REDUCING NUMBER OF OUT-OF-AUTO ADJUSTMENT'S RANGE OF MINIATURE CIRCUIT BREAKERS 2 AMPERE BY USING TWO LEVEL FULL FACTORIAL DESIGN OF EXPERIMENT AT PT. SCHNEIDER INDONESIA CIBITUNG MANUFACTURING PLANT

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An Internship Report submitted to the Faculty of Engineering President University in partial Fulfillment of the requirements of Bachelor Degree in Engineering Major in Industrial Engineering

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ACADEMIC ADVISOR
RECOMMENDATION LETTER

This internship report is prepared and submitted by **Veronika** in partial fulfillment of the requirements for the degree of Bachelor Degree in the Faculty of Engineering has been reviewed and found to have satisfied the requirements for a report fit to be examined.

Cikarang, Indonesia, August 22nd, 2014

Johan Oscar Ong, ST.,MT.

COMPANY'S SUPERVISOR RECOMMENDATION LETTER

Veronika has performed and completed an internship in **PT. SCHNEIDER INDONESIA SCM Plant**, in partial fulfillment of the requirements for the degree of Bachelor Degree in the Faculty of Engineering. I therefore recommend this report to be examined.

Cibitung, Indonesia, August 22nd, 2014

Helmi Ariyanto

INTERNSHIP REPORT IN PT. SCHNEIDER INDONESIA SCM PLANT, CIBITUNG, INDONESIA

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ABSTRACT

High variability and rework are definitely undesirable for a company which aspires to high efficiency such as PT. Schneider Indonesia SCM plant which manufactures Miniature Circuit Breaker (MCB). Currently, high number of defect and non-conformity MCB related to one of its part, welding S1 that are out of Auto Adjustment's range of tripping time are generated due to no standard for parameters of welding S1 machine. Thus, Design of Experiment is applied in which three controllable factors and two levels for each factor are used such as Distance between Lower Electrode and Jig Table (*term A*, 3.15 and 3.20 cm), Current (*term B*, 14 and 16 Ampere) and Welding Time (*term C*, 15 and 17 seconds). Meanwhile, the controlled variables are the 2 Ampere bimetals and the distance between upper and lower electrode which is 1.0 cm. Finally, through Analysis of Variance, term *A*, *B* and *AC* are found to have significant effects on number of out of Auto Adjustment's range of tripping time and a regression model is constructed. Residual analysis is done to check the model adequacy. Additionally, the best combination of levels of parameters that can reduce that number is 3.15 cm, 16 Ampere and 17 seconds.

Keywords: *Miniature Circuit Breaker, Welding S1, Auto Adjustment, Rework, Design of Experiment, Analysis of Variance, Residual Analysis*

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Auto Adjustment Process	:	One of the processes of manufacturing Miniature Circuit Breaker that adjusts the position of bimetal of welding S1 by screwing the thermal screw automatically using Auto Adjustment machine and giving current to the Miniature Circuit Breaker to check the time needed for the heated bimetal to touch the tripping bar and disconnect the circuit (tripping time).
Auto Adjustment's range(of tripping time)	:	The determined range or limits for tripping time of MCB in Auto Adjustment process which is 9 – 9.7 s.
Bimetal	:	A part of welding S1 that is made from two types of metal and it has function to touch the tripping bar in Auto Adjustment process.
Bimetal Support	:	A frame for holding bimetal
Distance B	:	Distance between bimetal and further side of bimetal support that is currently determined to be 27.4 ± 0.4 mm.
Electrode	:	A component of welding machines that has function to press and distribute the current to the welded parts.
Experimental Unit	:	Unit or product which is given treatment in Design of Experiment whose response is being examined
Factors	:	The controllable parameters that are tested and combined in Design of Experiment to see whether each of them and the interactions among them have effect on the response variable.
Factor Levels	:	Levels among the range of values of factors that are controlled to be given to the experiment units.
Jig table	:	A small table with a jig above it to place the components of welding S1 to be welded. It can be

		set upward and downward as well as forward and backward.
Manual Adjustment	:	A type of rework that is done to MCB that trip in the range of 8-8.9 s and more than 9.7 s by manually re-screwing the thermal screw and re-check the tripping time using Control machine.
Mini Adjustment	:	A code for MCB that trips less than 9 s in Auto Adjustment process. There will be two types of rework done for those which trip in the range of 8.5-8.9 s and those which trip less than 8.5 s.
MCB	:	*Miniature Circuit Breaker*; a mechanical device that has function to disconnect the circuit when there is overcurrent or short circuit.
Non-Conformity MCB	:	The MCB that have tripping time is between 8 – 9 seconds and more than 9.7 seconds.
Replication	:	A repetition of experiment that is conducted under similar treatments or conditions.
Response variable	:	The output of the experimental units that are measured and analyzed in Experimental Design
Rework	:	An additional process after Auto Adjustment process which re-open the MCB by drilling the rivet or punching the rivet out, repairing the defective parts and replacing the thermal screw with the new ones. This operation is considered as Waste.
SCM	:	*Schneider Cibitung Manufacturing*; one of the plants of PT. Schneider Indonesia that is located in Cibitung and manufactures MCB as well as adaption products such as ACB and MCCB.
S1M	:	A defect code in Rework Station for MCB that trips less than 8.5 s in Auto Adjustment process because position of bimetal of welding S1 is much closer to tripping bar before the screw is properly screwed.

Thermal Screw	:	A screw that is screwed closer to bimetal support to adjust the position of bimetal in Auto Adjustment process.
Treatments	:	Combinations of factor levels whose effect on the response variable is interest in Experimental Design.
Tripping bar	:	A part in MCB that is triggered by bimetal of welding S1 that will activate the toggle to trip and cut the current in the circuit.
Welding parameters	:	The parameters in Welding S1 machine that is frequently set and have influence on the result of welding S1. They are current, welding time, and distance between lower electrode and jig table as factors to be tested in Design of Experiment.
Welding S1	:	One component of MCB which is resulted in welding S1 process that has function to activate the tripping bar when there is overcurrent. It consists of bimetal, bimetal support, and shunt.

CHAPTER I
INTRODUCTION

1.1 Problem Background

High variability and rework are definitely undesirable for a company which aspires to high efficiency along with producing products with high quality. Moreover, these contribute to wastes and additional costs which are certainly intolerable for a production system which attempts to successfully fulfill the customers' numerous demands. As the requirement of quality, rework somehow may become one alternative to avoid total loss. Although it is considered as waste of time and money, it yet has important role to fix the defective or non-conformity products without having to scrap the whole products. However, if the products can be set to be within the determined criteria, consequently, the activity of rework can be reduced as well.

Having efficient production system and high quality products is one of the main goals of many companies as well as PT. Schneider Indonesia SCM plant, a part of Schneider Electric, a multinational French company and also the world's leading global specialist in energy management.

In SCM plant, Miniature Circuit Breakers (MCB) are manufactured with various types of current. There are two classifications of the MCB; small rating (2-10 A) and big rating (16-50 A).

The processes of manufacturing Miniature Circuit breakers are as follows: coiling, press bending cutting, welding (S1, S2, S3, S4, S56), M1, assembly M23, magnetic test, batch coding, riveting, dielectric test, auto adjustment, sampling thermal test and finally printing as well as packing.

At present, a high manufacturing defect rate of small rating MCB especially 2 Ampere is detected in Rework Station which is *S1M*. *S1M* is a defect code which means the MCB trips before 8 seconds that is caused by welding S1 (position of bimetal of welding S1 is much closer to tripping bar before the screw has been properly screwed) while the range of Auto Adjustment is 9 – 9.7 s. As the top position of defect list, *S1M* contributes to high rework cost since it is detected after the riveting has been done. Thus, the rivet must be pulled out and the MCB is opened to be reworked in Rework Station. On the other hand, the MCB that trip between 8 – 9 s and more than the 9.7 s (Maxi Adjustment) called Non-Conformity MCB will also be repaired but without having to move to Rework Station. However, this is considered as waste since extra time is needed to re-adjust the thermal screw manually and process the products in Manual Adjustment. Moreover, MCB that are Maxi Adjustment can indirectly cause other defects.

Welding S1 is one of the components in MCB which activates tripping bar when there is overcurrent in the circuit. It consists of bimetal, bimetal support and shunt. Distance between bimetal and bimetal support's further side (distance B) in welding S1 is currently limited to a range of 27.4 ± 0.4 mm which affects tripping time of MCB in Auto Adjustment process. As the consequence, MCB that trip out of the Auto Adjustment's range of tripping time must be reworked.

Currently, there are no standard for parameters of welding S1 machine which generates high variability of Distance B and tripping time. Three welding parameters that are most frequently set by the operator are current, welding time and distance between lower electrode and jig table. These three parameters are hypothesized to have effect on number of out of determined range of both distance B and tripping time.

Moreover, the existing reference of Distance B seems not applicable anymore since many welding S1 with over-ranged distances B can trip within Auto Adjustment's range. If the number of out of range of Auto Adjustment can be reduced as well as the new reference of distance B of welding S1 that can fit the Auto Adjustment requirement can be introduced by finding the best combination of welding parameters, the rework and manufacturing defect rate could also be accordingly reduced. Thus, further observation and research are conducted to reduce the number of out-of-range of Auto Adjustment which includes *S1M* and Non-conformity MCB.

1.2 Problem Statement

- How to find the parameters that significantly affect the number of Out-of-Auto Adjustment's range of tripping time?
- How to find the best combination of levels of welding parameters that can reduce the number of Out-of-Auto Adjustment's range of tripping time?

1.3 Objectives

The main objectives of this research are

- To find the parameters which significantly affect the number of Out-of-Range of Auto Adjustment.
- To find the best combination of levels of welding parameters that can reduce the number of Out-of-Auto Adjustment's range of tripping time
- Proposing new range of distance B based on the chosen optimum combination of welding parameters that fit the Auto Adjustment's range.

1.4 Scope

In this research, there will be several scopes due to the limitation of resources:

- The miniature circuit breaker used for experimental design is MCB 2 Ampere.
- The experiment is conducted using one welding S1 machine which is machine S1 C1-5.
- The auto adjustment process is done using machine Auto Adjustment E3-5 with the range of Auto Adjustment is determined to be 9 – 9.7 s.
- The welding parameters used for Experimental Design are limited to 3 types which then are called as factors. They are Current, Welding Time, and Distance between lower electrode and Jig table. The levels of each factor chosen are two and fixed.
- The experiment and data are taken during June-August 2014.

1.5 Assumption

- There is no additional cost during the experiment test.
- There is no machine breakdown during the experiment test.
- All of the parts of the experimental units are assumed to be the same which neglects the variance of resistance and response to heat.

- There is no change of distance between upper and lower electrode during the welding process in the experiment test.
- There is no change to the position of jig table due to the welding process during the experiment test.

1.6 Research Outline

Chapter I **Introduction**

This chapter consists of the problem background, research questions, objectives, scope and limitation of the research.

Chapter II **Literature Study**

This chapter includes all related and supporting concepts and theories as the guidance to keep the research on the right track such as Flowchart Diagram, Fish Bone Diagram, Design of Experiment, Analysis of Variance, Residual Analysis and Resistance Spot Welding.

Chapter III **Research Methodology**

All systematic steps and framework are provided in this chapter as the map for this research to be conducted methodically.

Chapter IV **Company Profile and Project**

In this chapter, there will be description of company profile, production system, product, as well as the project.

Chapter V **Data Collection and Analysis**

Data will be taken and collected during the research and finally be processed and analyzed whether the research could meet the objectives or not.

Chapter VI **Conclusion and Recommendation**

In this chapter, conclusion is drawn through the analysis of the data and recommendations are given for the prospective future research.

In this chapter, the problem background and statement have been explained thoroughly. Moreover, the scope and assumptions have also been clearly stated. This is as the direction of this research to the path of achieving the objectives mentioned. The literature studies will be presented in Chapter II.

CHAPTER II
LITERATURE STUDY

2.1 Flowchart Diagram

A Flowchart diagram is a type of diagram which represents flow or sequence of processes through several types of boxes or symbols and arrows as the connectors. There are “Start” and “End” symbols represented by circles, ovals or rounded rectangles. The two most common types of boxes used in a flowchart are rectangular box which represents a processing step or activity and diamond which denotes decision. A structure of basic flowchart is shown in Figure 2.1.

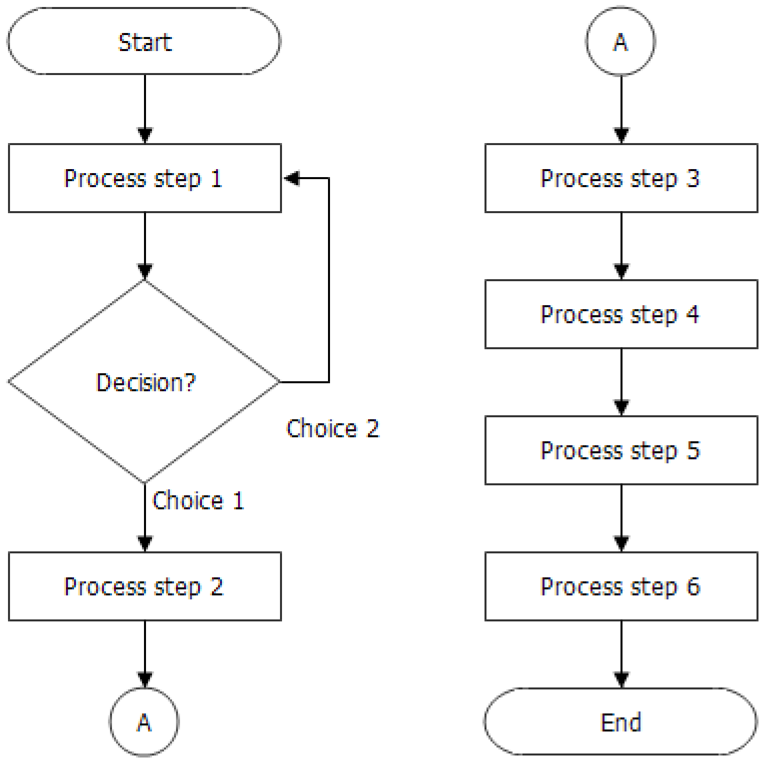


Figure 2.1 Basic Flowchart

2.2 Pareto Chart

A Pareto chart is a type of chart that contains both vertical bar and line graph which visually represents frequency of data and summarizes the significance of each data by arranging the bars in descending order from left to right. This chart is very helpful to depict the most significant data to focus on when there are lots of problems or causes.

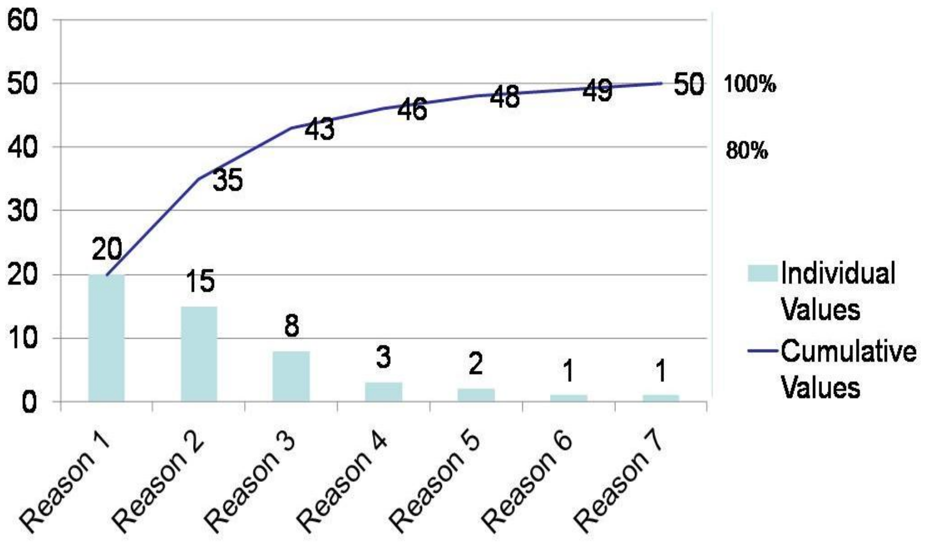


Figure 2.2 Structure of Pareto Chart

2.3 Fish Bone Diagram

Fish Bone Diagram or Cause-and-Effect Diagram is a causal diagram created by Kaoru Ishikawa (1968) that identifies many possible causes of an effect or problem. This diagram is called fishbone diagram because it is drawn as the skeleton of a fish with the main causal categories drawn as "bones" that are attached to the spine of the fish. The structure of Fish Bone Diagram is shown is Figure 2.3. The main causes are typically grouped into several categories that are used in manufacturing industry which include:

- ❖ People : anyone that is involved in the process.
- ❖ Methods : the way the process is performed and the specific requirements for doing it such as procedures, rules and etc.
- ❖ Machines : any equipment or tools that are used to accomplish the process.
- ❖ Materials : raw materials that are used to produce final product in the process.
- ❖ Measurements : data generated from the process to evaluate its quality.
- ❖ Environment : the conditions, such as location, time, temperature and culture in which the process is done.

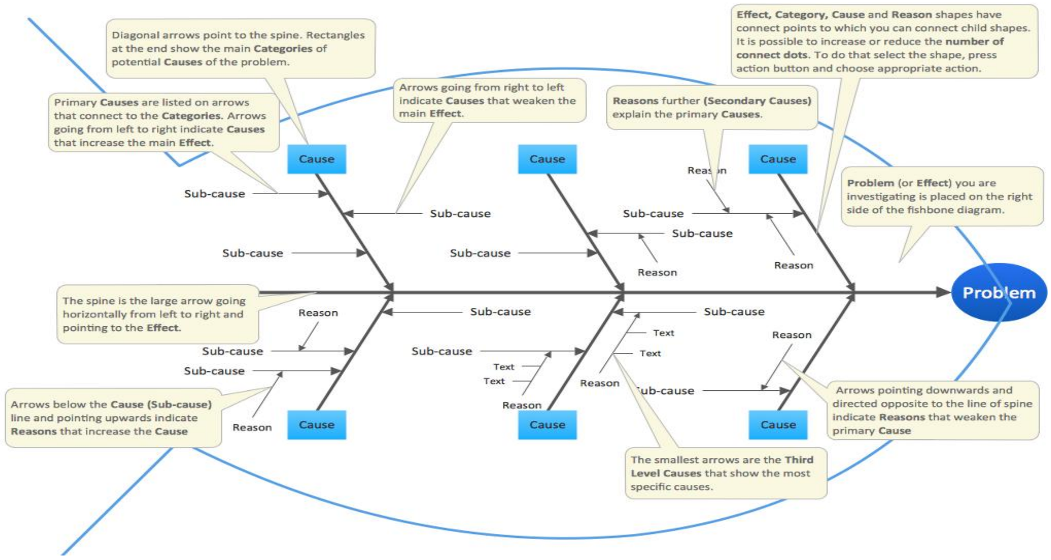


Figure 2.3 Structure of Fish Bone Diagram

2.4 Design of Experiment

Design of Experiments or DOE is a branch of applied statistics that deals with planning, conducting, analyzing and interpreting controlled tests to find the relationship between different independent **controllable parameters** or factors and their effects on an output or **response variable**. In other words, the interest of experimental design is the effect on the response variable from a certain combination of **factor levels** or called **treatment** (Mitra, 1998). Key concepts in creating a designed experiment include randomization, replication and blocking. Randomization refers to the order in which the trials of an experiment are performed. A randomized sequence helps eliminate effects of unknown or uncontrolled variables. On the other hand, replication means repetition of a complete experimental treatment, including the setup. The idea of blocking is to arrange similar experimental units into groups or blocks so that variability within blocks can be smaller than variability between blocks.

A well–performed experiment may provide answers to questions such as:

- What are the key factors in a process?
- At what settings would the process deliver acceptable performance?
- What are the key, main and interaction effects in the process?
- What settings would bring about less variation in the output?

There are several types of Design of Experiment or Experimental Design: Completely Randomized Design, Randomized Block Design, Latin Square Design, and Factorial Design.

2.4.1 Factorial Design

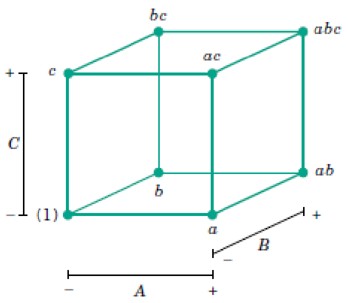
In a factorial design, all levels of each independent variable are combined with all levels of the other independent variables to produce all possible conditions to study the joint effect of the independent variables. Factorial Design is divided into several types such as general full factorial design, two-level full factorial design, two-level fractional factorial design, Plackett-Burman design, and Taguchi's Orthogonal Array.

2.4.1.1 Two-Level Full Factorial Design (The 2^k Factorial Design)

This is one type of factorial design where the number of levels for each *k* factor is restricted to two. Restricting the levels to two and running a full factorial experiment reduces the number of treatments (compared to a general full factorial experiment) and allows for the investigation of all the factors and all their interactions. If all factors are quantitative, then the data from such experiments can be used for predictive purposes, provided a linear model is appropriate for modeling the response (since only two levels are used, curvature cannot be modeled).

2.4.1.1.1 The 2^3 Factorial Design

In this design, there are three factors, A, B and C and each factor has two levels. Thus, there will be at least 8 runs for this type of full factorial design. The geometric view and design matrix are shown in figure 2.4.



(*a*) Geometric view

Run	*A*	*B*	*C*	Label
1	−	−	−	(1)
2	+	−	−	*a*
3	−	+	−	*b*
4	+	+	−	*ab*
5	−	−	+	*c*
6	+	−	+	*ac*
7	−	+	+	*bc*
8	+	+	+	*abc*

(*b*) The test matrix

Figure 2.4 The 2^3 Factorial Design

Source: (Engineering Statistics. Page 376)

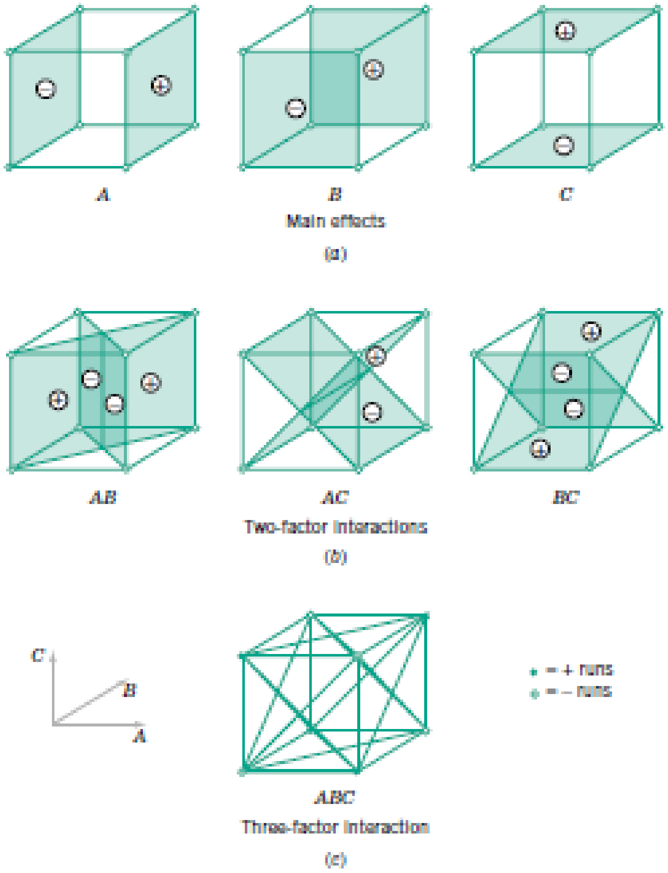


Figure 2.5 Geometric presentation of contrasts corresponding to the main effects and interaction in the 2^3 design. (a) Main effects (b) Two-factor interactions (c) Three-factor interaction

Source: (Engineering Statistics. Page 377)

In Minitab software, the normal probability plot and the Pareto chart of the standardized effects are shown to see which effects influence the response.

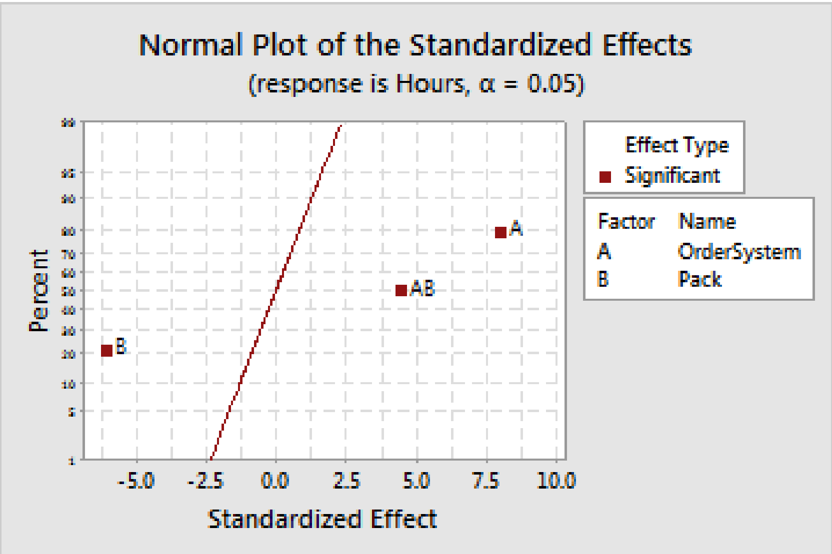


Figure 2.6 Example of Normal Plot of the Standardized Effects in Minitab

Minitab also displays the absolute value of the effects on the Pareto chart. Any effects that extend beyond the reference line are significant.

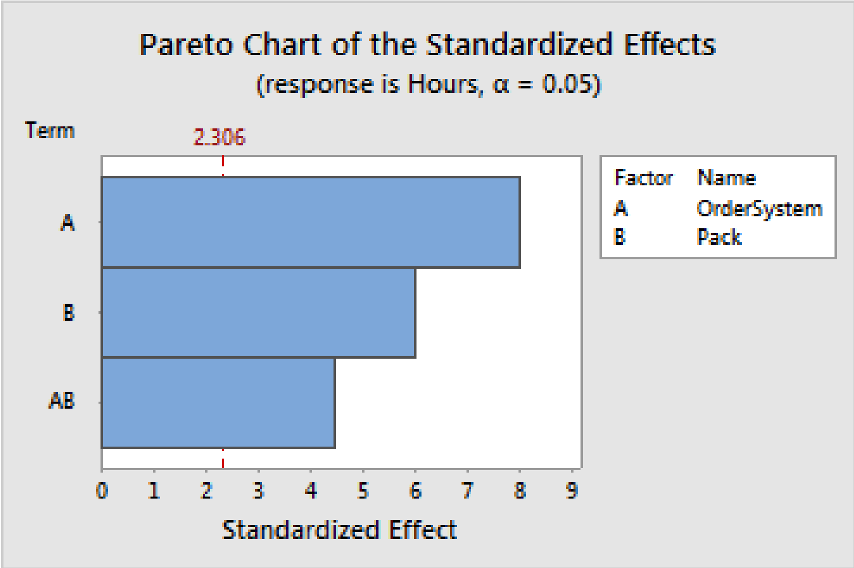


Figure 2.7 Example of Pareto Chart of the Standardized Effects in Minitab

Often the impacts of changing factor levels are described as effect sizes. A **main effect** is the difference in the mean response between two levels of a factor which is a quick and efficient way to visualize effect size. Effect sizes determine which factors have the most significant impact on the results. Calculations in ANOVA determine the significance of each factor. In Minitab, the main effects plot and interaction plots are displayed in **Analyze Factorial Plots.** There are two types of means available in Factorial Plots. Data means are the raw response variable means for each factor level combination whereas fitted means use least squares to predict the mean response values of a balanced design. Therefore, the two types of means are identical for balanced designs but can be different for unbalanced designs. Fitted means are useful for observing response differences due to changes in factor levels rather than differences due to the disproportionate influence of unbalanced experimental conditions.

Figure 2.7 shows the example of Main Effects Plot shown in Minitab. The grand mean, 2, is plotted as a horizontal line. The average result is represented by dots for each factor level. The Y axis is always the same for each factor in Main Effects Plots. Factors with steeper slopes have larger effects and thus larger impacts on the results.

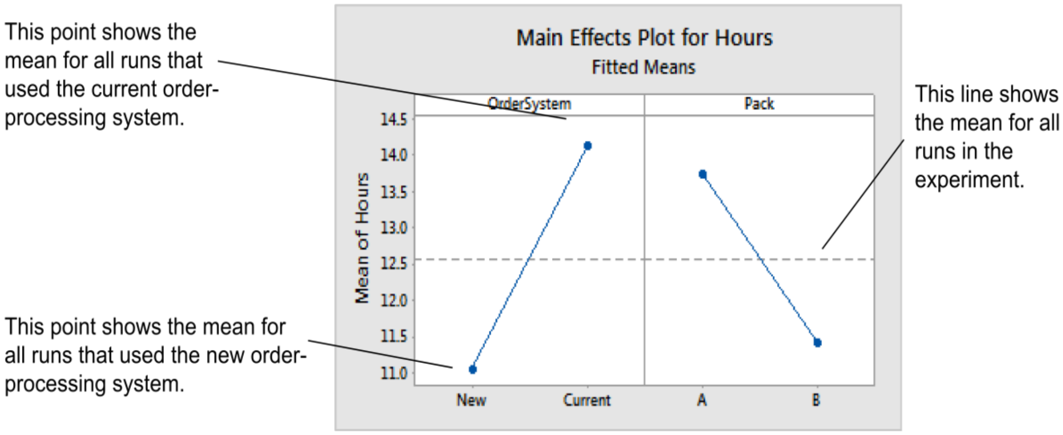


Figure 2.8 Example of Main Effects Plot for a response variable in Minitab

If there were no significant interactions between the factors, a main effects plot would adequately describe the relationship between each factor and the response. However, if the interaction is significant, the interaction plot should also be examined. A significant interaction between two factors can affect the interpretation of the main effects. An **interaction** occurs when one factor affects the results differently depending on a second factor. If the lines are not parallel, the plot indicates that there is an interaction between the two factors.

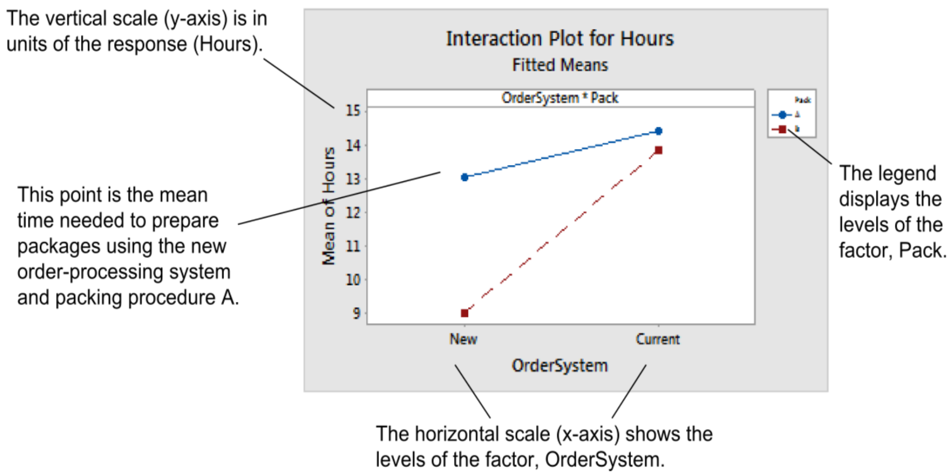


Figure 2.9 Example of Interaction Plot for a response variable in Minitab

Effect plots help visualize the impact of each factor combination and identify which factors are most influential. However, a statistical hypotheses test is needed in order to determine if any of these effects are significant. **Analysis of variance (ANOVA)** consists of simultaneous hypothesis tests to determine if any of the effects are significant.

2.5 Analysis of Variance

Analysis of Variance or ANOVA is a statistical technique that is used to investigate and model the relationship between a response variable and one or more independent variables. Figure 2.10 and Figure 2.11 show the output of Minitab consisting t-statistic and summary of analysis of variance focusing on the types of terms in the model. *t*-statistic is reported in the upper portion to display the effect estimates and regression coefficients for each factorial effect. The row entitled “main effects’’ under source refers to the three main effects. The column headed “Seq SS’’ (an abbreviation for sequential sum of squares) reports how much the model sum of squares increases when each group of terms is added to a model that contains the terms listed *above* the groups. The first number in the “Seq SS’’ column presents the model sum of squares for fitting a model having only the three main effects. The row labeled “2-Way Interactions’’ refers to *AB*, *AC*, and *BC*, and the sequential sum of squares reported here is the increase in the model sum of squares if the interaction terms are added to a model containing only the main effects. Similarly, the sequential sum of squares for the three-way interaction is the increase in the model sum of squares that results from adding the term *ABC* to a model containing all other effects. The column headed “Adj SS’’ (an abbreviation for adjusted sum of squares) reports how much the model sum of squares increases when each group of terms is added to a model that contains *all* the other terms. Now since any 2*k* design with an equal number of replicates in each cell is an orthogonal design, the adjusted sum of squares will equal the sequential sum of squares. Therefore, the *F*-tests for each row in the Minitab analysis of variance table are testing the significance of each group of terms (main effects, two-factor interactions, and three-factor interactions) as if they were the last terms to be included in the model.

Estimated Effects and Coefficients for Roughness

Term	Effect	Coef	StDev Coef	T	P
Constant		11.0625	0.3903	28.34	0.000
Feed	3.3750	1.6875	0.3903	4.32	0.003
Depth	1.6250	0.8125	0.3903	2.08	0.071
Angle	0.8750	0.4375	0.3903	1.12	0.295
Feed*Depth	1.3750	0.6875	0.3903	1.76	0.116
Feed*Angle	0.1250	0.0625	0.3903	0.16	0.877
Depth*Angle	−0.6250	−0.3125	0.3903	−0.80	0.446
Feed*Depth*Angle	1.1250	0.5625	0.3903	1.44	0.188

Figure 2.10 Example of Minitab Output containing *t*-statistic

Analysis of Variance for Roughness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	3	59.188	59.188	19.729	8.09	0.008
2-Way Interactions	3	9.187	9.187	3.062	1.26	0.352
3-Way Interactions	1	5.062	5.062	5.062	2.08	0.188
Residual Error	8	19.500	19.500	2.437		
Pure Error	8	19.500	19.500	2.437		
Total	15	92.938				

Figure 2.11 Example of Minitab Output containing ANOVA F-test

The observations of designed experiments may be described by a linear statistical model. The complete interaction model for a three-factor completely randomized design is:

$$Y_{ijkl} = \mu + \tau_i + \beta_j + \gamma_k + (\tau\beta)_{ij} + (\tau\gamma)_{ik} + (\beta\gamma)_{jk} + (\tau\beta\gamma)_{ijk} \qquad (2\text{-}1)$$

$$+ e_{ijkl} \begin{cases} i = 1, 2, \ldots, a & Factor\ A \\ j = 1, 2, \ldots, b & Factor\ B \\ k = 1, 2, \ldots, c & Factor\ C \\ l = 1, 2, \ldots, n & Replication \end{cases}$$

Source: (Applied Statistics and Probability for Engineers. Page 591)

Where:

μ : the baseline mean

τ_i : the main factor effect for A

β_j : the main factor effect for B

γ_k : the main factor effect for C

$(\tau\beta)_{ij}$: the two-factor interaction effects for interaction AB

$(\tau\gamma)_{ik}$: the two-factor interaction effects for interaction AC

$(\beta\gamma)_{jk}$: the two-factor interaction effects for interaction BC

$(\tau\beta\gamma)_{ijk}$: the three-factor interaction effects for the ABC interaction.

e_{ijkl} : the random error of the k^{th} observation from the $(i, j, k)^{th}$ treatment. Assume $e_{ijkl} \sim IID\ N(0, \sigma^2)$ which means the random error component is having normal distribution with mean zero and variance σ^2.

Analysis of Variance (ANOVA) will then be used to test the hypotheses. Reject H_0 if ***p-value*** is smaller than α. In other words, if the ***p-value*** $> \alpha$**,** the conclusion is statistically insignificant and if the ***p-value*** $< \alpha$, the conclusion is statistically significant.

- Test highest order interactions first

  H_0: $(\tau\beta\gamma)_{ijk} = 0$ for all ijk

  H_1: $(\tau\beta\gamma)_{ijk} \neq 0$ for some ijk

- If not significant, then consider the second order interactions

  H_0: $(\tau\beta)_{ij} = 0$ for all ij

  H_1: $(\tau\beta)_{ij} \neq 0$ for some ij

  H_0: $(\tau\gamma)_{ik} = 0$ for all ik

  H_1: $(\tau\gamma)_{ik} \neq 0$ for some ik

  H_0: $(\beta\gamma)_{jk} = 0$ for all jk

  H_1: $(\beta\gamma)_{jk} \neq 0$ for some jk

- If no significant interaction contains

  (1) Subscript i (Factor A) then consider testing

  H_0: $\tau_i = 0$ for all i

  H_1: $\tau_i \neq 0$ for some i

  (2) Subscript j (Factor B) then consider testing

  H_0: $\beta_j = 0$ for all j

  H_1: $\beta_j \neq 0$ for some j

  (3) Subscript k (Factor C) then consider testing

  H_0: $\gamma_k = 0$ for all k

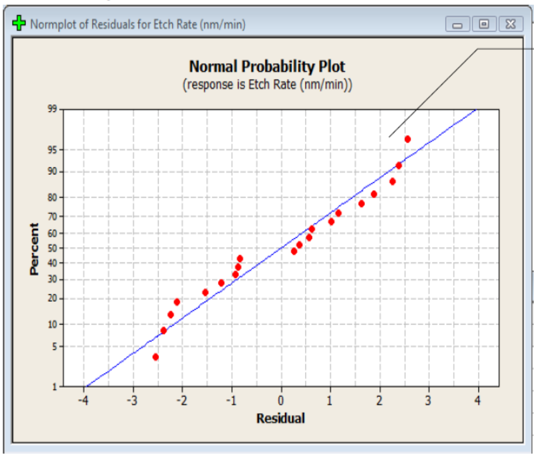
  H_1: $\gamma_k \neq 0$ for some k

2.5 Residual Analysis

The residuals are the differences between the observed and fitted values of y of regression model (Montgomery, 2012). The residual plots are used to examine the goodness of model fit in regression and Analysis of Variance. There are three assumptions or called ordinary least squares assumptions in ANOVA analysis: normality, constant variance and independence. In other words, the residuals must meet the assumptions that they are identical, independent and distributed normally (IID $N(0, \sigma^2)$).

The normality plot of the residuals is used to check the normality of the treatment data. The points in this plot should generally form a straight line if the residuals are normally distributed. If the points on the plot depart from a straight line, the normality assumption may be invalid. The example of normal distribution patter is shown in Figure 2.12. Besides, Kolmogorov-Smirnov normality test can also be used to check the distribution of the residual. If the p-value of the test is less than α, null hypothesis is rejected and it is concluded that the population is nonnormal.

Normality



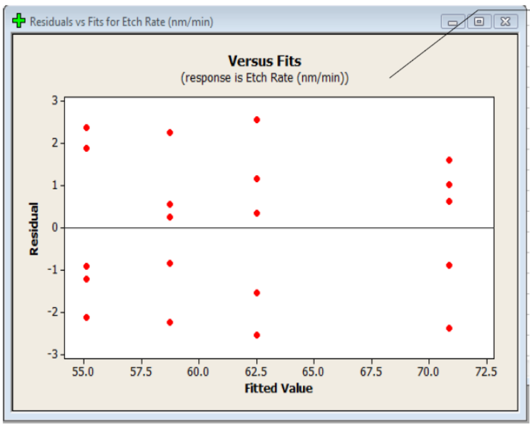
Normality – ANOVA requires the population in each treatment from which you draw your sample ***be normally distributed.***

The population normality can be checked with a *normal probability plot of residuals*. If the distribution of residuals is normal, the plot will resemble a straight line.

Figure 2.12 Normality test for residual

The constant variance or identical assumption is checked by the plot of residuals versus fitted values. If the plot of residual vs. fitted values (treatment) does not show any pattern, the constant variance assumption is satisfied. For instance, if the spread of residual values tend to increase as the fitted values increase, then this may violate the constant variance assumption. Runs test can also be used to see if the data order is random.

Constant Variance



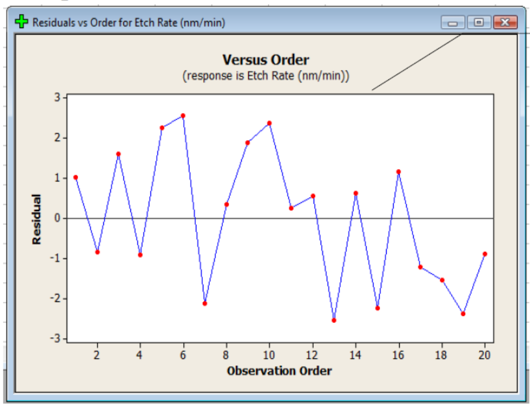
Constant Variance -- ***The variance of the observations in each treatment should be equal.***
The constant variance assumption can be checked with *Residuals versus Fits* plot. This plot should show a random pattern of residuals on both sides of 0, and should not show any recognizable patterns.

A common pattern is that the residuals increase as the fitted values increase.

Figure 2.13 Constant variance or Identical test for residual

On the other hand, if the plot of residual vs. run order (time order of data collection) does not reveal any pattern, the independence assumption is satisfied. This is a plot of all residuals in the order that the data was collected and can be used to find non-random error, especially of time-related effects. This plot helps to check the assumption that the residuals are uncorrelated with each other. This assumption can also be tested using **Autocorrelation Function** in which the residuals are uncorrelated with each other if the lags are within the margin error.

Independence



Independence – ANOVA requires that *the observations should be randomly selected from the treatment population.* The independence, especially of time-related effects, can be checked with the *Residuals versus Order* (time order of data collection) plot. A positive correlation or a negative correlation means the assumption is violated. If the plot does not reveal any pattern, the independence assumption is satisfied.

Figure 2.14 Independence test for residual

2.6 Resistance Spot Welding

Resistance spot welding is accomplished when current is caused to flow through electrode tips and the separate pieces of metal to be joined. The resistance of the base metal to electrical current flow causes localized heating in the joint, and the weld is made. The resistance spot weld is unique because the actual weld nugget is formed internally in relation to the surface of the base metal. Figure 2.14 shows a resistance spot weld nugget compared to a gas tungsten-arc (TIG) spot weld.

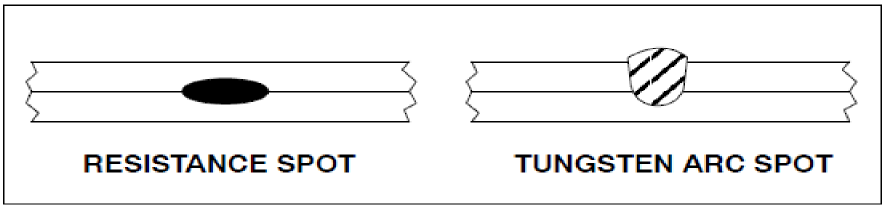


Figure 2.15 Resistance And TIG Spot Weld Comparison

The resistance spot weld nugget is formed when the interface of the weld joint is heated due to the resistance of the joint surfaces to electrical current flow. In all cases, of course, the current must flow or the weld cannot be made. The pressure of the electrode tips on the workpiece holds the part in close and intimate contact during the making of the weld. Welding time is defined as the time for the current flows in the welding process.

CHAPTER III
RESEARCH METHODOLOGY

3.1 Theoretical Framework

In order to successfully conduct the research, a research methodology must be clearly defined and constructed to acutely achieve the objectives. Hereby the steps that are performed for the systematic research:

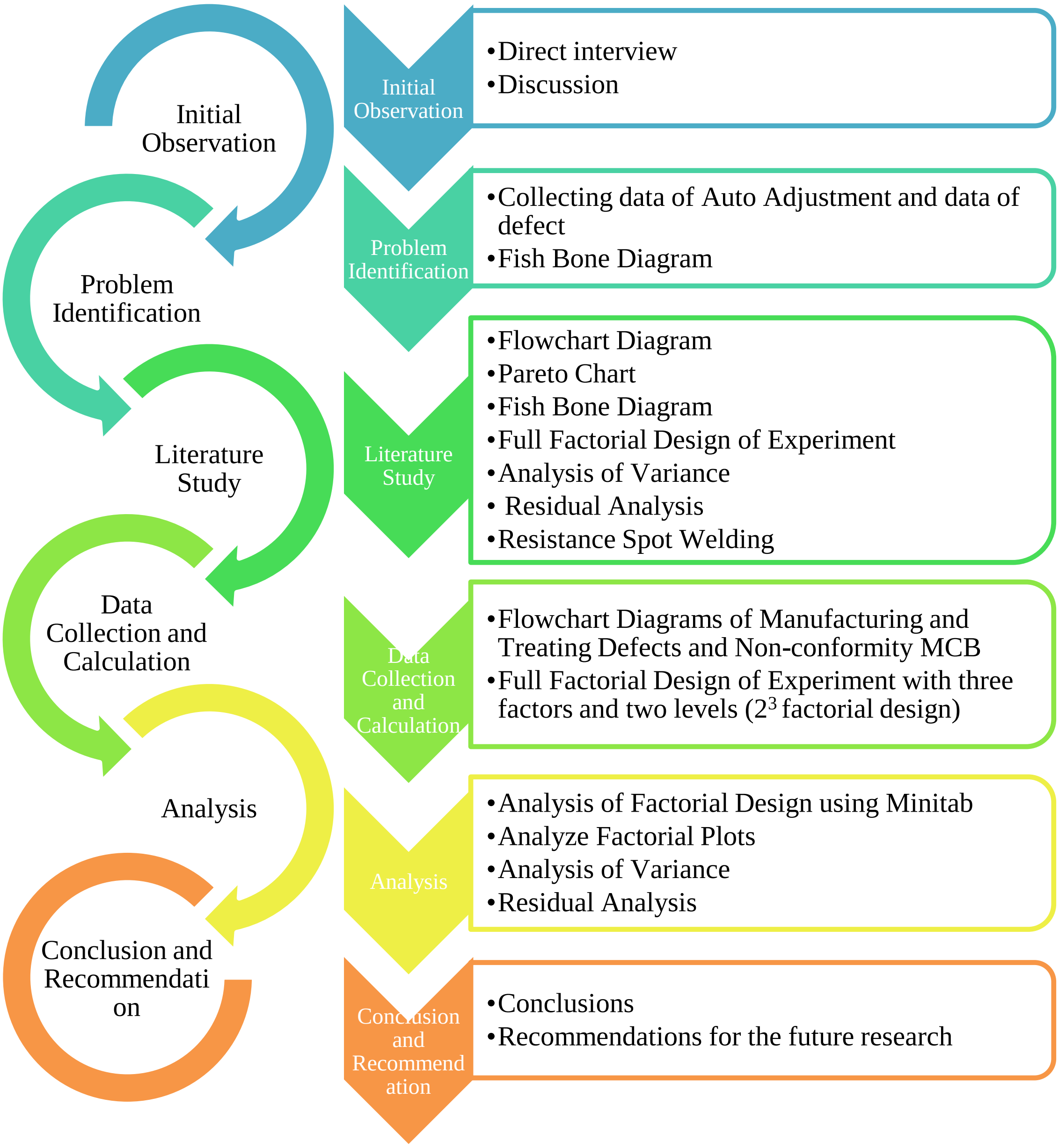


Figure 3.1 Research Framework

3.2 Description

3.2.1 Initial Observation

In the initial observation, it is found that there is high variability and rework from Auto Adjustment process in which many of the MCB trip out of Auto Adjustment's range (9 – 9.7 s). Moreover, the top defect from Auto Adjustment process recorded in Rework Station is related with welding S1 and called *S1M*. A high number of Non-Conformity MCB is also detected in Manual Adjustment station. Therefore, further discussion and interview are conducted to analyze the problem more deeply.

3.2.2 Problem Identification

After collecting the data of defect in Rework Station and data of Non-Conformity MCB in Manual Adjustment station, a root cause analysis is conducted to identify the causes. One main problem is that there is no standard for welding parameters in Welding S1 machine in which the operator may set them differently at other time. There are three main welding parameters that are frequently set by operators and those parameters are hypothesized to have influence on the results of welding S1: current, welding time and distance between lower electrode and jig table.

3.2.3 Literature Study

The research is guided by several literatures as prior references such as Flowchart diagram, Pareto Chart, Fish bone diagram, Hypothesis Testing, Design of Experiment especially Full Factorial Design, Analysis of Variance (ANOVA), Residual Analysis and Resistance Spot Welding.

3.2.4 Data Collection and Calculation

First of all, the process of manufacturing circuit breaker and flow of Defects and Non-conformity MCB treatment process are shown in Flowchart diagram. Identification of cause and effect is done through construction of Fish bone diagram. Pre-experiment is conducted to find the probable levels of experimental factors that could result in good condition of welding S1 as they could pass the Destructive test. Full factorial design of experiment is conducted afterwards in Welding S1 machine by taking into account three influential welding parameters (distance between lower electrode and jig table, current and welding time) as factors with each factor consists of two levels and there are three replications done for each combination. On the other hand, the controlled variables are the same type of bimetals (2 Ampere) and fixed distance between upper and lower electrode. In each combination, there will be 12 experimental units used for Design of Experiment. The run order of the experimental design is defined and randomized using Minitab software. After welding process, all of the experimental units are measured by line inspector using S1 jig to collect the data of Distance B. Next, those parts are continued to next processes until Auto Adjustment process without having Batch Coding process. Each tripping time of the experimental units in Auto Adjustment process is then recorded. The response will be number of MCB that trip out of Auto Adjustment process or Number of Out-Of-Range of Auto Adjustment.

3.2.5 Analysis

In this part, there is Analysis of Factorial Design by using Minitab software to find which parameters have significant effect on number of Out-of-Auto Adjustment's range among 12 products in each combination. Factorial Plots are also analyzed to see which combination of the three parameters' levels is the optimum one for reducing the number of out-of-Auto Adjustment's range including *S1M* and Non-Conformity MCB. Analysis of Variance will also be provided to statistically determine the correlations among the three factors and generate a model. After that, residual analysis is provided to verify the model assumptions. At the end, a new range of Distance B is proposed based on the chosen optimum combination of parameters that fit the Auto Adjustment's range of tripping time.

3.2.6 Conclusion and Recommendation

At the end of the research, conclusions can be drawn to summarize the results of the research and experimental design. Moreover, some recommendations are provided for future research due to scope and limitations of this research.

CHAPTER IV
COMPANY PROFILE AND PROJECT

4.1 Company Profile

Schneider Electric is a leading global manufacturer of equipment for electrical power distribution and for industrial control and automation. As the world's leading global specialist in energy management with operations in over 190 countries, it focuses on making energy safe, reliable, efficient, productive and green. Schneider Electric delivers efficient solutions across the global energy chain, enabling people to experience and transform efficiency together at home, in enterprise, across the grid, in towns and cities, and in energy-poor countries. The company was formerly known as Schneider Group and changed its name to Schneider Electric S.A. in May 1999. Schneider Electric S.A. was founded in 1836 and is currently headquartered in Rueil Malmaison, Hauts De Seine, France.

PT. Schneider Indonesia, one of Schneider Electric's local operations in Indonesia, has been operating since 1973 started with the opening of Merlin Gerin office in Jakarta which distributed Merlin Gerin's products. In 2009, PT. Schneider Indonesia changed the brands to Schneider Electric. Its current head office is located on 7th floor of Ventura Building, Jakarta. It presently employs over 4500 people in its 7 factories (2 in Batam, 3 in Cibitung, 1 in Cikarang and Pulogadung), 8 sales offices (Balikpapan, Bandung, Lampung, Makassar, Medan, Palembang, Semarang, Surabaya) and etc.

4.1.1 Brief History

Table 4.1 History of Schneider Electric

Year	Milestones
1836	Groupe Schneider was founded by two siblings, Adolphe and Eugene Schneider at Le Creusot, a small town in Burgundy, France
1871	Being one of Europe's leading weapons manufacturers
1988	The French company Telemecanique was acquired

Table 4.1 History of Schneider Electric (continued)

1991	The US company Square D joined Groupe Schneider
1992	The French company Merlin Gerin was wholly owned
1996	AEG and Modular Digital Control (Modicon) was fully acquired
1999	Groupe Schneider was renamed **Schneider Electric**
2005	New^2 management program was introduced
2006	Jean Pascal Tricoire became the President and Chief Executive Officer
2009 – 2011	a company program called "One" was introduced
2012 – 2014	A new company program "Connect" was launched

4.1.2 Business Operation

Until 2013, Schneider Electric operations were organized in five businesses (Partner, Infrastructure, Industry, IT and Buildings), built around key technologies. In 2014, Schneider Electric decided to regroup its Buildings and Partner businesses into a single business to provide its customers a complete offer to address the buildings market. Hence, the Group is now organized in four businesses: Buildings & Partner Infrastructure, Industry and IT.

Schneider Electric serves customers in four principal markets: Non-residential & residential Buildings; Utilities and Infrastructures; Industries and Machine manufacturers; Data Centers and Networks.

The businesses in each of its four business segments offer products and solutions. Solutions are comprised of systems, such as highly customized products or combinations of the products, and services. Schneider Electric's products and solutions businesses have different revenue growth and profitability profiles, with solutions business complementing the products business.

4.1.3 Schneider Cibitung Manufacturing (SCM) Factory

SCM factory is one of PT. Schneider Indonesia's factories located in MM2100 Industrial Park, Cibitung, Bekasi. It is as the latest relocation place for the production of Miniature Circuit Breakers. At first, Miniature Circuit Breakers were manufactured since 1986 in Surabaya with capacity of 3.5 million poles.

After 27 years, the capacity was increased of 71% as the production was relocated to Cikarang in 1998. Finally, in January 2012, the production line of Miniature Circuit Breakers was moved to Cibitung whose capacity is 12.5 million poles or 92% increase of the previous capacity. This factory is certified with **ISO 14001** since 2004, **OHSAS 18001** since 2007 and **ISO 9001** since 2008.

4.1.3 Organizational Structure

In PT. Schneider Indonesia Schneider Cibitung Manufacturing (SCM) plant, a plant general manager is supported by several divisions such as Human Resources, Finance, Supply Chain, Production, Maintenance & Utility, Method, Tooling & Technical Antenna, Quality, Safety, Health and Environment as well as Schneider Production System and Continuous Improvement Deployment. Schneider Cibitung Manufacturing also shares the same building with T2C or Tooling Competency Center Asia, one of PT. Schneider Indonesia's factories which specially produces molds for internal Schneider Electric.

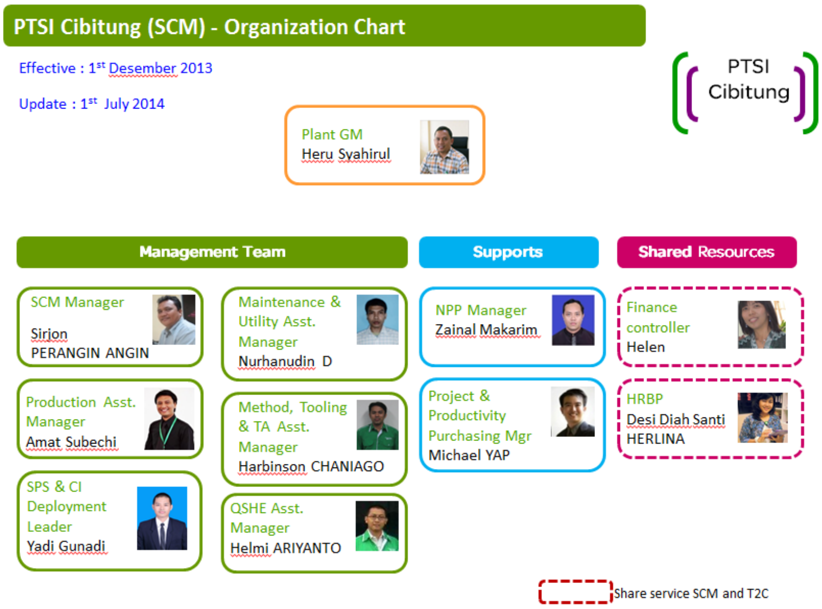


Figure 4.1 Organizational Structure of Schneider Cibitung Manufacturing

4.2 Production System and Products

4.2.1 Schneider Production System

Schneider Production System or SPS is a production system that is standardized for all companies of Schneider Electric. SPS is defined in 40 principles which are divided into 3 domains.

Figure 4.2 Schneider Production System with 3 Domains

4.2.1.1 People Commitment

Quality, productivity and elasticity come from the willingness of staff rather than a particular technique. Competitiveness depends on the initiative and intelligence of everyone. People commitment must be supported by a consistent social policy and management system for the whole site. The first ten principles that belong to "People Commitment" are:

1. Give the operators a sense of responsibility, especially for product quality and elasticity requirements
2. Encourage mutual aid and promote team work and team spirit
3. Increase skill levels and autonomy to control processes. Make use of operator versatility.
4. Implement Short Interval Management (SIM) and cross functional status reviews, which are consistent for all employees of the plant
5. Focus support function resources towards satisfying customer and production requirements
6. Establish standardized performance, accountability and workload measurements for everyone
7. Include operators when re-thinking the system and generating ideas for improvement
8. Shorten information and communication lines.
9. Manage the key jobs, linked skills and adaptability programs (training …)
10. Guarantee the balance between objectives and resources including quality, productivity, and respect for humanity.

4.2.1.2 Product-process Engineering

Engineering respects the Industrial Process Design Approach (IPDA). Each product/process combination must be:

- Simple (Lean manufacturing)
- Reliable (Design for Six Sigma)
- Flexible (almost zero change over time)
- Elastic (very quick changes in capacity) in order to meet the customer's exact requirements

The next twenty principles of Schneider Production System in Product-process Engineering domain are:

11. From the beginning of a project, involve all contributors, internal customers and partners (suppliers and distributors)
12. Adhere to ergonomics, safety and environmental rules and standards. (Adhere to the stricter of either country or Schneider standards)
13. Apply the BAT (Best Available Techniques)
14. Design processes to allow step by step investment.
15. Formalize each of the main processes of production
16. Follow Lean Manufacturing concepts when designing process architectures
17. Rationalize and standardize raw materials, product designs, processes and equipment as much as possible
18. Supply work stations and evacuate the containers, without interrupting operators
19. Eliminate interruptions to flow, rework, handling and container transfers, and maximize WIP
20. Obtain production lead times close to the sum of the operation cycle times
21. Reduce handling: involve supplier to use same containers between suppliers and work stations. Dedicate employees for material handling.
22. Product Reliability: control industrial processes to a capability / Cpk > 1.50
23. Perform only customer-required and legally mandated inspections, by process control (internal & external)
24. Do it right as much as possible and transfer all product to the next stage
25. Flexibility: promote late product differentiation and maximum component standardization
26. Flexible: Promote "one piece flow" production
27. Strive for high changeover time performed by the operator.

28. Elasticity: Size the capacity according to service objectives.
29. Systematically facilitate mutual aid by having work stations close together.
30. Quality Related to Product Transfers or New Products: Invest to obtain quality and track costs, as a function of quantities manufactured and PPM: MDR/FFR/PRR. (costs should follow the learning curve)

4.2.1.3 Management of Industrial and Logistic Processes

The Global Supply Chain of Schneider Electric includes manufacturing, the upstream and downstream supply chain, purchasing and quality. The design and implementation of the supply chain must conform to the guidelines stipulated in the Industrial and Quality Policies.

Here are the last ten principles of Schneider Production System that are divided into domain of Management of Industrial and Logistic Processes:

31. Meet the customer’s exact requirements (delivery, quality, design)
32. Minimize interruption to flow caused by outsourcing sub-assembly operations inside a process.
33. The Master Production Schedule (MPS) is the key process for high level of global logistic performance.
34. Schneider manufacturing utilizes a pull production and materials system based on real customer demand and each link of the supply chain is under a formal delivery time contract
35. Include the suppliers in the planning and manufacturing process
36. Manufacture the strict minimum and adhere to "just in time“ principles (such as FIFO).
37. The goal is Zero Defect. Continuously improve and control processes, measured in ppm: MDR, PRR, FFR
38. Simplify and then synchronize information flow of the supply chain.
39. Identify, quantify in hours, target, and then eliminate waste & non-quality causes (waiting time, transportation, rework, m2, etc...)
40. Implement the recommended quality and industrial KPI's (key performance indicators). Share objectives and performance assessment results with Product Departments and Operating Division Quality

4.2.2 Products

The products of Schneider Electric are mostly related with electrical distribution and energy management such as High Voltage, Medium Voltage, Low Voltage switchgears, transformers, protection control and monitoring relays, remote terminal units, and Operation Management Software. In PT. Schneider Indonesia especially its Schneider Cibitung Manufacturing Plant, the products that are manufactured include Miniature Circuit Breakers range 2A – 50 A with 32 references. Moreover, it now starts the adaption process for Air Circuit Breaker and Molded-Case Circuit Breaker.

4.3 Project

During the internship period in Quality, Safety, Health and Environment (QSHE) Department, the activities performed are including preparing for drafts of Hazard Identification, Risk Assessment and Risk Control (HIRARC) and Environmental Aspect Impact for re-certification of ISO 9001, ISO 14001 and OHSAS 18001, observing the workplaces to identify the potential hazards and interviewing some operators to determine the occurrences of the hazards, conducting meeting with supervisors of each department to discuss HIRARC and Environmental Aspect Impact, assisting supervisor in delivering Safety Talks and making the summaries, designing and attaching the notices about emergency team and instructions for using fire extinguishers in the whole plant, collecting and translating the documents of Material Safety Data Sheet (MSDS) of chemical substances used in production line and maintenance, participating in Root Cause Analysis with Quality team members regarding defects of welding S1 and Auto Adjustment process, conducting trials and finding the optimum parameters in welding S1 to reduce the non-conformity products by conducting Three Factors Two Level Full Factorial Design of Experiment, making Process Control Plan and Process Failure Mode and Effects Analysis (PFMEA) of Adaptation products (Air Circuit Breaker and Moulded-Case Circuit Breaker) as well as conducting Gage Repeatability and Reproducibility (Gage R&R) Study of Magnetic Test for all ratings of Miniature Circuit Breakers.

CHAPTER V
DATA AND ANALYSIS

5.1 Data Collections

Below are the collections of data that are needed as the beginning of the research to gradually identify the problems as well as the solutions to deal with them.

5.1.1 Flowchart Diagram of Manufacturing MCB process

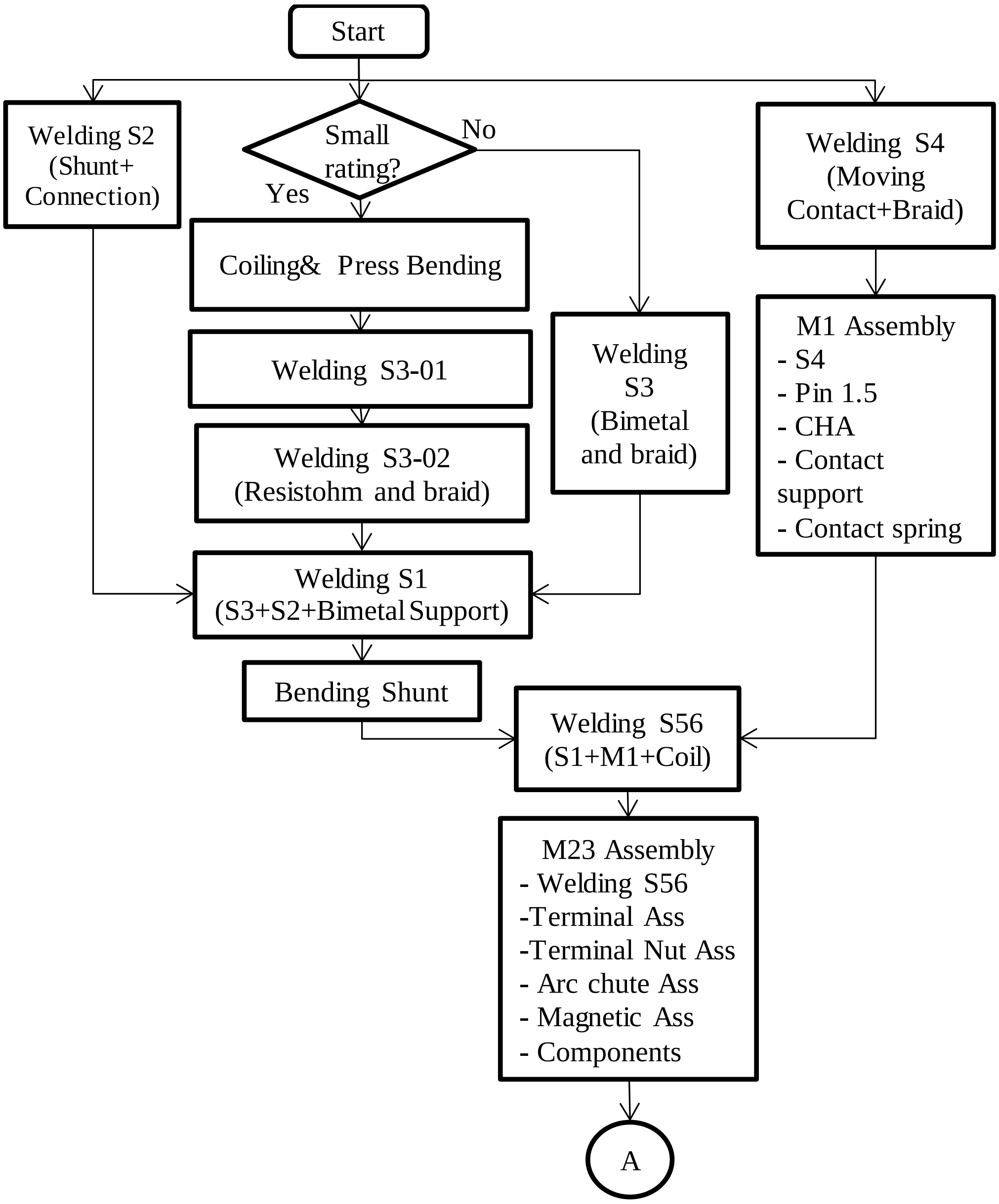


Figure 5.1 Flowchart Diagram of Manufacturing MCB process (Part 1)

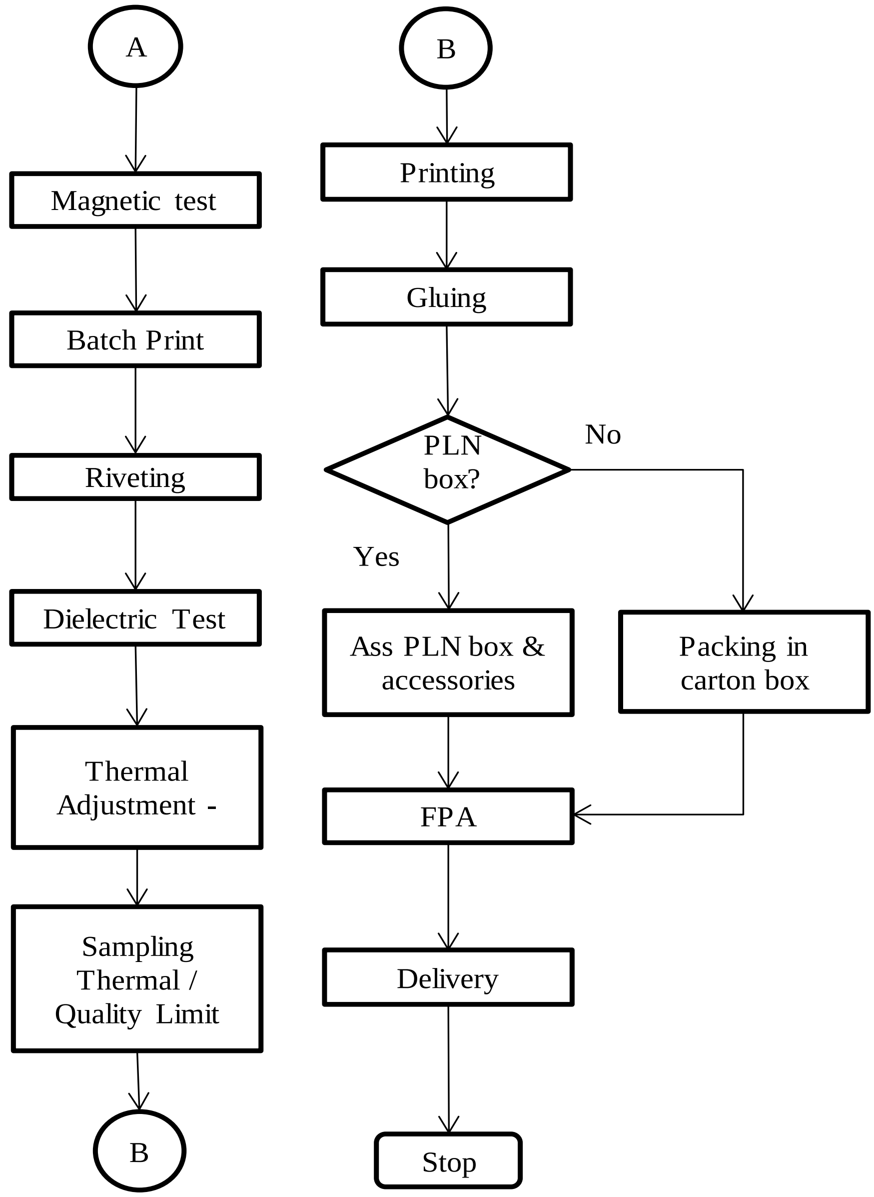


Figure 5.2 Flowchart Diagram of Manufacturing MCB process (Part 2)

The Flowchart Diagrams above describe the flow process of manufacturing Miniature Circuit Breaker. In the first part, the processes include coiling, press bending cutting and welding processes. There are 7 types of welding processes, S1, S2, S3, S3-01, S3-02, S4 and S56 that are differentiated based on the welded parts. The distinction of small rating and big rating MCB can be seen through the result of S3 in which small rating MCB have bimetals that are coiled with resistohm. In the second part, the result of welding S56 as the final welding will be assembled with other components in the final assembly, then to magnetic test, batch print, riveting, dielectric test, thermal adjustment (Auto Adjustment), sampling thermal control, printing, gluing and packing. Further explanation of welding S1 process and the result is described in section below. Excluded from the production process, rework is done after the Auto Adjustment process. The flow process of rework is explained in Figure 5.5.

5.1.2 Welding S1

In welding S1, the bimetal support is welded with shunt (result of welding S2) and bimetal (result of welding S3). The shunt is placed between the edge of bimetal and the support of bimetal support. A good result of welding S1 is indicated by the parallel position of both bimetal and closer side of bimetal support on bimetal's left. The result of welding S1 is clearly shown in Figure 5.3. In welding S1 process, there is a measurement of distance between bimetal and further side of bimetal support (Distance B). At the final assembly, bimetal will be placed beside tripping bar, thus it has function to touch the tripping bar when the current is given and the thermal screw is screwed automatically in Auto Adjustment process. The tripping bar will then activate the toggle to disconnect the circuit. Currently, the distance has determined range which is 27.4 ± 0.4 mm.

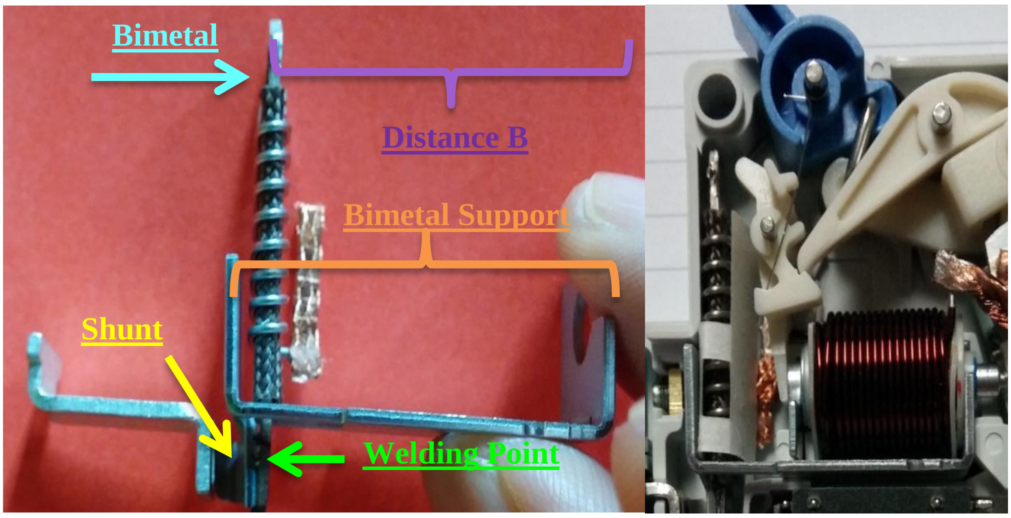


Figure 5.3 Result of Welding S1 (*Left*) and S1 in MCB (*Right*)

In welding S1 process, there are three influential factors that are mostly set by the operator. They are the distance between lower electrode and jig table, welding current, and welding time. Figure 5.4 shows the two electrodes and jig table used in welding S1.

Figure 5.4 Welding S1 Machine

After conducting interview and pre-experiment, two levels of each factor are defined to be included in the full factorial design of experiment. In addition, the levels have passed the destructive test in welding S1 station. Two levels of the distance between lower electrode and jig table are 3.15 cm and 3.20 cm while two levels of welding current are 14 Ampere and 16 Ampere. Last, the two levels of welding time that are chosen in this design of experiment are 15 seconds and 17 seconds. On the other hand, the variables that are controlled in this experiment is the type of bimetals used which is 2 Ampere and the fixed distance between upper electrode and lower electrode which is 1 cm.

5.1.3 Flowchart Diagram of Defects & Non-Conformity Treatment process

The flow process of treatment to Defects and Non-Conformity MCB is shown in Figure 5.5. The decision of processing the Out-of-Range MCB to manual adjustment or rework station is made in Auto Adjustment station. The limits for the tripping time in Auto Adjustment process is 9 – 9.7 seconds. If the MCB trips before 9 s which are then called Mini Adjustment, there will be 2 types of repair done, manual adjustment and brought to rework station. MCB will be brought to Rework Station and called defects if they trip very fast or abnormally (less than 8 s). In the rework station, the rivet of MCB must be pulled out to open the MCB so that the defects can be repaired. Moreover, the thermal screw must also be renewed. Meanwhile, manual adjustment will be done to those which trip in the range of 8 – 8.9 s by re-screwing the thermal nut without having to pull out the rivet. Meanwhile, On the other hand, manual adjustment will also be done to those that trip more than 9.7 s (Maxi Adjustment).

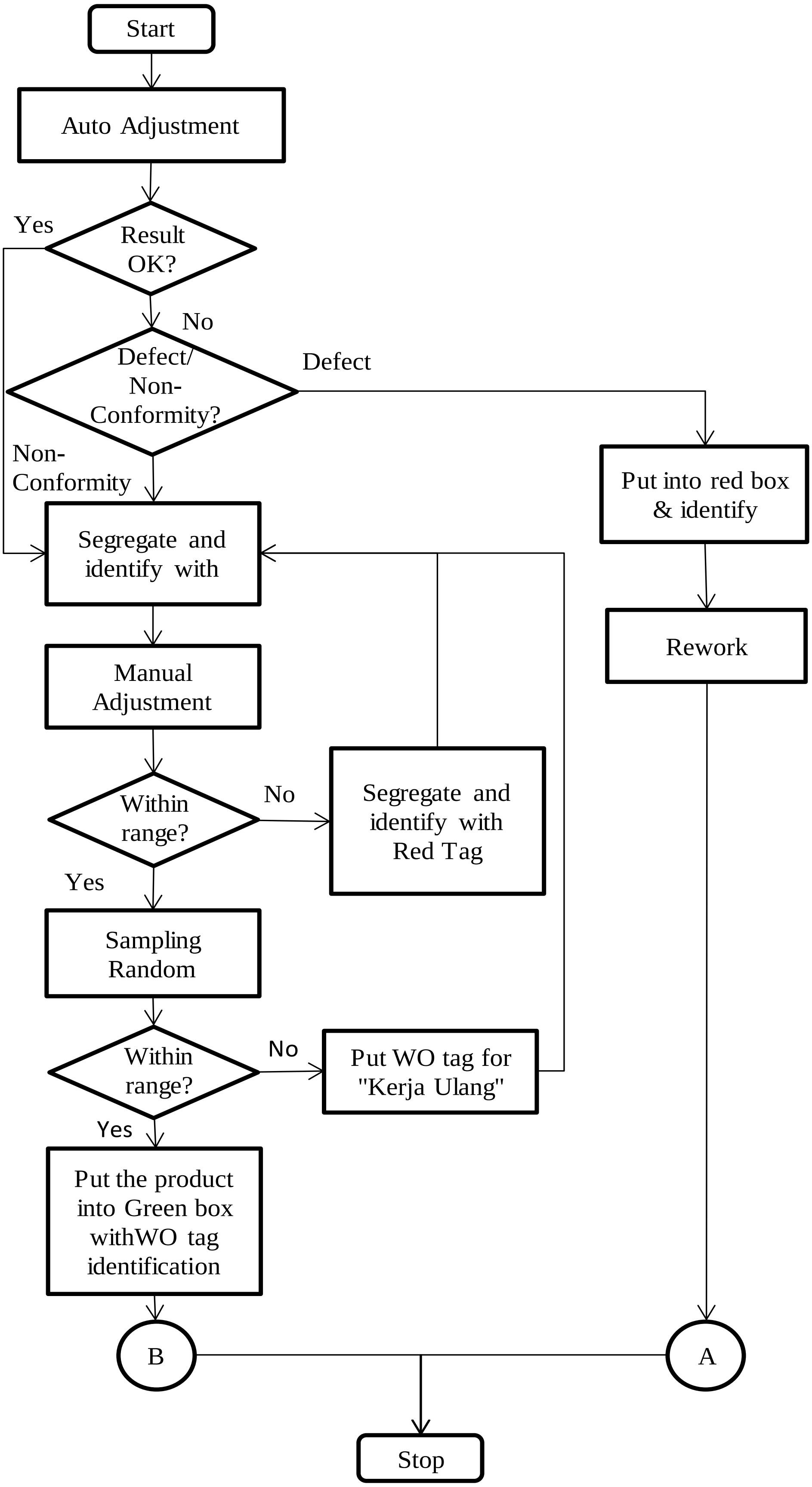


Figure 5.5 Flowchart Diagram of Defects and Non-Conformity Treatment Process

5.1.4 Pareto Chart

Pareto Chart is a graph which consists of bar and line graph to depict frequency or number from the highest to the smallest. The Pareto chart shown in Figure 5.6 displays the data of defects of MCB 2 Ampere in June in Rework station. It can be seen that the highest number of defect belongs to *S1M* or the defect code for MCB that trips below 8 seconds due to welding S1 (position of bimetal of welding S1 is much closer to tripping bar before the screw has been properly screwed) with the percentage of 83%.

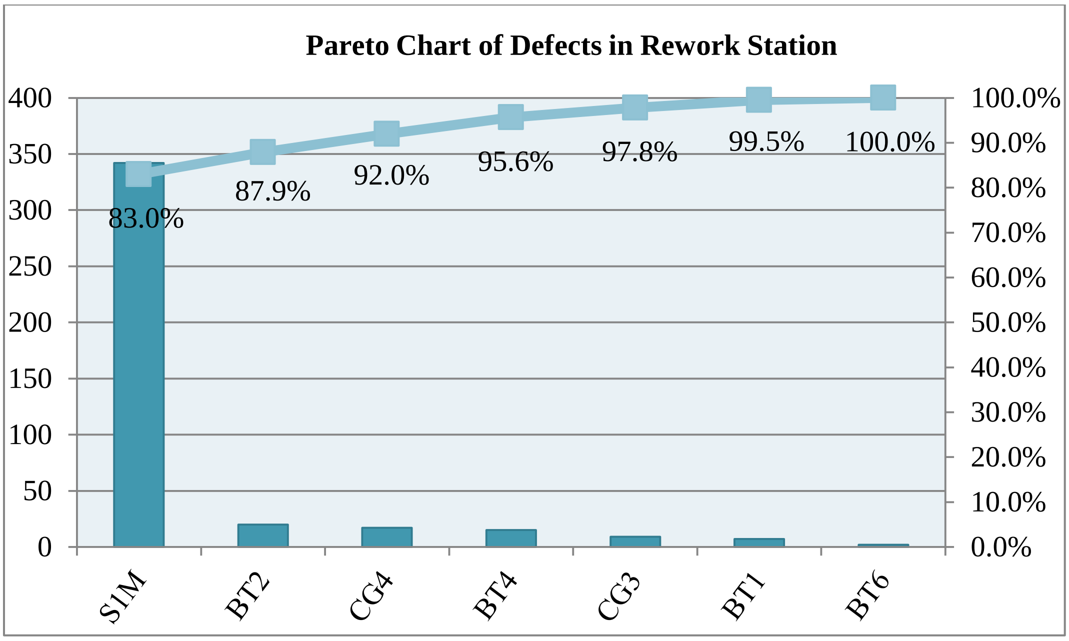


Figure 5.6 Pareto Chart of Defects in Rework Station

In addition, the table below shows the number of Non-conformity MCB 2 Ampere that are sent to Manual Adjustment control station in June.

Table 5.1 Table of Number of Non-Conformity MCB in June

Manual Adjustment Station	Number of Non-Conformity MCB
Station 1	769
Station 2	1023
Station 3	191
Total	1983

Therefore, a further analysis is necessary to be conducted to find the root cause and solution.

5.1.5 Fish Bone Diagram

Figure 5.7 depicts the Fish Bone Diagram or Cause and Effects Diagram of Out-of-Range of Auto Adjustment. The causes are mostly taken from welding S1 process since the result of welding S1 takes the biggest part in Auto Adjustment process. The big causes are man, machine, and method. The sub causes from man factor are lack of skill and knowledge of the welding operators about welding process and detecting *S1M*, lack of awareness of the welding operators to put the welded part into the jig inspection to prevent *S1M* (the condition of distance B in which if the bimetal is too close to the tripping bar in the molded case, the tripping time would be much faster than it should be) and lack of concentration that the welding operators unintentionally let the defect parts go.

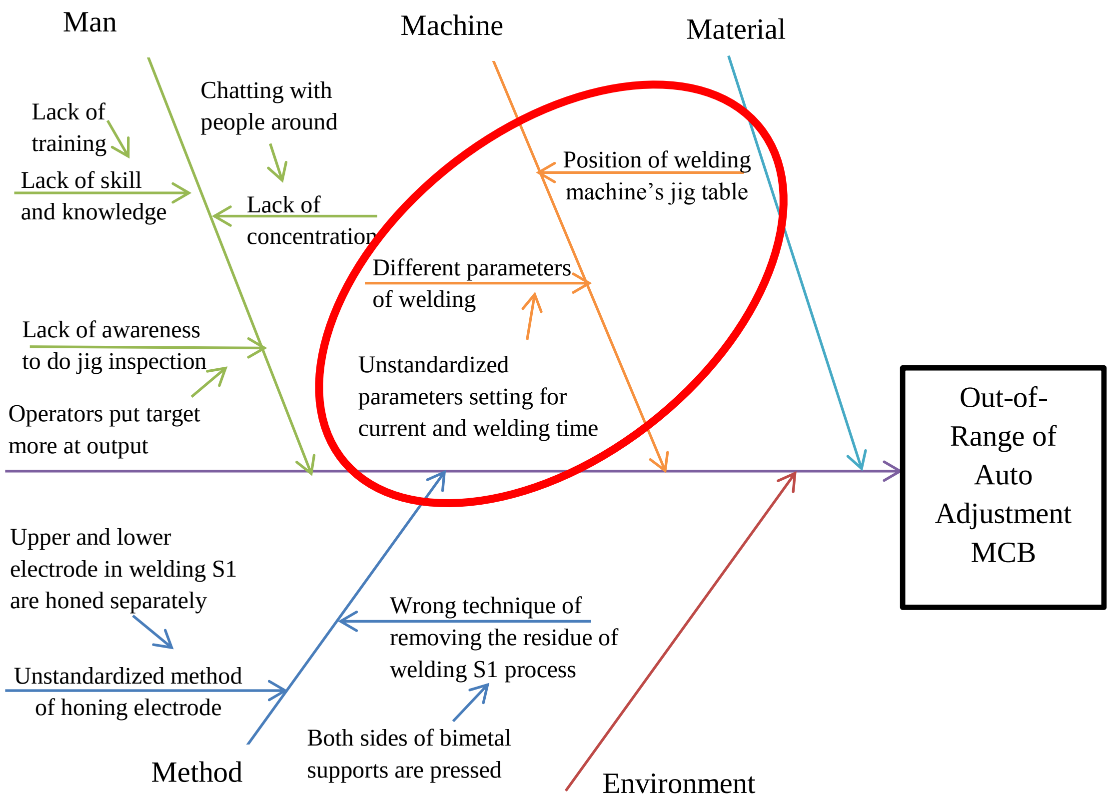


Figure 5.7 Fish Bone Diagram of Out-of-Range of Auto Adjustment

From the factor of machine, the sub causes are different setting of parameter of spot welding current and welding time that could lead to the size and position of the residue of welding. This residue of welding could affect the position of bimetal which can be closer to tripping bar. Next, the unstable welding machine's jig also gives contribution to this defect since it can give impact on the position and distance between bimetal and bimetal support including Distance B shown in Figure 5.3.

Last but not least, the causes of Out-of-Range of Auto Adjustment MCB come from the category of method. There are several issues regarding the methods during the process of welding which are the method of honing electrode which could transform the surface of the electrode and the technique of removing the residue of welding process in which the operators tend to place their fingers in each side of the bimetal support and this could deform the bimetal support.

After having discussions and analysis, a research is conducted to deal with the problem of parameter settings. Hence, a designed experiment is chosen as the way to find the optimum combination of levels of the parameters to reduce the number of out-of range-of Auto Adjustment products. The parameters that are included in the designed experiment as factors are distance between lower electrode and jig table, current and welding time in welding S1 process. As companion, the distance between upper and lower electrode is controlled to 1 cm and the bimetals used are 2 Ampere as all experimental units.

5.1.6 Two-Level-Full Factorial Design of Experiment

Since the factors included in the Design of Experiment are more than two and all possible combinations of the factors are tested, Factorial Design is chosen as the method to find the optimum combination of the parameters. In addition, the experimental uses Completely Randomized Design in which no blocking is used and the runs are randomized using Minitab Software. Two factors levels of each factor are selected in which the combination of the levels could successfully pass the destructive test in welding S1 station. The experiment is then designed in Minitab Software with the steps shown in the pictures below.

The factorial design can be found in **Stat → DOE → Factorial → Create Factorial Design.** The first step is clicking the type of factorial design and choosing the number of the factors. There are several types of Factorial Design that are provided in Minitab. The sub-dialog is shown in Figure 5.8. After choosing 2-level factorial (default generators), click the **Designs**.

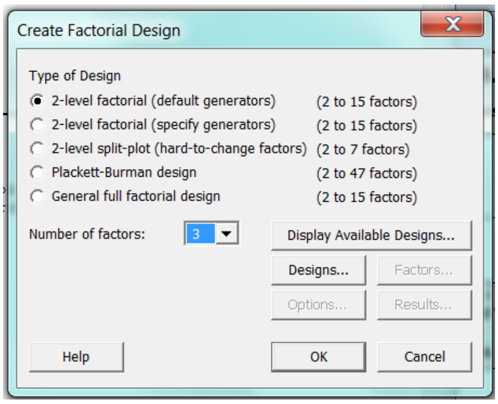


Figure 5.8 Step 1 of Creating Factorial Design in Minitab

In **Designs,** there are two options for the designs of the experiment. Full factorial design is selected in this research with 3 replications. Since there is no blocking in the design, the number of blocks is 1. Then click **OK**.

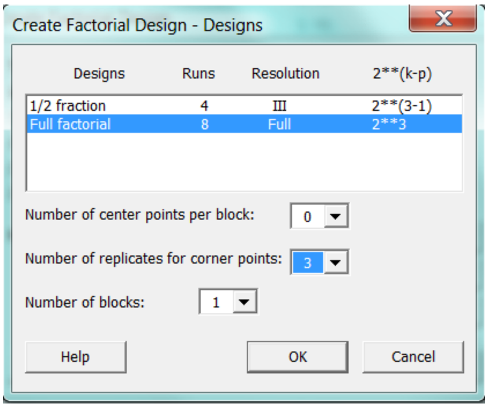


Figure 5.9 Step 2 of Creating Factorial Design in Minitab

In step 3, click the **Factors** to change the name, type and levels of the factors. Factor A is the distance between lower electrode and jig table with the levels are 3.15 cm and 3.2 cm. Meanwhile, Factor B is current with the levels chosen are 14 Ampere and 16 Ampere. Last but not least, Factor C represents welding time with the levels used in the experimental design are 15 seconds and 17 seconds.

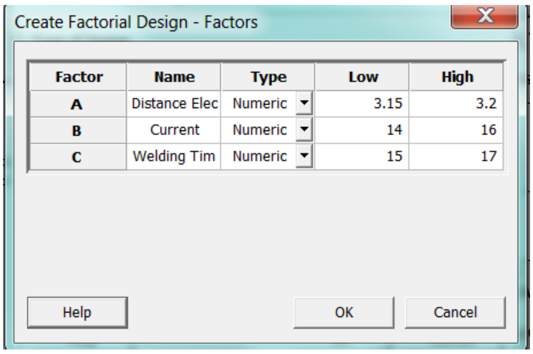


Figure 5.10 Step 3 of Creating Factorial Design in Minitab

The next step is **Options** which provides the options of folding and randomization of runs as well as storing the design in the worksheet.

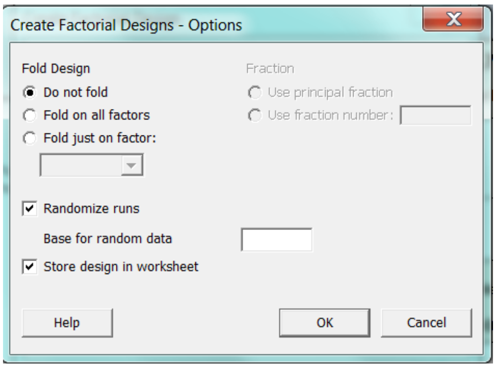
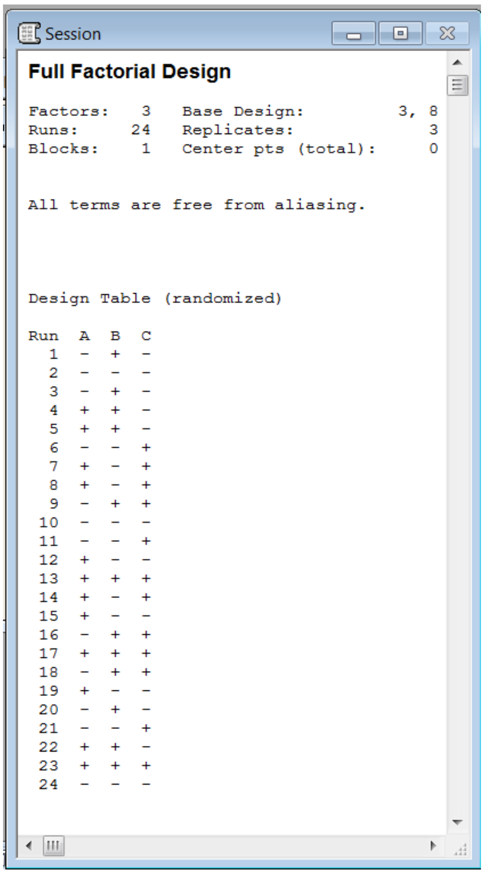


Figure 5.11 Step 4 of Creating Factorial Design in Minitab

Finally, the randomized design table is shown in **Session** shown in Figure 5.12**.** It can be seen that there are 24 randomized runs with 3 replications for each combination. The "+" sign shows that the level of the factor used for the run is high level while the "-" sign shows the inverse. There are 24 runs because they include all of the combinations of three factors and 2 levels with each combination is replicated three times. Thus, the total runs become 2 x 2 x 2 x 3 = 24 runs.


Session

Full Factorial Design

```
Factors:   3   Base Design:         3, 8
Runs:     24   Replicates:             3
Blocks:    1   Center pts (total):     0


All terms are free from aliasing.



Design Table (randomized)

Run  A  B  C
  1  -  +  -
  2  -  -  -
  3  -  +  -
  4  +  +  -
  5  +  +  -
  6  -  -  +
  7  +  -  +
  8  +  -  +
  9  -  +  +
 10  -  -  -
 11  -  -  +
 12  +  -  -
 13  +  +  +
 14  +  -  +
 15  +  -  -
 16  -  +  +
 17  +  +  +
 18  -  +  +
 19  +  -  -
 20  -  +  -
 21  -  -  +
 22  +  +  -
 23  +  +  +
 24  -  -  -
```

Figure 5.12 Design Table in Minitab

5.1.7 Results of Distance B of Experimental Units

After conducting the randomized runs with 12 experimental units in each run in welding S1 process, the distance B of welding S1's results are then measured using a digital meter. The detailed results of measurement are provided in Appendix 1. The red color on the numbers indicates that the numbers are out of the range of 27 – 27.8 mm. The table 5.2 displays the summary of the total number of out of range in each run.

Table 5.2 Table of Number of OUT-OF-27-27.8 mm in Each Run

Run	Number of OUT-OF-27-27.8 mm	Run	Number of OUT-OF-27-27.8 mm
1	8	**13**	0
2	2	**14**	12
3	4	**15**	12
4	11	**16**	8
5	9	**17**	4
6	1	**18**	12
7	2	**19**	12
8	3	**20**	9
9	3	**21**	0
10	2	**22**	11
11	2	**23**	11
12	12	**24**	0

5.1.8 Results of Tripping Time of Experimental Units in Auto Adjustment

After welding S1 process, the experimental units are then moved to the next processes. Afterwards, the tripping time of each unit in Auto Adjustment process is recorded. The details of tripping time are shown in Appendix 2. The total number of out-of-range of Auto Adjustment (9.0 - 9.7 s) in each run are then computed in Minitab as the response variable. Figure 5.13 displays the details of runs and response variable. The **StdOrder** shows the original orders of the runs while **RunOrder** shows the randomized orders of runs. After inputting the response variable, click **Stat→ DOE→Factorial Design→ Analyze Factorial Design** to fit a model and assess the effects.

	StdOrder	RunOrder	CenterPt	Blocks	Distance Electrode-Jig	Current	Welding Time	Number of OUT-OF 9.0 - 9.7 s
1	19	1	1	1	3.15	16	15	1
2	9	2	1	1	3.15	14	15	3
3	3	3	1	1	3.15	16	15	1
4	12	4	1	1	3.20	16	15	4
5	4	5	1	1	3.20	16	15	5
6	13	6	1	1	3.15	14	17	4
7	14	7	1	1	3.20	14	17	3
8	22	8	1	1	3.20	14	17	5
9	23	9	1	1	3.15	16	17	0
10	1	10	1	1	3.15	14	15	0
11	5	11	1	1	3.15	14	17	5
12	10	12	1	1	3.20	14	15	9
13	8	13	1	1	3.20	16	17	1
14	6	14	1	1	3.20	14	17	10
15	18	15	1	1	3.20	14	15	10
16	15	16	1	1	3.15	16	17	1
17	16	17	1	1	3.20	16	17	1
18	7	18	1	1	3.15	16	17	0
19	2	19	1	1	3.20	14	15	10
20	11	20	1	1	3.15	16	15	0
21	21	21	1	1	3.15	14	17	2
22	20	22	1	1	3.20	16	15	6
23	24	23	1	1	3.20	16	17	8
24	17	24	1	1	3.15	14	15	0

Figure 5.13 Worksheet of Factorial Design in Minitab

5.2 Data Calculations and Analysis

5.2.1 Analysis of Factorial Design for Tripping Time

In **Analyze Factorial Design**, the column of response variable is inputted in **Responses**. **Terms** is clicked to choose which factors to be included in the model. In **Graphs,** there are Effects Plots to display which factors or terms are significant and Residual Plots to verify model assumptions. In Normal Plot shown in Figure 5.14, it can be seen that terms *Distance Electrode-Jig* (A), *Current* (B), and *Distance Electrode-Jig*Welding Time* (AC) are significant with α = 0.05.

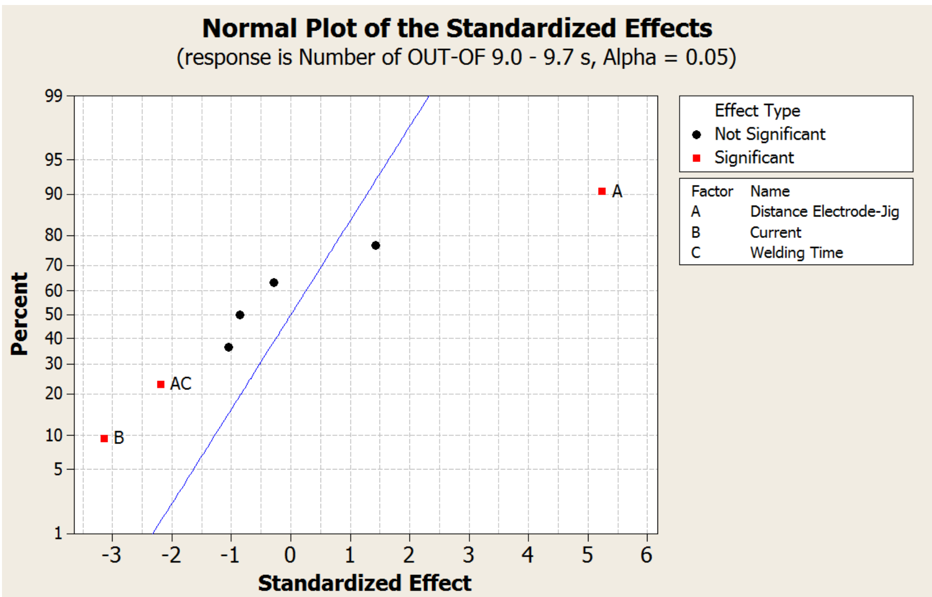


Figure 5.14 Normal Plot of the Standardized Effects in Minitab

In addition to Normal Plot, Minitab also provides Pareto Chart of the standardized effects to determine the magnitude and the importance of the effect. Any effect that exceeds the reference line (red line) is potentially important or significant. It is shown that term *Distance Electrode-Jig* (A) is the most important term followed by *Current* (B) in the second position and *Distance Electrode-Jig*Welding Time* (AC) as the last important term that passes the reference line at the 5% level of significance.

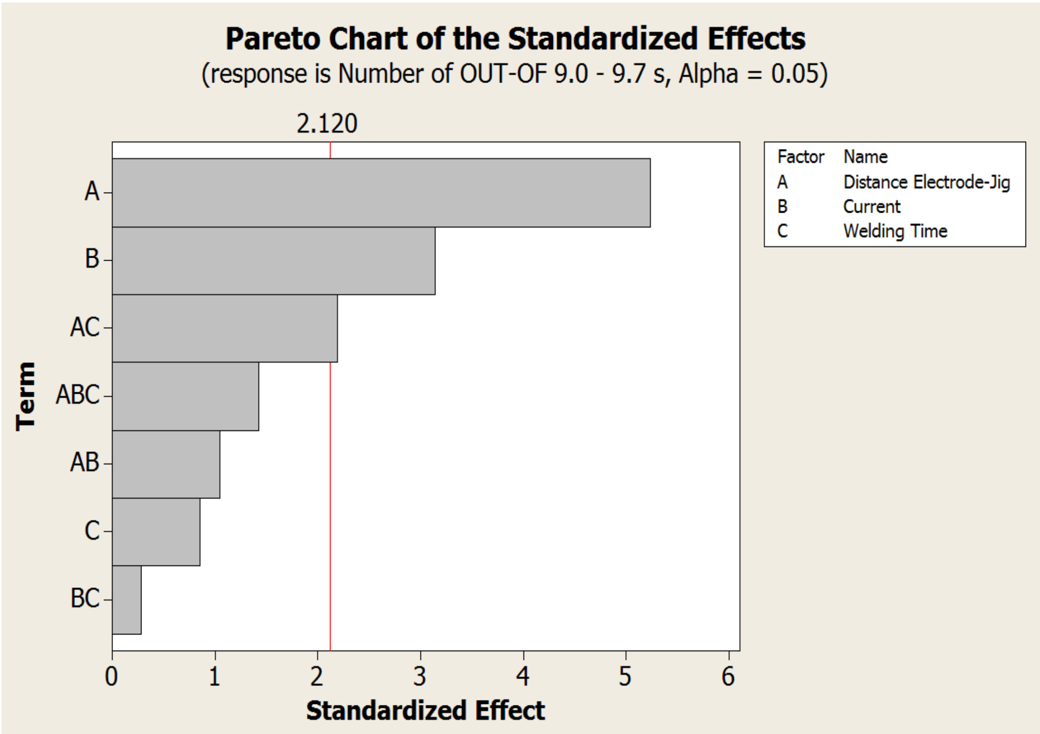


Figure 5.15 Pareto Chart of the Standardized Effects in Minitab

As the two plots of standardized effects are displayed, Minitab stores the result of Estimated Effects and Coefficients using t-statistic and Analysis of Variance using F-statistic for the response variable in **Session.** The p-value will then be used in the hypothesis testing to test whether the main effects as well as the interactions are significant. Both results will be displayed and further analyzed in the section of **Analysis of Variance**.

In **Analyze Factorial Design**, not only the plots of standardized effects are displayed, but also residual plots which contain Normal Probability Plot, Histogram, Residual Versus Fits, and Residual Versus Order. The residuals from a factorial experiment play an important role in assessing model adequacy and the validity of the model assumptions. The residual analysis is provided in section 5.3.

5.2.2 Interpret Factorial Plots

The factorial plots include main effects plot to show how each factor in its level affects the response variable and the interaction plot to depict the impact of two factors on the response. Fitted means is chosen in the factorial plots as they are useful for observing response differences due to changes in the levels of factors. In figure 5.16, main effects plot display the mean number of out-of-9-9.7 s for all levels of the factors. The horizontal line shows the mean number of out-of-9-9.7 s for all runs. For term *Distance Electrode-Jig* (A), the graph indicates that lower level or 3.15 cm produces smaller number of out-of-9-9.7 s as compared to higher level 3.20 cm. On the other hand, the higher level of term *Current* (B) which is 16 Ampere produces smaller number of out-of-9-9.7 rather than 14 Ampere. This also applies to term *Welding Time* (C) in which 17 s results in smaller number of out-of-9-9.7 than 15 s.

As the effects plot in section 5.2.1 have displayed that term *Distance Electrode-Jig* (A) has the largest effect on the number out-of-9-9.7 as the response variable, main effects plot also give additional proof through the slope of the line of Term *Distance Electrode-Jig* (A) in which its slope is the steepest among all. The second largest effect on the response variable belongs to the term *Current* (B). Last but not least, there is no significant effect from the term *Welding Time* (C) since there is only a very small difference of mean number of out-of-9-9.7 s between its two levels.

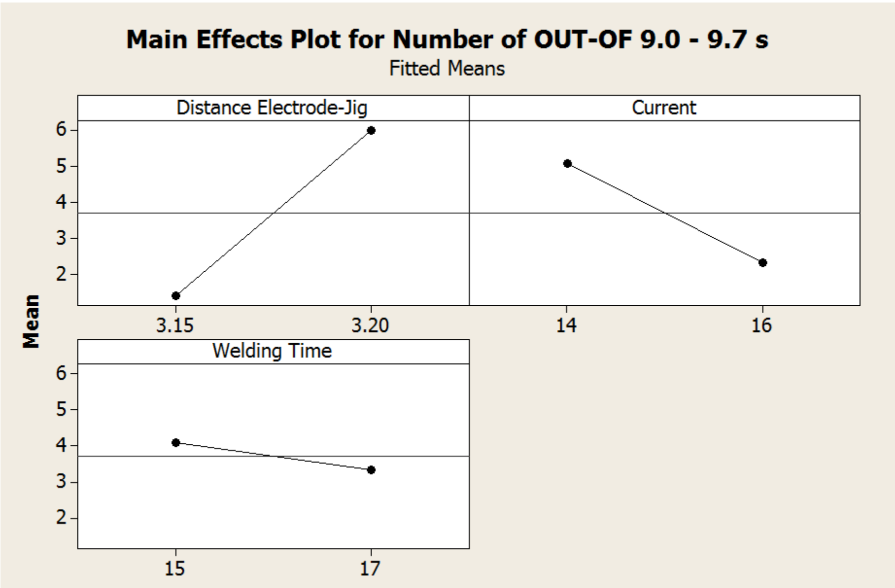


Figure 5.16 Main Effects Plot (Fitted Means) in Minitab

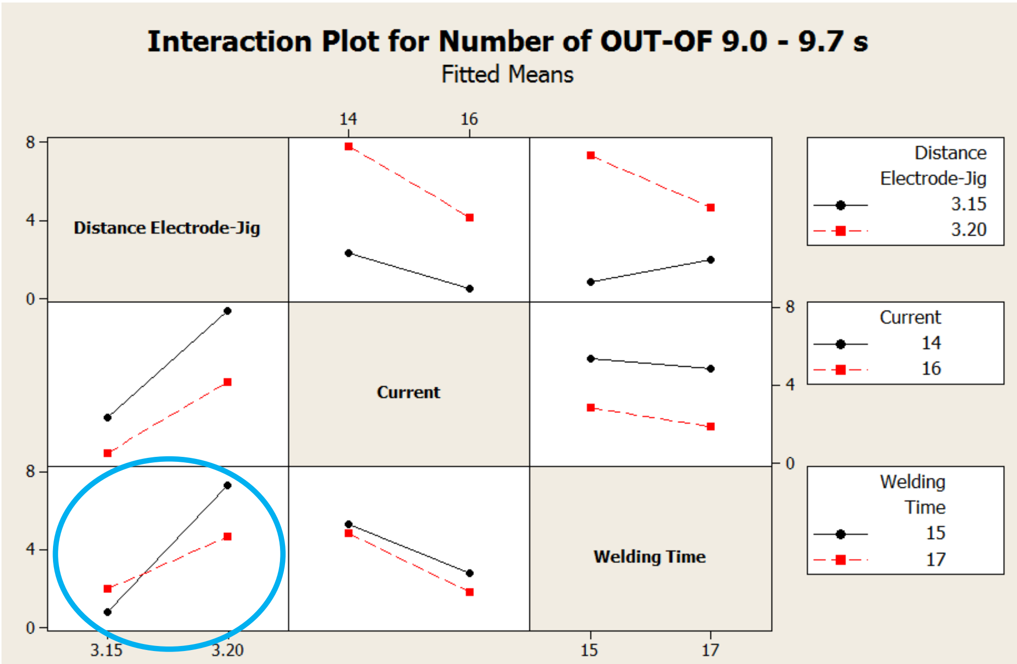


Figure 5.17 Interaction Plot (Fitted Means) in Minitab

The interaction plot shown in Figure 5.17 depicts the interactions of two factors in each of their levels. Among all of the interaction plots, only the lines of terms *Distance Electrode-Jig* (A) and *Welding Time* (C) are crossing each other. This means that the interaction between these two factors is significant.

In interaction plot of *Distance Electrode-Jig* (A) and *Welding Time* (C), it can be seen that the smallest number of out-of-9-9.7 s (approximately 1 product) is produced when the distance between lower electrode and jig table is 3.15 cm and the welding time is 15 s while the biggest number of out-of-9-9.7 s (approximately 7 products) is produced if the distance between lower electrode and jig table is 3.2 cm and the welding time used is 15 s. As the slope of the black line or 3.15 cm is steeper, it can be concluded that the 3.15 cm of distance between lower electrode and jig table has a greater effect when welding time 15 s is used instead of welding time 17 s.

In addition to main effects plot and interaction plot in **Analyze Factorial Plots**, Minitab also provides cube plot to show the relationships among the three factors. it can been seen in Figure 5.18 that the smallest means number of out-of-9-9.7 s is produced in the combination of 3.15 cm of distance between lower electrode and jig table, 16 Ampere of current and 17 s of welding time.

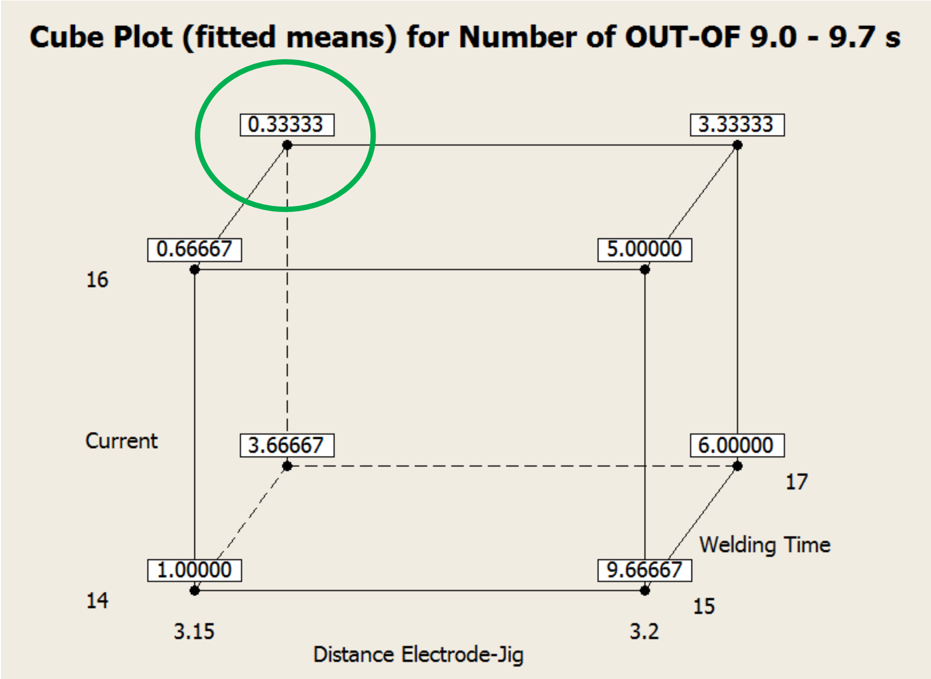


Figure 5.18 Cube Plot (Fitted Means) in Minitab

5.2.3 Analysis of Variance (Full Model)

After the effects plot and factorial plots are displayed and analyzed, Analysis of Variance (ANOVA) provided by Minitab is then used to test the hypotheses.

Analysis of Variance for Number of OUT-OF 9.0 - 9.7 s (coded units)

Source	DF	Seq SS	Adj SS	Adj MS
Main Effects	3	174.792	174.792	58.264
Distance Electrode-Jig	1	126.042	126.042	126.042
Current	1	45.375	45.375	45.375
Welding Time	1	3.375	3.375	3.375
2-Way Interactions	3	27.458	27.458	9.153
Distance Electrode-Jig*Current	1	5.042	5.042	5.042
Distance Electrode-Jig*Welding Time	1	22.042	22.042	22.042
Current*Welding Time	1	0.375	0.375	0.375
3-Way Interactions	1	9.375	9.375	9.375
Distance Electrode-Jig*Current*Welding Time	1	9.375	9.375	9.375
Residual Error	16	73.333	73.333	4.583
Pure Error	16	73.333	73.333	4.583
Total	23	284.958		

Source	F	P
Main Effects	12.71	0.000
Distance Electrode-Jig	27.50	0.000
Current	9.90	0.006
Welding Time	0.74	0.404
2-Way Interactions	2.00	0.155
Distance Electrode-Jig*Current	1.10	0.310
Distance Electrode-Jig*Welding Time	4.81	0.043
Current*Welding Time	0.08	0.779
3-Way Interactions	2.05	0.172
Distance Electrode-Jig*Current*Welding Time	2.05	0.172
Residual Error		
Pure Error		
Total		

Figure 5.19 Analysis of Variance for Number of Out-Of-9-9.7s

H_0 or Null Hypothesis states that there is no main effect or interaction effect of the factors. H_0 is rejected if ***p-value*** is smaller than α. In other words, if the ***p-value* >** α**,** the conclusion is statistically insignificant and if the ***p-value*** < α, the conclusion is statistically significant.

- Testing highest order interactions

  H_0: $(\tau\beta\gamma)_{ijk} = 0$ for all *ijk*

  H_1: $(\tau\beta\gamma)_{ijk} \neq 0$ for some *ijk*

  $\alpha = 0.05$

  As shown in Figure 5.19, the p-value for three-way interactions is 0.172 which is higher than the alpha, thus the null hypothesis is accepted and it is concluded that the interaction among the three factors is not significant or it has no effect on the number of out-of-9-9.7s.

- If not significant, then consider the second order interactions

  a. Interaction between factor A and B

     H_0: $(\tau\beta)_{ij} = 0$ for all *ij*

     H_1: $(\tau\beta)_{ij} \neq 0$ for some *ij*

     $\alpha = 0.05$

     In ANOVA result shown by Minitab, the p-value for interaction between term *Distance Electrode-Jig* (A) and *Current* (B) is 0.310 which is higher than the alpha, thus the null hypothesis is accepted and it is concluded that the interaction among the these two factors is not significant.

  b. Interaction between factor A and C

     H_0: $(\tau\gamma)_{ik} = 0$ for all *ik*

     H_1: $(\tau\gamma)_{ik} \neq 0$ for some *ik*

     $\alpha = 0.05$

     Based on the ANOVA result, the p-value for interaction between term *Distance Electrode-Jig* (A) and *Welding Time* (C) is 0.043 which is smaller than the alpha, thus the null hypothesis is rejected and it is concluded that the interaction among the these two factors is statistically significant.

c. Interaction between factor B and C

H_0: $(\beta\gamma)_{jk} = 0$ for all *jk*

H_1: $(\beta\gamma)_{jk} \neq 0$ for some *jk*

$\alpha = 0.05$

As shown in Figure 5.19, the p-value for interaction between term *Current* (B) and *Welding Time* (C) is 0.779 which is higher than the alpha, thus the null hypothesis is accepted and it is concluded that the interaction among the these two factors is statistically insignificant.

- If no significant interaction contains

(1) Subscript *i* (Factor A) then consider testing

H_0: $\tau_i = 0$ for all *i*

H_1: $\tau_i \neq 0$ for some *i*

$\alpha = 0.05$

In ANOVA, the p-value for term *Distance Electrode-Jig* (A) is 0.000 which is smaller than the alpha, thus the null hypothesis is rejected and it is concluded that the effect sizes of this factor are significantly large.

(2) Subscript *j* (Factor B) then consider testing

H_0: $\beta_j = 0$ for all *j*

H_1: $\beta_j \neq 0$ for some *j*

$\alpha = 0.05$

In Figure 5.19, the p-value for term *Current* (B) is 0.006 which is smaller than the alpha, thus the null hypothesis is rejected and it is concluded that the levels of the corresponding factor are significantly different.

(3) Subscript *k* (Factor C) then consider testing

H_0: $\gamma_k = 0$ for all *k*

H_1: $\gamma_k \neq 0$ for some *k*

$\alpha = 0.05$

In the result of ANOVA in Minitab, the p-value for term *Welding Time* (C) is 0.404 which is higher than the alpha, thus the null hypothesis is accepted and it is concluded that this factor has no significant effect on the number of out-of-9-9.7 s.

In addition to Analysis of Variance, Minitab provides Estimated Effects and Coefficients for the response variable which uses t-statistic. It can be seen that the p-values resulted are the same as the p-values in F-statistic of ANOVA. The coefficients of the significant terms will be included in the model.

Factorial Fit: Number of OU versus Distance Ele, Current, Welding Time

Estimated Effects and Coefficients for Number of OUT-OF 9.0 - 9.7 s (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		3.708	0.4370	8.49	0.000
Distance Electrode-Jig	4.583	2.292	0.4370	5.24	0.000
Current	-2.750	-1.375	0.4370	-3.15	0.006
Welding Time	-0.750	-0.375	0.4370	-0.86	0.404
Distance Electrode-Jig*Current	-0.917	-0.458	0.4370	-1.05	0.310
Distance Electrode-Jig*Welding Time	-1.917	-0.958	0.4370	-2.19	0.043
Current*Welding Time	-0.250	-0.125	0.4370	-0.29	0.779
Distance Electrode-Jig*Current* Welding Time	1.250	0.625	0.4370	1.43	0.172

S = 2.14087 PRESS = 165
R-Sq = 74.27% R-Sq(pred) = 42.10% R-Sq(adj) = 63.01%

Figure 5.20 Estimated Effects and Coefficients for Response Variable

The model includes the significant terms. Since interaction AC is significant, the main effect C need to be included in the model. Thus, the model for the 2^3 factorial design in terms of the coded values can be written as

$$Y = 3.708 + 2.292A - 1.375B - 0.375C - 0.958\,AC$$

5.2.4 Residual Analysis

Obs	StdOrder	Number of OUT-OF 9.0 - 9.7 s	Fit	SE Fit	Residual	St Resid
1	19	1.0000	0.6667	1.2360	0.3333	0.19
2	9	3.0000	1.0000	1.2360	2.0000	1.14
3	3	1.0000	0.6667	1.2360	0.3333	0.19
4	12	4.0000	5.0000	1.2360	-1.0000	-0.57
5	4	5.0000	5.0000	1.2360	0.0000	0.00
6	13	4.0000	3.6667	1.2360	0.3333	0.19
7	14	3.0000	6.0000	1.2360	-3.0000	-1.72
8	22	5.0000	6.0000	1.2360	-1.0000	-0.57
9	23	0.0000	0.3333	1.2360	-0.3333	-0.19
10	1	0.0000	1.0000	1.2360	-1.0000	-0.57
11	5	5.0000	3.6667	1.2360	1.3333	0.76
12	10	9.0000	9.6667	1.2360	-0.6667	-0.38
13	8	1.0000	3.3333	1.2360	-2.3333	-1.33
14	6	10.0000	6.0000	1.2360	4.0000	2.29R
15	18	10.0000	9.6667	1.2360	0.3333	0.19
16	15	1.0000	0.3333	1.2360	0.6667	0.38
17	16	1.0000	3.3333	1.2360	-2.3333	-1.33
18	7	0.0000	0.3333	1.2360	-0.3333	-0.19
19	2	10.0000	9.6667	1.2360	0.3333	0.19
20	11	0.0000	0.6667	1.2360	-0.6667	-0.38
21	21	2.0000	3.6667	1.2360	-1.6667	-0.95
22	20	6.0000	5.0000	1.2360	1.0000	0.57
23	24	8.0000	3.3333	1.2360	4.6667	2.67R
24	17	0.0000	1.0000	1.2360	-1.0000	-0.57

R denotes an observation with a large standardized residual.

Figure 5.21 Residuals

Residual plots must be examined to determine whether the model is adequate and the assumptions of regression have been met. If the model is correct and if the assumptions are satisfied, the residuals should be structureless. They should be unrelated to any other variable including the predicted response variable.

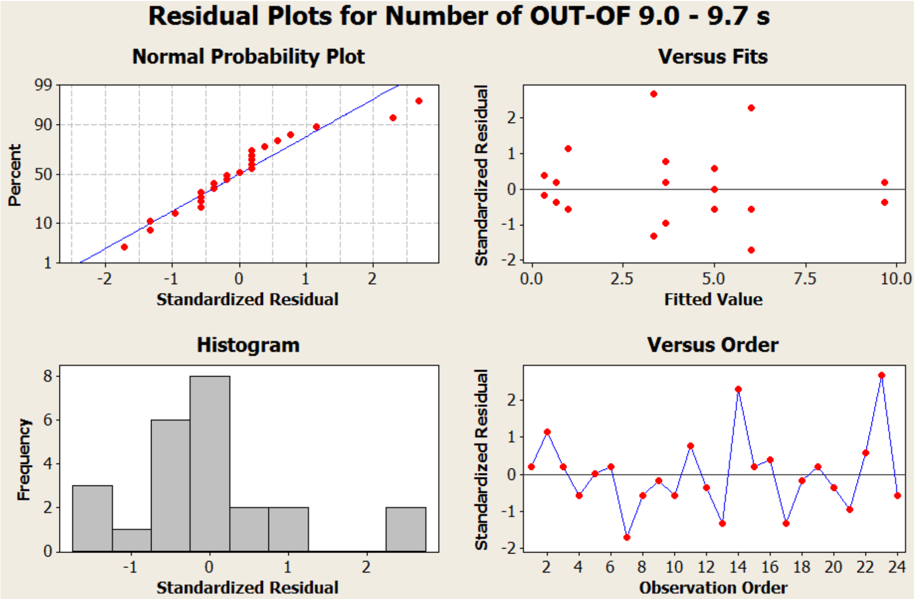


Figure 5.22 Residual Plots

5.2.4.1 Normality Assumption

The first assumption is that the residuals are normally distributed. This can be checked in the normal probability plot in residual plots. If the points are placed along the straight line, the residuals are normally distributed. Another test to check its normality is Kosmogorov-Smirnov normality test.

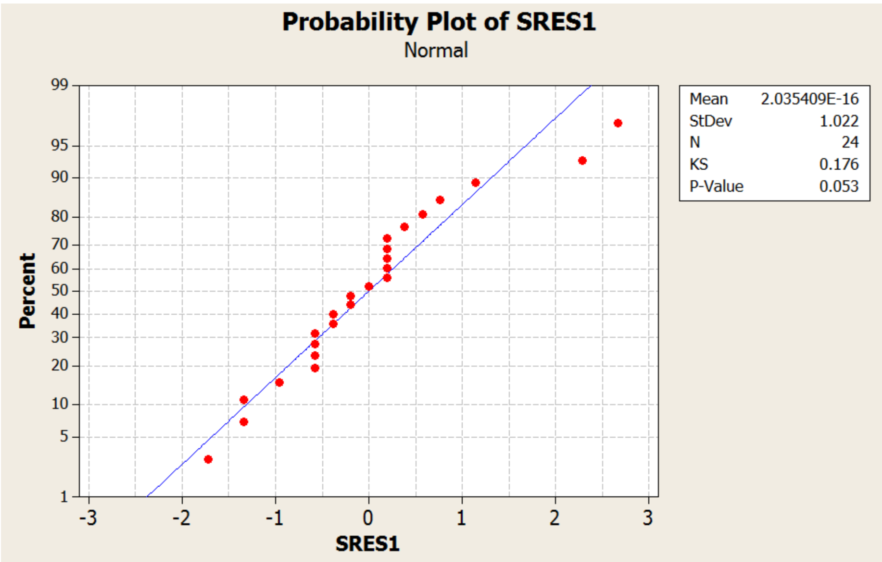


Figure 5.23 Kosmogorov-Smirnov Normality Test for Residuals

H_0 : the residual is normally distributed

H_1 : the residual is not normally distributed

$\alpha = 0.05$

In figure 5.22, the p-value is 0.053 which is higher than the level of significance. Thus, the null hypothesis is accepted and the conclusion is that the residual has normal distribution. As conclusion, the assumption of normality is successfully met.

5.2.4.2 Constant Variance Assumption

The second assumption is that the residuals have constant variance or identical. This can be checked with *Residual Versus Fits* plot. If the plot shows no certain pattern, it can be concluded that the residuals have equal variance.

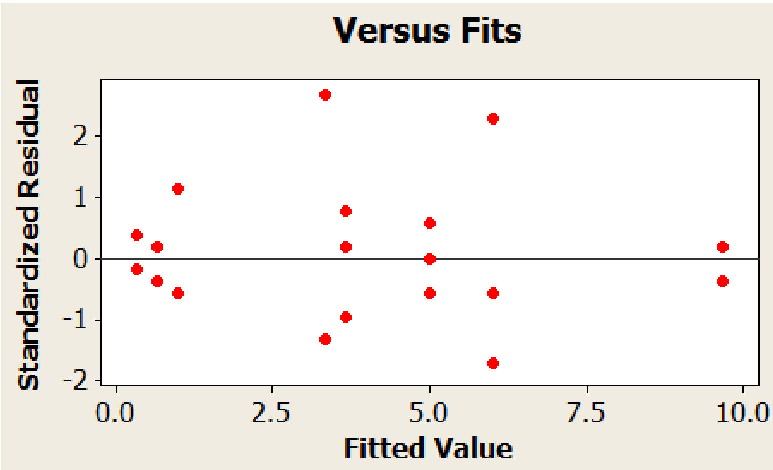


Figure 5.24 *Residual Versus Fits* plot

Another test for checking this assumption is Runs test.

Runs Test: SRES1

```
Runs test for SRES1

Runs above and below K = 2.035409E-16

The observed number of runs = 12
The expected number of runs = 12.9167
11 observations above K, 13 below
P-value = 0.700
```

Figure 5.25 Runs Test

Since the p-value is higher than the alpha level of 0.05, it is concluded that the data are in random order.

5.2.4.3 Independence Assumption

Last but not least, the assumption is that the residuals are independent to each other. This can be checked with *Residuals Versus Order* plot. If there is no pattern shown by this plot, it can be concluded that the residuals are independent.

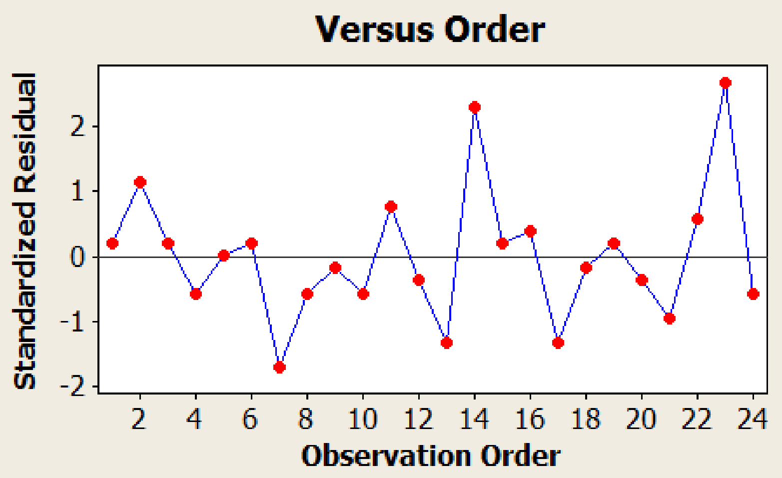


Figure 5.26 *Residual Versus Order* plot

Another test is Autocorrelation Function. If the lags are within the margin error, it means that the residuals are not correlated with each other or in other words, they are independent to each other. As the result is shown in figure 5.26, it can be concluded that the assumption of independence is met.

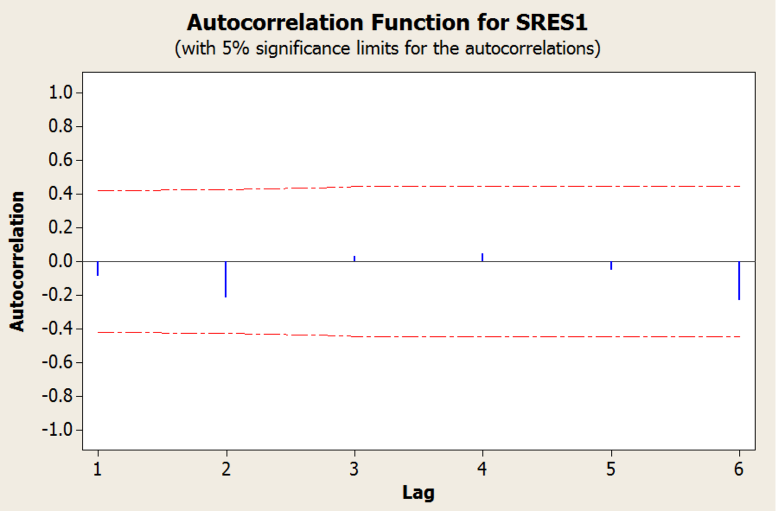


Figure 5.27 Autocorrelation Function for Residuals

Since all of the assumptions for the residuals have been met, the model adequacy is successfully checked.

5.2.5 New Range of Distance B

In the factorial plots, it is noticeable that the best combination of levels of parameters that can produce the smallest number of out-of-9-9.7 seconds is 3.15 cm of distance between lower electrode and jig table, 16 Ampere of current and 17 s of welding time. Thus, a new range of distance B is taken from the results of this combination and proposed to reduce the number of out-of-9-9.7. The proposed new range is 27.4 – 28.6 mm. Further detail can be viewed in Appendix 1.

CHAPTER VI
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

After conducting the data collections, calculations and analysis, there are several conclusions that can be drawn to meet the objectives of the research. The conclusions are listed as follows:

1. Full factorial design can be one appropriate and effective solution to determining the significant factors and best combination of levels of parameters.
2. Among the 8 terms that are included in the analysis of full factorial design, terms *Distance Electrode-Jig* (A), *Current* (B) and the *Distance Electrode-Jig* (A)**Welding Time* (C) have significant effects on number of out-of-9-9.7 s or Auto Adjustment's range of tripping time.
3. The best combination of levels of the three parameters to reduce the number that are out of Auto Adjustment range is 3.15 cm of distance between lower electrode and jig table, 16 Ampere of current and 17 s of welding time.
4. The model for the 2^3 factorial design in terms of the coded values is $Y = 3.708 + 2.292A - 1.375B - 0.375C - 0.958\,AC$
5. The residuals of the Analysis of Variance meet the assumptions of Normality, Constant Variance and Independence through Kosmogorov-Smirnov Normality Test, Runs Test for random order and Autocorrelation Function. Thus, the model fitting is proved to be adequate.
6. The proposed new range of distance B based on the results of the best combination of levels of parameters in the factorial design is 27.4 – 28.6 mm.

6.2 Recommendation

Due to the limitation of scopes and assumptions in this research, some recommendations are then provided for further research. Hopefully, these recommendations can be beneficial as additional considerations for further research to result in more accurate data and analysis as well as contribute more improvements.

1. In further research and experiment, other factors that might affect the result of welding S1 must also be considered such as the distance between upper and lower electrode, the areas of the surfaces of the electrodes, the surface of the jig and etc.
2. In order to successfully collect stable data, the position of jig table must also be maintained well. Moreover, a more precise ruler is necessary to measure the distance between the lower electrode and jig table.

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APPENDIX 1

Distance	Current	Welding Time
3.15	14	15
2	1	27.9
	2	27.7
	3	27.7
	4	27.7
	5	27.6
	6	27.8
	7	27.7
	8	27.7
	9	27.5
	10	27.7
	11	27.5
	12	28.1
10	1	27.6
	2	27.6
	3	27.7
	4	27.7
	5	27.6
	6	28.2
	7	27.4
	8	27.5
	9	27.7
	10	27.1
	11	27.9
	12	27.6
24	1	27.3
	2	27.4
	3	27.5
	4	27.4
	5	27.3
	6	27.1
	7	27.4
	8	27.4
	9	27.4
	10	27.4
	11	27.5
	12	27.2
	Min	27.1
	Max	28.2
	Range	1.1
	Std Dev	0.242392179

Distance	Current	Welding Time
3.15	14	17
6	1	27.7
	2	28
	3	27.7
	4	27.8
	5	27.5
	6	27.8
	7	27.5
	8	27.6
	9	27.6
	10	27.3
	11	27.4
	12	27.5
11	1	27.7
	2	28.1
	3	27.6
	4	27.6
	5	27.6
	6	27.4
	7	27.5
	8	27.6
	9	27.6
	10	27.4
	11	28.2
	12	27.8
21	1	27.3
	2	27.1
	3	27.2
	4	27.2
	5	27.4
	6	27
	7	27.3
	8	27.5
	9	27.4
	10	27.3
	11	27
	12	27.5
	Min	27
	Max	28.2
	Range	1.2
	Std Dev	0.272364718

Distance	Current	Welding Time
3.15	16	15
1	1	27.7
	2	28.1
	3	28
	4	28.2
	5	28.4
	6	28.2
	7	28.2
	8	27.6
	9	28
	10	27.8
	11	27.6
	12	28.1
3	1	27.7
	2	28.1
	3	27.7
	4	28
	5	28.2
	6	27.8
	7	27.5
	8	27.6
	9	27.8
	10	27.6
	11	27.8
	12	28
20	1	28.3
	2	27.8
	3	28
	4	28.2
	5	28.2
	6	27.8
	7	28.1
	8	28.2
	9	28
	10	28.1
	11	27.5
	12	28.2
	Min	27.5
	Max	28.4
	Range	0.9
	Std Dev	0.248982055

Distance	Current	Welding Time
3.15	16	17
9	1	27.6
	2	27.6
	3	27.9
	4	27.7
	5	27.7
	6	27.5
	7	27.6
	8	27.9
	9	27.4
	10	27.9
	11	27.6
	12	27.8
16	1	27.9
	2	28
	3	28.1
	4	27.8
	5	28
	6	27.6
	7	28.1
	8	27.8
	9	28
	10	28.2
	11	27.7
	12	28.1
18	1	28.6
	2	28.4
	3	28.5
	4	28.1
	5	28.4
	6	27.9
	7	28.3
	8	28.1
	9	28.5
	10	28.5
	11	28.4
	12	28.2
	Min	27.4
	Max	28.6
	Range	1.2
	Std Dev	0.322932987

Distance	Current	Welding Time
3.2	14	15
12	1	26.6
	2	26.6
	3	26.7
	4	26.4
	5	26.5
	6	26.7
	7	26.5
	8	26.9
	9	26.6
	10	26.5
	11	26.4
	12	26.6
15	1	26.6
	2	26.5
	3	26.5
	4	26.7
	5	26.6
	6	26.5
	7	26.4
	8	26.7
	9	26.7
	10	26.5
	11	26.7
	12	26.4
19	1	26.7
	2	26.8
	3	26.7
	4	26.6
	5	26.6
	6	26.9
	7	26.5
	8	26.5
	9	26.5
	10	26.6
	11	26.6
	12	26.4
	Min	26.4
	Max	26.9
	Range	0.5
	Std Dev	0.130444904

Distance	Current	Welding Time
3.2	14	17
7	1	27.1
	2	27.3
	3	27.2
	4	27.1
	5	27.2
	6	27.4
	7	26.8
	8	27
	9	27
	10	27.1
	11	27.1
	12	26.8
8	1	27
	2	27.1
	3	27
	4	27
	5	27
	6	26.9
	7	27.1
	8	26.9
	9	26.6
	10	27
	11	27
	12	27.1
14	1	26.6
	2	26.7
	3	26.4
	4	26.6
	5	26.7
	6	26.8
	7	26.6
	8	26.7
	9	26.5
	10	26.7
	11	26.7
	12	26.7
	Min	26.4
	Max	27.4
	Range	1
	Std Dev	0.238430716

Distance	Current	Welding Time
3.2	16	15
4	1	26.9
	2	27
	3	26.8
	4	26.4
	5	26.5
	6	26.7
	7	26.8
	8	26.9
	9	26.7
	10	26.7
	11	26.4
	12	26.4
5	1	26.7
	2	26.7
	3	26.6
	4	26.5
	5	26.7
	6	27
	7	27
	8	26.8
	9	27.1
	10	26.9
	11	26.7
	12	26.7
22	1	27.2
	2	26.8
	3	26.8
	4	26.9
	5	26.6
	6	26.6
	7	26.8
	8	26.5
	9	26.9
	10	26.4
	11	26.6
	12	26.5
	Min	26.4
	Max	27.2
	Range	0.8
	Std Dev	0.205093862

Distance	Current	Welding Time
3.2	16	17
13	1	27.5
	2	27.3
	3	27
	4	27.2
	5	27.2
	6	27
	7	27
	8	27
	9	27.3
	10	27
	11	27.4
	12	27
17	1	26.9
	2	27
	3	27
	4	27.2
	5	26.9
	6	27
	7	27
	8	27.2
	9	26.7
	10	27.1
	11	26.9
	12	27
23	1	26.6
	2	26.7
	3	26.8
	4	26.5
	5	26.7
	6	26.7
	7	26.4
	8	26.6
	9	26.5
	10	26.6
	11	27
	12	26.5
	Min	26.4
	Max	27.5
	Range	1.1
	Std Dev	0.272146086

APPENDIX 2

Distance	Current	Welding Time
3.15	14	15
2	1	9.7
	2	9.8
	3	9.7
	4	9.7
	5	9.8
	6	9.6
	7	9.7
	8	9.7
	9	9.6
	10	9.8
	11	9.6
	12	9.7
10	1	9.7
	2	9.1
	3	9.4
	4	9.5
	5	9.6
	6	9.7
	7	9.3
	8	9.4
	9	9.6
	10	9.4
	11	9.6
	12	9.6
24	1	9.6
	2	9.4
	3	9.6
	4	9.3
	5	9.4
	6	9
	7	9.4
	8	9.4
	9	9.7
	10	9.3
	11	9.6
	12	9.4
	Min	9
	Max	9.8
	Range	0.8
	Std Dev	0.191651138

Distance	Current	Welding Time
3.15	14	17
6	1	10
	2	9.7
	3	9.7
	4	9.8
	5	9.7
	6	9.7
	7	9.6
	8	9.7
	9	10
	10	9.7
	11	9.8
	12	9.7
11	1	9.8
	2	9.7
	3	9.5
	4	9.8
	5	9.7
	6	9.5
	7	9.6
	8	9.8
	9	9.7
	10	9.5
	11	9.8
	12	9.9
21	1	9.5
	2	9.2
	3	9.7
	4	9.8
	5	9.4
	6	8.5
	7	9.5
	8	9.4
	9	9
	10	9.5
	11	9.4
	12	9.5
	Min	8.5
	Max	10
	Range	1.5
	Std Dev	0.278715876

Distance	Current	Welding Time
3.15	16	15
1	1	9.6
	2	9.7
	3	9.1
	4	9.5
	5	9.6
	6	9.5
	7	9.3
	8	9.5
	9	9.9
	10	9.6
	11	9.4
	12	9.5
3	1	9.6
	2	9.7
	3	9.3
	4	9.8
	5	9.6
	6	9.5
	7	9.5
	8	9.6
	9	9.5
	10	9.4
	11	9.5
	12	9.5
20	1	9.6
	2	9.5
	3	9.4
	4	9.5
	5	9.7
	6	9.4
	7	9.1
	8	9.5
	9	9.4
	10	9.4
	11	9.3
	12	9.6
	Min	9.1
	Max	9.9
	Range	0.8
	Std Dev	0.164726806

Distance	Current	Welding Time
3.15	16	17
9	1	9.3
	2	9.2
	3	9.6
	4	9.6
	5	9.5
	6	9.3
	7	9.3
	8	9.5
	9	9.2
	10	9.4
	11	9.3
	12	9.5
16	1	11.1
	2	9.3
	3	9.4
	4	9.5
	5	9.5
	6	9.5
	7	9.2
	8	9.4
	9	9.5
	10	9.5
	11	9.4
	12	9.5
18	1	9.6
	2	9.6
	3	9.3
	4	9.4
	5	9.6
	6	9.6
	7	9.3
	8	9.6
	9	9.6
	10	9.1
	11	9.4
	12	9.5
	Min	9.1
	Max	11.1
	Range	2
	Std Dev	0.311104025

Distance	Current	Welding Time
3.2	14	15
12	1	8.2
	2	8.8
	3	8.8
	4	6.7
	5	9.2
	6	8.1
	7	9.1
	8	8.3
	9	8.9
	10	7.8
	11	7.7
	12	9.1
15	1	8.8
	2	7.8
	3	9.4
	4	8
	5	8.4
	6	7.1
	7	8.3
	8	8.7
	9	8.9
	10	9.1
	11	8.7
	12	8.1
19	1	9
	2	8.9
	3	8.8
	4	8.8
	5	7.8
	6	8.8
	7	8.8
	8	9
	9	8.9
	10	6.9
	11	8.9
	12	7.8
	Min	6.7
	Max	9.4
	Range	2.7
	Std Dev	0.663946833

Distance	Current	Welding Time
3.2	14	17
7	1	9.7
	2	9.7
	3	9.8
	4	9.5
	5	9.9
	6	9.7
	7	9.6
	8	9.6
	9	10
	10	9.5
	11	9.5
	12	9.6
8	1	9.8
	2	9.7
	3	9.6
	4	9.6
	5	9.6
	6	7.6
	7	9.7
	8	9.5
	9	9.8
	10	9.8
	11	9.7
	12	9.9
14	1	8.8
	2	8
	3	8
	4	8.7
	5	8.2
	6	8.7
	7	9.1
	8	9.3
	9	8.2
	10	7.2
	11	7.7
	12	7.2
	Min	7.2
	Max	10
	Range	2.8
	Std Dev	0.831001499

Distance	Current	Welding Time
3.2	16	15
4	1	8.9
	2	9.2
	3	9
	4	9.1
	5	9.1
	6	9.2
	7	9.1
	8	9.3
	9	9.3
	10	8.6
	11	8.7
	12	7
5	1	8.7
	2	8.6
	3	9.2
	4	8.7
	5	8.8
	6	8.8
	7	9.2
	8	9.2
	9	9.6
	10	9.1
	11	9.3
	12	9.3
22	1	9
	2	7.7
	3	7.8
	4	9.1
	5	9
	6	8.9
	7	8.9
	8	9.2
	9	9
	10	8.2
	11	9
	12	7.9
	Min	7
	Max	9.6
	Range	2.6
	Std Dev	0.532104239

Distance	Current	Welding Time
3.2	16	17
13	1	9.6
	2	9.4
	3	9.1
	4	9.4
	5	9
	6	8.9
	7	9.2
	8	9.2
	9	9.4
	10	9.4
	11	9.6
	12	9.4
17	1	9.4
	2	9.5
	3	9.5
	4	9.5
	5	9.1
	6	9.6
	7	9.2
	8	9.2
	9	8.8
	10	9.1
	11	9.3
	12	9.4
23	1	8.5
	2	8.5
	3	9.6
	4	8.9
	5	8.9
	6	8.5
	7	9.3
	8	8.8
	9	8.3
	10	9.3
	11	9.4
	12	7.9
	Min	7.9
	Max	9.6
	Range	1.7
	Std Dev	0.405938067

APPENDIX 3

Factorial Fit: Number of OU versus Distance Ele, Current, Welding Time

Estimated Effects and Coefficients for Number of OUT-OF 9.0 - 9.7 s (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		3.708	0.4370	8.49	0.000
Distance Electrode-Jig	4.583	2.292	0.4370	5.24	0.000
Current	-2.750	-1.375	0.4370	-3.15	0.006
Welding Time	-0.750	-0.375	0.4370	-0.86	0.404
Distance Electrode-Jig*Current	-0.917	-0.458	0.4370	-1.05	0.310
Distance Electrode-Jig*Welding Time	-1.917	-0.958	0.4370	-2.19	0.043
Current*Welding Time	-0.250	-0.125	0.4370	-0.29	0.779
Distance Electrode-Jig*Current* Welding Time	1.250	0.625	0.4370	1.43	0.172

S = 2.14087   PRESS = 165
R-Sq = 74.27%   R-Sq(pred) = 42.10%   R-Sq(adj) = 63.01%

Analysis of Variance for Number of OUT-OF 9.0 - 9.7 s (coded units)

Source	DF	Seq SS	Adj SS	Adj MS
Main Effects	3	174.792	174.792	58.264
Distance Electrode-Jig	1	126.042	126.042	126.042
Current	1	45.375	45.375	45.375
Welding Time	1	3.375	3.375	3.375
2-Way Interactions	3	27.458	27.458	9.153
Distance Electrode-Jig*Current	1	5.042	5.042	5.042
Distance Electrode-Jig*Welding Time	1	22.042	22.042	22.042
Current*Welding Time	1	0.375	0.375	0.375
3-Way Interactions	1	9.375	9.375	9.375
Distance Electrode-Jig*Current*Welding Time	1	9.375	9.375	9.375
Residual Error	16	73.333	73.333	4.583
Pure Error	16	73.333	73.333	4.583
Total	23	284.958		

Source	F	P
Main Effects	12.71	0.000
Distance Electrode-Jig	27.50	0.000
Current	9.90	0.006
Welding Time	0.74	0.404
2-Way Interactions	2.00	0.155
Distance Electrode-Jig*Current	1.10	0.310
Distance Electrode-Jig*Welding Time	4.81	0.043
Current*Welding Time	0.08	0.779
3-Way Interactions	2.05	0.172
Distance Electrode-Jig*Current*Welding Time	2.05	0.172
Residual Error		
Pure Error		
Total		

Obs	StdOrder	Number of OUT-OF 9.0 - 9.7 s	Fit	SE Fit	Residual	St Resid
1	19	1.0000	0.6667	1.2360	0.3333	0.19
2	9	3.0000	1.0000	1.2360	2.0000	1.14
3	3	1.0000	0.6667	1.2360	0.3333	0.19
4	12	4.0000	5.0000	1.2360	-1.0000	-0.57
5	4	5.0000	5.0000	1.2360	0.0000	0.00
6	13	4.0000	3.6667	1.2360	0.3333	0.19
7	14	3.0000	6.0000	1.2360	-3.0000	-1.72
8	22	5.0000	6.0000	1.2360	-1.0000	-0.57
9	23	0.0000	0.3333	1.2360	-0.3333	-0.19
10	1	0.0000	1.0000	1.2360	-1.0000	-0.57
11	5	5.0000	3.6667	1.2360	1.3333	0.76

12	10	9.0000	9.6667	1.2360	-0.6667	-0.38
13	8	1.0000	3.3333	1.2360	-2.3333	-1.33
14	6	10.0000	6.0000	1.2360	4.0000	2.29R
15	18	10.0000	9.6667	1.2360	0.3333	0.19
16	15	1.0000	0.3333	1.2360	0.6667	0.38
17	16	1.0000	3.3333	1.2360	-2.3333	-1.33
18	7	0.0000	0.3333	1.2360	-0.3333	-0.19
19	2	10.0000	9.6667	1.2360	0.3333	0.19
20	11	0.0000	0.6667	1.2360	-0.6667	-0.38
21	21	2.0000	3.6667	1.2360	-1.6667	-0.95
22	20	6.0000	5.0000	1.2360	1.0000	0.57
23	24	8.0000	3.3333	1.2360	4.6667	2.67R
24	17	0.0000	1.0000	1.2360	-1.0000	-0.57

R denotes an observation with a large standardized residual.

Estimated Coefficients for Number of OUT-OF 9.0 - 9.7 s using data in uncoded units

Term	Coef
Constant	-22161.2
Distance Electrode-Jig	6980.00
Current	1328.83
Welding Time	1313.83
Distance Electrode-Jig*Current	-418.333
Distance Electrode-Jig*Welding Time	-413.333
Current*Welding Time	-79.5000
Distance Electrode-Jig*Current* Welding Time	25.0000

Least Squares Means for Number of OUT-OF 9.0 - 9.7 s

	Mean	SE Mean
Distance Electrode-Jig		
3.150	1.4167	0.6180
3.200	6.0000	0.6180
Current		
14	5.0833	0.6180
16	2.3333	0.6180
Welding Time		
15	4.0833	0.6180
17	3.3333	0.6180
Distance Electrode-Jig*Current		
3.150 14	2.3333	0.8740
3.200 14	7.8333	0.8740
3.150 16	0.5000	0.8740
3.200 16	4.1667	0.8740
Distance Electrode-Jig*Welding Time		
3.150 15	0.8333	0.8740
3.200 15	7.3333	0.8740
3.150 17	2.0000	0.8740
3.200 17	4.6667	0.8740
Current*Welding Time		
14 15	5.3333	0.8740
16 15	2.8333	0.8740
14 17	4.8333	0.8740
16 17	1.8333	0.8740
Distance Electrode-Jig*Current*Welding Time		
3.150 14 15	1.0000	1.2360
3.200 14 15	9.6667	1.2360
3.150 16 15	0.6667	1.2360
3.200 16 15	5.0000	1.2360
3.150 14 17	3.6667	1.2360
3.200 14 17	6.0000	1.2360
3.150 16 17	0.3333	1.2360
3.200 16 17	3.3333	1.2360