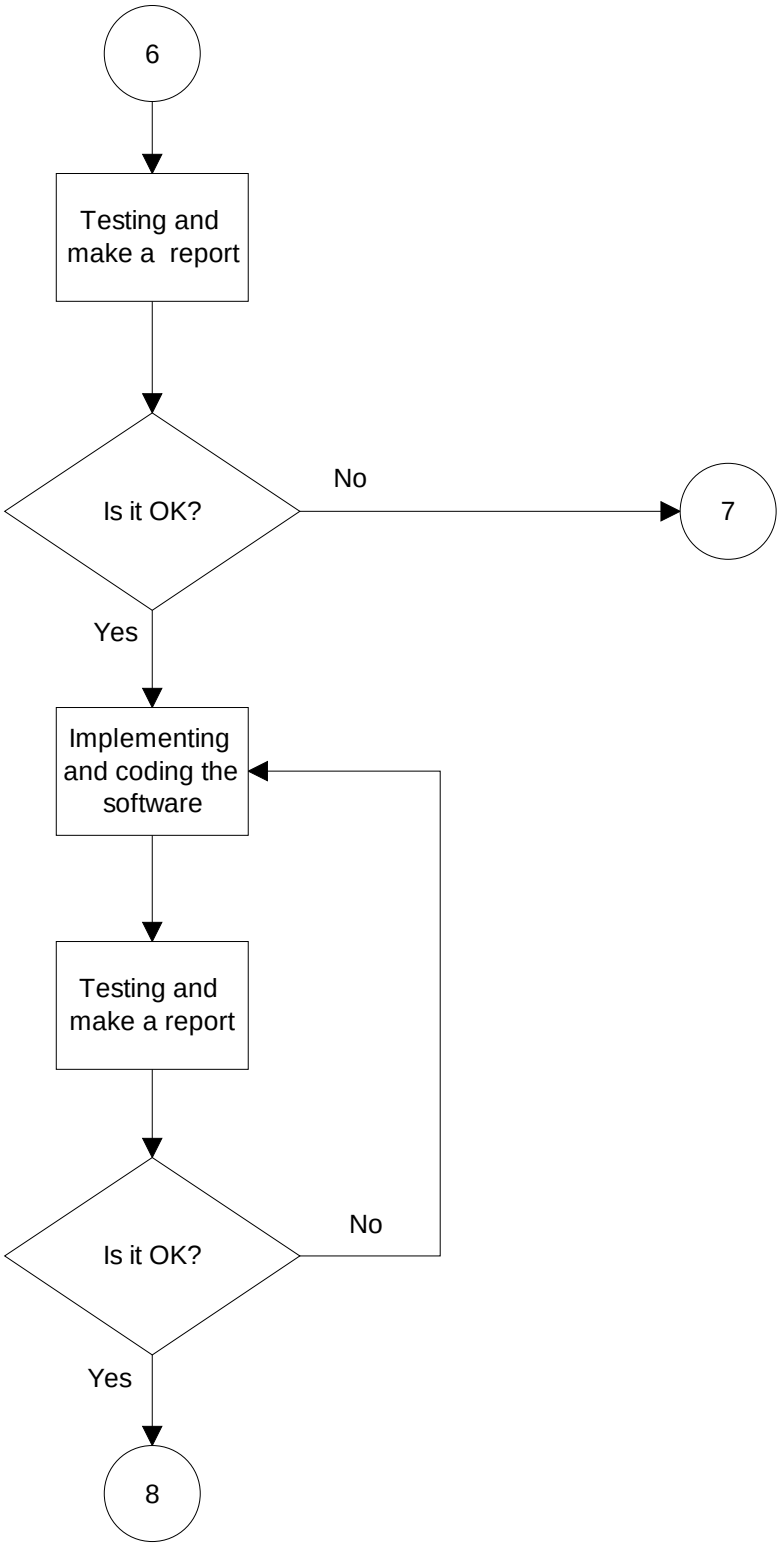
1.4 – Research Methodology: Flowchart

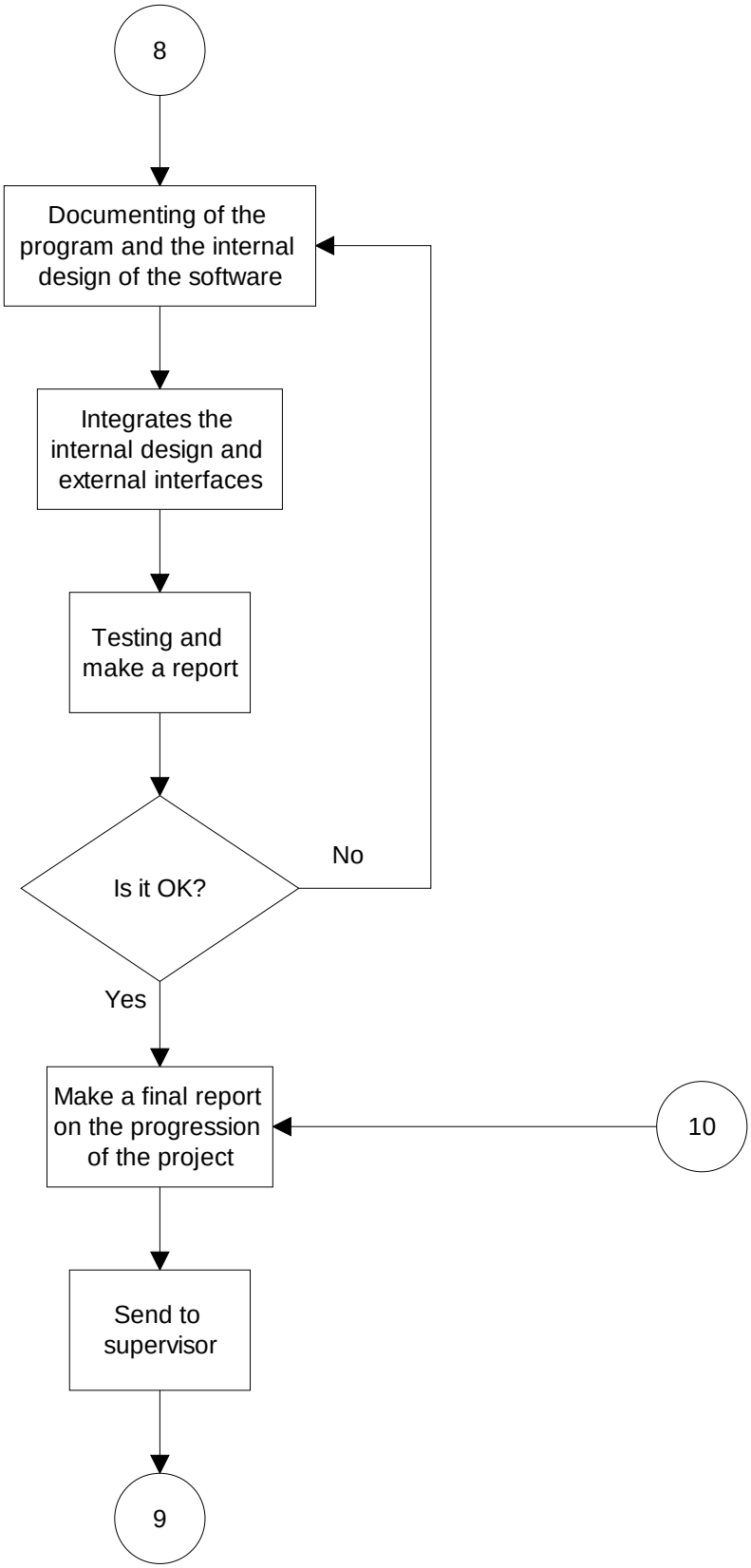


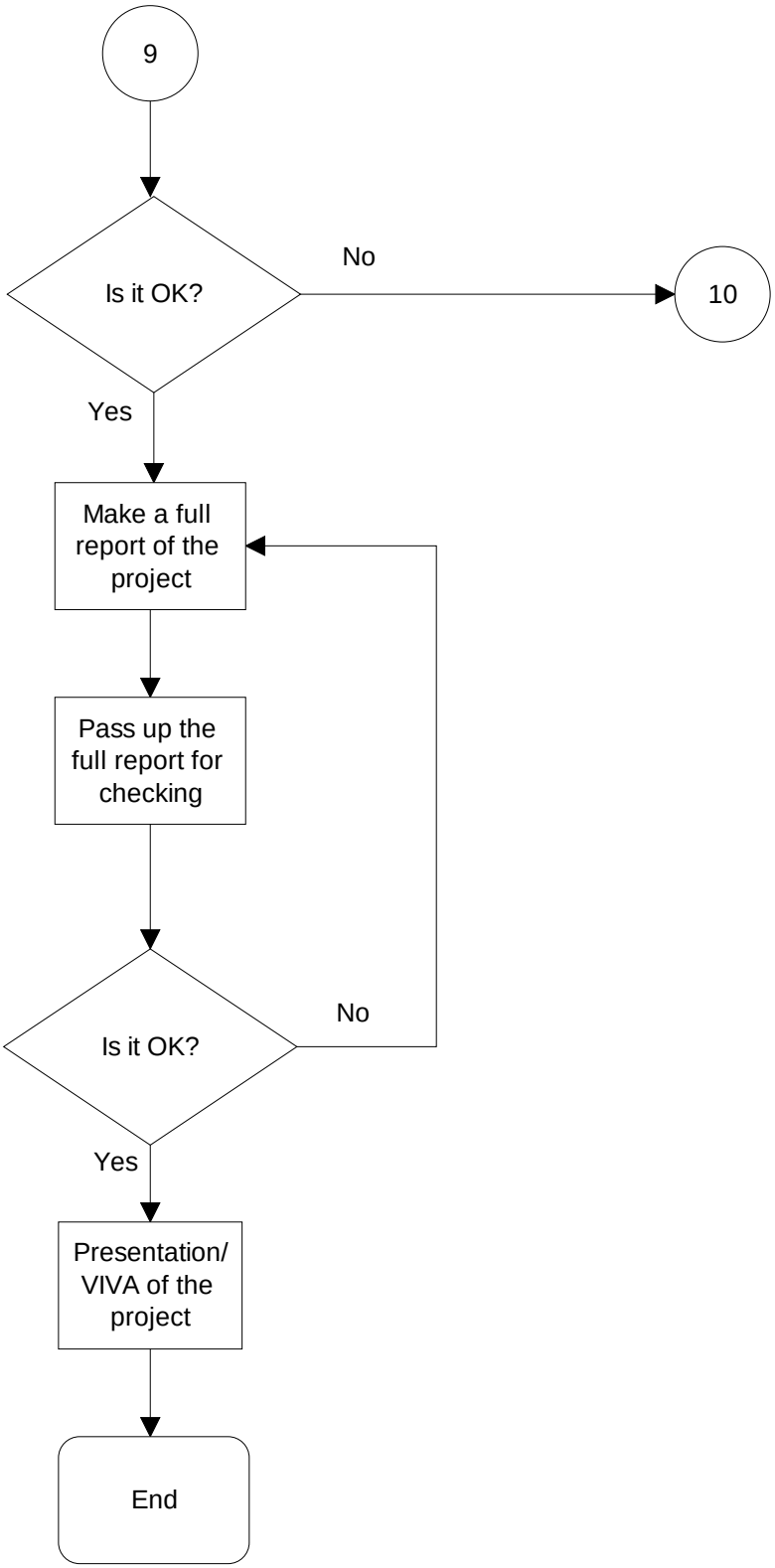

1
Refer to supervisor
Redo
Learning Software Engineering
Survey for the Requirements of Analysis
Find minimum 3 Books on DOE courses
Did I find the requirement?
No
Refer to supervisor
Yes
Make a proposal
3
Check with the supervisor
2


2
Any errors?
Yes
3
No
Find the specification of the requirements
Make a checklist
Send to supervisor
Did my report is approved?
No
Yes
5
4


4
Checking the functional specification
Any errors?
Yes
5
No
Designing the programming languages
Testing and make a report
Is it OK?
No
Yes
Build the architecture part of the software
7
6


6
Testing and make a report
Is it OK?
No
7
Yes
Implementing and coding the software
Testing and make a report
Is it OK?
No
Yes
8


8
Documenting of the program and the internal design of the software
Integrates the internal design and external interfaces
Testing and make a report
Is it OK?
No
Yes
Make a final report on the progression of the project
10
Send to supervisor
9


9
Is it OK?
No
10
Yes
Make a full report of the project
Pass up the full report for checking
Is it OK?
No
Yes
Presentation/ VIVA of the project
End

1.5 – Gantt Chart of Project

1.6 – Keywords

DOE, 2FFD, FD, CRD, ANOVA, SS, MS, DF, MEE, MAC, Test Statistics, FEM, Replication, Main Effect, Interaction, Quantitative, Regression Model, Run, Treatments, Observations, Replication, Repeated Measurement, Randomization, Experimental Error, Robust, Sample Mean, Sample Variance, Residuals, Hypotheses Testing, Model Adequacy Checking, Normal Probability Plot, Dot Diagram, General Arrangement, Statistics, UML, Waterfall Model, V-Model, Evolutionary Model, Spiral Model.

1.7 – Terminology

DOE – Design of Experiments
FD – Factorial Designs
2FFD – Two-factor Factorial Designs
CRD – Completely Randomized Design
ANOVA – Analysis of Variances
SS – Sum of Square
MS – Mean of Square
DF – Degree of Freedom
FEM – Fixed Effect Models
UML – Unified Modeling Language
MEE – Main Effect Estimation
MAC – Model Adequacy Checking

1.8 – Structures of Thesis

CHAPTER ONE This chapter will describe about the introduction, the objective, and the scope of the project, the research methodology by represent the Flowchart Diagram and Gantt Chart, several keywords and terminologies, and also the structures of thesis.

CHAPTER TWO This chapter will explain briefly about Design of Experiment (DOE), Two-Factor Factorial Designs (2FFD), Software Development Process, Unified Modeling Language (UML), and Programming Language: Borland C++ Builder.

CHAPTER THREE This chapter will explain from the beginning on designing and creating the software, several diagram about the software design of this project and the evaluation of the Software Design Development.

CHAPTER FOUR This chapter focusing on software testing activities on the definition and the methodology of a Unit Testing and Usability Testing.

CHAPTER FIVE This chapter is shows the result of this project. In this chapter, all feedback will be review in Review of Questionnaires, and the results analysis. Several discussions have been made in this chapter.

CHAPTER SIX This is the last chapter which explain the summary of the project and several recommendations for student's future works.

CHAPTER 2: LITERATURE REVIEW

2.1 – Introduction

This chapter is about literature review which been conducted for to introduce to the reader about one of **DOE** techniques that is Factorial Designs (**FD**) and its advantages. Specifically, this research is focusing on an experiment which involves two factors only. With the aid of computer, this research also been constructed to develop a single simple statistical software that will be capable to run an analysis of an experiment by using the **FD** design and the experiment only consist two factors.

Before that, this chapter also will give an explanation in more details about what is the exactly meaning of **DOE** and what is the **FD**. Meanwhile, reader also will learn about the software development process which includes the definition, the process and the steps which involved and also the process models. Almost every information in this chapter are comes from the notes of lecturer at School Electric and Electronic, USM and also from the resources of the internet.

2.2 – Design and Analysis of Experiments

DOE or in the other word is **"Design of Experiments"**, and some researcher use **ED** which stands for **Experimental Designs**. Referring to (Montgomery, 2001), experiment is a test or in formally, experiment can be define as a test or series of tests in which purposeful changes are made to the input variables of a process or system so that we may observe and identify the reasons for changes that may be observed in the output response. Also from (Montgomery, 2001), **DOE** is about planning and conducting experiments and about analyzing the resulting data so that valid and objective conclusions are obtained.

According to the internet resources from isixSigma's website reference [9], a Design of Experiment (**DOE**) is a structured, organized method for determining the relationship between factors (Xs) affecting a process and the output of that process (Y). In the same website, there another definition of **DOE** which are:

1 Conducting and analyzing controlled tests to evaluate the factors that control the value of a parameter or group of parameters.

2 "Design of Experiments" (**DOE**) refers to experimental methods used to quantify indeterminate measurements of factors and interactions between factors statistically through observance of forced changes made methodically as directed by mathematically systematic tables.

DOE nowadays is very famous, used by many researchers in their studies or research development. The example of DOE's application in the real world is found in the **ATTACHMENT C**.

2.3 – The Two-Factor Factorial Designs (2FFD)

Most industrial and research experiments involve the investigation of many variables such as temperature, process time, material type, humidity, and else in order to determine their effects on product quality and efficiency of manufacturing processes. Dr.Zalina Abd Aziz,(1999). Besides, in **FD** designs,

- The number of levels for each of the factors is selected by the experimenter before the experiment is carried out.
- The number of possible combinations for the experiment is obtained by multiplying the levels of all the factors together.
- Whenever possible, the combinations are then carried out in a random order. A random number table can be used for randomizing the order of the combinations.

When all of the combinations are carried out, the design is known as a full factorial design. When only some of the combinations are carried out, the design is known as a fractional factorial designs.

2.3.1 – Basic Definitions and Principles of Factorial Designs

According to (Montgomery, 2001), many experiments involve the study of the effects of two or more factors. In general, **FD** or **"Factorial Designs"** are most efficient for this type of experiment. By using a **FD**, we will capable in investigating all possible combinations of the levels of the factors in each complete trial or replication of the experiment. For example as in (Montgomery, 2001), if there are "a" levels of factor A and "b" levels of factor B, each replicate contains all "ab" treatment combinations. When factors are arranged in a factorial design, they are seems to be **crossed**.

The effect of a factor is defined to be change in response produced by a change in the level of the factor. This is frequently called a **main effect** because it refers to the

primary factors of interest in the experiment. For example, consider the simple experiment in Figure 2.1. This is a two-factor factorial experiment with both design factors at two levels. We have called these levels “low” and “high” and denoted them “-“ and “+”, respectively. The main effect of factor A in this two-level design can be thought of as the difference between the average response at the low level of A and the average response at the high level of A. Numerically, this is

$$A = \frac{40+52}{2} - \frac{20+30}{2} = 21 \qquad (2.1)$$

That is, increasing factor A from the low level to the high level causes an average response increase of 21 units. Similarly, the main effect of B is

$$B = \frac{30+52}{2} - \frac{20+40}{2} = 11 \qquad (2.2)$$

If the factors appear at more than two levels, the above procedure must be modified because there are other ways to define the effect of a factor. This point is discussed more completely later.

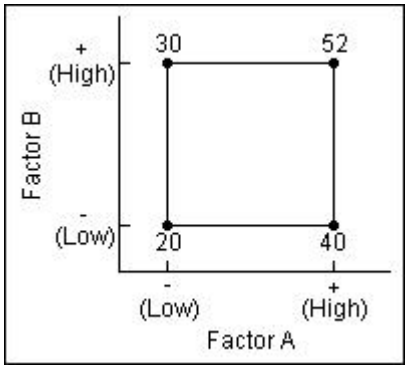


Figure 2.1: A two-factor factorial experiment,
with the response (y) shown at the corners.

In some experiments, we may find that the difference in response between the levels of one factor is not the same at all levels of the other factors. When this occurs, there is an interaction between the factors. For example, consider the two-factor factorial experiment shown in Figure 2.2. At the low level of factor B (or B^-), the A affect is

$$A = 50 - 20 = 30 \quad (2.3)$$

and at the high level of factor B (or B^+), the A effect is

$$A = 12 - 40 = -28 \quad (2.4)$$

Because the effect of A depends on the level chosen for factor B, there is an interaction between A and B can be seen. The magnitude of the interaction effect is the average difference in these two A effects, or AB = (-28 – 30)/2 = -29. Clearly, the interaction is large in this experiment.

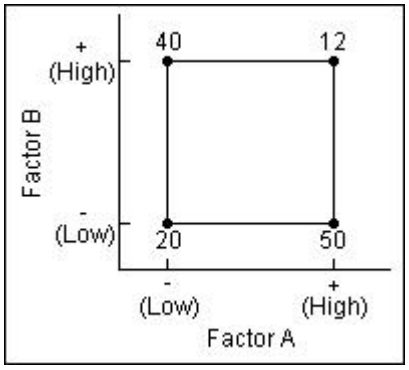


Figure 2.2: A two-factor factorial experiment with interaction.

These ideas may be illustrated in graphical method. Figure 2.3 plots the response data in Figure 2.1 against factor A for both levels of factor B. From it note that B- and B+ lines are approximately parallel, indicating a lack of interaction between factors A and B. Similarly, Figure 2.4 plots the response data in Figure 2-2. Here we can see that the B- and B+ lines are not parallel. This indicates an interaction between factors A and B.

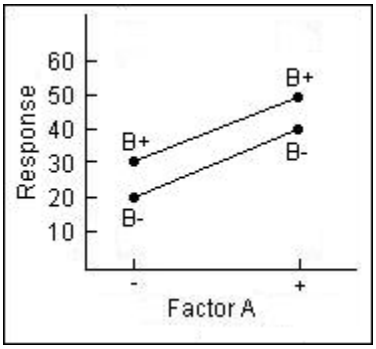


Figure 2.3: A factorial experiment without interaction.

Graphs such as these are frequently very useful in interpreting significant interactions and in reporting results to no statistically trained personnel. However, they should not be utilized as the sole technique of data analysis because their interpretation is subjective and their appearance is often misleading.

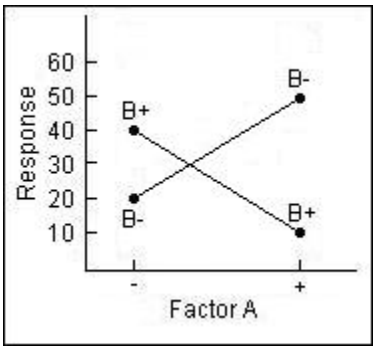


Figure 2.4: A factorial experiment with interaction.

Generally, when an interaction is large, the corresponding main effects have little practical meaning. For the experiment in Figure 2-2, we would estimate the main effect of A to be

$$A = \frac{50+12}{2} - \frac{20+40}{2} = 1 \qquad (2.5)$$

Which is very small, and we are tempted to conclude that there is no effect due to A. however, when we examine the effects of A at different levels of factor B, we see that this is not the case. Factor A has an effect, but it depends on the level of factor B. That is, knowledge of the AB interaction is more useful than knowledge of the main effect. A significant interaction will often mask the significance of main effects. These points are clearly indicated by the interaction plot in Figure 2.4. In the presence of significant interaction, the experimenter must usually examine the levels of one factor, say A, with levels of the other factors fixed to draw conclusions about the main effect of A.

2.3.2 – The Advantage of Factorial Designs

Montgomery (2001) noted that the advantage of factorial designs is easily to understand by an illustration. Suppose there are two factors A and B, each is at two levels. We denote the levels of the factors by A^-, A^+, B^-, and B^+. Information on both factors could be obtained by varying the factors one at a time, as shown in Figure 2.5. The effect of changing factor A is given by $A^+B^- - A^-B^-$ and the effect of changing factor B is given by $A^-B^+ - A^-B^-$. Because experimental error is present, it is desirable to take two observations, as at each treatment combination and estimate the effects of the factors using average responses. Thus, total of six observations are required.

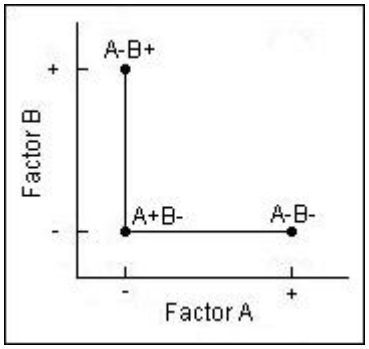


Figure 2.5: A one-factor-at-a-time experiment

If a factorial experiment had been performed, an additional treatment combination, A^+B^+, would have been taken. Now, using just four observations, two estimates of the A effect can be made: $A^+B^- - A^+B^+$ and $A^+B^+ - A^-B^+$. Similarly, two estimates of the B effect can be made. These two estimates of each main effect could be averaged to produce average main effects that are just as precise as those from the single-factor experiment, but only four total observations are required and we would say that the relative efficiency of the factorial design to the one-factor-at-a-time experiment is (6/4) = 1.5. Generally, this relative efficiency will increase as the number of factors increases, as shown in Figure 2.6.

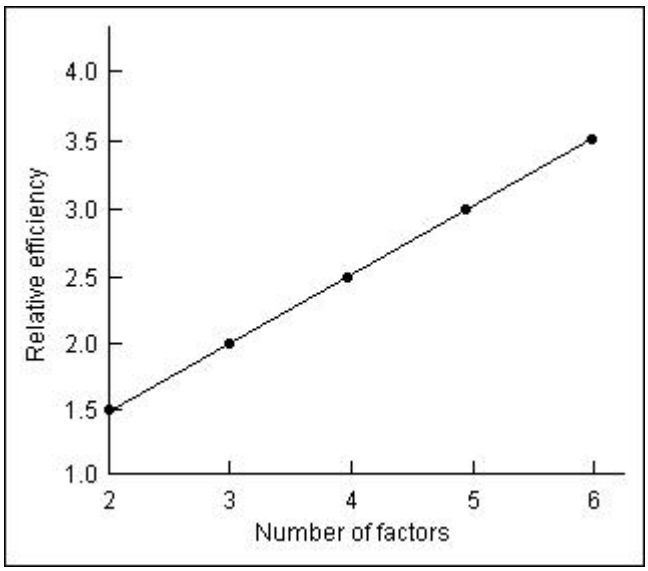


Figure 2.6: Relative efficiency of a factorial design to a one-factor-at-a-time experiment (two factor levels).

If we consider the interaction is present, as if the one-factor-at-a-time design indicated that A^-B^+ and A^+B^- gave better responses than A^-B^-, a logical conclusion would be that A^+B^+ would be even better. However, if interaction is present, this conclusion may be seriously in error. For an example, refer to the experiment in Figure 2-2.

In summary, note that factorial designs have several advantages. They are more efficient than one-factor-at-a-time experiments. Furthermore, a factorial design is necessary when interactions may be present to avoid misleading conclusions. Finally, factorial designs allow the effects of a factor to be estimated at several levels of the other factors, yielding conclusions that are valid over range of experimental conditions.

2.3.3 – The Example of Minitab Usage

Minitab is famous statistical software which helps many researcher on doing their research and experiment. Minitab is capable on analyze data by using the DOE techniques. For this project, Minitab have been used as the exercises and learning

methods. The example of 2FFD by using the Minitab is shown in diagram in several steps as below.

To create factorial design:

1. Firstly, click on Minitab icon to run the software. Minitab will be shown as in Figure 2.7.

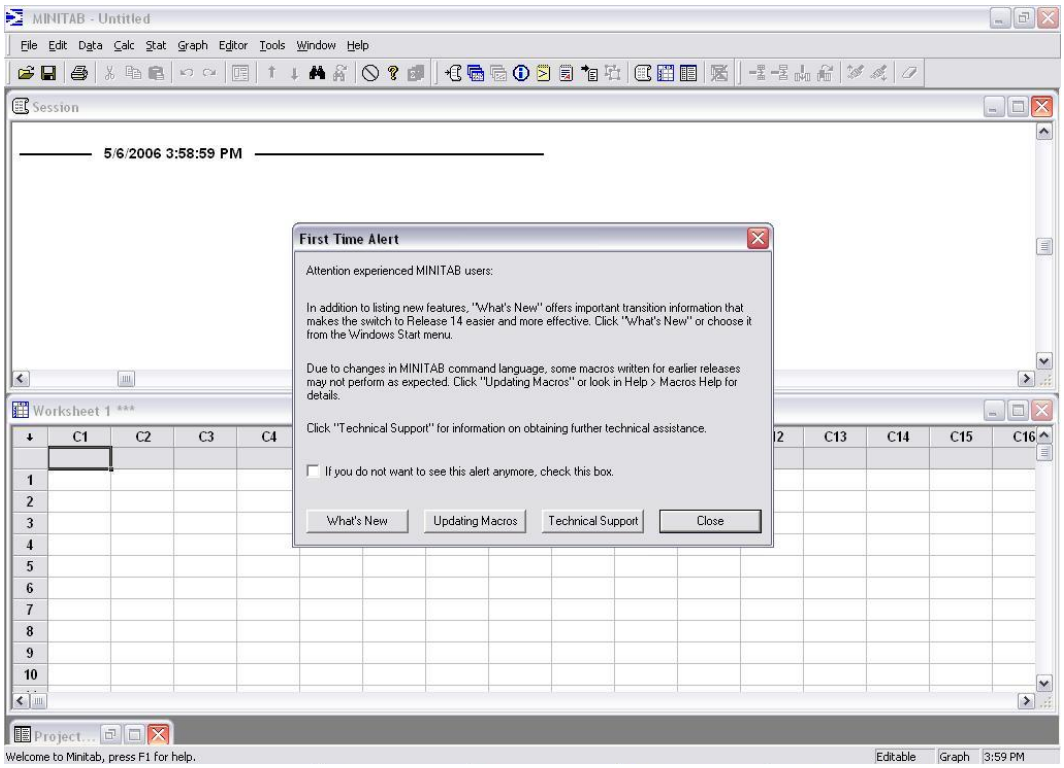


Figure 2.7: Main window Minitab.

2. Click the **Close** to close the “First Time Alert”.
3. Next, user need to create a factorial design. Click **Stat > DOE > Factorial > Create Factorial Design.** Refer Figure 2.8.

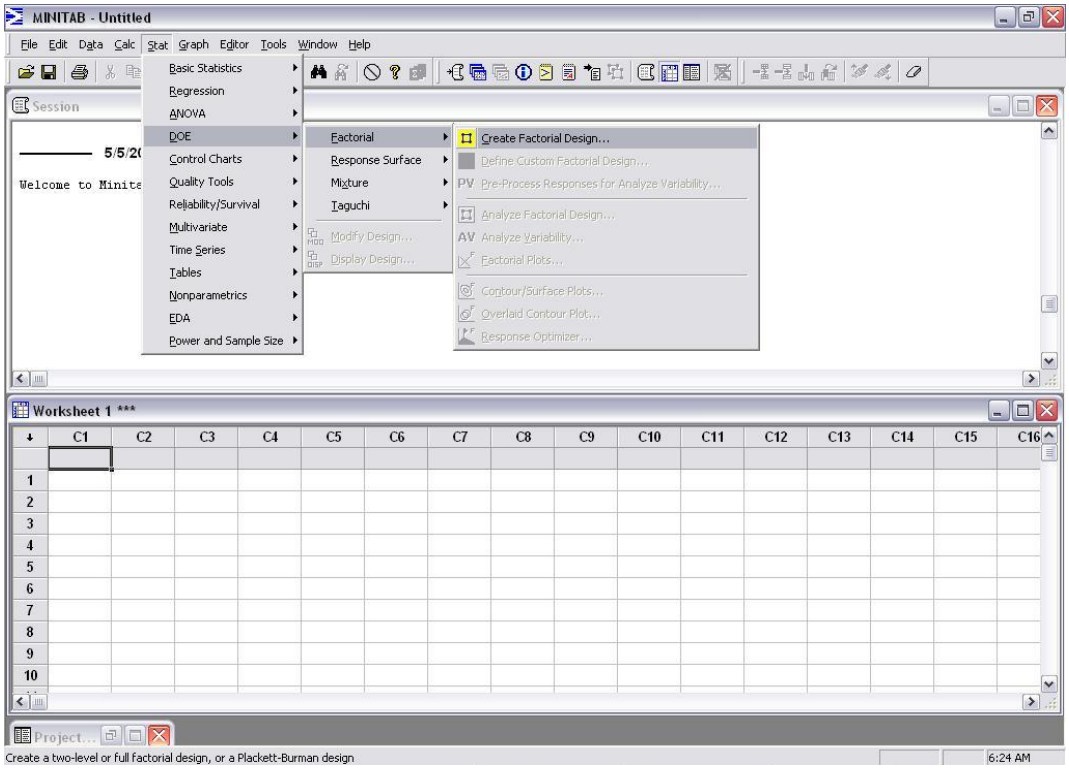


Figure 2.8: Create Factorial Design.

4. Click **Display Available Designs**. Refer Figure 2.9. Use this table to compare design features. Click **OK**.
5. Under **Type of Design**, choose 2-level factorial (default generators). From **Number of factors**, choose number 2. Click **OK**. Refer Figure 2.10.
6. Click **Designs**. Choose no. of replicates equal to 2. Click **OK**. Refer Figure 2.11.
7. Click **Factors** under the **Type of Design**. User may change the name of factors involve, level display style, in numeric or text and change the level value of the factors. Click **OK**. Refer Figure 2.12.
8. In Figure 2.13, user may set the option of the design.
9. In Figure 2.14, user may change the printed result to show several different type of display.
10. Click **OK** on the Type of Design window. A 2-level full factorial designs have been created. Refer Figure 2.15.

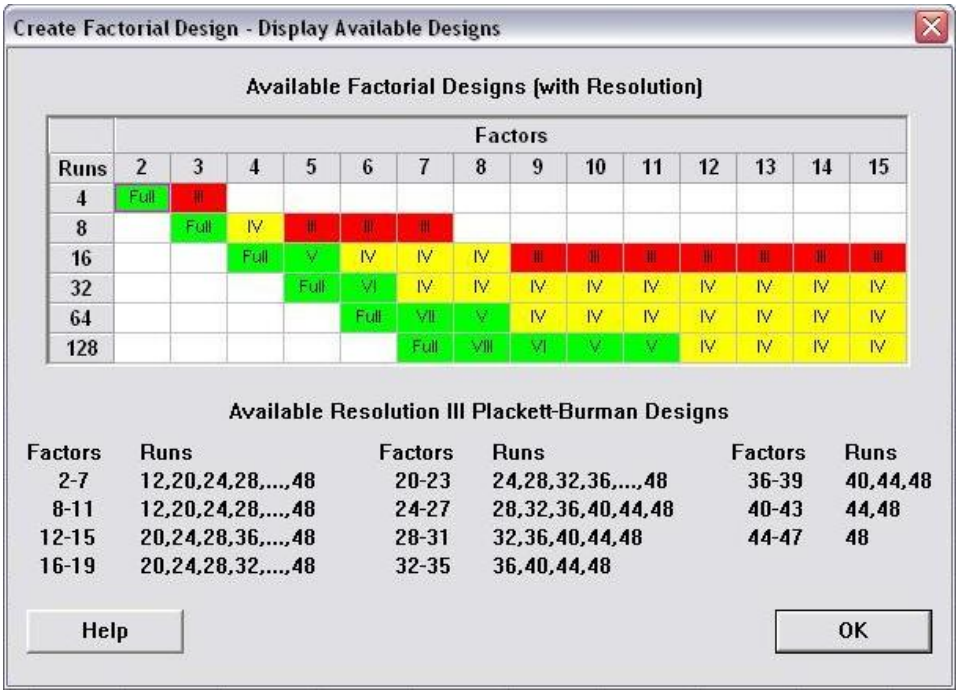


Figure 2.9: Display available designs.

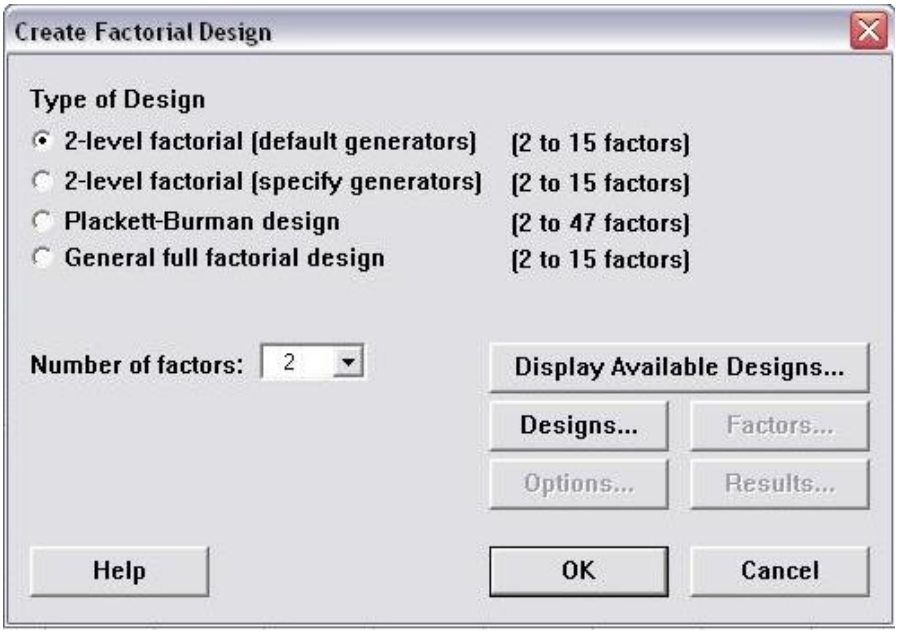


Figure 2.10: Type of design.