PRODUCTIVITY IMPROVEMENT FOR FURNITURE INDUSTRY BY USING WITNESS SIMULATION SOFTWARE

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PRODUCTIVITY IMPROVEMENT FOR FURNITURE INDUSTRY BY USING WITNESS SIMULATION SOFTWARE

TEE CHUN TECK

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for the award of the degree of
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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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DEDICATION

Specially dedicated to

my beloved family, and those who have guided and inspired me

throughout my journey of learning.

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First of all, I would like to express my sincere gratitude to my supervisor, Mr. Hadi Bin Abdul Salaam for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his passion towards his job and his tolerance of my naïve mistakes. I would also like to thank him for the time spent proofreading and correcting my many mistakes.

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ABSTRACT

A furniture industry typically involves a number of stages, including receiving raw materials, cutting, sanding, laminating, shaping, drilling, brushing, assembly, and finishing. The longer of process cycle time, the frequent of machine downtime, and the poor layout of the factory have added to the complexity and challenges of furniture industry. With respect to the project title, Productivity Improvement for Furniture Industry by using WITNESS Simulation Software, Lein Hua Furniture Industry Sdn. Bhd. (LHF) has been selected to be improved. The objective for LHF has always been to achieve better productivity, reduce the processing time, minimize the machine downtime, and meet regulatory requirements. This study focuses on applying simulation method to improve the operations in the LHF industry. Therefore, the project objectives can be briefly explained as to design and improve the floor layout of LHF, analyze the designed layout and select the best solution. The project is started by evaluating and identifying the problems existed in the industry, continued by data collection for the data analysis and proceeds to applying simulation modelling step. Meantime, there are three alternatives for improving productivity are suggested and the best of it to be chosen. By running an experiment on the suggested alternatives to improve the output of chairs, these alternatives are modeled in the WITNESS Simulation software and run for the experimental time of 8 hours. These results are analyzed by Kruskal-Wallis and one way ANOVA test for the best solution selection. The experimented results are then being compared with the Cost-Effectiveness Analysis to determine the most efficient layout that are able to produce high output of chairs with lowest cost. From the findings, the most productivity improvement method is the Alternative 3, which is additional of a Laminating machine and reduction of a Brushing machine, as well as combination of Sanding II and Sanding III process after Drilling process. This approach increases the daily output of chairs from 44 to 46 units and the cost of chair per unit from RM45.53 reduced to RM43.63. Therefore, the objectives of this project have been achieved and the selected alternative will be proposed to the LHF for implementation.

ABSTRAK

Lazimnya sebuah industri perabot memerlukan beberapa peringkat, termasuk penerimaan bahan mentah, pemotongan, pelicinan, pelapisan, pembentukan, pelubangan, pemberusan, pemasangan, dan penyelesaian. Kitaran masa proses yang lama, kebarangkalian kerosakan mesin yang tinggi, serta kelemahan susun atur kilang, sememangnya menyumbang kepada kerumitan dan sebagai cabaran terhadap kilang perabot. Dengan tajuk projek yang berbunyi "Peningkatan penghasilan produk di kilang perabot melalui perisian simulasi WITNESS", *Lein Hua Furniture Industry Sdn. Bhd.* (LHF) telah dipilih untuk ditingkatkan penghasilan produknya. Objektif LHF selama ini adalah untuk mencapai penghasilan produk yang baik, mengurangkan masa pemprosesan, mengurangkan kekerapan kerosakan mesin, serta menepati syarat keperluan. Tesis ini menfokus kepada pengaplikasi kaedah simulasi untuk menambahbaik operasi-operasi di industri LHF. Oleh demikian, objektif projek boleh diringkas seperti mana untuk reka dan menambahbaik susun atur kilang LHF, analisis terhadap susun atur yang direka serta memilih antara yang terbaik. Projek ini dimula dengan penelitian dan penentuan masalah yang terdapat di industri, kemudian mengambil data untuk analisis serta diteruskan dengan mengaplikasi kaedah simulasi. Pada masa yang sama, tiga alternatif disaran dan antara yang terbaik akan dipilih. Dengan menjalankan ujian terhadap alternatif yang bertujuan untuk meningkat jumlah kerusi dihasil, kesemua model alternatif akan diuji dengan perisian simulasi WITNESS untuk 8 jam simulasi. Keputusan yang diperoleh akan dianalisis dengan *Kruskal-Wallis* dan ujian *one way ANOVA* untuk pilihan alternatif terbaik. Keputusan eksperimen inin kemudian dibanding dengan *Cost-Effectiveness Analysis* untuk menentukan tapak susun atur yang paling efisien dan mampu menghasilkan jumlah kerusi yang tinggi malah dengan kos terendah. Dari penemuan, kaedah yang paling berkesan dalam peningkatan produktiviti merupakan kaedah ketiga dimana ia adalah penambahan satu mesin pelapisan dengan pengurangan satu mesin pemberusan, serta penggabungan proses pelicinan II dan pelicinan III selepas proses pelubangan. Kaedah ini meningkat penghasilan kerusi harian dari 44 kepada 46 serta kos satu kerusi dari RM45.53 menjadi RM43.63. Justeru, tujuan projek ini telah dicapai dan alternatif yang dipilih akan dicadangkan kepada LHF untuk pelaksanaannya.

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LIST OF SYMBOLS

$\bar{X}$, μ	Mean
s, σ	Standard deviation
α	Significant level
∑	Sum or total value
≈	Approximately equals to

LIST OF ABBREVIATIONS

LHF	Lein Hua Furniture Industry Sdn. Bhd.
MTIB	Malaysian Timber Industry
MIER	Malaysian Institute of Economic Research
ANOVA	Analysis of Variance
FYP	Final Year Project
CEA	Cost-Effectiveness Analysis
WIP	Work In Progress
RM	Ringgit Malaysia

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

In today competitive market, the survival of any industry is greatly depends on response time, production costs and flexibility in manufacturing (Chase et al. 2001). For almost all manufacturing industry, an increased productivity and better overall efficiency of the production line are the most important goals. Most industries would like to find the recipe for the ultimate productivity improvement strategy. However, those same industries that are searching for this holy grail are likely to have found themselves unable to take full advantage of the methodologies and techniques so far tried. Part of this is because many of them simply do not understand what productivity really means. (Baines A., 1997).

In order to overcome the lower productivity problem, a thorough understanding and research of the process in the existing company is necessary so that an efficient improvement can be generated to increase the productivity in the researched company. In fact, there is a good number of management techniques such as zero inventory (ZI), just-in-time (JIT), flexible manufacturing system (FMS), optimized production technology (OPT) and total quality management (TQM) that support the implementation of productivity improvement plans. (McTavish R. et al. 1996). However, there is another method which is the most welcoming among these methods – productivity improvement via simulation method.

Simulation is a process of building a model that mimics reality. It provides a greater understanding of the company layout or system being studied. In a manufacturing industry, simulation is a concept of creating the existing production floor using simulation software. The reason of creating the existing production floor is to analyze and evaluate the existing production floor performance which in turn, leads to cost and time reduction, increment of revenue as well as production productivity.

This chapter provides an overview of the case study titled “Productivity Improvement for Furniture Industry by using WITNESS Simulation Software”. Generally, problem statements will briefly discuss about the problems that furniture industry faced during the production of a product.

In this chapter, an overview of the objectives of this case study and scope of this case study will be reviewed. Basically, the objective of this study is to find an alternative way to increase productivity. This study will be done in one of the furniture industries in Malaysia. In this chapter, the review of the report arrangement will be discussed in general.

1.2 PROBLEM STATEMENTS

In furniture industry, production floor layout involves the arrangement of machines that used to produce a product, the buffer that used in the production floor to store the parts temporarily, and the raw material storage that will be sent to manufacture products. There are several methods available to design, analyze and redesign of production floor layout to improve productivity of a production line.

The furniture industry of Lein Hua Furniture Industry Sdn. Bhd. is selected after some inspection is due to the unsatisfactory of the existing floor layout that causes the low daily production. Therefore, analysis and improvement for the production floor layout will be done in this project in order to enhance the productivity of the industry.

Today, there are plenty of simulation software such as ARENA, Quest, ProModel and WITNESS were developed to allow users to model current existing production floor layout for evaluation. By applying simulation software, the actual problems can be modeled in the software rather than rearranging the actual machine first before evaluation as it might be risky.

This study would illustrate the process flow of the current existing production floor layout to evaluate the current production performance. Designs of a few more alternatives will be proposed to assist the company to improve the productivity maintaining or even reducing the operating cost.

1.3 OBJECTIVES

The objectives of this study are:

1. To identify problems in existing production floor layout.
2. To design and improve manufacturing production floor layout by using simulation software and by observation during the collection data of cycle time as well as machine downtime.
3. To measure manufacturing performance such as production quantity, lead time, bottle neck and by using cost effectiveness analysis.

1.4 PROJECT SCOPES

This study will analyze an industry specific problem of production floor layout in order to increase the productivity and solve it through several alternative production floor layouts.

i. This study is conducted at Lein Hua Furniture Industry Sdn. Bhd. (LHF) which located at Semambu, Kuantan, Pahang.
ii. One production line involved, which is the chair production.
iii. Production floor layout evaluation will be done with WITNESS Simulation Software and results analysis will be done by using Cost-effectiveness Analysis and Minitab Software.
iv. This study evaluates daily output of production and average processing time generated from the simulation experimentation.

1.5 REPORT ARRANGEMENT

This study is divided into seven chapters. In the first chapter, the introduction of the study will be discussed. This chapter will be provided with the problem statements and objectives of the study. An overview of scopes of the study will be discussed. Then, the report arrangement of this project also will be reviewed in this chapter.

For chapter two, the literature review of the study will be discussed. This chapter provides with the introduction to furniture industry in Malaysia. Besides, the definition of productivity will be discussed. The interpretation of simulation and simulation methodology will be reviewed in this chapter. Lastly, the previous researches that related to this study will be included in this chapter.

In chapter three, the introduction of the furniture industry background is to be reviewed. The company profile including organization history of establishment, company logo, company objectives, vision and mission are shown in this chapter. In addition, the company organization chart and its production floor layout are attached for reference. Lastly, the process flow of the chair production line is described in detail.

In chapter four, the flow of methodology will be reviewed. The discussion of the methodology used in conducting this study from the beginning until the study is completed is shown in this chapter. The design of the study and the framework of the study will be reviewed at first. Then, the project flow chart for final year project semester 1 and semester 2 also will be included in this chapter.

In chapter five, a conceptual model is included as to reflect the pre-model of the production floor layout. Then, the performance measure and the decision variables are discussed. It proceeds with the discussion of method used to analyze data. Furthermore, the model description, model assumptions, and model construction are included and explained in details. Lastly, this chapter ends with determining the required number of replications before proceed to ANOVA analysis.

Chapter six, on the other hand, consists of the discussion of the existing layout performance and the proposed alternatives layout results. Three alternatives have been suggested in this chapter in order to improve the low productivity of the existing layout. The results generated from the WITNESS Simulation software is tested using Minitab software. The result analysis is then discussed in general. Lastly, the cost-effectiveness analysis for the existing layout and proposed layouts is determined in this chapter.

In chapter seven, it summarizes the results that obtained in previous chapter. The project summary and project findings are discussed in this chapter. The most efficiency layout among the suggested alternatives will be proposed to the LHF. Further improvement and recommendations for this company is also included in this chapter.

1.6 CONCLUSIONS

As a conclusion, the overview of this project is reviewed. It introduces a brief concept of the project by developing the idea of the problems faced by the furniture industry. The problem statements are identified after selecting the suitable researched company. The objectives and scopes of the project are stated to specify the boundary of the study to avoid any deviation from the title of the project. Lastly, the arrangement of report displayed the summary of each chapter discussed in this project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discussed about literature review of simulation study in improving the productivity of a furniture industry, which is Lein Hua Furniture Industry Sdn. Bhd. (LHF). It began with the introduction to furniture industry and the definition of productivity. The simulation including its areas of application, advantages and disadvantages, and its importance are discussed in general. This followed by the general procedure for simulation methodology. Finally, a total of ten previous researches that are related to this study are included as references.

2.2 INTRODUCTION TO FURNITURE INDUSTRY IN MALAYSIA

The furniture industry in Malaysia plays a key role in the country economy. Since the late of 1970s, the government has considered it as a strategic one and encouraged its development with investment in infrastructures and incentives to export. Therefore, a traditional sector based on small craftsmanship enterprises has gradually transformed into a major industry.

In 2007, there were about 2,965 furniture plants in Malaysia, with 2,630 in Peninsular Malaysia, 120 in Sabah and 215 in Sarawak. It is estimated that 70% were small scale plants such as workshops and backyard factories using low level production technology and catering to domestic markets (MTIB, 2007). The remaining 30% were large and medium sized furniture plants which have penetrated the export markets

(MTIB, 2007). In terms of ownership, it is estimated that more than 75% of the furniture companies are either wholly or majority Malaysia owned (MIER, 2008).

Generally, the Malaysian furniture manufacturers can be categorized into four categories:

i. Small and medium scale industries established and operating in the furniture village.
ii. Small scale industries established and operating outside the furniture village.
iii. Medium and large manufacturing companies – local owned.
iv. Large manufacturing companies – joint venture and foreign owned.

The furniture mills in Peninsular Malaysia are more developed and most of these mills are located on the West Coast (MIER, 2008). The highest number of furniture exporter manufacturing plants are in the state of Johor, followed by Selangor, Perak, and Kedah (MTIB, 2009). In Johor, the highest concentration and most productive manufacturing plants are in Muar, while in Selangor they are in the Klang Valley area. The location of furniture establishments in these states are greatly influenced by proximity to the supply, distance to the export exit points, access to labors, and the availability of good infrastructure, supporting industries, and facilities.

Furniture of both wood and rattan are the stars of the timber sector. Under the concerted efforts of the various development agencies, exports of furniture have increased tremendously nowadays. The United States represents the largest single market for Malaysian furniture, in which in the year of 2007, the United States accounted for 42% of Malaysian furniture exports. The U.S. imports from Malaysia consisted mainly of wooden chairs and miscellaneous wooden furniture, dining tables, and furniture parts.

Japan is the second largest wood furniture importing country after the United States. The European furniture market is the largest in terms of consumption and value in the world. However, the European Union remains a difficult market for Malaysian furniture exporters to penetrate. The United Kingdom and the Netherlands are the two largest markets for Malaysian furniture, too. Other major markets are Singapore and

Taiwan. Currently, most of the furniture is segmented for the medium and lower end market.

Nonetheless, there are factors affecting the export of furniture from a country, which can be divided into domestic and international trade factors. The domestic factors include the supply of raw materials from both domestic log productions and import sources, and the export levy and quota rules. International trade factors, on the other hand, are the currency exchange rates and import price indexes. All in all, the most important factors influencing the success of a furniture mill are the mill's primary characteristics, decision maker's expectation of exporting and global marketing strategy.

2.3 PRODUCTIVITY

Productivity can be defined as the application of the various resources or inputs of an organization, industry or country, in order to achieve certain planned and desired results or outputs. In other words, productivity more broadly means production rate per unit of input, especially per unit of labor, for goods or services (Young and Murray, 2005). It is one of the key factors affecting the overall competitiveness of an organization, in such a way that by improving productivity means improving efficiency.

Productivity improvement can be considered as a process to achieve higher levels of output while consuming same or lesser amounts of input resources. Additionally, if the same output level is reached in a shorter time period, it indicates improved productivity as well. Today's global competition requires increased throughput levels over lesser time horizons.

2.3.1 Productivity Measurement

Productivity can be measured in two ways: single-factor productivity and multifactor productivity. By definition, the use of just one resource input to measure productivity, as shown in Eq. (2.1), is known as single-factor productivity. Multifactor productivity, however, is defined as a broader view of productivity, which includes all inputs, such as labor, material, capital, energy, and miscellaneous. It is also known as total factor productivity and is calculated by combining the inputs units as shown in Eq. (2.2). (Heizer and Render, 2008).

$$Productivity = \frac{Units\ produced}{Inputs\ used} \qquad Eq. 2.1$$

$$Productivity = \frac{Output}{Labor + Material + Energy + Capital + Miscellaneous} \qquad Eq. 2.2$$

The two productivity measurements above help in determining the production performance. However, the results can be expected to vary. This is because if labor productivity growth is entirely the results of capital spending, measuring just labor distorts the results. Therefore, multifactor productivity is usually more suitable to use although it is more complicated. The measure of multifactor productivity provides better information about the trade-offs among factors, but substantial measurement problems remain. According to Heizer and Render (2008), the measurement problems include the change of quality when the quantity of inputs and outputs remains constant, external elements may cause an increase or decrease in productivity for which the system under study may not be directly responsible, and also the precise units of measure may be lacking.

2.4 SIMULATION

Simulation is an important problem-solving methodology for the solution of many real-world problems in the manufacturing industry. A traditional definition of simulation is the act or process of simulating, feigning, the imitative representation of the functioning of one system or process by means of the functioning of another, which the examination of a problem often not subject to direct experimentation by means of a simulating device. However, simulation software designers generally define simulation as imitating the operations of various kinds of real-world facilities or processes, the process of designing a mathematical-logical model of a real system and experimenting with this model on a computer.

According to Holst and Bolmsjo (2001), simulation provides analysis, description and evaluation capabilities of systems, and if successfully applied can support collaborative work across organizational boundaries and thereby improve information and communication. In addition, simulation can significantly improve system knowledge, shorten development lead time and support decision making throughout an organization. The understanding of systems behavior and the parameters that affect performance is vital in design, development and operations of manufacturing systems.

The behavior of a system as it evolves over time can be studied by constructing a simulation model. When the model has been developed, the analyst can manipulate certain variables to measure the effects of changes on the operating characteristics of interests such as waiting lines, resource utilization, machine downtime and such. The simulation model can be used to study alternative solutions of a certain problem, but not to prescribe what should be done on the problem. After alternative solutions have been tried in the simulation model, the best solution will be selected in order to solve the problem.

2.4.1 Areas of Simulation Application

Holst and Bolmsjo (2001), identified three typical application areas in simulation, which are, explorative studies of existing systems to improve them, studies of existing systems with some changes made to them, which is similar to the first purpose but used to validate a specific alternative, and the third is for design and validation of new systems. In practice, simulation projects are often a combination of these three applications. However, to be more specific, simulation is applied in some of the common areas below:

i. Production and manufacturing systems
ii. Inventory management
iii. Waiting lines for complex queuing systems
iv. Service operations. For example, post office, hospital, airport, police station, and other public service systems.

v. Capital investment and budgeting
vi. Environmental and resource analysis

2.4.2 Advantages and Disadvantages of Simulation

Simulation is intuitively appealing to a client because it mimics what happens in a real system or what is perceived for a system that is in the design stage. Thus, simulation is frequently the technique of choice in problem solving. Simulation has many advantages, but some disadvantages (Banks et al., 2010). The advantages of simulation are:

1. Exploration on new policies, operating procedures, decision rules, information flows, organizational procedures, and so on without disrupting the actual or real system.
2. Testing on new hardware designs, physical layouts, transportation systems, and so on without committing resources for their acquisition.
3. Hypotheses about how or why certain phenomena occur can be tested for feasibility.
4. Compress and expand time to allow the user to speed-up or slow-down behavior or phenomena to facilitate in-depth research.
5. Diagnose problems by understanding the interaction among variables that make up complex systems.
6. Bottleneck analysis can be performed to discover where work in process, information, materials, and so on are being delayed excessively.
7. Develop understanding by observing how a system operates rather than predictions about how it will operate.
8. “What if” questions can be answered especially useful in the new system design.

Some disadvantages of simulation include:

1. Model building is an art that is learned over time and through experience. If two models are constructed by different competent individuals, they might have similarities, but it is highly unlikely that they will be the same.

2. Simulation results can be difficult to interpret. Most simulation outputs are essentially random variables, which they are usually based on random inputs, so it can be hard to distinguish whether an observation is the result of system interrelationships or of randomness.
3. Simulation modelling and analysis can be time consuming and expensive. Skimping on resources for modelling and analysis could result in a simulation model or analysis that is not sufficient to the task.
4. Simulation is used in some cases when an analytical solution is possible, or even preferable. This might be particularly true in the simulation of some waiting lines where closed-form queueing models are available.

However, these disadvantages can be offset in order to defend simulation:

1. Simulation software has been developed into packages that contain models that need only input data for their operation. These models have the generic tag "simulator" or "template".
2. Vendors of simulation software have developed output-analysis capabilities within their packages for performing very thorough analyses.
3. The advances in hardware and in many simulation packages making the simulation can be performed faster today.
4. Closed-form models are unable to analyze most of the complex systems that are encountered in practice. During many years of consulting practice by two of the authors, not one problem was encountered that could have been solved by a closed-form solution.

2.4.3 The Importance of Modelling and Simulation

Modelling and simulation is an effective tool for strategic decision-making ranging from product mix to activity scheduling. Systems that are too precarious or too obscure to be studied analytically can be successfully modelled by simulation approaches. Modelling and simulation is very important to manufacturing industry nowadays. In manufacturing systems, activity planning and scheduling require strategic allocation and timing of resources to achieve specific manufacturing goals in an efficient and timely manner. Activity planning, scheduling, and control are the basic elements of managing a manufacturing system.

Currently, there are plenty of manufacturing industries applying modelling and simulation software in order to check their maximum line capacity and meantime trying to increase their output or productivity.

In general, the important of modelling and simulation software to the industrial sector can be summarized as below:

1. Improvement of productivity
2. Operation costs reduced
3. Time saving
4. Problems in production line can be analyzed easily
5. Production line can be upgraded easily
6. Many options can be applied quickly and easily

2.5 SIMULATION METHODOLOGY

According to Banks et al. (2010), there are about 12 steps in a simulation study. The 12 steps are discussed below and summarized as shown in Figure 2.1.

2.5.1 Problem Formulation

Every study should begin with a statement of the problem. If the statement is provided by the policymakers, or those have the problem, the analyst must ensure that the problem being described is clearly understood. If a problem statement is being developed by the analyst, it is important that the policymakers understand and agree with the formulation. Although not shown in Figure 2.1, there are circumstances where the problem must be reformulated as the study progresses. Policymakers and analyst are usually aware that there is a problem long before the nature of the problem is known.

2.5.2 Setting Objectives and Overall Project Plan

Usually, the objectives indicate the questions to be answered by simulation. At this point, a determination should be made concerning whether simulation is the appropriate methodology for the problem as formulated and objectives as stated. Assuming that it is decided that simulation is appropriate, the overall project plan should include a statement of the alternatives. It should also include the plans for the study in terms of the number of people involved, the cost of the study, and the number of days required to accomplish each phase of the work, along with the results expected at the end of each stage.

2.5.3 Model Conceptualization

The art of modeling is enhanced by an ability to abstract the essential features of a problem, to select and modify basic assumptions that characterize the system, and then to enrich and elaborate the model until a useful approximation results. Therefore, it is best to start with a simple model and build toward greater complexity. However, the model complexity need not exceed that required to accomplish the purposes for which the model is intended. Violation of this principle will only add to model-building and computer expenses. It is not necessary to have a one-to-one mapping between the model and the real system, but only the essence of the real system is needed.

2.5.4 Data Collection

In a simulation project, data is usually required to enable user to build the simulation model, to set the initial level of various factors in the model, and also to validate the model once built.

As the complexity of the model changes, the required data elements will also be changed. Besides, since data collection takes a large portion of the total time required to perform a simulation, it is essentially to begin it as early as possible, usually together with the early stages of model building.

2.5.5 Model Translation

A great deal of information storage and computation works to insert as the input for computer is required in order to convert a real-system into a computer-recognizable model. Thus, the term “program” is used though it is possible to accomplish the desired results in many instances with little or no actual coding. The modeler must decide whether to program the model in simulation language, or to use special-purpose simulation software. There are plenty types of simulation software available in the market nowadays. Simulation languages are powerful and flexible. However, if the problem is amenable to solution with the simulation software, the model development time is greatly reduced. Moreover, most of the simulation-software packaged has added features that enhance their flexibility, even though the amount of flexibility varies greatly.

2.5.6 Verification

Verification pertains to the computer program prepared for the simulation model. It is not easy to verify a complex model, if not impossible, to translate a model correctly in its entirely without a good deal of debugging; as the input parameters and logical structures are represented in computer with error free, that indicates the verification has been complete.

2.5.7 Validation

Validation usually is achieved through the calibration of the model, which is an iterative process of comparing the model against actual system behavior and using the discrepancies between the two, and the insights gained, to improve the model. This process is repeated until model accuracy is judged acceptable.

2.5.8 Experimental Design

Prior to all, the alternatives that are to be simulated must be determined. Often, the decision concerning which alternatives to simulate will be a function of runs that have been completed and analyzed. For each system design that is simulated, decisions need to be made concerning the length of the initialization period, the length of simulation runs, and the number of replications to be made of each run.

2.5.9 Production Run and Analysis

Production runs, and their subsequent analysis, are normally used to estimate measure of performance for the system designs that are being simulated.

2.5.10 More Runs?

When given the analysis of runs that have been completed, the analyst needs to determine whether additional runs are needed and what design those additional experiments should follow.

2.5.11 Documentation and Reporting

Generally, there are two types of documentation, which are program and progress. Documentation is important for numerous reasons. If the program is going to be used again by the same or different analysts, it could be necessary to understand how the program operates. This will create confidence in the program, so that model users and policymakers can make decision based on the analyst. Moreover, if the program is to be modified by the same or different analyst, this step can be greatly facilitated by adequate documentation. One experience with an inadequately documented program is usually enough to convince an analyst of the necessity of this important stop. Another reason for documentation a program is so that model and output measures of performance or to discover the input parameters that “optimize” some output measure performance.

Musselman (1998) discusses progress report that provides the important written history of a simulation project. Project reports give a chronology of work done and decision made. This can prove to be of great value in keeping the project on course. Musselman (1998) suggest frequent reports (monthly, at least) so that even those not involved in the day-to-day operation can keep abreast. Furthermore, Musselman (1998) also suggests maintaining a project log providing a comprehensive record of accomplishments, change request, key decisions, and other items of importance.

On the reporting side, Musselman (1998) suggests that frequent deliverable. These may or may not be the results of major accomplishments. Possibilities prior to the final report include a model specification, prototype demonstrations, animations, training results, intermediate analyses, program documentation, progress reports, and presentation.

All the analysis's results should be reported clearly and concisely in final report. This will enable the model user to review the final formulation, the alternative systems that were addressed, the criterion by which the alternatives were compared, the results of the experiments, and the recommended solution to the problem. Furthermore, if decisions have to be justified at a higher level, the final report should provide a vehicle of certification for the model user/decision maker and add to the credibility of the model and of the model-building process.

2.5.12 Implementation

According to Pritsker (1995), the success of the implementation phase is greatly depends on how well the previous 11 steps have been performed. It is also contingent upon how thoroughly the analyst has involved the ultimate model user during the entire simulation process. If the model user has been thoroughly involved during the model-building process and if the model user understands the nature of the model and its outputs, the likelihood of a vigorous implementation is enhanced. However, if the model and its underlying assumptions have not been properly communicated, implementation will probably suffer, regardless of the simulation have not been properly communicated, implementation will probably suffer, regardless of the simulation model's validity. Validation is the most essential step among this whole process, because an invalid model will lead to erroneous results, which, if implemented, negative result such as causing costly, hazardous or both results will obtained.

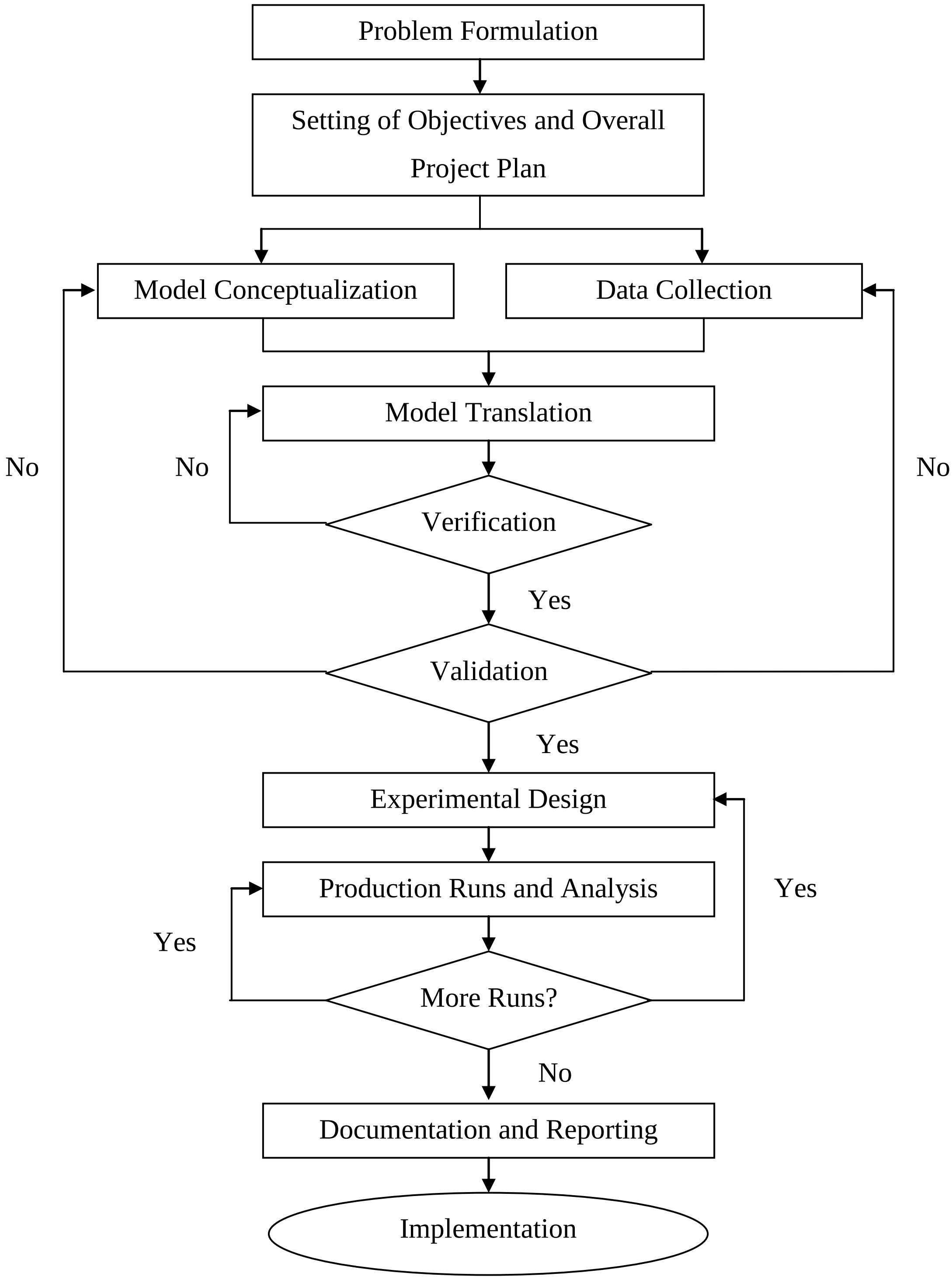

Figure 2.1: Steps in a simulation study (Banks et al., 2010)

2.6 MODEL VERIFICATION

According to Banks et al. (2010), verification is concerned with the building the model right. It is utilized in the comparison of the conceptual model to the computer representation that implements the conception. However, Harrell et al. (2004) describes model verification as the process of determining whether the simulation model correctly reflects the conceptual model. It does not necessarily mean that the model is valid, only that if it runs correctly. In essence, verification is the process of debugging the model. A verified model is a bug-free model.

2.6.1 Verification Techniques

According to Harrell et al. (2004), to ensure that the model has been built correctly and a standard for comparison has been established, few techniques can be used to verify the model.

One of the techniques is conduct model code reviews. Model code review can be performed either by the modeler or people that familiar to both the modeled system and modeling techniques. This technique is mainly to check for errors or inconsistencies. Simulation model can be tested by either a bottom-up or top-down methods. Bottom-up testing method is called unit testing where lowest modules are tested and verified first. Proceed with testing two or more modules until the model can be tested as a single system. For top-down method, on the other hand, the verification begins with the main modules to lower modules. The outputs of modules for top level method are usually same as expected given by the inputs.

In addition, the techniques also include, check the output for reasonableness since the operational relationships and quantitative values are predictable from simulation. For simple models, one way to help determine reasonableness of the output is to replace random times and probabilities into the entities to determine the outcomes in the model. This would allow analyst to predict precisely since the determined results should match the results of simulation.

Another model verification technique can be used is watching the animation, which it can be used to visually verified the simulation model whether it operates the way user think it should. The animation can be adjusted to slow motion and enable the analyst to follow along visually. However, the amount of time required to observe a complete simulation run would be extremely long. If the animation is speed up, the run time will be smaller and causing inconsistencies which led to difficulties in detecting this error. Thus, the user can view the status of machines to see if the variables are correctly being set.

In addition, the use of the trace and debug facilities provided with the software is useful to find out what actually happens during simulation which usually hidden. Most simulation software comes with some sort of trace and debugging facility. Trace messages can be utilized to reveal the hidden information event by event and it can be turn on or off as analyst desire.

A typical trace message might be the time that an entity enters particular location or the time that a specific resource is feed. Debugger is a utility that displays and steps through the actual logic entered by users to define the model. Like trace messaging, debugging can be turned on either interactively or programmatically. This technique will ensure the event occurrences and state variables can be examined and compared with hand calculations to see if the operating program is running as it should.

2.7 MODEL VALIDATION

According to Hoover and Perry (1990), validation is the process of determining whether the model is meaningful and accurate representation of the real system. Harrell et al. (2004), however, defined model validation as the process of determining whether the conceptual model correctly reflects the real system. Since the process of validation can be very time-consuming and ultimately elusive, only functional validity becomes the concern, but not interested in achieving absolute validity.

2.7.1 Validation Techniques

There is no any simple test to determine the validity of model (Harrell et al., 2004). Validation is an inductive process in which it requires the modeler to draw conclusion about the accuracy of the model based on the evidence that available. According to Sargent (2004), there are several techniques on model validation. Some of them tend to be rather subjective, while others lend themselves to statistical tests such as hypothesis tests and confidence intervals. Many of the techniques are the same as those used to verify a model, only now the customer and others who are acknowledgeable about the system need to be involved. As with model verification, it is common to use a combination of techniques when validating a model.

One of the techniques to validate the model is watching the animation by comparing the visual animation with one's knowledge about the real system behaves. This might includes dynamic plots and counters that provide dynamic visual feedback. Other techniques are by comparing with the actual system or other models. Users can run both of the actual and a designed model under similar conditions to observe if the results match. In case that the other valid model have been built of process such as analytic models, spreadsheet models and even other valid simulation models, the output of simulation can be compared to these known results.

Conducting degeneracy and extreme condition tests is known situation for which models model behavior degenerates, causing a particular response variable to grow infinitely large under extremely conditions.

Additionally, user can also check for face validity by asking the acknowledgeable person about the system whether the model behavior appear reasonable. This technique is generally testing for the logical in conceptual model if it is correct and if the model's input-output relationships are reasonable.

Other than that, performing sensitivity analysis by varying the model input is essential to determine the effect on model's behavior and output. It is necessary for the modeler to have an intuitive idea of how to model will react for the changing of input as the direct relationship occurs in the model as in the real system.

A sequence of events can be traced through the model processing logic to see if it follows the logical track as reflecting in the existing system. Therefore, conducting a Turing test by asking the experienced person to discriminate the model and actual outputs is another piece of evidence to use in favor of the model being valid.

2.8 PREVIOUS RESEARCH IN MANUFACTURING INDUSTRY

Jay et al. (2006) in the journal titled "Enhancing business process management with simulation optimization" studied about how to optimize simulation models, by presenting two examples of simulation optimization using OptQuest simulation software. In the first case, they construct a discrete event simulation model of a hospital emergency room to determine a configuration of resources that results in the shortest average cycle time for patient. In the second case, they develop a simulation model to minimize staffing levels for personal claims processing in an insurance company. They also summarize some of the most relevant approaches that have been developed for the purpose of optimizing simulated systems and conclude with a metaheuristic black box approach that leads the field of practical applications.

Onur M. Ülgen, (2001) in journal of title "Productivity improvement in the automotive industry" studied about the role of process and robotics simulation in the automotive industry. The study investigated four different types of shipping deployments which are a base case and three competing deployment methods. The results for an additional dock reduced the number of racks required in the system down to 1055 from 1699. It saved of almost one-third of the capital invested in racks in the system. It further reduced costs of storage and maintenance of racks. Management implemented this scenario and after eighteen months of actual operation, all predictions of the simulation model held to within 4% of the actual.

Harrell and Gladwin (2007) in the journal titled "Productivity improvement in appliance manufacturing" studied about an application in which simulation was used to identify the bottle-neck of a dishwasher tub manufacturing line. Engineers were then able to determine and verify a solution to the bottleneck which resulted in an annual cost savings of $275,000. This project was completes in two weeks using Pro-Model software and service. By eliminating the additional partial shift, the company realized an annual savings of $275,000. The return on investment in the first year alone from this project was 1,100% and the payback period was less than 2 months.

Mosca and Revetria (2005) in the journal titled “Simulation as support for production planning in small and medium enterprise: a case study” described he proposed application is related to an Italian small factory that produces, assembles, and sells mechanical components for awnings. The paper demonstrates practically the applicability of the proposed methodology to a real-life application. In particular the implemented simulation framework demonstrates a high degree of flexibility serving different simulation exercise with minor changes. The workflow structured in a relational database instead of into the simulator itself fosters reusability and interoperability reducing dramatically the time and cost requirement of a complex simulation application. Obtained results have shown great potentiality in identifying relationship among KPI and ad hoc objective function enabling managers to easily identify and evaluate strategies and criticalities.

Comparisons between Artificial Neural Networks and traditional Full Quadratic Meta-Models have been presented showing congruent results and offering alternative views of the real Response Surface. A real life application was presented and discussed serving as base case for further implementation of the proposed methodology.

Türkseven and Ertek, (2003) in journal titled “Simulation modelling for quality and productivity in steel cord manufacturing” described the application of simulation modelling to estimate and improve quality and productivity performance of a steel cord manufacturing system. They also describe the typical steel cord manufacturing plant, emphasize its distinguishing characteristics, identify various production settings and discuss applicability of simulation as a management decision support tool. Besides presenting the general structure of the developed simulation model, they focus on wire fractures, which can be an important source of system disruption.

Baesler et al., (2002) with journal titled “Productivity improvement in the wood industry using simulation and artificial intelligence” described the results in the application of a simulation optimization methodology in a wood processing plant. The solution achieved using the methodology converged to an alternative that decreases the average time in system of the products in approximately 18%. The results were obtained evaluating just 1.6% of the whole solution space. Therefore, the implementation of the propose solution has to be evaluated economically by the company, since important investments are required.

Arons and Asperen, (2000) in journal titled “Computer assistance for model definition”. Study about the uses of ARENA simulation software. This study used two approaches. The approaches are: one is knowledge-based support and the other one is reuse existing simulation implementation models. In this study, the findings are Simulation models need to be known in advance. Besides that, a knowledge-based system selects one of a simulation model and attempts to gather the necessary information based on the hypothesis.

Ingemansson, A. et. al. (2005) in journal titled “Reducing bottle-necks in a manufacturing system with automatic data collection and discrete-event simulation” study about engine block manufacturing systems which present a methodology for working with bottle-neck reduction by using automatic data collection and discrete-event simulation (DES). In this study, the findings are it shows an improvement of the availability in one machine from 58.5% to 60.2%. Besides that, a single alteration with minimum investment result 3% increase of overall output.

Ingemansson and Bolmsjo (2004) in journal titled “Improved efficiency with production disturbance reduction in manufacturing systems based on discrete-event simulation” study about two different case study; one is produces equipment and machine to the window-blind industry and the other is manufactures forklift trucks for warehouse; the goal is to introduce a methodology based on DES for reducing disturbance in manufacturing systems and to make both academic and industrial areas more aware of the important of disturbance reduction. The outcomes of this study show the potential for improvement in manufacturing systems. This study shows an increase of 14% and 18% for two different cases.

Hlupic and Paul (1993) in journal titled "Simulation modelling of an automated system for electrostatic powder coating" study about electrostatic powder coating. This study describes an application of simulation to an automated manufacturing environment. The findings of this study are the best results were achieve by model 2 (increase 56%), where the number of parts per flight bars were double. The result was higher because time loading and unloading at the conveyor was terminated.

Refers to all those previous researches above, we can conclude that most industry are applying simulation and it is an efficiency method which is widely used in manufacturing industry especially as a tool in model constructing for waiting lines solver, staffing scheduling and predicting the efficiency of a company. Yet, there are still many demands on simulation to provide better performance instead of solving these ordinary matters.

Table 2.1 shows the summary of previous researches that have been done in manufacturing industry that mentioned above.

Table 2.1: The summary of previous researches

Author(s)	Methodology	Summary
Jay et al. (2006)	Simulation OptQuest	Study about how to optimize simulation models, by presenting two examples of simulation optimization using OptQuest. In the first case, they construct a discrete event simulation model of a hospital emergency room to determine a configuration of resources that results in the shortest average cycle time for patient. In the second case, they develop a simulation model to minimize staffing levels for personal claims processing in an insurance company. They also summarize some of the most relevant approaches that have been developed for the purpose of optimizing simulated systems and conclude with a metaheuristic black box approach that leads the field of practical applications.
Ülgen (2001)	Process and Robotics Simulation	Study about the role of process and robotics simulation in the automotive industry. Uses of simulation during the different phases of an engineering project are addressed. The phases of an engineering project are identified as the conceptual design, detailed design, launching and fully-operational phases. The management implemented one of the scenario and after eighteen months of actual operation under that particular scenario, all predictions of the simulation model held to within 4% of the actual.
Harrell and Gladwin (2007)	Simulation Pro-Model	Study about an application in which simulation was used to identify the bottle-neck of a dishwasher tub manufacturing line. Engineers were then able to determine and verify a solution to the bottleneck which resulted in an annual cost savings of $275,000. This project was completes in two weeks using Pro-Model software and service. By eliminating the additional partial shift, the company realized an annual savings of $275,000. The return on investment in the first year alone from this project was 1.100% and the payback period was less than 2 months.

Mosca et al. (2005)	SIMAN simulation language	The paper demonstrates practically the applicability of the proposed methodology to a real-life application. In particular the implemented simulation framework demonstrates a high degree of flexibility serving different simulation exercise with minor changes. The workflow structured in a relational database instead of into the simulator itself fosters reusability and interoperability reducing dramatically the time and cost requirement of a complex simulation application. Obtained results have shown great potentiality in identifying relationship among KPI and ad hoc objective function enabling managers to easily identify and evaluate strategies and criticalities. Comparisons between Artificial Neural Networks and traditional Full Quadratic Meta-Models have been presented showing congruent results and offering alternative views of the real Response Surface. A real life application was presented and discussed serving as base case for further implementation of the proposed methodology.
Türkseven and Ertek, (2003)	C++ language	Study the application of simulation modelling to estimate and improve quality and productivity performance of a steel cord manufacturing system and the typical steel cord manufacturing plant, emphasize its distinguishing characteristics, identify various production settings and discuss applicability of simulation as a management decision support tool, they focus on wire fractures, which can be an important source of system disruption. The program was used to determine optimal spool lengths within a constrained search space. The accuracy of the simulation can be increased through increasing simulation run lengths and number of simulations and applying experimental design and output analysis techniques.
Baesler et al. (2002)	Simulation (ARENA)	Study about the use of ARENA. The study present the results obtained after using a simulation optimization methodology applied to a production line from a secondary manufacturing wood processing plant of a well known Chilean mill. The results after applying ARENA show that using a different configuration of the plant resources, it is possible to reduce the total average cycle time in

		18%. The resource configuration needed to reach this result was obtained just 1.6% of the total number of possible combinations.
Arons and Asperen, (2000)	Simulation (ARENA)	Study about the use of ARENA. Used two approaches; one is knowledge-based support and the other one is reuse existing simulation implementation models. Simulation models need to be known in advance. A knowledge-based system selects one of a simulation model and attempts to gather the necessary information based on the hypothesis.
Ingemansson, A. et. al. (2005)	Simulation (QUEST)	Study in engine block manufacturing; present a methodology for working with bottle-neck reduction by using automatic data collection and discrete-event simulation (DES). This study shows an improvement of the availability in one machine from 58.5% to 60.2%. Single alteration with minimum investment result 3% increase of overall output.
Ingemansson and Bolmsjo (2004)	Simulation (QUEST)	Two different case study; one is produces equipment and machine to the window-blind industry and the other is manufactures forklift trucks for warehouse; the goal is to introduce a methodology based on DES for reducing disturbance in manufacturing systems and to make both academic and industrial areas more aware of the important of disturbance reduction. The outcomes of this study show the potential for improvement in manufacturing systems. This study shows an increase of 14% and 18% for two different cases.
Hlupic and Paul (1993)	Simulation (WITNESS)	Study in electrostatic powder coating; describes an application of simulation to an automated manufacturing environment. The best results were achieve by model 2 (increase 56%), where the number of parts per flight bars were double. Results higher because time loading and unloading at the conveyor was terminated.

2.9 CONCLUSIONS

Literature reviews that regarding to this project title has been done in this chapter. In this chapter, details descriptions of the related subject in this topic and some case studies of the previous research are being reviewed. In addition, some techniques for using simulation software had been included in this chapter. Nevertheless, the details of the selected company for research will be presented in the next chapter.

CHAPTER 3

COMPANY BACKGROUND

3.1 INTRODUCTION

This chapter described a brief introduction to the company background. The company profile such as its history of establishment, main market of the furniture, company's objective, vision, and mission will be shown in this chapter. The description of the company's logo will also be explained. In addition, the company organization chart and production floor layout will be attached for reference. Lastly, a conceptual model of the current layout will be displayed with explanation of each process or entity.

3.2 COMPANY PROFILE

Lein Hua Furniture Industry Sdn. Bhd. (LHF) was established in 1977 as one of the leading furniture manufacturer in Malaysia. Their products are mainly made from quality rubber wood for both traditional and contemporary designs such as dining sets, rocking chairs, barstools, bedroom sets and cabinets.

The target of LHF began in local market, which subsequently develops for export purpose. Today, LHF has grown to be a large manufacturer of quality wooden furniture for export markets. The company has successfully tapped into the international markets such as Australia, United States, Korea, United Kingdom, Canada, Japan, Ireland, Middle East and other countries for about 10 years.

In the future, they are looking to expand and develop mutually beneficial relational in the global market. They aim to provide quality products and can ensure good service to customers worldwide.

3.3 COMPANY LOGO

Figure 3.1: Logo of Lein Hua Furniture Industry Sdn. Bhd.

The logo of LHF represents the private, government and individual parties which it continuously provides better services in order to meet customer's need with the wood-based product.

3.4 COMPANY OBJECTIVES

i. *Membuat, menghantar tempahan pelanggan mengikut permintaan pelanggan.*
ii. *Mempromosikan kualiti dan kuantiti barang tempahan serta mendapatkan tempahan maksimum di samping menjamin kualitinya.*
iii. *Memberi sepenuhnya komitmen terhadap barang tempahan.*
iv. *Menyediakan persekitaran yang selamat dan selesa.*
v. *Melahirkan sumber manusia yang berdisiplin dan mahir.*

3.5 COMPANY VISION

"Customer is right" *melalui pendekatan tersebut kami berusaha memberikan layanan serta buatan barangan yang terbaik memenuhi hampir keseluruhan permintaan dan kehendak dari pelanggan.*

3.6 COMPANY MISSIONS

i. *Kami berusaha untuk mendapatkan keyakinan pelanggan terhadap barangan buatan kami agar pelanggan mudah untuk berurusan dengan kami buat kali kedua dan seterusnya.*
ii. *Kami berusaha menghasilkan perabut yang berkualiti di samping menyiapkan tempahan dalam masa yang ditetapkan.*
iii. *Meningkatkan tahap kualiti produk dan perkhidmatan.*

3.7 LHF ORGANIZATION CHART

LHF is directed by Mr. Wan Hassan Bin Wan Omar, who is helped by the Vice Director, Ms. Chian Yoke Seam. They are mainly assisting their employees and ensuring the company provides good quality of furniture to meet customer's need.

There are three major executive, namely account executive, marketing executive, and shipping executive. Besides that, there are three clerks available in LHF, which are general clerk, purchasing clerk, and human resource clerk.

In addition, LHF also consists of one head of marketing and one technician, Richard Yon and Mohd Asri respectively. There are seven supervisors altogether in LHF, in which each of them supervise on their own production line.

The organization chart of LHF is summarized as shown in Figure 3.2.

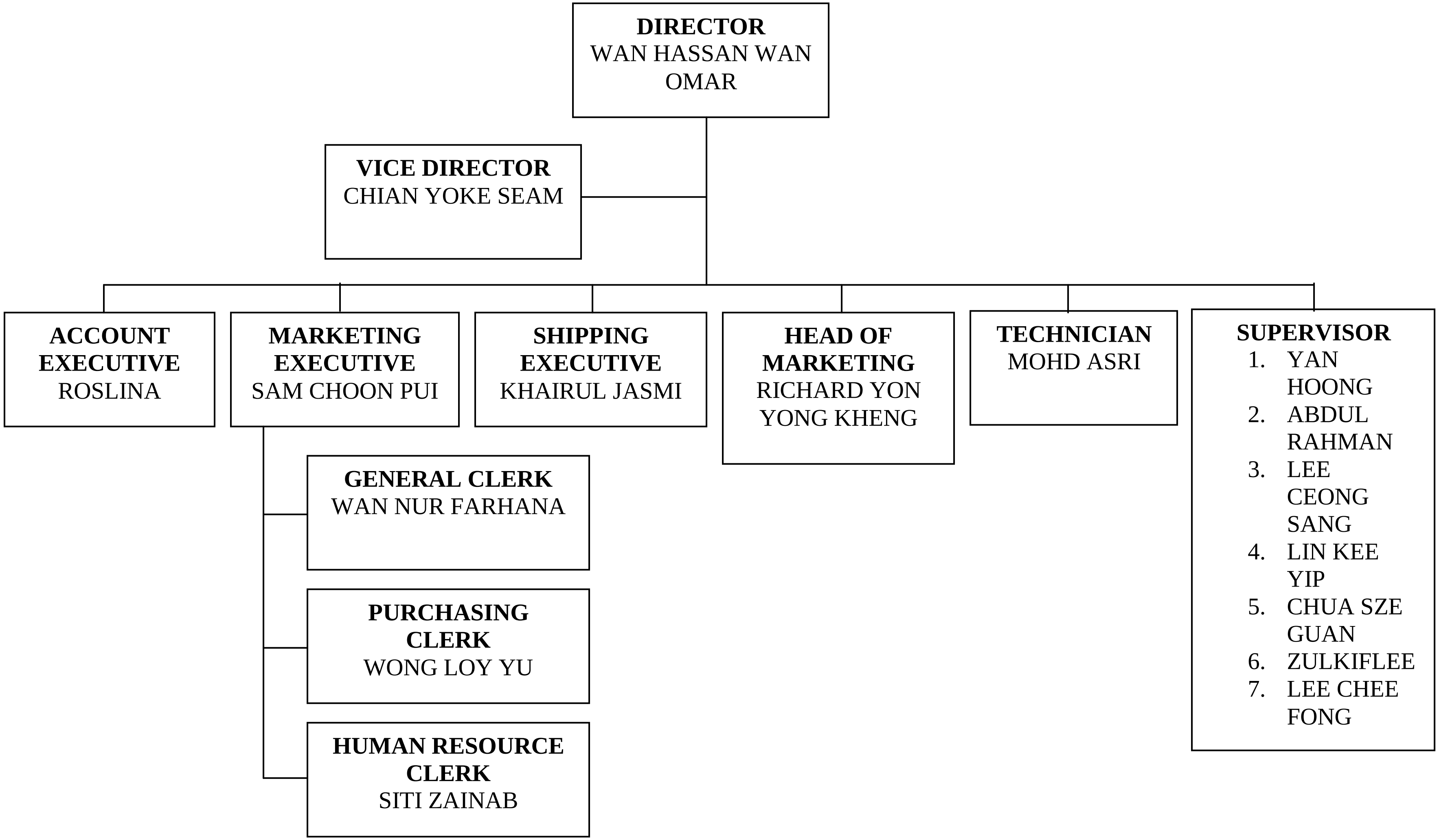

Figure 3.2: The organization chart of LHF of year 2010.

3.8 LHF PRODUCTION FLOOR LAYOUT

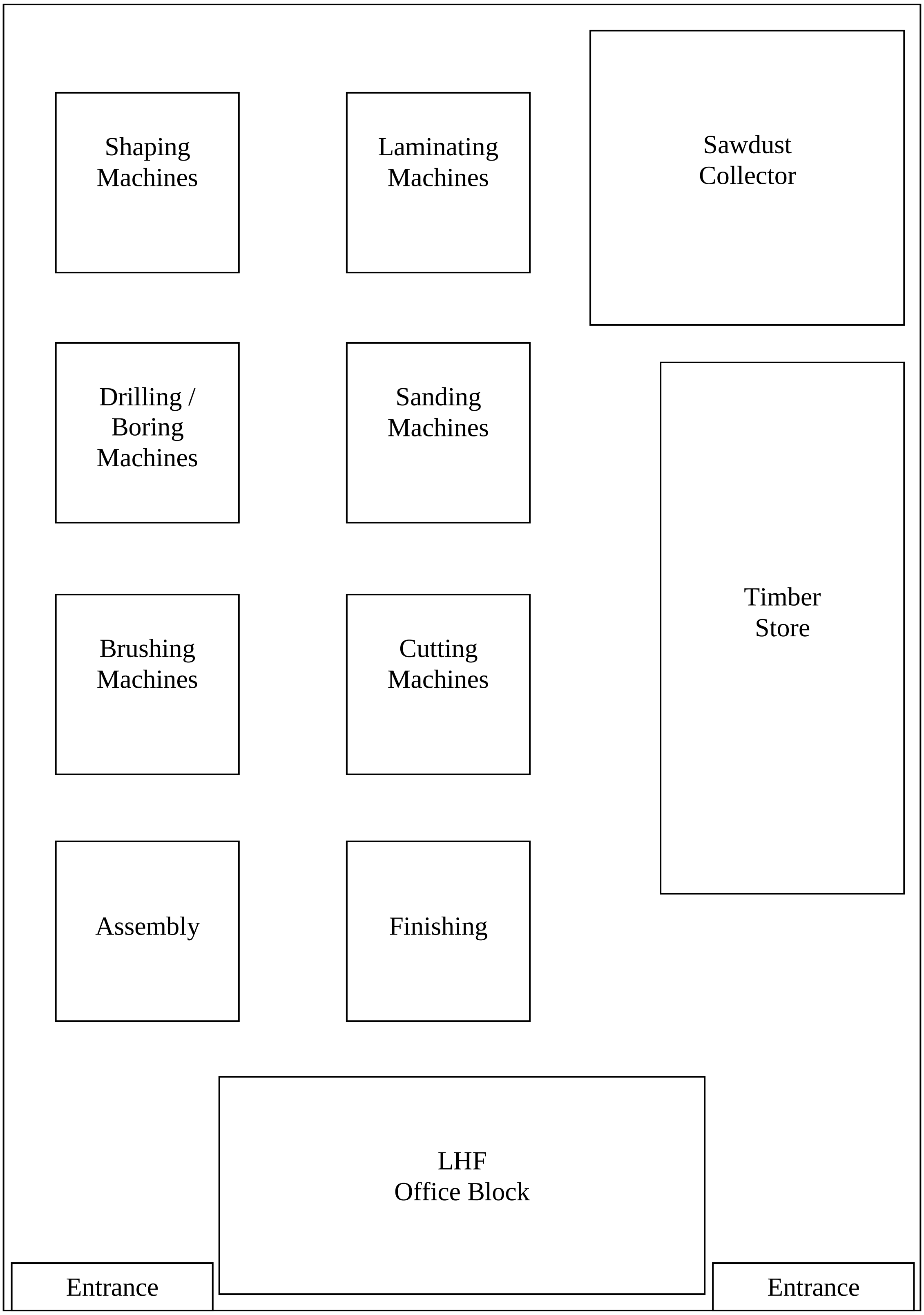

Figure 3.3: The production floor layout of LHF.

3.9 PROCESS FLOW DESCRIPTION

In this study, the process of producing a chair is the major concern. The chair namely Oxford Folding Side Chair is chosen in this study as its productivity is low. A fully finished of this type of chair is shown in Figure 3.4. By referring to the LHF production floor layout in Figure 3.3, the process flow of the production will be described as below.

Firstly, the timber will be delivered from the timber store to the first station, which is cutting station. For every delivering of timber or wood from station to station, fork-lift will be used as the main transportation to ease the manpower. In the cutting station, the timber or wood will be cut into smaller size accordingly with each having the same dimension. When the cutting process has done, the wood will be sent for sanding process. The wood need to be sanded in order to minimize the surface roughness and to make it smooth when touch.

Next, the wood will go for laminating process, which it requires glue to combine the bar-shaped wood to each other in order to make a bigger and flat surface of wood. This process takes the longest time as it needs to wait the glue to dry before it can proceed to the next station. When the glue is dried, the wood will then be sent to shaping process. In this process, the bigger flat wood will be cut into shape according to the shape of the chair that wanted to produce. After that, the part that produced will undergo sanding process again.

The process of drilling or boring will starts once the part sent to this station from sanding station. This process is mainly to make hole on the parts. After making holes, there might have a lot of burrs produced, and thus it will be sent for sanding again, which in a whole cycle of production, three times of sanding process is required.

Prior to assembly, the parts will be sent for brushing station. The brushing process is necessary to eliminate all the dust and ensure no residues on it. When this process has done, it only can proceed to assembly line for assembly. Lastly, finishing process of the chairs will be carried out. The finishing process includes, spraying, painting, and packing.

When the finishing process is complete, the products will be carried away by lorry for selling and export. At the end of the day, with completing all those processes mentioned above, there would be a complete cycle time observed for the data collection.

Figure 3.4: The studied chair – Oxford Folding Side Chair.

3.10 CONCLUSIONS

The company background with introduction and the profile are discussed in detail in this chapter. The company logo's description, company objectives, vision and mission are also shown in this chapter. In addition, the organization chart of the company and the current production floor layout are presented respectively in this chapter. Lastly, the process flow description for the current production floor layout is discussed in general.

CHAPTER 4

METHODOLOGY

4.1 INTRODUCTION

This chapter discussed the methodology that used in conducting this project from the beginning until the project is completed. This chapter started with the design of project study, where the methodology used in conducting this project is discussed. The project flow charts will also be shown in this chapter.

4.2 DESIGN OF PROJECT STUDY

This project begins with confirming the project title with supervisor. The project continues with the discussion with the assigned supervisor to detail out the project problem statement, project objectives and project scopes. At the same time, weekly appointment with the supervisor is arranged.

Next is finding an appropriate company to do this study. In order to do research in manufacturing industry, application letter was drafted and sent to a few companies around Kuantan. After being rejected by some companies, LHF gives a feedback that they agreed to allow the project to be done at their company. Upon acceptance, the project can be started immediately.

The appointment of company visit is done each time before visiting. During the visit, the owner of the company briefly explained the background of the company, types of furniture that they supply to customers and how the furniture is produced. After the briefing, a visit to the production floor was organized by one of the supervisors to get the whole picture of how the chair is produced. A few problems in the production line were highlighted by the supervisor and all the problems are jotted down for analysis purposes.

After analyzing the problems existed, major problem that causing the low productivity is to be solved by simulation method. The selected problem to be solved in this project is the chair production problem, in which the laminating process takes the longest time causing the whole process flow to be slowed down. At the end of the day, the productivity of the chair is lower than targeted.

Next, frequent random visits to the company was planned to collect the required information to build simulation model such as the production floor plan, process flow, process cycle time and machine downtime. Then the project proceeds with data analysis. Ten readings of process cycle time and machine downtime data were collected for each process and their sample size adequacy is determined. During the data analysis process, the collected cycle time data was to times with 1.15 due to the labor efficiency of 85 percent. This labor efficiency was taken into account considering that all the processes are human oriented. After that, the probability distribution type is being determined using Chi-Square test with 50 sets of data for each process.

By completing calculation of the sample size, the values are being tabulated in Appendix B and Appendix C. For Appendix D, on the other hand, the data collected will be tested to determine how good a fit has been obtained by using uniform distribution test, exponential distribution test, and normal distribution test. The most appropriate distribution is chosen as the input data to construct the desired model. The same goes to machine downtime data, as tabulated in Appendix E, Appendix F and Appendix G.

The project proceeds with simulation and modeling stage in which the simulation of the process is done on WITNESS simulation software. The process cycle times and machine downtimes for each process were being inserted as input to the simulation model. The simulation model is run and verified by watching the animation simulated for correct behavior. Three alternatives layout were designed in order to improve productivity. The three alternatives proposed include, additional of 1 Laminating machine and reduction of 1 Brushing machine, combining of Sanding II and Sanding III process after Drilling process, and lastly combination of alternative 1 and alternative 2.

Then the model validation is carried out by watching the animation and compared the output of chair with the actual system. Both model verification and model validation are made to ensure that the sketched models are accurately reflected the conceptual model. Next, the results of the simulation model are being generated.

For analyzing the results for all the simulation models, each simulation model has to run five times generating five outputs. Then, the average outputs for each model are taken. The results obtained will brings forward for Kruskal-Wallis non-parametric test, ANOVA analysis, and Cost-effectiveness Analysis. The Kruskal-Wallis non-parametric test was done by using Minitab software to compare the medians between inserted samples to determine if they come from different populations. Next, ANOVA one way with multiple comparison tests were applied on the three alternatives layout to identify the best option to be chosen for the study. Lastly, in order to determine the best alternative that generates the most outputs with the least cost, Cost-effectiveness Analysis was done by comparing the cost needed for each alternative.

By making a few necessary assumptions, calculations, graphs plotting and the Cost-effectiveness Analysis, the best layout is being chosen and will be proposed to LHF. The results that generated by all the tests were documented properly and presented to the panels at the final stage of this project. The summary for design of the study for this project is shown in Figure 4.1 and Figure 4.2.

4.2.1 Project Flow Chart for Final Year Project

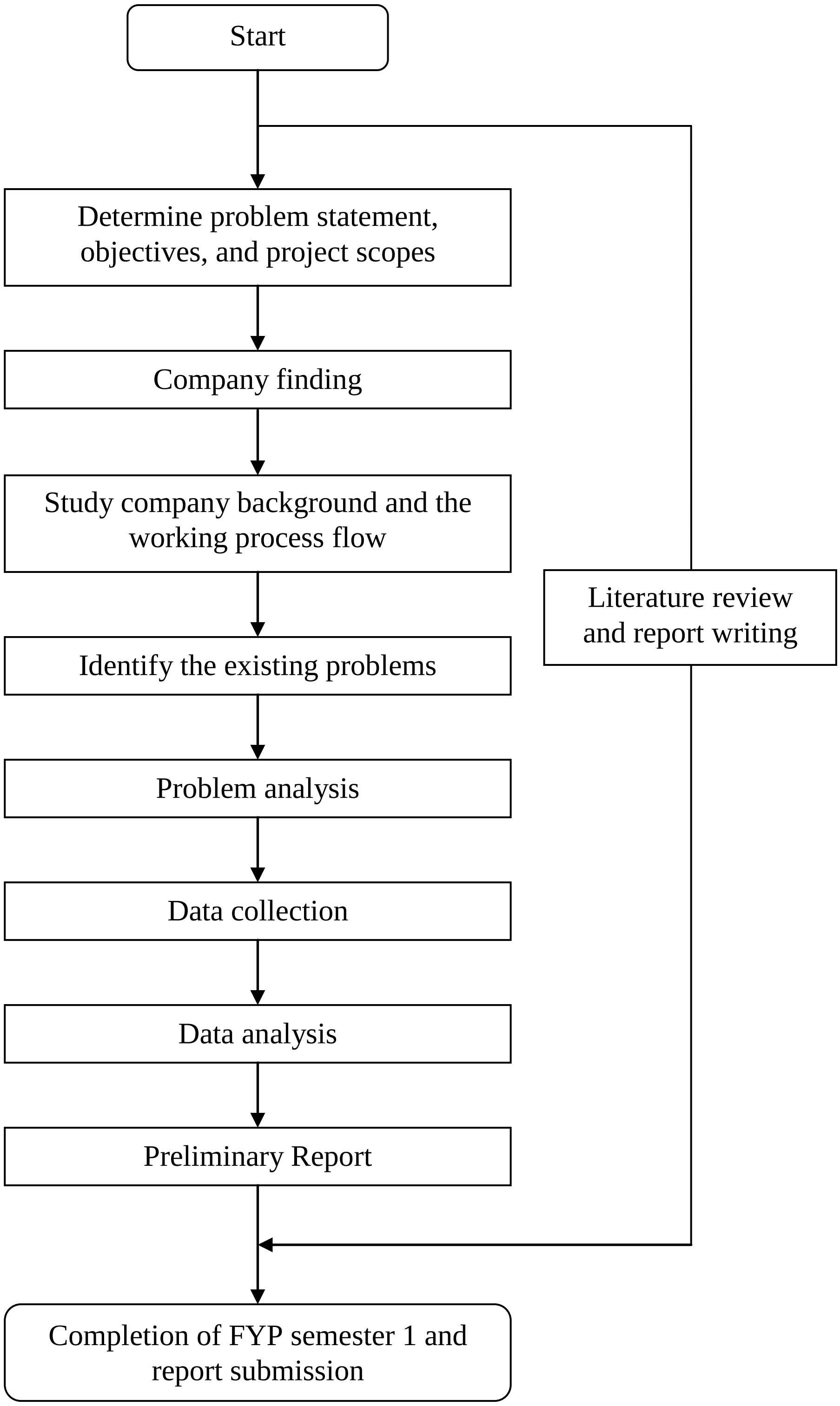

Figure 4.1: Project Flow Chart for FYP Semester 1

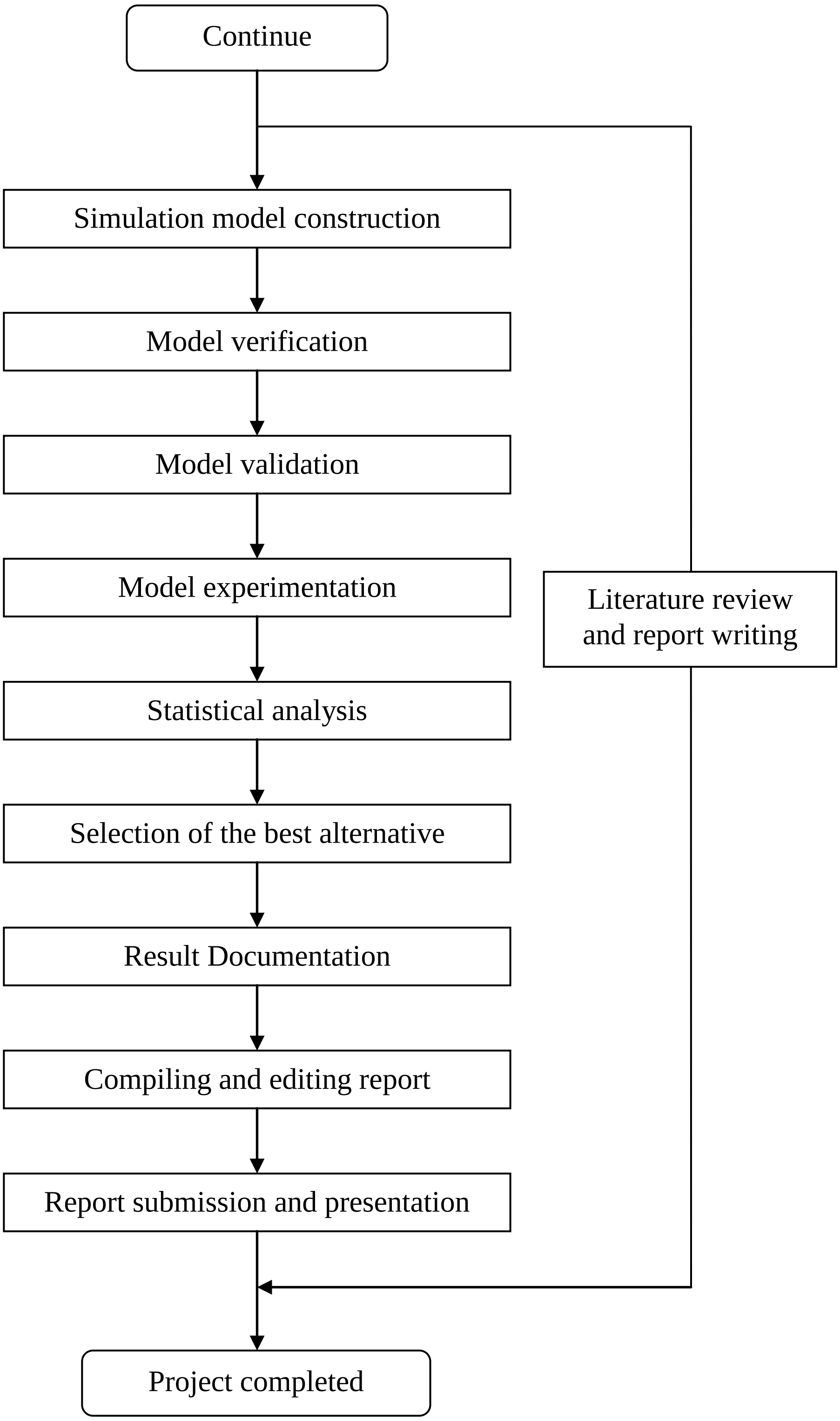

Figure 4.2: Project Flow Chart for FYP Semester 2

4.3 CONCLUSIONS

In conclusion, this chapter discussed the methodology on how the research was carried out. This chapter begins with the design of project study, from the beginning to the end. Then, the detail of the project flow is summarized in the project flow charts in the end of this chapter.

CHAPTER 5

DATA ANALYSIS AND MODELLING

5.1 INTRODUCTION

This chapter provides a discussion of data analysis and building of simulation model of the production line in LHF. The conceptual model is first to be explained in general. It followed by discussion of performance measure and decision variables. Discussion on how the data were analyzed is included in this chapter. Then, the model description, model assumptions, and model construction are briefly discussed. Lastly, this chapter ends with determining the required number of replications.

5.2 CONCEPTUAL MODEL

Conceptual model is the results of data collecting effort and formulation in the user mind which is supplemented with notes and diagrams of how a certain system is being operated (Harrel et al. 2003). In order to build a simulation model, a conceptual model is essentially to be built first. The conceptual model is then converted into simulation model in simulation software. A conceptual model basically consists of inputs, outputs, buffer for temporary transferring while waiting the parts to proceed with next process, and machines. Figure 5.1 shows the conceptual model of the layout layout studied in this project. It consists of ten processes in order to produce a complete chair. They are Cutting, Sanding I, Laminating, Shaping, Sanding II, Drilling or Boring, Sanding III, Brushing, Assembly, and Finishing process.

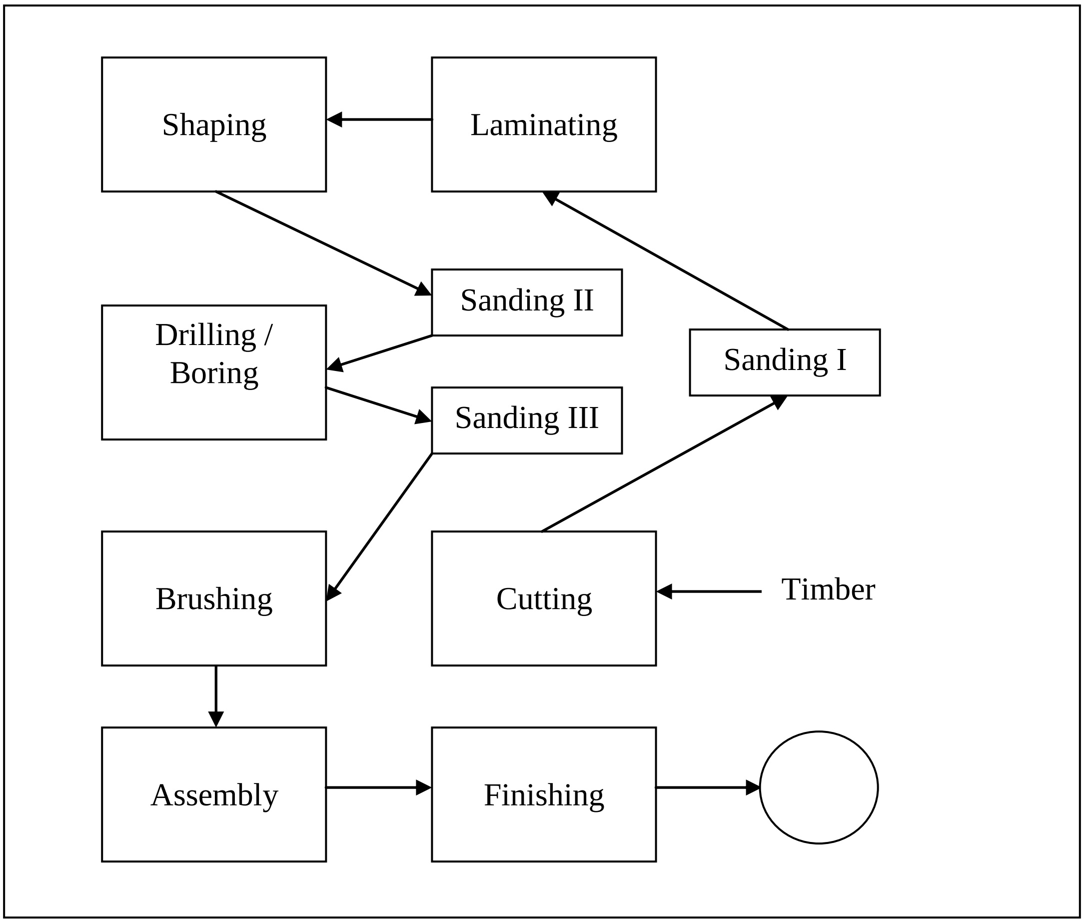

Figure 5.1: Conceptual model of chair manufacturing process.

5.3 PERFORMANCE MEASURE

There are plenty of methods that can be applied in order to measure performance or efficiency of a modelling system. The project objective is to increase the output or productivity of the company so that it can meet customer demand. Other than productivity enhancement, time is also considered as a key resource. Therefore, for any company, an increase in outputs while consuming same or lesser amounts of input resources become one of the best methods used to meet customer demand. However, if the production costs are corresponding higher, the changes proposed might not be used or applied considering their profit margin is low.

5.4 DECISION VARIABLES

There are two types of variables used in this project, which are controllable variables and uncontrollable variables. Controllable variables are those that can be controlled by worker such as number of worker at the chair production line and the process sequence. Uncontrollable variables, however, are those that cannot be controlled by human such as cycle time and machine downtime for each process.

5.5 DATA ANALYSIS

In simulation study, after the required data have been collected, it was analyzed to determine their adequacy for simulation and the distributions of the data were also tested by using Chi-Square test. The sample size for process cycle time was calculated after an initial of 10 sets data. The example of sample size calculation using this method was shown in Appendix B and the overall results for every other process were shown in Appendix C. A total of 50 sets data was collected and tested by using Chi-Square test which is shown in Appendix D.

Similarly, the sample size for machine downtime was calculated for the ten sets data and the example was shown in Appendix E and its overall results were shown in Appendix F. The data distribution also needs to be tested using Chi-Square test which is shown in Appendix G. Data distributions for both process cycle time and machine downtime show the same pattern, which is uniformly distributed. The summary of the cycle time for all processes involved in the simulation are shown in Table 5.1, whereas the summary of the machine downtime for all processes involved are shown in Table 5.2.

Table 5.1: Summary of process cycle time for each process.

Process	Process Cycle Time (s)		
	Distribution	**Min Value**	**Max Value**
Cutting	Uniform	314.410	387.275
Sanding I	Uniform	265.450	337.605
Laminating	Uniform	1911.170	1979.245
Shaping	Uniform	545.440	578.650
Sanding II	Uniform	335.675	384.250
Drilling / Boring	Uniform	453.125	523.905
Sanding III	Uniform	350.920	429.140
Brushing	Uniform	296.245	329.450
Assembly	Uniform	905.235	997.750
Finishing	Uniform	635.855	708.430

Table 5.2: Summary of machine downtime for each process.

Process	Machine Downtime (s)		
	Distribution	**Min Value**	**Max Value**
Cutting	Uniform	3029.0	3697.2
Sanding I	Uniform	1821.3	2487.6
Laminating	Uniform	3524.7	4285.6
Shaping	Uniform	2309.7	3065.9
Sanding II	Uniform	2017.4	2695.0
Drilling / Boring	Uniform	1712.4	2483.2
Sanding III	Uniform	1811.2	2483.7
Brushing	Uniform	1911.7	2483.6
Assembly	Uniform	1710.4	2384.0
Finishing	Uniform	1808.7	2580.5

5.6 MODEL DESCRIPTION

The simulation model consists of major components that required in a production line. There is one part that acts as timber for starting of the simulation, then machines that process the parts, and buffers that act as a temporary storage during process. The timbers will first be pushed to Cutting station for cutting process. After cutting, the parts are temporary stored at buffer before proceed to next process. The parts will be pushed to other processes based on the attributes that have been set in each station. The simulation model and the process flow of the parts are shown in Figure 5.2.

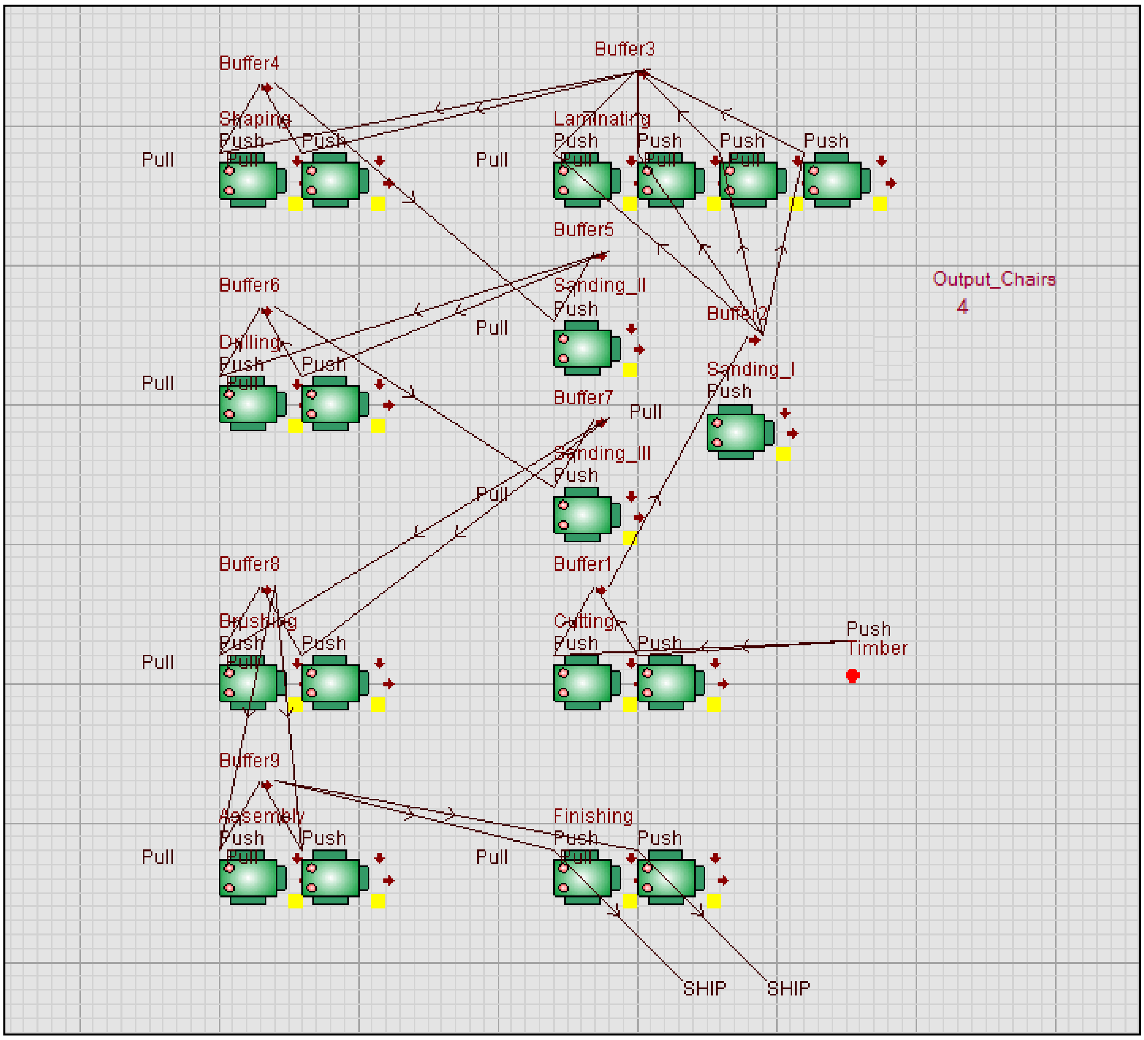

Figure 5.2: Simulation model for the process flow in chair production line.

5.7 MODEL ASSUMPTIONS

In order to achieve a reasonable and feasible simulation model, some assumptions have to be made:

1. The manufacturing process operates 8 hours per day and 6 days per week.
2. The company working hour schedule is as below:

Working Hour	8:00 a.m. – 5:30 p.m.
Break / Rest Time	10:30 a.m. – 10:45 a.m.
	1:00 p.m. – 2:00 p.m.
	4:00 p.m. – 4:15 p.m.

3. Each machine can process only one part at a time, except for Laminating Machine which can process three parts at a time.
4. The process cycle time and machine downtime for Laminating process is divided by three, so that a precise output will be obtained.
5. There is no interruption when the production operation is started.
6. There is no reject or rework parts occur.
7. Machine breakdown and the time needed for repairing are considered as machine downtime.
8. Efficiency of 85 percent is taken into account due to all the processes are human oriented.

5.8 MODEL CONSTRUCTION

In this project, the simulation model was built by using WITNESS Simulation software. In the current existing production floor, the work in progress (WIP) timbers are always available and processing sequence of the timbers or parts need to be specified. Therefore, the sequence rules in WITNESS have been used for the input rule.

Since the Laminating process is able to produce three parts at a time, its cycle time and machine downtime is necessarily to be divided by three. The simulation model is now representing the existing production line flow more accurately. Pull and push rules are used to connect the movement of the parts from one machine to another.

In every single process, there is a buffer which acts as temporary storage for the parts. The parts will be sent to next machine collectively from the buffer to perform the next process. Lastly, the parts will be out from the simulation area by using ship rule.

Furthermore, three distribution tests are used in analyzing the process cycle time and machine downtime for the production floor, which are uniform distribution, exponential distribution and normal distribution. The results from the tests show that it is uniformly distributed. In order to display the total output of chairs produced, integer attributes are used in the simulation.

After constructing the model, the model will then be verified stage by stage to ensure that the model and the results generated are acceptable. When it has been completed and verified, it is validated by comparing the results with the real situation.

5.9 DETERMINING REQUIRED NUMBER OF REPLICATIONS

In terms of analyzing the output data, there are two types of simulations: terminating simulation and steady-state simulation. A terminating simulation is a simulation in which the desired measures of system performance are defined relative to the interval of simulated time. A steady-state simulation, however, is one in which the measures of performance are defined as limits as the length of the simulation goes to infinity.

The purpose of simulating terminating systems is to understand their behavior during a certain period of time, and this is also referred to as studying the transient behavior of the system. Since the company starts operate at 8 a.m. and ends at 5:30 p.m. with a total working hour of eight per day, the amount of time is fixed and known. Thus, the terminating system is used in this study.

To determine the required number of replications, the simulation model is run for five times with run length of 28800 seconds which represents the eight hours of working time per day. The example of calculation in determining the number of replications is shown below:

Table 5.3: Determination of number of replications required for actual layout.

Observation (n)	**Output (X_i)**	$(X_i - \bar{X})$	$(X_i - \bar{X})^2$
1	46	2	4
2	38	– 6	36
3	40	– 4	16
4	53	9	81
5	43	– 1	1
Total	220		138

$$\text{Mean, } \bar{X} = \Sigma X_i/5$$
$$= 220/5$$
$$= 44\ units$$

$$\text{Standard Deviation, } s = \sqrt{\Sigma(X_i - \bar{X})^2 / n - 1}$$
$$= \sqrt{138/5 - 1}$$
$$= 5.87$$

$$\text{By using 90\% of confidence level, } \alpha = 0.10$$
$$Z_{\alpha/2} = Z_{0.05} = 1.6449$$

$$\text{Half-width, } e = (High\ interval - \bar{X})/2$$
$$= (53 - 44)/2$$
$$= 4.5$$
$$\approx 5\ units$$

$$\text{Number of Replication, } n = [(Z_{\alpha/2})s/e]^2$$
$$= [(1.6449 \times 5.87)/5]^2$$
$$= 3.73$$
$$\approx 4$$

From the calculation above, the number of replication required is determined to be 4. Therefore, 5 observations tabulated are sufficient to proceed to statistical and cost-effectiveness analysis. There is no additional replication needed.

5.10 CONCLUSIONS

In conclusion, this chapter discussed the construction of the conceptual model for the existing production floor. Then, the performance measure and decision variables have been identified. The data for process cycle time and machine downtime have been collected and tested for their type of distribution. After the simulation model had been constructed from the conceptual model and the data analysis, the simulation model was verified stage by stage and validated by comparing the outputs produced with the actual system. Lastly, the number of replication for each layout was determined.

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 INTRODUCTION

In this chapter, the discussion of the existing production line performance and the proposed alternatives layout results will be discussed. In order to improve the productivity of the existing layout, three alternatives have been suggested. The results generated by using WITNESS Simulation software were tested using Minitab Statistical software. In addition, non-parametric tests were being conducted to identify whether there were a significant differences between the results for the actual layout with the proposed alternative layouts. Finally, the best layout would be proposed to the company based on the one way ANOVA with multiple comparisons test result and by comparing the cost using Cost-effectiveness Analysis.

6.2 EVALUATION FOR THE EXISTING PRODUCTION FLOOR LAYOUT

The actual system layout is important to be evaluated first in order to identify the problems of the floor layout. The problems can be seen clearly and thus alternatives can be made accordingly. From Figure 6.1, the simulation model shows that the buffer at Sanding I process having plenty of parts accumulated before the parts proceeds to Laminating process. This is because the time taken at the Laminating process is longer causing the parts at buffer of Sanding I to pause while waiting it. Besides, the brushing machine taking shorter time and yet there is two brushing operating at the same time.

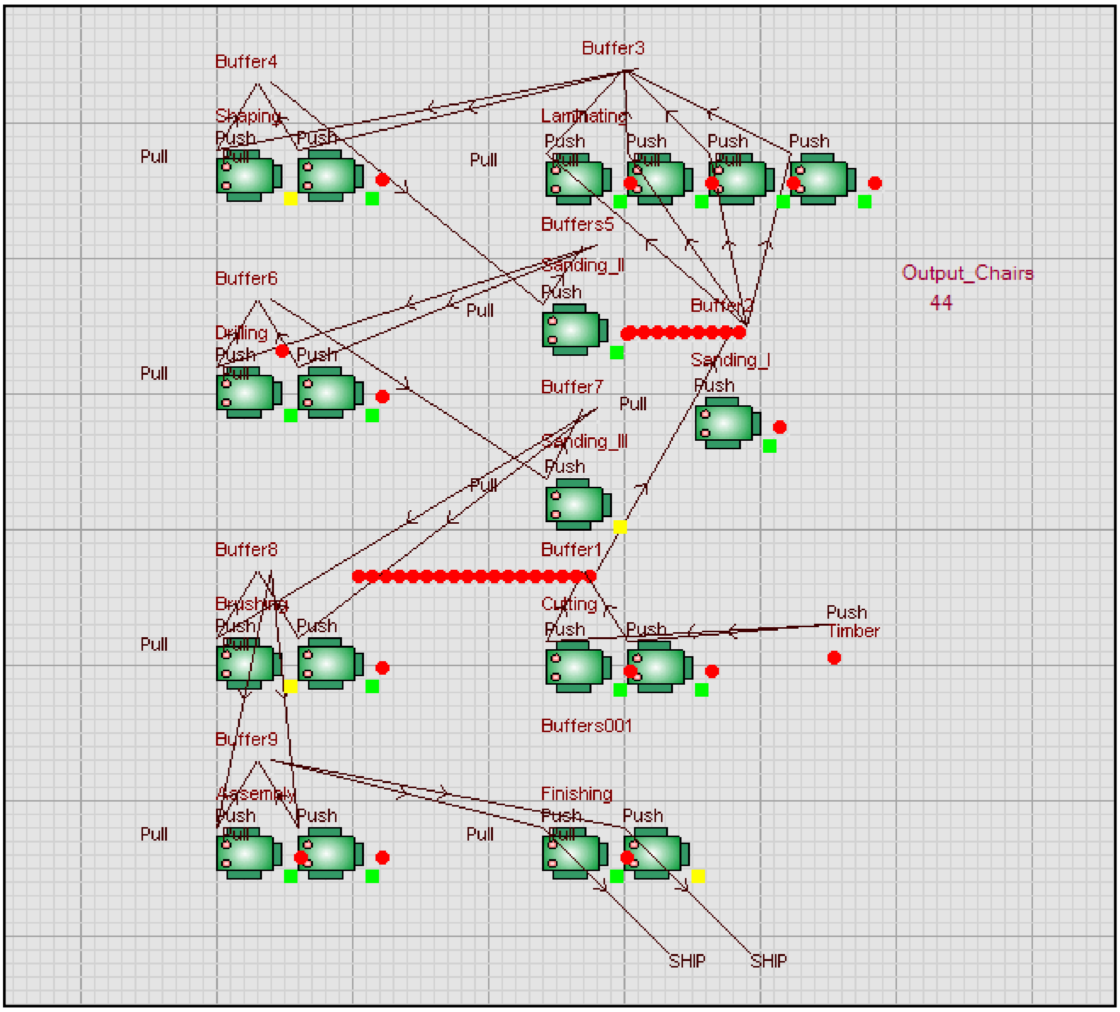

Figure 6.1: Simulation model for existing production floor layout in LHF.

The actual numbers of output chairs produced in the existing production layout for duration of 28800 seconds are tabulated in Appendix H. The average output chairs produced in this existing layout is 42 units, whereas the simulation having its average chairs of 44 units. The difference between this simulation and existing system is 4.76% which is less than 5% of variation or error. Thus, a confidence level of 95% is applied and the simulation model is considered valid.

In the simulation model, the time length of 28800 seconds is implemented into the system and the output chairs which generated are 46, 38, 40, 53, and 43 units. In this time length, an average number of 44 chairs are produced with an optimum time of 492.67 seconds. This indicates that at least 8 minutes is required to produce a chair. The simulated results of this existing layout are recorded below:

Table 6.1: Results of output chair for the existing production floor layout.

Product		**Replication**					**Average**
		1	**2**	**3**	**4**	**5**	
Chair	Output	46	38	40	53	43	44
	Avg. Time (s)	613.95	405.91	406.24	594.74	442.51	492.67

Since the main problem in the existing layout was identified, the layout is to be improved in order to increase the output of chairs with proposing three alternatives.

6.3 ALTERNATIVE 1: ADDITIONAL OF 1 LAMINATING MACHINE AND REDUCTION OF 1 BRUSHING MACHINE

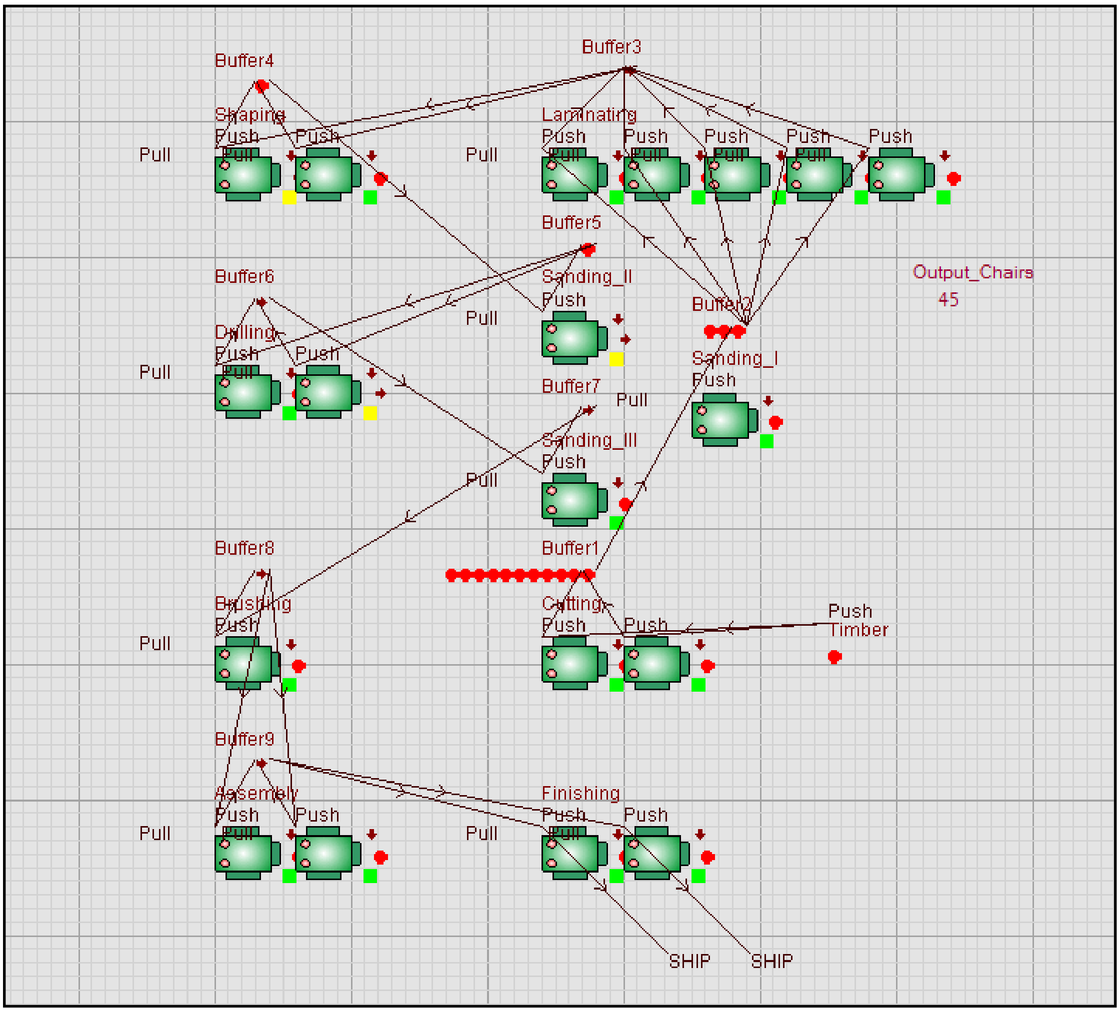

Figure 6.2: Simulation model for Alternative 1 by adding 1 Laminating machine and reducing 1 Brushing machine.

The first alternative that applied to this model is adding a Laminating machine and reducing a Brushing machine as shown in Figure 6.2. Laminating process takes the longest time because it involves the usage of glue to stick several pieces of wood together. The worker needs to ensure the glue is dried before proceed to next process. Therefore, an additional Laminating machine is necessary to overcome this problem.

Besides, the Brushing machine takes less time to finish a part, yet there is two Brushing machine running at the same time. In some circumstances, the Brushing machines are experiencing idle time which they need to wait the parts from previous station. Thus, alternative 1 is proposed so that the amount of chairs produced can be increased.

This alternative is run for few times. The output of chairs produced shows an average increment of 1 unit while the average processing time period is exactly the same as existing layout. The average output for this alternative is 45 units of chair. The results are recorded in Table 6.2 below:

Table 6.2: Results of output chair for the layout Alternative 1.

Product		**Replication**					**Average**
		1	**2**	**3**	**4**	**5**	
Chair	Output	44	45	44	46	45	45
	Avg. Time (s)	439.54	583.57	417.14	531.17	491.93	492.67

6.4 ALTERNATIVE 2: COMBINING OF SANDING II AND SANDING III PROCESS AFTER DRILLING PROCESS

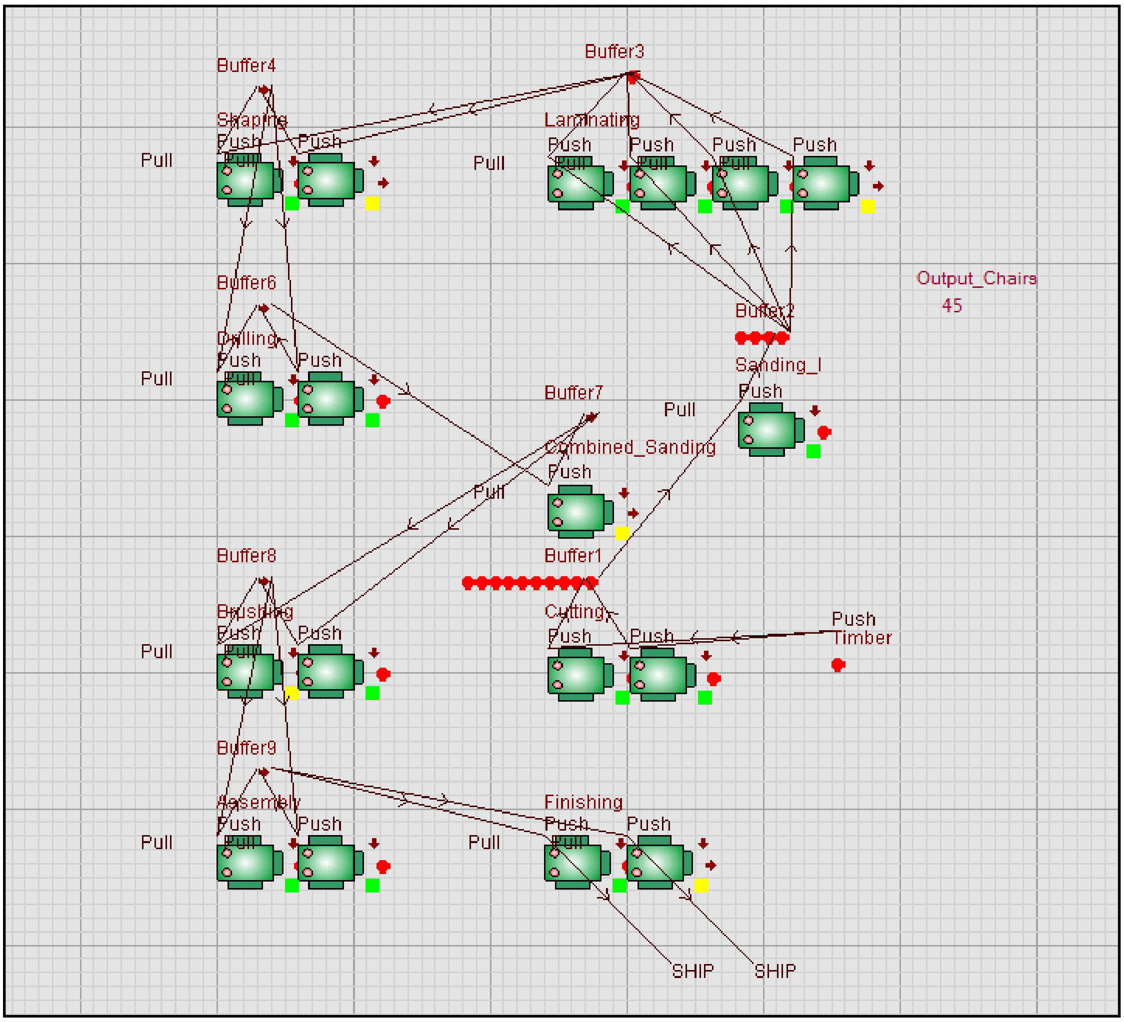

Figure 6.3: Simulation model for Alternative 2 by combining Sanding II and Sanding III process after Drilling process.

In the second alternative, the Sanding II and Sanding III process are combined together and putting it right after the drilling process, as shown in Figure 6.3 above. According to the supervisor of the production line, this alternative is feasible and applicable since the two processes are the same and thus can do it together after drilling process. In other words, a Sanding machine is eliminated in this proposed layout.

After repeating few simulation runs with 28800 seconds of available time, a constant output of chairs can be found to be 45 units. However, the average processing time of 501.04 seconds showing an increment of 8.37 seconds from the existing layout. The simulated results are recorded in Table 6.3.

Table 6.3: Results of output chair for the layout Alternative 2.

Product		**Replication**					**Average**
		1	**2**	**3**	**4**	**5**	
Chair	Output	45	45	45	45	45	45
	Avg. Time (s)	459.01	537.84	410.15	612.96	485.26	501.04

6.5 ALTERNATIVE 3: COMBINATION OF ALTERNATIVE 1 AND ALTERNATIVE 2

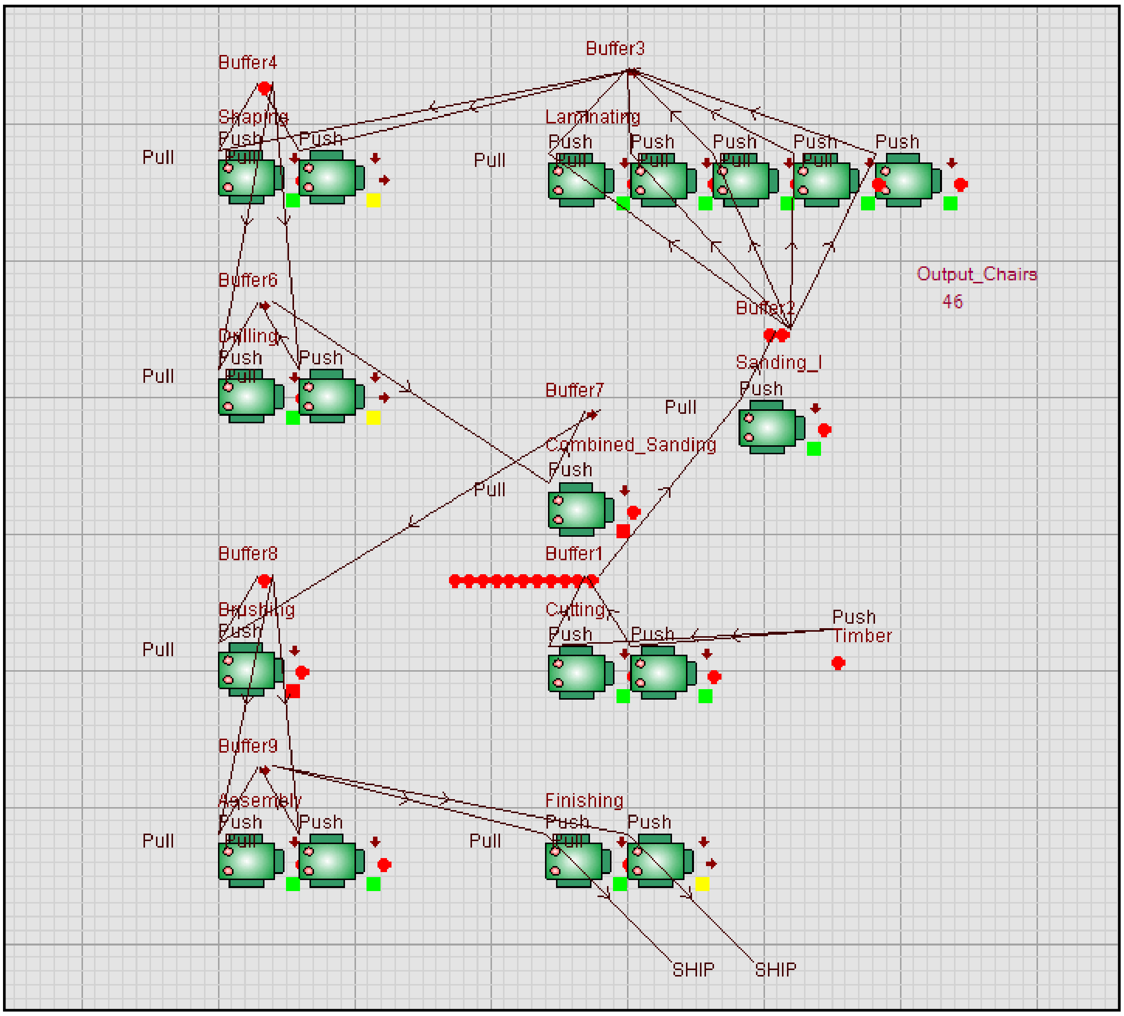

Figure 6.4: Simulation model for Alternative 3 by combining Alternative 1 and Alternative 2.

In this alternative, the proposed solution is to combine the Alternative 1 and Alternative 2, as shown in Figure 6.4. In other words, this alternative is carried out by adding a Laminating machine, reducing a Brushing machine, as well as combining Sanding II and Sanding III process after Drilling process.

Referring to Table 6.4, the average output of chairs produced is the highest among the three proposed solutions. The simulation model generated the output of 47 units, 45 units, 45 units, 46 units, and 46 units with an average output of 46 units. The average time is found to be shorter than the previous two alternatives, which is 483.39 seconds.

Table 6.4: Results of output chair for the layout Alternative 3.

Product		Replication					Average
		1	2	3	4	5	
Chair	Output	47	45	45	46	46	46
	Avg. Time (s)	429.76	580.46	409.01	613.95	383.78	483.39

6.6 RESULT ANALYSIS

After simulating the result of outputs for the existing layout and alternatives layout, the statistical analysis is being done by utilization of Minitab software. Kruskal-Wallis test in Minitab software is used, which is a type of test under the non-parametric family to evaluate the significant difference among the layouts if the differences between the tested alternative groups are large. Figure 6.5 shows the summary of Kruskal-Wallis test results on the average output chairs. The H-value and P-value show that the differences are significant among the groups. In addition, the P-value of 0.382 and 0.335 indicate that hypothesis will not be rejected since these P-value is smaller than 0.5.

```
Kruskal-Wallis Test on Output_Chairs

Layout             N  Median  Ave Rank      Z
Actual Existing    5   43.00       8.5  -0.87
Alternative1       5   45.00       9.1  -0.61
Alternative2       5   45.00      10.0  -0.22
Alternative3       5   46.00      14.4   1.70
Overall           20              10.5

H = 3.06  DF = 3  P = 0.382
H = 3.39  DF = 3  P = 0.335  (adjusted for ties)
```

Figure 6.5: Summary of Kruskal-Wallis test results on the average output chairs.

When the Kruskal-Wallis test is done, one way ANOVA analysis is carried out with Hsu's MCB (Multiple Comparison with the Best) applying a family error of 10% and confidence level of 90%. Referring to results in Figure 6.6, Alternative 1 and Alternative 2 have the upper value of 2.474 and 2.674 respectively, which indicates that the efficiency on improving the output chairs is less than Alternative 3. Thus, the best approach among the groups is the Alternative 3 which having an upper level value of 4.274.

```
Hsu's MCB (Multiple Comparisons with the Best)

Family error rate = 0.1
Critical value = 1.83

Intervals for level mean minus largest of other level means

Level              Lower  Center  Upper
Actual Existing   -5.274  -1.800  1.674
Alternative1      -4.474  -1.000  2.474
Alternative2      -4.274  -0.800  2.674
Alternative3      -2.674   0.800  4.274

Level                +---------+---------+---------+--------
Actual Existing      (-------------*-------------)
Alternative1            (-------------*-------------)
Alternative2             (-------------*-------------)
Alternative3                   (-------------*-------------)
                     +---------+---------+---------+--------
                   -5.0      -2.5       0.0       2.5
```

Figure 6.6: Summary of one way ANOVA test with Hsu's MCB (Multiple Comparisons with the Best).

6.7 COST-EFFECTIVENESS ANALYSIS

According to Henry & Patrick (2001), cost-effective analysis (CEA) is the evaluation of alternatives according to both their costs and their effects with regard to producing some outcome. In other words, it can be defined as an examination of the cost and the outcomes of the alternative means of accomplishing an objective, in order to select the one with the highest effectiveness relative to its cost.

The purpose of CEA in industrial sector is to ascertain which alternative or combination of alternatives can achieve particular objectives at the lowest cost. In this project, CEA is chosen as an appropriate tool that performs well in determining which alternative is more costly and which alternative is more effective. At the end of the day, the alternative that consumes the lowest cost while producing the highest output will be selected.

6.7.1 Assumptions for Cost-Effectiveness Analysis

Prior to start the CEA, several assumptions have to be made in order to achieve a more precise outcome. The assumptions include:

1. The manufacturing process operates 8 hours per day and 6 days per week.
2. The processing cycle time and machine downtimes are recorded in second.
3. There is no interruption when the production operation is started.
4. The timber is available all the time.
5. Fork-lift will be used for delivering timbers or parts from one station to another.
6. Efficiency of 85 percent is considered due to all the processes are human oriented, which defining that there is possibility for worker to excuse himself/ herself for wash room and having a short break during the fatigue condition.

6.7.2 Cost Estimation for Existing Layout

The calculation is made on this basis:

1. Admin officer's salary per month = RM 2,200 X 6 = RM 13,200
2. Clerk's salary per month = RM 1,200 X 3 = RM 3,600
3. Supervisor's salary per month = RM 1,800 X 1 = RM 1,800
4. Technician's salary per month = RM 1,000 X 1 = RM 1,000
5. Local worker's salary per month = RM 700 X 5 = RM 3,500
6. Foreign worker's salary per month = RM 500 X 20 = RM 10,000
7. Five percent interest of machine instalment is charged for 10 years duration.
8. Total chairs per hour = 5.5 units
9. Operating hour = 8 hours a day, 6 days a week, 4 weeks a month = 192 hours

Table 6.5: Cost estimation for existing production floor layout.

Cost Element	Cost per Month (RM)	Total Hours per Month	Cost per Hour (RM)
Direct Cost			
Raw Material Cost	5,023	192	26.16
Machine Cost			
- Cutting	522	192	2.72
- Sanding	419	192	2.18
- Laminating	1,565	192	8.15
- Shaping	561	192	2.92
- Drilling / Boring	659	192	3.43
- Brushing	307	192	1.60
- Finishing	2,880	192	15.00
Labor Cost			
- Admin	13,200	192	68.75
- Clerk	3,600	192	18.75
- Supervisor	1,800	192	9.38
- Technician	1,000	192	5.21
- Local Worker	3,500	192	18.23
- Foreign Worker	10,000	192	52.08
Overhead Cost			
Electricity	2,000	192	10.42
Water Usage	120	192	0.63
Maintenance	800	167.26	4.78
Total Cost per Hour			250.39
Cost for one Chair			45.53

6.7.3 Cost Estimation for Alternative 1 Layout

The calculation is made on this basis:

1. Admin officer's salary per month = RM 2,200 X 6 = RM 13,200
2. Clerk's salary per month = RM 1,200 X 3 = RM 3,600
3. Supervisor's salary per month = RM 1,800 X 1 = RM 1,800
4. Technician's salary per month = RM 1,000 X 1 = RM 1,000
5. Local worker's salary per month = RM 700 X 5 = RM 3,500
6. Foreign worker's salary per month = RM 500 X 20 = RM 10,000
7. Five percent interest of machine instalment is charged for 10 years duration.
8. Total chairs per hour = 5.6 units
9. Operating hour = 8 hours a day, 6 days a week, 4 weeks a month = 192 hours

Table 6.6: Cost estimation for Alternative 1 production floor layout.

Cost Element	Cost per Month (RM)	Total Hours per Month	Cost per Hour (RM)
Direct Cost			
Raw Material Cost	5,023	192	26.16
Machine Cost			
- Cutting	522	192	2.72
- Sanding	419	192	2.18
- Laminating	1,954	192	10.18
- Shaping	561	192	2.92
- Drilling / Boring	659	192	3.43
- Brushing	154	192	0.80
- Finishing	2,880	192	15.00
Labor Cost			
- Admin	13,200	192	68.75
- Clerk	3,600	192	18.75
- Supervisor	1,800	192	9.38
- Technician	1,000	192	5.21
- Local Worker	3,500	192	18.23
- Foreign Worker	10,000	192	52.08
Overhead Cost			
Electricity	2,000	192	10.42
Water Usage	120	192	0.63
Maintenance	800	167.26	4.78
Total Cost per Hour			251.62
Cost for one Chair			44.93

6.7.4 Cost Estimation for Alternative 2 Layout

The calculation is made on this basis:

1. Admin officer's salary per month = RM 2,200 X 6 = RM 13,200
2. Clerk's salary per month = RM 1,200 X 3 = RM 3,600
3. Supervisor's salary per month = RM 1,800 X 1 = RM 1,800
4. Technician's salary per month = RM 1,000 X 1 = RM 1,000
5. Local worker's salary per month = RM 700 X 5 = RM 3,500
6. Foreign worker's salary per month = RM 500 X 20 = RM 10,000
7. Five percent interest of machine instalment is charged for 10 years duration.
8. Total chairs per hour = 5.6 units
9. Operating hour = 8 hours a day, 6 days a week, 4 weeks a month = 192 hours

Table 6.7: Cost estimation for Alternative 2 production floor layout.

Cost Element	Cost per Month (RM)	Total Hours per Month	Cost per Hour (RM)
Direct Cost			
Raw Material Cost	5,023	192	26.16
Machine Cost			
- Cutting	522	192	2.72
- Sanding	278	192	1.45
- Laminating	1,565	192	8.15
- Shaping	561	192	2.92
- Drilling / Boring	659	192	3.43
- Brushing	307	192	1.60
- Finishing	2,880	192	15.00
Labor Cost			
- Admin	13,200	192	68.75
- Clerk	3,600	192	18.75
- Supervisor	1,800	192	9.38
- Technician	1,000	192	5.21
- Local Worker	3,500	192	18.23
- Foreign Worker	10,000	192	52.08
Overhead Cost			
Electricity	2,000	192	10.42
Water Usage	120	192	0.63
Maintenance	800	167.26	4.78
Total Cost per Hour			249.66
Cost for one Chair			44.58

6.7.5 Cost Estimation for Alternative 3 Layout

The calculation is made on this basis:

1. Admin officer's salary per month = RM 2,200 X 6 = RM 13,200
2. Clerk's salary per month = RM 1,200 X 3 = RM 3,600
3. Supervisor's salary per month = RM 1,800 X 1 = RM 1,800
4. Technician's salary per month = RM 1,000 X 1 = RM 1,000
5. Local worker's salary per month = RM 700 X 5 = RM 3,500
6. Foreign worker's salary per month = RM 500 X 20 = RM 10,000
7. Five percent interest of machine instalment is charged for 10 years duration.
8. Total chairs per hour = 5.75 units
9. Operating hour = 8 hours a day, 6 days a week, 4 weeks a month = 192 hours

Table 6.8: Cost estimation for Alternative 3 production floor layout.

Cost Element	Cost per Month (RM)	Total Hours per Month	Cost per Hour (RM)
Direct Cost			
Raw Material Cost	5,023	192	26.16
Machine Cost			
- Cutting	522	192	2.72
- Sanding	278	192	1.45
- Laminating	1,954	192	10.18
- Shaping	561	192	2.92
- Drilling / Boring	659	192	3.43
- Brushing	154	192	0.80
- Finishing	2,880	192	15.00
Labor Cost			
- Admin	13,200	192	68.75
- Clerk	3,600	192	18.75
- Supervisor	1,800	192	9.38
- Technician	1,000	192	5.21
- Local Worker	3,500	192	18.23
- Foreign Worker	10,000	192	52.08
Overhead Cost			
Electricity	2,000	192	10.42
Water Usage	120	192	0.63
Maintenance	800	167.26	4.78
Total Cost per Hour			250.89
Cost for one Chair			43.63

6.7.6 Results on Cost-Effectiveness Analysis

From the cost-effectiveness analysis above, the existing layout cost estimation for manufacturing a chair is RM 45.53. For Alternative 1, the cost of RM 44.93 is estimated for the proposed alternative. The cost needed for Alternative 2 and Alternative 3 are RM 44.58 and RM 43.63 respectively. The overall results of the cost estimation for all the layouts are summarized in Table 6.9.

Table 6.9: Summary of cost estimation for each layout.

Layout	Output Chair per Hour (Units)	Cost Estimated per Chair (RM)
Existing	5.50	45.53
Alternative 1	5.60	44.93
Alternative 2	5.60	44.58
Alternative 3	5.75	43.63

6.8 DISCUSSIONS

From Table 6.9, the layout that producing the lowest output of chairs is the actual existing layout, with 5.5 units per hour. In addition, for this actual existing layout, the cost estimated for one unit of chair is RM45.53, which is the highest if compared with the three proposed layouts.

For the proposed layout of Alternative 1, which is adding a Laminating machine while one Brushing machine is reduced, the output of chairs produced per hour is 5.6 units, which is little increment from the existing layout. Furthermore, the cost estimated for this alternative is RM44.93 for one chair, which is 1.34% reduction from the existing layout.

In Alternative 2, the output of chairs produced is the same with Alternative 1 which is 5.6 units per hour. Although there is no increment from Alternative 1, but it increases from 5.5 units of existing layout to 5.6 units. On the other hand, the estimated cost for this alternative is RM44.58, which is lower than the cost of existing and Alternative 1.

Lastly, for the proposed layout of Alternative 3, the output of chairs produced is the optimum among all, which has a total of 5.75 units of chair per hour. This figure is of 4.55% higher than existing layout and 2.68% higher than Alternative 1 and 2. Moreover, this alternative is able to produce a chair in the shortest time of 483.39s and lowest cost of RM43.63, which is RM1.90 lesser than the existing layout. This would be the best alternative suggested among the three proposed layouts. Besides, it has the highest upper value of 4.274 in the one way ANOVA test with multiple comparison results on the output chairs. Therefore, Alternative 3 can be identified as the most efficient production floor layout in improving productivity while reducing costs.

The summary of the output of chairs per hour and the production cost for one unit of chair are plotted in the graphs as shown in Figure 6.7 and Figure 6.8 respectively.

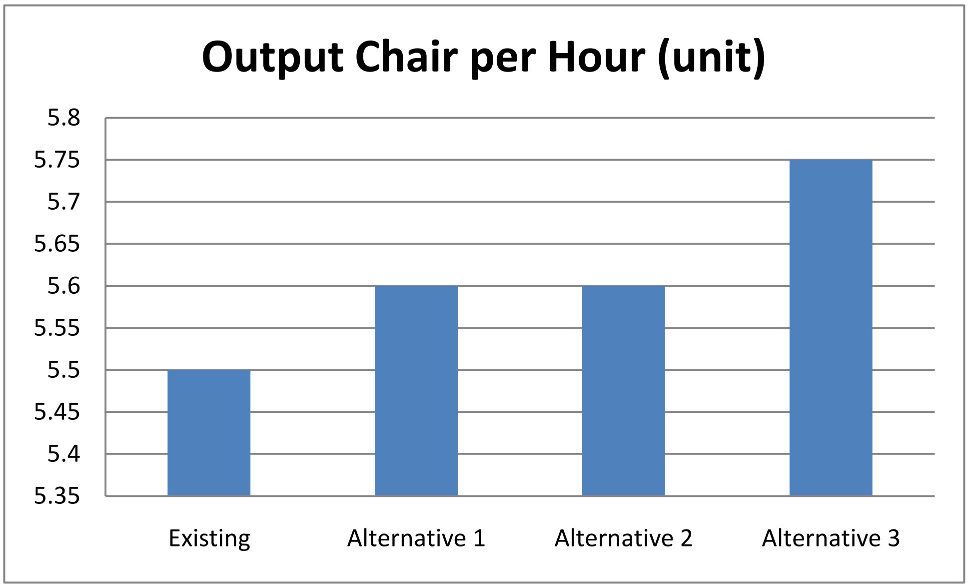

Figure 6.7: Graph of output chair per hour.

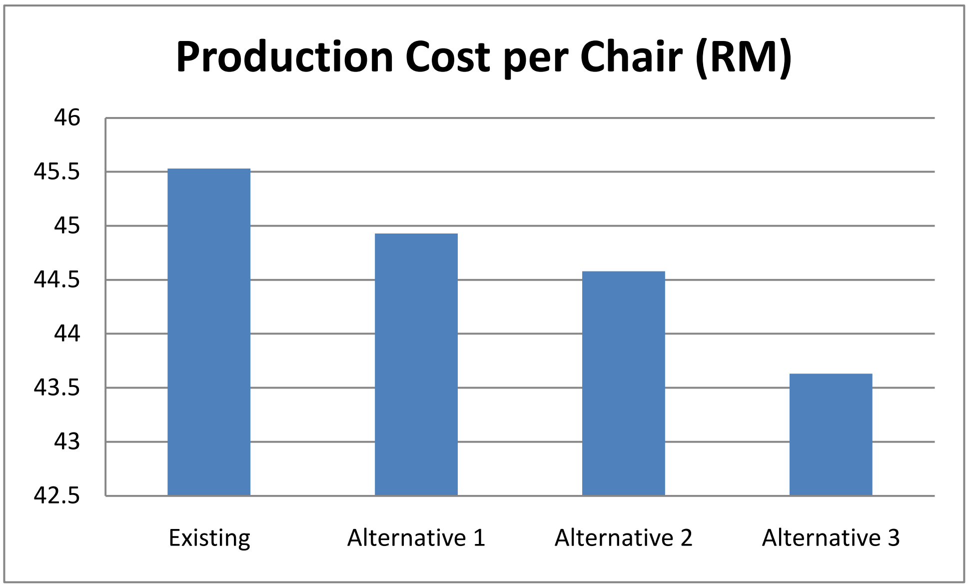

Figure 6.8: Graph of production cost per chair.

6.9 CONCLUSIONS

This chapter discussed the results generated from the simulation existing layout and the three alternative layouts to increase the output of chairs. The statistical method of non-parametric test and one way ANOVA test were used after simulation. The Cost-effectiveness Analysis has also been done in order to select the most productivity excel production floor layout. This chapter ends with the discussion of the reasonable and feasible of the results obtained.

CHAPTER 7

CONCLUSIONS

7.1 INTRODUCTION

In this chapter, the conclusion and project summary will be discussed. The most efficient layout out of all the suggested alternatives should be chosen to improve the company productivity and to be proposed to the company. This chapter continues with project findings, and further recommendations to further improve the project in the future.

7.2 PROJECT SUMMARY

This project started with searching for a suitable production floor layout to be studied. The layout might be any kind of manufacturing industry. In this project, LHF had been chosen for the purpose of conducting this experiment considering its low productivity on chair production.

After selection of company, evaluation of the existing floor layout for the company is carried out and major problems are identified. These problems include the longer time taken at the laminating process which causing the congestion in the whole system. Besides, the extra of sanding machine and brushing machine contributing to the high cost of machine expenses. Therefore, scopes and objectives are created in order to solve these problems.

To overcome these problems, three alternatives layouts are suggested to improve the output of the production. These proposed alternatives are, additional of a

Laminating machine and reduction of a Brushing machine, combination of Sanding II and Sanding III process after Drilling process, and lastly is combination of the previous two alternatives.

7.3 FINDINGS

From the results obtained in previous chapter, the most efficient production floor layout would definitely be the Alternative 3 which suggests the combination of Alternative 1 and Alternative 2. This alternative able to produce the most output of 5.75 units of chair at the shortest time of 483.39s. Moreover, the cost for one chair is estimated to be RM43.63, which is the lowest cost if compared with the other alternatives. This selection was also supported by the one way ANOVA with multiple comparison tests, in which this alternative has the highest upper value of 4.274.

Alternative 1 and Alternative 2, on the other hand, are rejected due to the low productivity performance. Both of these alternatives give an average output of chair of 5.6 units per hour. Alternative 1, produce a chair in 492.67s, which is the same as the existing layout. However, it reduces the cost from RM45.53 of existing layout to RM44.93 of this proposed layout. Alternative 2, which is combining the Sanding II and Sanding III process after Drilling process, able to produce an output of 5.6 units of chair per hour, but in the longest time of 501.04s. Besides, the cost estimated for one chair of this alternative is RM44.58, which is 2.09% reduction from the existing layout. Anyway, these two alternatives are not the ideal one comparing to the Alternative 3.

7.4 FURTHER RECOMMENDATIONS

The Alternative 3 is applicable for the other production lines which use the same machine, process and machine arrangement. They would be production of table, dining sets, desks, barstools and such. Apart from the three suggested alternatives, there are several other alternatives that can be applied in order to increase the productivity. These include, rearrange the machines to shorten the distance from one station to another, rearrange the machines in sequence, add machines, or even add operator accordingly if the investments are practical.

In this project, the data for process cycle time and machine downtime were taken, however, set up time was not in the concern. This is due to the time taken for setting up machine is somewhat short, and thus it is not considered. Nevertheless, it is suggested that an extensive study consisting of set up time be included to achieve a more accurate outcome and reality production output.

In addition, criterion that must be considered in simulation is the rules that have been used in the simulation software such as push and sequence. In WITNESS Simulation software, there are a lot of details can be inserted. Other than the process cycle time, machine downtime, and the set up time, the types of machine can be selected too. The types of machine include single, batch, assembly, production, general, multiple cycle, and multiple station. It is recommended that the types of machine to be identified so that a correct results can be achieved.

7.5 CONCLUSIONS

In conclusion, the project has been carried out smoothly and achieved the project objectives. The production floor layout has been evaluated and the three alternatives to improve the productivity have been suggested. The alternatives proposed have been justified to be able to increase the productivity by WITNESS Simulation Model. At the end of the day, the best alternative that able to increase output and meantime reduce cost was selected and proposed to the LHF for implementation.

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APPENDIX A

PROJECT GANTT CHART

Name : Tee Chun Teck
Matrix No.: ME07060
Project Title : Productivity Improvement for Furniture Industry by using WITNESS Simulation Software
Supervisor : Mr. Hadi Bin Abdul Salaam
Session : 2009/2010 Sem 2 (FYP 1)

Week / Activity		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project Title Confirmation																
Discuss the idea of project with Supervisor	Planning															
	Actual	●														
Clarify the project title, objectives, and scopes	Planning															
	Actual	●														
I. Project Progress																
Arrange weekly meeting with Supervisor	Planning															
	Actual	●														
Search articles, journals and books relevant to the title	Planning															
	Actual	●	●	●	●	●	●	●	●	●	●	●	●			
Discussion about report content	Planning															
	Actual		●													
Find company for the project	Planning															
	Actual		●	●	●	●	●	●	●	●	●					
Writing on Introduction	Planning															
	Actual					●	●									
Writing on Literature Review	Planning															
	Actual						●	●	●	●						
Writing on Company Background	Planning															
	Actual											●				

Writing on Methodology	Planning										■	■	■			
	Actual									●	●	●				
Data collection and writing on Preliminary Results	Planning												■	■		
	Actual												●	●		
Checking and editing report	Planning													■	■	
	Actual													●	●	
Prepare presentation slides	Planning														■	
	Actual														●	
Presentation	Planning															■
	Actual															●

Activity \ Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
II. Simulation Progress																
Collect existing production layout plan	Planning							■	■	■						
	Actual											●				
Observe existing process flow	Planning									■	■					
	Actual											●	●			
Construct data collection table	Planning										■	■				
	Actual												●			
Data collection	Planning												■	■		
	Actual													●	●	
Determine sample size, n	Planning													■		
	Actual															●
Determine type of distribution	Planning														■	
	Actual															
Build conceptual model	Planning															■
	Actual															

Name : Tee Chun Teck
Matrix No.: ME07060
Project Title : Productivity Improvement for Furniture Industry by using WITNESS Simulation Software
Supervisor : Mr. Hadi Bin Abdul Salaam
Session : 2010/2011 Sem 1 (FYP 2)

Week / Activity		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
I. Project Progress																
Edit project report of FYP 1	Planning	■														
	Actual	●														
Problem analysis	Planning	■	■	■	■	■										
	Actual		●	●	●	●	●									
Data collection	Planning				■	■	■	■								
	Actual						●	●	●	●	●					
Data analysis	Planning								■							
	Actual										●	●				
Writing on Results	Planning								■	■	■					
	Actual										●	●	●			
Writing on Discussions	Planning										■	■	■			
	Actual												●	●		
Writing on Conclusions and Recommendations	Planning												■	■		
	Actual														●	
Checking and editing report	Planning														■	
	Actual														●	
Prepare presentation slides	Planning														■	
	Actual														●	
Presentation and thesis submission	Planning															■
	Actual															●

Week / Activity		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
II. Simulation Progress																
Determine type of distribution	Planning															
	Actual	●	●													
Build conceptual model	Planning															
	Actual			●	●											
Model verification	Planning															
	Actual						●	●	●							
Model validation	Planning															
	Actual									●	●					
Model experimentation	Planning															
	Actual											●	●			
Statistical analysis	Planning															
	Actual													●		
Results analysis	Planning															
	Actual														●	

APPENDIX B
EXAMPLE OF SAMPLE SIZE CALCULATION
(PROCESS CYCLE TIME)

Cycle Time for Cutting Process

Observation (n)	**Time, s (X_i)**	$(X_i - \bar{X})^2$
1	352.255	38.007
2	356.215	4.862
3	365.395	48.651
4	347.910	110.460
5	376.180	315.418
6	350.135	68.641
7	360.130	2.924
8	361.790	11.357
9	370.260	140.186
10	343.945	209.526
Total	3584.215	950.032

Mean, $\bar{X} = \Sigma X_i/10$

$= 3584.215/10$

$= 358.42\ s$

Standard Deviation, $s = \sqrt{\Sigma(X_i - \bar{X})^2/_{n-1}}$

$= \sqrt{950.032/_{10-1}}$

$= 10.274$

By using 95% of confidence level with $\pm 5\%$ of error, $t_{0.05,\,9} = 1.833$

Sample Size, $n = (ts/k\bar{X})^2$

$= [(1.833 \times 10.274)/(0.05 \times 358.42)]^2$

$= 1.104$

≈ 2

APPENDIX C

SUMMARY OF CYCLE TIME DATA AND SAMPLE SIZE

Observation (n)	Process Cycle Time (s)									
	Cutting	Sanding I	Laminating	Shaping	Sanding II	Drilling/ Boring	Sanding III	Brushing	Assembly	Finishing
1	352.255	297.765	1947.470	560.625	357.185	485.360	383.245	310.605	922.165	671.180
2	356.215	299.275	1943.225	556.845	351.610	485.730	375.190	301.060	922.395	673.675
3	365.395	282.295	1931.560	562.790	365.195	479.595	370.515	313.140	932.875	661.745
4	347.910	308.040	1957.035	572.670	368.260	474.465	390.555	321.995	938.030	657.865
5	376.180	294.890	1960.260	554.965	358.310	500.045	399.480	324.665	913.195	677.650
6	350.135	282.410	1945.905	545.440	342.145	503.660	385.770	309.435	910.025	687.105
7	360.130	307.960	1946.240	574.230	340.370	481.755	397.620	303.480	931.455	667.690
8	361.790	310.505	1956.545	561.705	356.580	469.790	368.425	299.945	941.415	688.710
9	370.260	292.745	1934.315	568.220	375.785	488.880	362.330	328.580	924.015	684.920
10	343.945	282.300	1932.770	565.500	372.515	504.050	395.955	310.860	915.945	665.670
Mean, $\bar{X}$	358.42	295.82	1945.53	562.30	358.80	487.33	382.91	312.38	925.15	673.62
s	10.274	10.974	10.350	8.605	11.942	11.929	13.226	9.902	10.562	10.786
n	1.104	1.850	0.038	0.315	1.489	0.805	1.603	1.350	0.175	0.345

APPENDIX D
DATA ANALYSIS WITH CHI-SQUARE TEST
(PROCESS CYCLE TIME)

APPENDIX D1

Chi-Square Test Calculation For Cutting Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	352.255	1.4104	1.98922816	0.040596493
2	356.215	5.3704	28.84119616	0.58859584
3	365.395	14.5504	211.7141402	4.320696738
4	347.910	-2.9346	8.61187716	0.175752595
5	376.180	25.3354	641.8824932	13.09964272
6	350.135	-0.7096	0.50353216	0.010276167
7	360.130	9.2854	86.21865316	1.75956435
8	361.790	10.9454	119.8017812	2.444934309
9	370.260	19.4154	376.9577572	7.693015452
10	343.945	-6.8996	47.60448016	0.971520003
11	318.725	-32.1196	1031.668704	21.05446335
12	316.570	-34.2746	1174.748205	23.97445317
13	328.665	-22.1796	491.9346562	10.03948278
14	382.115	31.2704	977.8379162	19.95587584
15	337.140	-13.7046	187.8160612	3.83298084
16	334.505	-16.3396	266.9825282	5.448623024
17	384.040	33.1954	1101.934581	22.48846084
18	346.170	-4.6746	21.85188516	0.44595684
19	362.890	12.0454	145.0916612	2.961054309
20	380.765	29.9204	895.2303362	18.27000686
21	352.395	1.5504	2.40374016	0.049055922
22	362.280	11.4354	130.7683732	2.668742309
23	315.225	-35.6196	1268.755904	25.89297764
24	357.260	6.4154	41.15735716	0.839946064
25	368.865	18.0204	324.7348162	6.627241146
26	316.765	-34.0796	1161.419136	23.70243135
27	385.260	34.4154	1184.419757	24.17183178
28	321.505	-29.3396	860.8121282	17.56759445
29	347.745	-3.0996	9.60752016	0.19607184
30	366.030	15.1854	230.5963732	4.706048432
31	314.410	-36.4346	1327.480077	27.09143015
32	380.675	29.8304	889.8527642	18.16026049
33	358.890	8.0454	64.72846116	1.320989003
34	338.640	-12.2046	148.9522612	3.039842064
35	336.450	-14.3946	207.2045092	4.228663452
36	373.415	22.5704	509.4229562	10.39638686
37	353.450	2.6054	6.78810916	0.13853284
38	317.745	-33.0996	1095.58352	22.35884735
39	333.135	-17.7096	313.6299322	6.40061086

40	360.880	10.0354	100.7092532	2.055290881
41	356.035	5.1904	26.94025216	0.549801064
42	316.960	-33.8846	1148.166117	23.43196157
43	387.275	36.4304	1327.174044	27.08518457
44	357.830	6.9854	48.79581316	0.995832922
45	355.395	4.5504	20.70614016	0.422574289
46	319.295	-31.5496	995.3772602	20.31382164
47	350.875	0.0304	0.00092416	1.88604E-05
48	370.415	19.5704	383.0005562	7.816337881
49	339.210	-11.6346	135.3639172	2.762528922
50	352.120	1.2754	1.62664516	0.03319684
Total				444.600006

Mean, μ = 350.8446

Standard Deviation, $\sigma = \sqrt{444.600006}$

$= 21.08554021$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	310 – 319.9	8	0.125	6.25	0.49
2	320 – 329.9	2	0.125	6.25	2.89
3	330 – 339.9	6	0.125	6.25	0.01
4	340 – 349.9	4	0.125	6.25	0.81
5	350 – 359.9	12	0.125	6.25	5.29
6	360 – 369.9	8	0.125	6.25	0.49
7	370 – 379.9	4	0.125	6.25	0.81
8	380 – 389.9	6	0.125	6.25	0.01
Total		50			10.80

Degree of freedom = K – 1 = 7;   Desired significant level, $\alpha = 0.05$

$\chi^2_{7,\,0.05} = 14.067$

$\chi^2_{calc} = 10.80$

Since $\chi^2_{calc} < \chi^2_{7,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	310 – 319.9	8	0.0029	0.0115	0.7372	71.5522
2	320 – 329.9	2	0.0029	0.0112	0.1790	18.5254
3	330 – 339.9	6	0.0029	0.0109	0.5217	57.5269
4	340 – 349.9	4	0.0029	0.0106	0.3379	39.6892
5	350 – 359.9	12	0.0029	0.0103	0.9846	123.2369
6	360 – 369.9	8	0.0029	0.0100	0.6377	84.9984
7	370 – 379.9	4	0.0029	0.0097	0.3097	43.9726
8	380 – 389.9	6	0.0029	0.0094	0.4513	68.2209
Total		50				507.7225

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 507.7225$

Since $\chi^2_{calc} > \chi^2_{6,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	310 – 319.9	8	0.0447	2.8608	9.2322
2	320 – 329.9	2	0.0885	1.4160	0.2409
3	330 – 339.9	6	0.1404	6.7392	0.0811
4	340 – 349.9	4	0.1786	5.7152	0.5148
5	350 – 359.9	12	0.1822	17.4912	1.7239
6	360 – 369.9	8	0.1490	9.5360	0.2474
7	370 – 379.9	4	0.0977	3.1264	0.2441
8	380 – 389.9	6	0.0514	2.4672	5.0586
Total		50			17.3430

Degree of freedom = K – 3 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 17.3430$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

APPENDIX D2

Chi-Square Test Calculation For Sanding I Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n - 1$
1	297.765	-2.4445	5.97558025	0.121950617
2	299.275	-0.9345	0.87329025	0.01782225
3	282.295	-17.9145	320.9293102	6.54957776
4	308.040	7.8305	61.31673025	1.251361842
5	294.890	-5.3195	28.29708025	0.577491434
6	282.410	-17.7995	316.8222002	6.465759189
7	307.960	7.7505	60.07025025	1.225923474
8	310.505	10.2955	105.9973203	2.163210617
9	292.745	-7.4645	55.71876025	1.137117556
10	282.300	-17.9095	320.7501902	6.54592225
11	265.450	-34.7595	1208.22284	24.65760898
12	270.910	-29.2995	858.4607002	17.51960613
13	301.260	1.0505	1.10355025	0.022521434
14	321.125	20.9155	437.4581403	8.927717148
15	286.280	-13.9295	194.0309702	3.959815719
16	332.485	32.2755	1041.7079	21.2593449
17	313.630	13.4205	180.1098203	3.675710617
18	284.320	-15.8895	252.4762102	5.152575719
19	276.345	-23.8645	569.5143602	11.62274205
20	298.160	-2.0495	4.20045025	0.085723474
21	328.360	28.1505	792.4506503	16.17246225
22	317.745	17.5355	307.4937603	6.275382862
23	266.725	-33.4845	1121.21174	22.88187225
24	318.690	18.4805	341.5288803	6.969977148
25	278.625	-21.5845	465.8906402	9.50797225
26	304.170	3.9605	15.68556025	0.320113474
27	320.550	20.3405	413.7359403	8.443590617
28	292.165	-8.0445	64.71398025	1.320693474
29	332.140	31.9305	1019.55683	20.80728225
30	297.340	-2.8695	8.23403025	0.168041434
31	302.135	1.9255	3.70755025	0.075664291
32	269.250	-30.9595	958.4906402	19.56103347
33	310.625	10.4155	108.4826403	2.213931434
34	327.180	26.9705	727.4078703	14.84505858
35	287.665	-12.5445	157.3644802	3.211520005
36	305.180	4.9705	24.70587025	0.504201434
37	277.130	-23.0795	532.6633202	10.87068001
38	303.395	3.1855	10.14741025	0.207090005
39	316.050	15.8405	250.9214403	5.120845719

40	325.505	25.2955	639.8623203	13.0584147
41	298.850	-1.3595	1.84824025	0.037719189
42	316.470	16.2605	264.4038603	5.395997148
43	268.125	-32.0845	1029.41514	21.00847225
44	311.420	11.2105	125.6753103	2.56480225
45	293.560	-6.6495	44.21585025	0.902364291
46	337.605	37.3955	1398.42342	28.53925347
47	283.205	-17.0045	289.1530202	5.901082046
48	308.360	8.1505	66.43065025	1.355727556
49	307.945	7.7355	59.83796025	1.221182862
50	296.160	-4.0495	16.39845025	0.33466225
Total				352.7365941

Mean, μ = 300.2095

Standard Deviation, $\sigma = \sqrt{352.7365941}$

$= 18.78128308$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	260 – 269.9	4	0.125	6.25	0.81
2	270 – 279.9	4	0.125	6.25	0.81
3	280 – 289.9	7	0.125	6.25	0.09
4	290 – 299.9	10	0.125	6.25	2.25
5	300 – 309.9	9	0.125	6.25	1.21
6	310 – 319.9	8	0.125	6.25	0.49
7	320 – 329.9	5	0.125	6.25	0.25
8	330 – 339.9	3	0.125	6.25	1.69
Total		50			7.60

Degree of freedom = K – 1 = 7;   Desired significant level, $\alpha = 0.05$

$\chi^2_{7,\,0.05} = 14.067$

$\chi^2_{calc} = 7.60$

Since $\chi^2_{calc} < \chi^2_{7,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	260 – 269.9	4	0.0033	0.0136	0.4361	29.1249
2	270 – 279.9	4	0.0033	0.0132	0.4219	30.3456
3	280 – 289.9	7	0.0033	0.0128	0.7145	55.2939
4	290 – 299.9	10	0.0033	0.0123	0.9875	82.2533
5	300 – 309.9	9	0.0033	0.0119	0.8599	77.0569
6	310 – 319.9	8	0.0033	0.0116	0.7396	71.2729
7	320 – 329.9	5	0.0033	0.0112	0.4472	46.3506
8	330 – 339.9	3	0.0033	0.0108	0.2596	28.9283
Total		50				420.6264

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 420.6264$

Since $\chi^2_{calc} > \chi^2_{6,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	260 – 269.9	4	0.0371	1.1872	6.6643
2	270 – 279.9	4	0.0859	2.7488	0.5695
3	280 – 289.9	7	0.1506	8.4336	0.2437
4	290 – 299.9	10	0.2001	16.0080	2.2549
5	300 – 309.9	9	0.2015	14.5080	2.0911
6	310 – 319.9	8	0.1539	9.8496	0.3473
7	320 – 329.9	5	0.0890	3.5600	0.5825
8	330 – 339.9	3	0.0391	0.9384	4.5292
Total		50			17.2825

Degree of freedom = K – 3 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 17.2825$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

APPENDIX D3

Chi-Square Test Calculation For Laminating Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	1947.470	1.6879	2.84900641	0.058142988
2	1943.225	-2.5571	6.53876041	0.13344409
3	1931.560	-14.2221	202.2681284	4.127920988
4	1957.035	11.2529	126.6277584	2.584239968
5	1960.260	14.4779	209.6095884	4.277746702
6	1945.905	0.1229	0.01510441	0.000308253
7	1946.240	0.4579	0.20967241	0.004279029
8	1956.545	10.7629	115.8400164	2.364081968
9	1934.315	-11.4671	131.4943824	2.683558825
10	1932.770	-13.0121	169.3147464	3.455402988
11	1978.845	33.0629	1093.155356	22.30929299
12	1967.645	21.8629	477.9863964	9.754824417
13	1940.250	-5.5321	30.60413041	0.62457409
14	1912.240	-33.5421	1125.072472	22.9606627
15	1973.450	27.6679	765.5126904	15.62270797
16	1956.420	10.6379	113.1649164	2.30948809
17	1925.505	-20.2771	411.1607844	8.391036417
18	1963.500	17.7179	313.9239804	6.406611845
19	1914.905	-30.8771	953.3953044	19.45704703
20	1944.050	-1.7321	3.00017041	0.061227968
21	1974.665	28.8829	834.2219124	17.02493699
22	1958.040	12.2579	150.2561124	3.066451274
23	1923.140	-22.6421	512.6646924	10.46254474
24	1917.330	-28.4521	809.5219944	16.52085703
25	1966.665	20.8829	436.0955124	8.899908417
26	1922.435	-23.3471	545.0870784	11.12422609
27	1911.170	-34.6121	1197.997466	24.44892789
28	1920.745	-25.0371	626.8563764	12.79298727
29	1961.125	15.3429	235.4045804	4.80417511
30	1943.160	-2.6221	6.87540841	0.140314457
31	1958.445	12.6629	160.3490364	3.272429314
32	1971.225	25.4429	647.3411604	13.21104409
33	1945.530	-0.2521	0.06355441	0.001297029
34	1951.335	5.5529	30.83469841	0.629279559
35	1938.830	-6.9521	48.33169441	0.98636111
36	1932.460	-13.3221	177.4783484	3.62200711
37	1979.245	33.4629	1119.765676	22.85236074
38	1927.845	-17.9371	321.7395564	6.566113396
39	1947.745	1.9629	3.85297641	0.078632172

40	1973.050	27.2679	743.5383704	15.17425246
41	1918.650	-27.1321	736.1508504	15.02348674
42	1935.575	-10.2071	104.1848904	2.126222253
43	1977.630	31.8479	1014.288734	20.69977009
44	1953.360	7.5779	57.42456841	1.171929968
45	1958.465	12.6829	160.8559524	3.282774539
46	1926.690	-19.0921	364.5082824	7.438944539
47	1944.350	-1.4321	2.05091041	0.041855314
48	1935.645	-10.1371	102.7607964	2.09715911
49	1917.640	-28.1421	791.9777924	16.16281209
50	1964.780	18.9979	360.9202044	7.365718457
Total				378.6763787

Mean, μ = 1945.7821

Standard Deviation, $\sigma = \sqrt{378.6763787}$

$= 19.4596089$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1910 – 1919.9	6	0.1429	7.145	0.1835
2	1920 – 1929.9	6	0.1429	7.145	0.1835
3	1930 – 1939.9	7	0.1429	7.145	0.0029
4	1940 – 1949.9	10	0.1429	7.145	1.1408
5	1950 – 1959.9	8	0.1429	7.145	0.1023
6	1960 – 1969.9	6	0.1429	7.145	0.1835
7	1970 – 1979.9	7	0.1429	7.145	0.0029
Total		50			1.7994

Degree of freedom = K – 1 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\ 0.05} = 12.592$

$\chi^2_{calc} = 1.7994$

Since $\chi^2_{calc} < \chi^2_{6,\ 0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1\text{-}e^{-\alpha k}) - (1\text{-}e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1910 – 1919.9	6	0.0005	1.9001E-3	0.0798	439.2076
2	1920 – 1929.9	6	0.0005	1.8906E-3	0.0794	441.4799
3	1930 – 1939.9	7	0.0005	1.8812E-3	0.0922	517.5456
4	1940 – 1949.9	10	0.0005	1.8718E-3	0.1310	743.4898
5	1950 – 1959.9	8	0.0005	1.8625E-3	0.1043	597.7189
6	1960 – 1969.9	6	0.0005	1.8532E-3	0.0778	450.8027
7	1970 – 1979.9	7	0.0005	1.8440E-3	0.0904	528.1258
Total		50				3718.3703

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 3718.3703$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1910 – 1919.9	6	0.0588	2.4696	5.0469
2	1920 – 1929.9	6	0.1146	4.8132	0.2926
3	1930 – 1939.9	7	0.1725	8.4525	0.2496
4	1940 – 1949.9	10	0.2006	14.0420	1.1635
5	1950 – 1959.9	8	0.1801	10.0856	0.4313
6	1960 – 1969.9	6	0.1249	5.2458	0.1084
7	1970 – 1979.9	7	0.0669	3.2781	4.2258
Total		50			11.5181

Degree of freedom = K – 3 = 4; Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\,0.05} = 9.488$

$\chi^2_{calc} = 11.5181$

Since $\chi^2_{calc} > \chi^2_{4,\,0.05}$; **Reject**

APPENDIX D4

Chi-Square Test Calculation For Shaping Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	560.625	-1.6302	2.65755204	0.054235756
2	556.845	-5.4102	29.27026404	0.597352327
3	562.790	0.5348	0.28601104	0.00583696
4	572.670	10.4148	108.468059	2.213633858
5	554.965	-7.2902	53.14701604	1.08463298
6	545.440	-16.8152	282.750951	5.770427572
7	574.230	11.9748	143.395835	2.926445613
8	561.705	-0.5502	0.30272004	0.00617796
9	568.220	5.9648	35.57883904	0.726098756
10	565.500	3.2448	10.52872704	0.21487198
11	546.610	-15.6452	244.772283	4.995352715
12	555.185	-7.0702	49.98772804	1.020157715
13	556.595	-5.6602	32.03786404	0.65383396
14	576.630	14.3748	206.634875	4.217038266
15	553.780	-8.4752	71.82901504	1.465898266
16	571.220	8.9648	80.36763904	1.640155899
17	563.445	1.1898	1.41562404	0.028890287
18	545.625	-16.6302	276.563552	5.644154123
19	557.620	-4.6352	21.48507904	0.438471001
20	575.860	13.6048	185.090583	3.777358838
21	567.325	5.0698	25.70287204	0.524548409
22	553.260	-8.9952	80.91362304	1.651298429
23	574.280	12.0248	144.595815	2.950935001
24	567.670	5.4148	29.32005904	0.598368552
25	548.810	-13.4452	180.773403	3.689253123
26	558.730	-3.5252	12.42703504	0.25361296
27	567.705	5.4498	29.70032004	0.60612898
28	563.220	0.9648	0.93083904	0.018996715
29	564.145	1.8898	3.57134404	0.072884572
30	564.755	2.4998	6.24900004	0.127530613
31	578.050	15.7948	249.475707	5.09134096
32	568.845	6.5898	43.42546404	0.88623396
33	578.650	16.3948	268.789467	5.485499327
34	568.965	6.7098	45.02141604	0.918804409
35	562.120	-0.1352	0.01827904	0.000373042
36	552.515	-9.7402	94.87149604	1.93615298
37	562.325	0.0698	0.00487204	9.94294E-05
38	565.610	3.3548	11.25468304	0.229687409
39	552.310	-9.9452	98.90700304	2.018510266

40	547.765	-14.4902	209.965896	4.285018287
41	573.060	10.8048	116.743703	2.382524552
42	555.645	-6.6102	43.69474404	0.89172947
43	568.025	5.7698	33.29059204	0.679399838
44	561.245	-1.0102	1.02050404	0.020826613
45	559.250	-3.0052	9.03122704	0.184310756
46	562.790	0.5348	0.28601104	0.00583696
47	569.230	6.9748	48.64783504	0.99281296
48	548.840	-13.4152	179.967591	3.67280798
49	564.620	2.3648	5.59227904	0.114128144
50	557.440	-4.8152	23.18615104	0.473186756
Total				78.24386629

Mean, μ = 562.2552

Standard Deviation, $\sigma = \sqrt{78.24386629}$

$= 8.845556302$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	545 – 549.9	6	0.1429	7.145	0.1835
2	550 – 554.9	5	0.1429	7.145	0.6440
3	555 – 559.9	8	0.1429	7.145	0.1023
4	560 – 564.9	12	0.1429	7.145	3.2990
5	565 – 569.9	10	0.1429	7.145	1.1408
6	570 – 574.9	5	0.1429	7.145	0.6440
7	575 – 579.9	4	0.1429	7.145	1.3843
Total		50			7.3979

Degree of freedom = K – 1 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 7.3979$

Since $\chi^2_{calc} < \chi^2_{6,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1\text{-}e^{-\alpha k}) - (1\text{-}e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	545 – 549.9	6	0.0018	3.2924E-3	0.1383	248.4420
2	550 – 554.9	5	0.0018	3.2629E-3	0.1142	209.0284
3	555 – 559.9	8	0.0018	3.2337E-3	0.1811	337.5770
4	560 – 564.9	12	0.0018	3.2047E-3	0.2692	511.1875
5	565 – 569.9	10	0.0018	3.1760E-3	0.2223	430.0649
6	570 – 574.9	5	0.0018	3.1475E-3	0.1102	216.9705
7	575 – 579.9	4	0.0018	3.1193E-3	0.0873	175.3634
Total		50				2128.6337

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 2128.6337$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	545 – 549.9	6	0.0557	2.3394	5.7280
2	550 – 554.9	5	0.1199	4.1965	0.1538
3	555 – 559.9	8	0.1890	10.5840	0.6309
4	560 – 564.9	12	0.2182	18.3288	2.1853
5	565 – 569.9	10	0.1844	12.9080	0.6551
6	570 – 574.9	5	0.1142	3.9970	0.2517
7	575 – 579.9	4	0.0518	1.4504	4.4818
Total		50			14.0866

Degree of freedom = K – 3 = 4; Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\,0.05} = 9.488$

$\chi^2_{calc} = 14.0866$

Since $\chi^2_{calc} > \chi^2_{4,\,0.05}$; **Reject**

APPENDIX D5

Chi-Square Test Calculation For Sanding II Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	357.185	-3.6244	13.13627536	0.268087252
2	351.610	-9.1994	84.62896036	1.72712164
3	365.195	4.3856	19.23348736	0.39252015
4	368.260	7.4506	55.51144036	1.132886538
5	358.310	-2.4994	6.24700036	0.127489803
6	342.145	-18.6644	348.3598274	7.109384232
7	340.370	-20.4394	417.7690724	8.525899436
8	356.580	-4.2294	17.88782436	0.36505764
9	375.785	14.9756	224.2685954	4.576910109
10	372.515	11.7056	137.0210714	2.796348395
11	336.625	-24.1844	584.8852034	11.93643272
12	381.140	20.3306	413.3332964	8.435373395
13	346.705	-14.1044	198.9340994	4.059879579
14	376.195	15.3856	236.7166874	4.830952803
15	373.670	12.8606	165.3950324	3.375408824
16	352.145	-8.6644	75.07182736	1.532078109
17	360.170	-0.6394	0.40883236	0.008343518
18	384.250	23.4406	549.4617284	11.21350466
19	347.670	-13.1394	172.6438324	3.523343518
20	358.610	-2.1994	4.83736036	0.09872164
21	377.500	16.6906	278.5761284	5.685227109
22	362.450	1.6406	2.69156836	0.054929967
23	374.200	13.3906	179.3081684	3.659350375
24	346.515	-14.2944	204.3298714	4.169997375
25	382.025	21.2156	450.1016834	9.18574864
26	368.310	7.5006	56.25900036	1.148142864
27	363.145	2.3356	5.45502736	0.111327089
28	351.195	-9.6144	92.43668736	1.886463007
29	371.845	11.0356	121.7844674	2.485397293
30	338.170	-22.6394	512.5424324	10.46004964
31	367.670	6.8606	47.06783236	0.960568007
32	380.260	19.4506	378.3258404	7.720935518
33	362.370	1.5606	2.43547236	0.049703518
34	349.220	-11.5894	134.3141924	2.741105967
35	356.580	-4.2294	17.88782436	0.36505764
36	335.675	-25.1344	631.7380634	12.89261354
37	355.145	-5.6644	32.08542736	0.65480464
38	372.610	11.8006	139.2541604	2.84192164
39	353.240	-7.5694	57.29581636	1.169302375

40	342.230	-18.5794	345.1941044	7.04477764
41	366.050	5.2406	27.46388836	0.560487518
42	383.185	22.3756	500.6674754	10.21770358
43	364.705	3.8956	15.17569936	0.30970815
44	339.250	-21.5594	464.8077284	9.485872007
45	358.680	-2.1294	4.53434436	0.09253764
46	378.240	17.4306	303.8258164	6.200526864
47	350.965	-9.8444	96.91221136	1.977800232
48	361.515	0.7056	0.49787136	0.01016064
49	348.440	-12.3694	153.0020564	3.122490946
50	373.950	13.1406	172.6753684	3.523987109
Total				186.8244425

Mean, μ = 360.8094

Standard Deviation, $\sigma = \sqrt{186.8244425}$

$= 13.66837381$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	330 – 339.9	4	0.1667	8.333	2.2531
2	340 – 349.9	8	0.1667	8.333	0.0133
3	350 – 359.9	12	0.1667	8.333	1.6137
4	360 – 369.9	11	0.1667	8.333	0.8536
5	370 – 379.9	10	0.1667	8.333	0.3335
6	380 – 389.9	5	0.1667	8.333	1.3331
Total		50			6.4003

Degree of freedom = K – 1 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5, 0.05} = 11.070$

$\chi^2_{calc} = 6.4003$

Since $\chi^2_{calc} < \chi^2_{5, 0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	(1-$e^{-\alpha k}$) – (1-$e^{-\alpha j}$)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	330 – 339.9	4	0.0028	0.0109	0.2616	53.4237
2	340 – 349.9	8	0.0028	0.0106	0.5088	110.2950
3	350 – 359.9	12	0.0028	0.0103	0.7416	170.9164
4	360 – 369.9	11	0.0028	0.0100	0.6600	161.9933
5	370 – 379.9	10	0.0028	0.0097	0.5820	152.4033
6	380 – 389.9	5	0.0028	0.0094	0.2820	78.9345
Total		50				727.9662

j = Class lower boundary;   k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 4;   Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\,0.05} = 9.488$

$\chi^2_{calc} = 727.9662$

Since $\chi^2_{calc} > \chi^2_{4,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	330 – 339.9	4	0.0509	1.2216	6.3192
2	340 – 349.9	8	0.1484	7.1232	0.1079
3	350 – 359.9	12	0.2590	18.6480	2.3700
4	360 – 369.9	11	0.2706	17.8596	2.6347
5	370 – 379.9	10	0.1694	10.1640	0.0026
6	380 – 389.9	5	0.0635	1.9050	5.0284
Total		50			16.4628

Degree of freedom = K – 3 = 3;   Desired significant level, $\alpha = 0.05$

$\chi^2_{3,\,0.05} = 7.815$

$\chi^2_{calc} = 16.4628$

Since $\chi^2_{calc} > \chi^2_{3,\,0.05}$; **Reject**

APPENDIX D6

Chi-Square Test Calculation For Drilling / Boring Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	485.360	-2.4185	5.84914225	0.11937025
2	485.730	-2.0485	4.19635225	0.085639842
3	479.595	-8.1835	66.96967225	1.366728005
4	474.465	-13.3135	177.2492823	3.617332291
5	500.045	12.2665	150.4670223	3.070755556
6	503.660	15.8815	252.2220423	5.147388617
7	481.755	-6.0235	36.28255225	0.74046025
8	469.790	-17.9885	323.5861323	6.603798617
9	488.880	1.1015	1.21330225	0.02476127
10	504.050	16.2715	264.7617123	5.40330025
11	465.360	-22.4185	502.5891423	10.25692127
12	491.395	3.6165	13.07907225	0.266919842
13	453.125	-34.6535	1200.865062	24.50745025
14	486.790	-0.9885	0.97713225	0.019941474
15	522.160	34.3815	1182.087542	24.12423556
16	476.505	-11.2735	127.0918023	2.59371025
17	515.765	27.9865	783.2441822	15.98457515
18	481.255	-6.5235	42.55605225	0.868490862
19	513.640	25.8615	668.8171822	13.64933025
20	483.665	-4.1135	16.92088225	0.345324128
21	471.105	-16.6735	278.0056023	5.673583719
22	497.170	9.3915	88.20027225	1.800005556
23	492.040	4.2615	18.16038225	0.370620046
24	458.620	-29.1585	850.2181223	17.35139025
25	481.930	-5.8485	34.20495225	0.69806025
26	504.215	16.4365	270.1585322	5.513439434
27	495.790	8.0115	64.18413225	1.30988025
28	486.630	-1.1485	1.31905225	0.026919434
29	473.215	-14.5635	212.0955323	4.32848025
30	498.115	10.3365	106.8432323	2.180474128
31	455.050	-32.7285	1071.154712	21.86030025
32	511.185	23.4065	547.8642423	11.1809029
33	466.620	-21.1585	447.6821223	9.136369842
34	486.135	-1.6435	2.70109225	0.055124332
35	523.905	36.1265	1305.124002	26.63518372
36	462.260	-25.5185	651.1938423	13.28967025
37	494.910	7.1315	50.85829225	1.037924332
38	517.130	29.3515	861.5105522	17.58184801
39	457.770	-30.0085	900.5100723	18.37775658

40	503.945	16.1665	261.3557223	5.33379025
41	482.650	-5.1285	26.30151225	0.536765556
42	515.135	27.3565	748.3780922	15.27302229
43	477.275	-10.5035	110.3235123	2.25150025
44	520.810	33.0315	1091.079992	22.26693862
45	494.180	6.4015	40.97920225	0.83631025
46	483.175	-4.6035	21.19221225	0.432494128
47	454.340	-33.4385	1118.133282	22.81904658
48	472.820	-14.9585	223.7567223	4.566463719
49	492.615	4.8365	23.39173225	0.477382291
50	495.195	7.4165	55.00447225	1.12254025
Total				353.1206217

Mean, $\mu = 487.7785$

Standard Deviation, $\sigma = \sqrt{353.1206217}$

$= 18.79150398$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	450 – 459.9	5	0.125	6.25	0.25
2	460 – 469.9	4	0.125	6.25	0.81
3	470 – 479.9	7	0.125	6.25	0.09
4	480 – 489.9	12	0.125	6.25	5.29
5	490 – 499.9	9	0.125	6.25	1.21
6	500 – 509.9	5	0.125	6.25	0.25
7	510 – 519.9	5	0.125	6.25	0.25
8	520 – 529.9	3	0.125	6.25	1.69
Total		50			9.84

Degree of freedom = K – 1 = 7; Desired significant level, $\alpha = 0.05$

$\chi^2_{7,\,0.05} = 14.067$

$\chi^2_{calc} = 9.84$

Since $\chi^2_{calc} < \chi^2_{7,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	450 – 459.9	5	0.0020	7.9709E-3	0.3188	68.7379
2	460 – 469.9	4	0.0020	7.8131E-3	0.2500	56.2500
3	470 – 479.9	7	0.0020	7.6584E-3	0.4289	100.6746
4	480 – 489.9	12	0.0020	7.5067E-3	0.7206	176.5541
5	490 – 499.9	9	0.0020	7.3581E-3	0.5298	135.4177
6	500 – 509.9	5	0.0020	7.2124E-3	0.2885	76.9436
7	510 – 519.9	5	0.0020	7.0696E-3	0.2828	78.6845
8	520 – 529.9	3	0.0020	6.9296E-3	0.1663	48.2854
Total		50				741.5478

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 741.5478$

Since $\chi^2_{calc} > \chi^2_{6,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	450 – 459.9	5	0.0468	1.8720	5.2267
2	460 – 469.9	4	0.1010	3.2320	0.1825
3	470 – 479.9	7	0.1655	9.2680	0.5550
4	480 – 489.9	12	0.2055	19.7280	3.0273
5	490 – 499.9	9	0.1935	13.9320	1.7460
6	500 – 509.9	5	0.1382	5.5280	0.0504
7	510 – 519.9	5	0.0748	2.9920	1.3476
8	520 – 529.9	3	0.0307	0.7368	6.9518
Total		50			19.0873

Degree of freedom = K – 3 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 19.0873$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

APPENDIX D7

Chi-Square Test Calculation For Sanding III Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	383.245	-5.893	34.727449	0.708723449
2	375.190	-13.948	194.546704	3.970340898
3	370.515	-18.623	346.816129	7.077880184
4	390.555	1.417	2.007889	0.040977327
5	399.480	10.342	106.956964	2.182795184
6	385.770	-3.368	11.343424	0.231498449
7	397.620	8.482	71.944324	1.46825151
8	368.425	-20.713	429.028369	8.755681
9	362.330	-26.808	718.668864	14.66671151
10	395.955	6.817	46.471489	0.948397735
11	420.730	31.592	998.054464	20.36845845
12	353.160	-35.978	1294.416484	26.41666294
13	381.125	-8.013	64.208169	1.310370796
14	408.830	19.692	387.774864	7.913772735
15	386.665	-2.473	6.115729	0.124810796
16	350.920	-38.218	1460.615524	29.80848008
17	418.275	29.137	848.964769	17.32581161
18	372.625	-16.513	272.679169	5.564881
19	363.105	-26.033	677.717089	13.830961
20	424.110	34.972	1223.040784	24.960016
21	411.650	22.512	506.790144	10.342656
22	392.245	3.107	9.653449	0.197009163
23	402.250	13.112	171.924544	3.508664163
24	355.940	-33.198	1102.107204	22.49198376
25	388.875	-0.263	0.069169	0.001411612
26	359.250	-29.888	893.292544	18.23046008
27	383.770	-5.368	28.815424	0.588069878
28	378.355	-10.783	116.273089	2.372920184
29	416.885	27.747	769.896009	15.71216345
30	396.170	7.032	49.449024	1.009163755
31	427.745	38.607	1490.500449	30.41837651
32	393.645	4.507	20.313049	0.41455202
33	353.450	-35.688	1273.633344	25.99251722
34	406.670	17.532	307.371024	6.272878041
35	401.040	11.902	141.657604	2.89097151
36	372.250	-16.888	285.204544	5.820500898
37	383.140	-5.998	35.976004	0.734204163
38	354.420	-34.718	1205.339524	24.5987658
39	378.260	-10.878	118.330884	2.414916

40	392.040	2.902	8.421604	0.171869469
41	402.785	13.647	186.240609	3.800828755
42	429.140	40.002	1600.160004	32.65632661
43	374.125	-15.013	225.390169	4.599799367
44	423.320	34.182	1168.409124	23.84508416
45	407.830	18.692	349.390864	7.130425796
46	385.015	-4.123	16.999129	0.346921
47	417.925	28.787	828.691369	16.91206876
48	388.580	-0.558	0.311364	0.006354367
49	377.860	-11.278	127.193284	2.595781306
50	393.640	4.502	20.268004	0.413632735
Total				454.1667592

Mean, μ = 389.138

Standard Deviation, $\sigma = \sqrt{454.1667592}$

$= 21.31118859$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	350 – 359.9	6	0.125	6.25	0.01
2	360 – 369.9	3	0.125	6.25	1.69
3	370 – 379.9	8	0.125	6.25	0.49
4	380 – 389.9	9	0.125	6.25	1.21
5	390 – 399.9	9	0.125	6.25	1.21
6	400 – 409.9	6	0.125	6.25	0.01
7	410 – 419.9	4	0.125	6.25	0.81
8	420 – 429.9	5	0.125	6.25	0.25
Total		50			5.68

Degree of freedom = K – 1 = 7; Desired significant level, $\alpha = 0.05$

$\chi^2_{7,\,0.05} = 14.067$

$\chi^2_{calc} = 5.68$

Since $\chi^2_{calc} < \chi^2_{7,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	350 – 359.9	6	0.0026	10.2288E-3	0.4910	61.8108
2	360 – 369.9	3	0.0026	9.9662E-3	0.2392	31.8646
3	370 – 379.9	8	0.0026	9.7105E-3	0.6215	87.5982
4	380 – 389.9	9	0.0026	9.4612E-3	0.6812	101.5890
5	390 – 399.9	9	0.0026	9.2184E-3	0.6637	104.7068
6	400 – 409.9	6	0.0026	8.9818E-3	0.4311	71.9384
7	410 – 419.9	4	0.0026	8.7513E-3	0.2800	49.4229
8	420 – 429.9	5	0.0026	8.5267E-3	0.3411	63.6334
Total		50				572.5641

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 572.5641$

Since $\chi^2_{calc} > \chi^2_{6,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	350 – 359.9	6	0.0519	2.4912	4.9421
2	360 – 369.9	3	0.0976	2.3424	0.1846
3	370 – 379.9	8	0.1477	9.4528	0.2233
4	380 – 389.9	9	0.1802	12.9744	1.2175
5	390 – 399.9	9	0.1771	12.7512	1.1035
6	400 – 409.9	6	0.1402	6.7296	0.0791
7	410 – 419.9	4	0.0894	2.8608	0.4536
8	420 – 429.9	5	0.0459	1.8360	5.4526
Total		50			13.6563

Degree of freedom = K – 3 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 13.6563$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

APPENDIX D8

Chi-Square Test Calculation For Brushing Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	310.605	-1.6072	2.58309184	0.05271616
2	301.060	-11.1522	124.3715648	2.538195201
3	313.140	0.9278	0.86081284	0.017567609
4	321.995	9.7828	95.70317584	1.953126038
5	324.665	12.4528	155.0722278	3.164739344
6	309.435	-2.7772	7.71283984	0.157404895
7	303.480	-8.7322	76.25131684	1.556149323
8	299.945	-12.2672	150.4841958	3.071106038
9	328.580	16.3678	267.9048768	5.467446466
10	310.860	-1.3522	1.82844484	0.037315201
11	325.175	12.9628	168.0341838	3.429269058
12	304.020	-8.1922	67.11214084	1.369635527
13	318.890	6.6778	44.59301284	0.910061487
14	296.245	-15.9672	254.9514758	5.203091344
15	304.220	-7.9922	63.87526084	1.303576752
16	317.005	4.7928	22.97093184	0.468794527
17	304.125	-8.0872	65.40280384	1.334751099
18	306.750	-5.4622	29.83562884	0.608890384
19	298.880	-13.3322	177.7475568	3.62750116
20	308.870	-3.3422	11.17030084	0.227965323
21	316.645	4.4328	19.64971584	0.401014609
22	329.450	17.2378	297.1417488	6.064117323
23	308.165	-4.0472	16.37982784	0.334282201
24	315.650	3.4378	11.81846884	0.241193242
25	303.930	-8.2822	68.59483684	1.399894629
26	297.785	-14.4272	208.1440998	4.247838772
27	305.335	-6.8772	47.29587984	0.965222038
28	312.125	-0.0872	0.00760384	0.00015518
29	317.745	5.5328	30.61187584	0.62473216
30	323.370	11.1578	124.4965008	2.540744915
31	322.750	10.5378	111.0452288	2.26622916
32	328.660	16.4478	270.5301248	5.521022956
33	319.240	7.0278	49.38997284	1.007958629
34	324.260	12.0478	145.1494848	2.962234384
35	303.740	-8.4722	71.77817284	1.46486067
36	296.280	-15.9322	253.8349968	5.180306058
37	327.505	15.2928	233.8697318	4.77285167
38	310.115	-2.0972	4.39824784	0.08976016
39	314.340	2.1278	4.52753284	0.092398629

40	297.625	-14.5872	212.7864038	4.34257967
41	311.550	-0.6622	0.43850884	0.00894916
42	303.240	-8.9722	80.50037284	1.642864752
43	321.125	8.9128	79.43800384	1.621183752
44	317.780	5.5678	31.00039684	0.63266116
45	326.165	13.9528	194.6806278	3.973074038
46	308.440	-3.7722	14.22949284	0.290397813
47	313.775	1.5628	2.44234384	0.049843752
48	298.770	-13.4422	180.6927408	3.687606956
49	320.235	8.0228	64.36531984	1.313577956
50	306.870	-5.3422	28.53910084	0.582430629
Total				94.82128996

Mean, $\mu = 312.2122$

Standard Deviation, $\sigma = \sqrt{94.82128996}$

$= 9.737622398$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	295 – 299.9	7	0.1429	7.145	0.0029
2	300 – 304.9	8	0.1429	7.145	0.1023
3	305 – 309.9	7	0.1429	7.145	0.0029
4	310 – 314.9	8	0.1429	7.145	0.1023
5	315 – 319.9	7	0.1429	7.145	0.0029
6	320 – 324.9	7	0.1429	7.145	0.0029
7	325 – 329.9	6	0.1429	7.145	0.1835
Total		50			0.3997

Degree of freedom = K – 1 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 0.3997$

Since $\chi^2_{calc} < \chi^2_{6,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	295 – 299.9	7	0.0032	6.0530E-3	0.2966	151.5023
2	300 – 304.9	8	0.0032	5.9569E-3	0.3336	176.1801
3	305 – 309.9	7	0.0032	5.8624E-3	0.2873	156.8407
4	310 – 314.9	8	0.0032	5.7693E-3	0.3231	182.4042
5	315 – 319.9	7	0.0032	5.6778E-3	0.2782	162.4105
6	320 – 324.9	7	0.0032	5.5876E-3	0.2738	165.2365
7	325 – 329.9	6	0.0032	5.4989E-3	0.2310	144.0752
Total		50				1138.6495

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\ 0.05} = 11.070$

$\chi^2_{calc} = 1138.6495$

Since $\chi^2_{calc} > \chi^2_{5,\ 0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	295 – 299.9	7	0.0645	3.1605	4.6644
2	300 – 304.9	8	0.1214	6.7984	0.2124
3	305 – 309.9	7	0.1767	8.6583	0.3176
4	310 – 314.9	8	0.1986	11.1216	0.8762
5	315 – 319.9	7	0.1724	8.4476	0.2481
6	320 – 324.9	7	0.1156	5.6644	0.3149
7	325 – 329.9	6	0.0599	2.5158	4.8254
Total		50			11.4590

Degree of freedom = K – 3 = 4; Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\ 0.05} = 9.488$

$\chi^2_{calc} = 11.4590$

Since $\chi^2_{calc} > \chi^2_{4,\ 0.05}$; **Reject**

APPENDIX D9

Chi-Square Test Calculation For Assembly Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n - 1$
1	922.165	-26.4424	699.2005178	14.26939832
2	922.395	-26.2124	687.0899138	14.02224314
3	932.875	-15.7324	247.5084098	5.051192036
4	938.030	-10.5774	111.8813908	2.283293689
5	913.195	-35.4124	1254.038074	25.59261375
6	910.025	-38.5824	1488.60159	30.37962428
7	931.455	-17.1524	294.2048258	6.004180118
8	941.415	-7.1924	51.73061776	1.055726893
9	924.015	-24.5924	604.7861378	12.34257424
10	915.945	-32.6624	1066.832374	21.77208926
11	975.430	26.8226	719.4518708	14.68269124
12	994.120	45.5126	2071.396759	42.27340324
13	986.460	37.8526	1432.819327	29.24121075
14	905.235	-43.3724	1881.165082	38.39112412
15	932.820	-15.7874	249.2419988	5.086571403
16	967.740	19.1326	366.0563828	7.470538424
17	952.125	3.5176	12.37350976	0.252520607
18	997.750	49.1426	2414.995135	49.285615
19	947.880	-0.7274	0.52911076	0.010798179
20	914.865	-33.7424	1138.549558	23.23570526
21	953.440	4.8326	23.35402276	0.476612709
22	982.620	34.0126	1156.856959	23.60932569
23	966.450	17.8426	318.3583748	6.497109689
24	924.365	-24.2424	587.6939578	11.99375424
25	907.870	-40.7374	1659.535759	33.86807671
26	954.845	6.2376	38.90765376	0.79403375
27	962.960	14.3526	205.9971268	4.204022995
28	974.060	25.4526	647.8348468	13.22111932
29	992.270	43.6626	1906.422639	38.90658446
30	967.745	19.1376	366.2477338	7.474443546
31	945.665	-2.9424	8.65771776	0.176688118
32	978.005	29.3976	864.2188858	17.63712012
33	909.250	-39.3574	1549.004935	31.61234561
34	941.030	-7.5774	57.41699076	1.171775322
35	958.860	10.2526	105.1158068	2.145220546
36	963.225	14.6176	213.6742298	4.360698567
37	937.815	-10.7924	116.4758978	2.377059138
38	955.045	6.4376	41.44269376	0.84576926
39	908.825	-39.7824	1582.63935	32.29876224

40	923.340	-25.2674	638.4415028	13.02941842
41	981.145	32.5376	1058.695414	21.60602885
42	983.330	34.7226	1205.658951	24.60528471
43	946.490	-2.1174	4.48338276	0.091497607
44	990.245	41.6376	1733.689734	35.38142314
45	926.740	-21.8674	478.1831828	9.758840464
46	985.350	36.7426	1350.018655	27.55140112
47	915.275	-33.3324	1111.04889	22.67446714
48	957.760	9.1526	83.77008676	1.709593607
49	978.240	29.6326	878.0909828	17.92022414
50	932.170	-16.4374	270.1881188	5.51404324
Total				756.2158584

Mean, μ = 948.6074

Standard Deviation, $\sigma = \sqrt{756.2158584}$

$= 27.49937924$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	900 – 919.9	9	0.2	10	0.1
2	920 – 939.9	12	0.2	10	0.4
3	940 – 959.9	11	0.2	10	0.1
4	960 – 979.9	9	0.2	10	0.1
5	980 – 999.9	9	0.2	10	0.1
Total		50			0.8

Degree of freedom = K – 1 = 4; Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\ 0.05} = 9.488$

$\chi^2_{calc} = 0.8$

Since $\chi^2_{calc} < \chi^2_{4,\ 0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	900 – 919.9	9	0.0011	8.0454E-3	0.3620	206.1189
2	920 – 939.9	12	0.0011	7.8704E-3	0.4722	281.4277
3	940 – 959.9	11	0.0011	7.6991E-3	0.4235	264.1378
4	960 – 979.9	9	0.0011	7.5316E-3	0.3389	221.3475
5	980 – 999.9	9	0.0011	7.3677E-3	0.3315	226.6754
Total		50				1199.7073

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 3; Desired significant level, $\alpha = 0.05$

$\chi^2_{3,\ 0.05} = 7.815$

$\chi^2_{calc} = 1199.7073$

Since $\chi^2_{calc} > \chi^2_{3,\ 0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	900 – 919.9	9	0.1097	4.9365	3.3449
2	920 – 939.9	12	0.2267	13.6020	0.1887
3	940 – 959.9	11	0.2822	15.5210	1.3169
4	960 – 979.9	9	0.2118	9.5310	0.0296
5	980 – 999.9	9	0.0957	4.3065	5.1153
Total		50			9.9954

Degree of freedom = K – 3 = 2; Desired significant level, $\alpha = 0.05$

$\chi^2_{2,\ 0.05} = 5.991$

$\chi^2_{calc} = 9.9954$

Since $\chi^2_{calc} > \chi^2_{2,\ 0.05}$; **Reject**

APPENDIX D10

Chi-Square Test Calculation For Finishing Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	671.180	-0.0425	0.00180625	3.68622E-05
2	673.675	2.4525	6.01475625	0.122750128
3	661.745	-9.4775	89.82300625	1.833122577
4	657.865	-13.3575	178.4228063	3.64128176
5	677.650	6.4275	41.31275625	0.843117474
6	687.105	15.8825	252.2538062	5.148036862
7	667.690	-3.5325	12.47855625	0.254664413
8	688.710	17.4875	305.8126562	6.241074617
9	684.920	13.6975	187.6215062	3.829010332
10	665.670	-5.5525	30.83025625	0.629188903
11	639.245	-31.9775	1022.560506	20.86858176
12	703.140	31.9175	1018.726806	20.79034298
13	675.800	4.5775	20.95350625	0.427622577
14	640.005	-31.2175	974.5323063	19.88841441
15	688.655	17.4325	303.8920562	6.201878699
16	708.430	37.2075	1384.398056	28.25302156
17	693.870	22.6475	512.9092562	10.46753584
18	642.440	-28.7825	828.4323063	16.90678176
19	680.200	8.9775	80.59550625	1.64480625
20	672.055	0.8325	0.69305625	0.014144005
21	655.880	-15.3425	235.3923063	4.803924617
22	674.450	3.2275	10.41675625	0.212586862
23	653.345	-17.8775	319.6050063	6.522551148
24	676.900	5.6775	32.23400625	0.657836862
25	683.380	12.1575	147.8048062	3.016424617
26	702.525	31.3025	979.8465062	19.99686747
27	647.715	-23.5075	552.6025563	11.27760319
28	657.340	-13.8825	192.7238063	3.933138903
29	673.480	2.2575	5.09630625	0.10400625
30	662.285	-8.9375	79.87890625	1.63018176
31	675.505	4.2825	18.33980625	0.37428176
32	648.830	-22.3925	501.4240563	10.23314401
33	692.205	20.9825	440.2653062	8.98500625
34	666.870	-4.3525	18.94425625	0.386617474
35	635.855	-35.3675	1250.860056	25.52775625
36	672.880	1.6575	2.74730625	0.056067474
37	653.375	-17.8475	318.5332563	6.500678699
38	705.240	34.0175	1157.190306	23.6161287
39	687.620	16.3975	268.8780062	5.48730625

40	665.740	-5.4825	30.05780625	0.613424617
41	697.905	26.6825	711.9558062	14.52971033
42	674.560	3.3375	11.13890625	0.227324617
43	665.440	-5.7825	33.43730625	0.682394005
44	659.405	-11.8175	139.6533063	2.850067474
45	663.390	-7.8325	61.34805625	1.252001148
46	701.145	29.9225	895.3560062	18.27257156
47	691.115	19.8925	395.7115562	8.075746046
48	646.780	-24.4425	597.4358063	12.19256747
49	638.745	-32.4775	1054.788006	21.52628584
50	651.170	-20.0525	402.1027563	8.206178699
Total				369.7557941

Mean, μ = 671.2225

Standard Deviation, $\sigma = \sqrt{369.7557941}$

$= 19.22903518$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	630 – 639.9	3	0.125	6.25	1.69
2	640 – 649.9	5	0.125	6.25	0.25
3	650 – 659.9	7	0.125	6.25	0.09
4	660 – 669.9	8	0.125	6.25	0.49
5	670 – 679.9	11	0.125	6.25	3.61
6	680 – 689.9	7	0.125	6.25	0.09
7	690 – 699.9	4	0.125	6.25	0.81
8	700 – 709.9	5	0.125	6.25	0.25
Total		50			7.28

Degree of freedom = K – 1 = 7;   Desired significant level, $\alpha = 0.05$

$\chi^2_{7,\,0.05} = 14.067$

$\chi^2_{calc} = 7.28$

Since $\chi^2_{calc} < \chi^2_{7,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1\text{-}e^{-\alpha k}) - (1\text{-}e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	630 – 639.9	3	0.0015	5.7292E-3	0.1375	59.5920
2	640 – 649.9	5	0.0015	5.6439E-3	0.2258	100.9432
3	650 – 659.9	7	0.0015	5.5599E-3	0.3114	143.6653
4	660 – 669.9	8	0.0015	5.4771E-3	0.3505	166.9468
5	670 – 679.9	11	0.0015	5.3956E-3	0.4748	233.3189
6	680 – 689.9	7	0.0015	5.3153E-3	0.2977	150.8929
7	690 – 699.9	4	0.0015	5.2361E-3	0.1676	87.6330
8	700 – 709.9	5	0.0015	5.1582E-3	0.2063	111.3890
Total		50				1054.3811

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 1054.3811$

Since $\chi^2_{calc} > \chi^2_{6,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	630 – 639.9	3	0.0356	0.8544	5.3881
2	640 – 649.9	5	0.0815	3.2600	0.9287
3	650 – 659.9	7	0.1431	8.0136	0.1282
4	660 – 669.9	8	0.1928	12.3392	1.5259
5	670 – 679.9	11	0.1994	17.5472	2.4429
6	680 – 689.9	7	0.1583	8.8648	0.3923
7	690 – 699.9	4	0.0965	3.0880	0.2693
8	700 – 709.9	5	0.0451	1.8040	5.6621
Total		50			16.7375

Degree of freedom = K – 3 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 16.7375$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

APPENDIX E
EXAMPLE OF SAMPLE SIZE CALCULATION
(MACHINE DOWNTIME)

Machine Downtime for Cutting Process

Observation (n)	**Time, s (X_i)**	$(X_i - \bar{X})^2$
1	3524.7	39295.1329
2	3136.3	36164.6289
3	3364.5	1446.2809
4	3218.9	11571.3049
5	3582.7	65653.8129
6	3427.6	10227.2769
7	3365.1	1492.2769
8	3029.0	88488.4009
9	3504.5	31694.6809
10	3111.4	46255.1049
Total	33264.7	332288.901

Mean, $\bar{X} = \Sigma X_i / 10$

$= 33264.7/10$

$= 3326.47\ s$

Standard Deviation, $s = \sqrt{\Sigma(X_i - \bar{X})^2 / n-1}$

$= \sqrt{332288.901 / 10-1}$

$= 192.148$

By using 95% of confidence level with $\pm 5\%$ of error, $t_{0.05,\,9} = 1.833$

Sample Size, $n = (ts/k\bar{X})^2$

$= [(1.833 \times 192.148)/(0.05 \times 3326.47)]^2$

$= 4.484$

≈ 5

APPENDIX F

SUMMARY OF MACHINE DOWNTIME DATA AND SAMPLE SIZE

Observation (n)	Machine Downtime (s)									
	Cutting	Sanding I	Laminating	Shaping	Sanding II	Drilling/ Boring	Sanding III	Brushing	Assembly	Finishing
1	3524.7	1963.7	3778.4	2568.3	2638.5	1966.9	1896.8	1967.7	1896.7	2194.4
2	3136.3	2020.3	4123.6	2456.7	2388.4	1897.4	1997.0	2134.3	2045.3	2038.4
3	3364.5	2143.5	4036.5	2859.1	2164.1	2343.2	2018.3	2385.6	2013.7	1987.4
4	3218.9	1966.5	3918.7	2547.6	2565.3	2202.1	1974.1	1927.5	2384.0	1921.1
5	3582.7	2364.1	3781.5	2639.2	2117.9	2013.8	2301.4	2302.7	2352.1	2133.2
6	3427.6	2225.4	3667.1	2876.7	2209.4	2117.9	2313.1	1964.0	1865.7	2246.0
7	3365.1	1845.6	3781.4	2763.8	2436.8	1923.7	2014.0	2311.7	1977.6	2383.5
8	3029.0	2310.9	3864.0	2974.9	2695.0	1886.0	2115.5	2012.3	1998.2	2017.4
9	3504.5	2003.6	3925.1	2654.9	2383.5	1920.7	1949.5	2114.9	2009.3	1985.5
10	3111.4	1944.3	3766.3	2871.8	2411.4	2017.9	1896.7	1976.4	2111.4	2333.2
Mean, $\bar{X}$	3326.47	2078.79	3864.26	2721.30	2401.03	2028.96	2047.64	2109.71	2065.40	2124.01
s	192.148	172.676	138.702	172.127	195.695	149.586	150.776	168.869	174.039	159.419
n	4.484	9.273	1.731	5.377	8.928	7.305	7.287	8.611	9.543	7.571

APPENDIX G
DATA ANALYSIS WITH CHI-SQUARE TEST
(MACHINE DOWNTIME)

APPENDIX G1

Chi-Square Test Calculation For Cutting Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	3524.7	171.1	29275.21	597.4532653
2	3136.3	-217.3	47219.29	963.6589796
3	3364.5	10.9	118.81	2.424693878
4	3218.9	-134.7	18144.09	370.287551
5	3582.7	229.1	52486.81	1071.159388
6	3427.6	74	5476	111.755102
7	3365.1	11.5	132.25	2.698979592
8	3029.0	-324.6	105365.16	2150.309388
9	3504.5	150.9	22770.81	464.7104082
10	3111.4	-242.2	58660.84	1197.16
11	3298.5	-55.1	3036.01	61.95938776
12	3108.6	-245	60025	1225
13	3366.8	13.2	174.24	3.555918367
14	3274.1	-79.5	6320.25	128.9846939
15	3637.5	283.9	80599.21	1644.881837
16	3311.2	-42.4	1797.76	36.68897959
17	3418.2	64.6	4173.16	85.16653061
18	3263.7	-89.9	8082.01	164.9389796
19	3047.6	-306	93636	1910.938776
20	3188.7	-164.9	27192.01	554.9389796
21	3461.0	107.4	11534.76	235.4032653
22	3382.0	28.4	806.56	16.46040816
23	3652.8	299.2	89520.64	1826.951837
24	3378.4	24.8	615.04	12.55183673
25	3587.2	233.6	54568.96	1113.652245
26	3055.8	-297.8	88684.84	1809.894694
27	3429.6	76	5776	117.877551
28	3327.4	-26.2	686.44	14.00897959
29	3482.5	128.9	16615.21	339.0859184
30	3285.5	-68.1	4637.61	94.64510204
31	3493.2	139.6	19488.16	397.717551
32	3345.6	-8	64	1.306122449
33	3697.2	343.6	118060.96	2409.407347
34	3399.2	45.6	2079.36	42.43591837
35	3087.3	-266.3	70915.69	1447.25898
36	3394.5	40.9	1672.81	34.13897959
37	3443.2	89.6	8028.16	163.84
38	3245.6	-108	11664	238.0408163
39	3521.3	167.7	28123.29	573.9446939

40	3466.7	113.1	12791.61	261.0532653
41	3623.8	270.2	73008.04	1489.96
42	3372.1	18.5	342.25	6.984693878
43	3077.6	-276	76176	1554.612245
44	3412.3	58.7	3445.69	70.32020408
45	3143.6	-210	44100	900
46	3321.9	-31.7	1004.89	20.50795918
47	3596.4	242.8	58951.84	1203.098776
48	3093.7	-259.9	67548.01	1378.530816
49	3456.7	103.1	10629.61	216.9308163
50	3266.3	-87.3	7621.29	155.5365306
Total				30894.82939

Mean, μ = 3353.600

Standard Deviation, $\sigma = \sqrt{30894.82939}$

$= 175.7692504$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	3000 – 3099.9	6	0.1429	7.145	0.1835
2	3100 – 3199.9	5	0.1429	7.145	0.6440
3	3200 – 3299.9	7	0.1429	7.145	0.0029
4	3300 – 3399.9	12	0.1429	7.145	3.2990
5	3400 – 3499.9	10	0.1429	7.145	1.1408
6	3500 – 3599.9	6	0.1429	7.145	0.1835
7	3600 – 3699.9	4	0.1429	7.145	1.3843
Total		50			6.8380

Degree of freedom = K – 1 = 6;   Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 6.8380$

Since $\chi^2_{calc} < \chi^2_{6,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	3000 – 3099.9	6	0.000298	0.0120	0.5040	59.9326
2	3100 – 3199.9	5	0.000298	0.0116	0.4060	51.9824
3	3200 – 3299.9	7	0.000298	0.0113	0.5537	75.0493
4	3300 – 3399.9	12	0.000298	0.0110	0.9240	132.7682
5	3400 – 3499.9	10	0.000298	0.0106	0.7420	115.5129
6	3500 – 3599.9	6	0.000298	0.0103	0.4326	71.6504
7	3600 – 3699.9	4	0.000298	0.0100	0.2800	49.4229
Total		50				556.3187

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 556.3187$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	3000 – 3099.9	6	0.0523	2.1966	6.5856
2	3100 – 3199.9	5	0.1164	4.0740	0.2105
3	3200 – 3299.9	7	0.1889	9.2561	0.5499
4	3300 – 3399.9	12	0.2237	18.7908	2.4541
5	3400 – 3499.9	10	0.1933	13.5310	0.9214
6	3500 – 3599.9	6	0.1219	5.1198	0.1513
7	3600 – 3699.9	4	0.0561	1.5708	3.7567
Total		50			14.6295

Degree of freedom = K – 3 = 4; Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\,0.05} = 9.488$

$\chi^2_{calc} = 14.6295$

Since $\chi^2_{calc} > \chi^2_{4,\,0.05}$; **Reject**

APPENDIX G2

Chi-Square Test Calculation For Sanding I Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	1963.7	-159.242	25358.01456	517.5105013
2	2020.3	-102.642	10535.38016	215.0077584
3	2143.5	20.558	422.631364	8.625129878
4	1966.5	-156.442	24474.09936	499.4714156
5	2364.1	241.158	58157.18096	1186.881244
6	2225.4	102.458	10497.64176	214.237587
7	1845.6	-277.342	76918.58496	1569.76704
8	2310.9	187.958	35328.20976	720.9838727
9	2003.6	-119.342	14242.51296	290.6635299
10	1944.3	-178.642	31912.96416	651.2849829
11	2368.8	245.858	60446.15616	1233.595024
12	2184.1	61.158	3740.300964	76.33267273
13	1862.3	-260.642	67934.25216	1386.413309
14	2487.6	364.658	132975.457	2713.784836
15	1976.4	-146.542	21474.55776	438.2562809
16	2017.3	-105.642	11160.23216	227.7598401
17	1887.0	-235.942	55668.62736	1136.094436
18	2166.4	43.458	1888.597764	38.54281151
19	2033.8	-89.142	7946.296164	162.1693095
20	1874.2	-248.742	61872.58256	1262.705767
21	2204.3	81.358	6619.124164	135.0841666
22	2463.2	340.258	115775.5066	2362.76544
23	2183.0	60.058	3606.963364	73.61149722
24	2082.4	-40.542	1643.653764	33.54395437
25	1892.1	-230.842	53288.02896	1087.510795
26	2177.8	54.858	3009.400164	61.41632988
27	1963.2	-159.742	25517.50656	520.7654401
28	2163.1	40.158	1612.664964	32.91152988
29	2410.9	287.958	82919.80976	1692.241016
30	1920.3	-202.642	41063.78016	838.0363299
31	2015.6	-107.342	11522.30496	235.1490809
32	2241.0	118.058	13937.69136	284.4426809
33	1821.3	-301.642	90987.89616	1856.89584
34	2183.2	60.258	3631.026564	74.10258294
35	2035.0	-87.942	7733.795364	157.8325584
36	2274.2	151.258	22878.98256	466.9180115
37	2431.1	308.158	94961.35296	1937.986795
38	2347.7	224.758	50516.15856	1030.942012
39	2097.4	-25.542	652.393764	13.31415845

40	1833.6	-289.342	83718.79296	1708.546795
41	2163.2	40.258	1620.706564	33.07564416
42	2206.8	83.858	7032.164164	143.5135544
43	1931.1	-191.842	36803.35296	751.088836
44	2001.4	-121.542	14772.45776	301.4787299
45	2301.3	178.358	31811.57616	649.2158401
46	2294.7	171.758	29500.81056	602.0573584
47	2455.2	332.258	110395.3786	2252.966909
48	2177.2	54.258	2943.930564	60.08021559
49	2018.7	-104.242	10866.39456	221.7631544
50	2211.3	88.358	7807.136164	159.3293095
Total				34328.67391

Mean, μ = 2122.942

Standard Deviation, $\sigma = \sqrt{34328.67391}$

$= 185.2799879$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1800 – 1899.9	7	0.1429	7.145	0.0029
2	1900 – 1999.9	7	0.1429	7.145	0.0029
3	2000 – 2099.9	10	0.1429	7.145	1.1408
4	2100 – 2199.9	9	0.1429	7.145	0.4816
5	2200 – 2299.9	7	0.1429	7.145	0.0029
6	2300 – 2399.9	5	0.1429	7.145	0.6440
7	2400 – 2499.9	5	0.1429	7.145	0.6440
Total		50			2.9191

Degree of freedom = K – 1 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\ 0.05} = 12.592$

$\chi^2_{calc} = 2.9191$

Since $\chi^2_{calc} < \chi^2_{6,\ 0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^1/_\mu$	$(1\text{-}e^{-\alpha k}) - (1\text{-}e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1800 – 1899.9	7	0.000471	0.0197	0.9653	37.7267
2	1900 – 1999.9	7	0.000471	0.0188	0.9212	40.1127
3	2000 – 2099.9	10	0.000471	0.0179	1.2530	61.0615
4	2100 – 2199.9	9	0.000471	0.0171	1.0773	58.2653
5	2200 – 2299.9	7	0.000471	0.0163	0.7987	48.1484
6	2300 – 2399.9	5	0.000471	0.0156	0.5460	36.3335
7	2400 – 2499.9	5	0.000471	0.0148	0.5180	38.7805
Total		50				320.4286

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\, 0.05} = 11.070$

$\chi^2_{calc} = 320.4286$

Since $\chi^2_{calc} > \chi^2_{5,\, 0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1800 – 1899.9	7	0.0737	3.6113	3.1798
2	1900 – 1999.9	7	0.1389	6.8061	0.0055
3	2000 – 2099.9	10	0.1970	13.7900	1.0416
4	2100 – 2199.9	9	0.2103	13.2489	1.3626
5	2200 – 2299.9	7	0.1690	8.2810	0.1982
6	2300 – 2399.9	5	0.1021	3.5735	0.5694
7	2400 – 2499.9	5	0.0465	1.6275	6.9885
Total		50			13.3456

Degree of freedom = K – 3 = 4; Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\, 0.05} = 9.488$

$\chi^2_{calc} = 13.3456$

Since $\chi^2_{calc} > \chi^2_{4,\, 0.05}$; **Reject**

APPENDIX G3

Chi-Square Test Calculation For Laminating Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n - 1$
1	3778.4	-124.774	15568.55108	317.7255322
2	4123.6	220.426	48587.62148	991.5841118
3	4036.5	133.326	17775.82228	362.7718832
4	3918.7	15.526	241.056676	4.919524
5	3781.5	-121.674	14804.56228	302.133924
6	3667.1	-236.074	55730.93348	1137.365989
7	3781.4	-121.774	14828.90708	302.6307567
8	3864.0	-39.174	1534.602276	31.3184138
9	3925.1	21.926	480.749476	9.811213796
10	3766.3	-136.874	18734.49188	382.3365689
11	4120.7	217.526	47317.56068	965.6645036
12	3910.6	7.426	55.145476	1.125417878
13	3866.0	-37.174	1381.906276	28.2021689
14	4285.6	382.426	146249.6455	2984.686642
15	3712.7	-190.474	36280.34468	740.4151975
16	3524.7	-378.474	143242.5687	2923.317728
17	4020.1	116.926	13671.68948	279.0140709
18	3933.7	30.526	931.836676	19.01707502
19	3805.5	-97.674	9540.210276	194.6981689
20	3602.8	-300.374	90224.53988	1841.31714
21	4027.6	124.426	15481.82948	315.9557036
22	4201.8	298.626	89177.48788	1819.948732
23	3554.6	-348.574	121503.8335	2479.670071
24	3917.6	14.426	208.109476	4.247132163
25	4027.5	124.326	15456.95428	315.4480464
26	3985.6	82.426	6794.045476	138.6539893
27	4133.6	230.426	53096.14148	1083.594724
28	3876.3	-26.874	722.211876	14.73901788
29	4006.5	103.326	10676.26228	217.8829036
30	3566.8	-336.374	113147.4679	2309.131997
31	3811.7	-91.474	8367.492676	170.7651567
32	4033.6	130.426	17010.94148	347.1620709
33	3624.9	-278.274	77436.41908	1580.335083
34	3783.2	-119.974	14393.76068	293.7502179
35	4264.1	360.926	130267.5775	2658.521989
36	3828.8	-74.374	5531.491876	112.8875893
37	3955.6	52.426	2748.485476	56.09154033
38	4184.0	280.826	78863.24228	1609.453924
39	3877.6	-25.574	654.029476	13.34754033

40	4076.8	173.626	30145.98788	615.2242424
41	3587.9	-315.274	99397.69508	2028.524389
42	3792.7	-110.474	12204.50468	249.071524
43	3930.6	27.426	752.185476	15.350724
44	3672.4	-230.774	53256.63908	1086.870185
45	4083.1	179.926	32373.36548	660.6809281
46	3819.6	-83.574	6984.613476	142.5431322
47	4253.2	350.026	122518.2007	2500.371442
48	3824.5	-78.674	6189.598276	126.3183322
49	4122.6	219.426	48147.76948	982.6075403
50	3908.9	5.726	32.787076	0.669124
Total				37769.87502

Mean, μ = 3903.174

Standard Deviation, $\sigma = \sqrt{37769.87502}$

$= 194.3447324$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H$_o$ Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	3500 – 3599.9	4	0.125	6.25	0.81
2	3600 – 3699.9	4	0.125	6.25	0.81
3	3700 – 3799.9	7	0.125	6.25	0.09
4	3800 – 3899.9	9	0.125	6.25	1.21
5	3900 – 3999.9	9	0.125	6.25	1.21
6	4000 – 4099.9	8	0.125	6.25	0.49
7	4100 – 4199.9	5	0.125	6.25	0.25
8	4200 – 4299.9	4	0.125	6.25	0.81
Total		50			5.68

Degree of freedom = K – 1 = 7; Desired significant level, $\alpha = 0.05$

$\chi^2_{7,\ 0.05}$ = 14.067

χ^2_{calc} = 5.68

Since $\chi^2_{calc} < \chi^2_{7,\ 0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^1/_{\mu}$	$(1\text{-}e^{-\alpha k}) - (1\text{-}e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	3500 – 3599.9	4	0.000256	0.0103	0.3296	40.8733
2	3600 – 3699.9	4	0.000256	0.0100	0.3200	42.3200
3	3700 – 3799.9	7	0.000256	0.0098	0.5488	75.8345
4	3800 – 3899.9	9	0.000256	0.0095	0.6840	101.1051
5	3900 – 3999.9	9	0.000256	0.0093	0.6696	103.6373
6	4000 – 4099.9	8	0.000256	0.0091	0.5824	94.4725
7	4100 – 4199.9	5	0.000256	0.0088	0.3520	61.3747
8	4200 – 4299.9	4	0.000256	0.0086	0.2752	50.4147
Total		50				570.0321

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 570.0321$

Since $\chi^2_{calc} > \chi^2_{6,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	3500 – 3599.9	4	0.0403	1.2896	5.6965
2	3600 – 3699.9	4	0.0884	2.8288	0.4849
3	3700 – 3799.9	7	0.1497	8.3832	0.2282
4	3800 – 3899.9	9	0.1955	14.0760	1.8305
5	3900 – 3999.9	9	0.1972	14.1984	1.9033
6	4000 – 4099.9	8	0.1535	9.8240	0.3387
7	4100 – 4199.9	5	0.0922	3.6880	0.4667
8	4200 – 4299.9	4	0.0427	1.3664	5.0760
Total		50			16.0248

Degree of freedom = K – 3 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 16.0248$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

APPENDIX G4

Chi-Square Test Calculation For Shaping Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	2568.3	-119.876	14370.25538	293.2705179
2	2456.7	-231.476	53581.13858	1093.492624
3	2859.1	170.924	29215.01378	596.2247709
4	2547.6	-140.576	19761.61178	403.2981995
5	2639.2	-48.976	2398.648576	48.95201176
6	2876.7	188.524	35541.29858	725.332624
7	2763.8	75.624	5718.989376	116.7140689
8	2974.9	286.724	82210.65218	1677.768412
9	2654.9	-33.276	1107.292176	22.59779951
10	2871.8	183.624	33717.77338	688.117824
11	2766.8	78.624	6181.733376	126.157824
12	2621.4	-66.776	4459.034176	91.00069747
13	2309.7	-378.476	143244.0826	2923.348624
14	2731.6	43.424	1885.643776	38.48252604
15	2970.4	282.224	79650.38618	1625.518085
16	2783.4	95.224	9067.610176	185.0532689
17	3065.9	377.724	142675.4202	2911.743269
18	2618.0	-70.176	4924.670976	100.5034893
19	2582.1	-106.076	11252.11778	229.6350567
20	2674.3	-13.876	192.543376	3.929456653
21	2980.7	292.524	85570.29058	1746.332461
22	2714.3	26.124	682.463376	13.927824
23	2673.9	-14.276	203.804176	4.159268898
24	3023.6	335.424	112509.2598	2296.107342
25	2794.2	106.024	11241.08858	229.4099709
26	2590.3	-97.876	9579.711376	195.5043138
27	2319.8	-368.376	135700.8774	2769.405661
28	2801.4	113.224	12819.67418	261.6260036
29	2462.8	-225.376	50794.34138	1036.619212
30	2632.3	-55.876	3122.127376	63.71688522
31	2350.7	-337.476	113890.0506	2324.286746
32	2573.8	-114.376	13081.86938	266.976926
33	2731.3	43.124	1859.679376	37.95264033
34	3043.2	355.024	126042.0406	2572.286542
35	2455.7	-232.476	54045.09058	1102.961032
36	2603.2	-84.976	7220.920576	147.365726
37	2948.6	260.424	67820.65978	1384.095097
38	2688.5	0.324	0.104976	0.002142367
39	2715.0	26.824	719.526976	14.684224

40	2365.5	-322.676	104119.801	2124.893897
41	2517.0	-171.176	29301.22298	597.9841424
42	2743.4	55.224	3049.690176	62.23857502
43	2431.2	-256.976	66036.66458	1347.687032
44	2670.9	-17.276	298.460176	6.091024
45	3055.4	367.224	134853.4662	2752.111555
46	2688.1	-0.076	0.005776	0.000117878
47	2564.8	-123.376	15221.63738	310.6456607
48	2810.6	122.424	14987.63578	305.8701179
49	2388.6	-299.576	89745.77978	1831.546526
50	2733.4	45.224	2045.210176	41.73898318
Total				39749.3688

Mean, $\mu = 2688.176$

Standard Deviation, $\sigma = \sqrt{39749.3688}$

$= 199.3724374$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	2300 – 2399.9	5	0.125	6.25	0.25
2	2400 – 2499.9	4	0.125	6.25	0.81
3	2500 – 2599.9	7	0.125	6.25	0.09
4	2600 – 2699.9	11	0.125	6.25	3.61
5	2700 – 2799.9	10	0.125	6.25	2.25
6	2800 – 2899.9	5	0.125	6.25	0.25
7	2900 – 2999.9	4	0.125	6.25	0.81
8	3000 – 3099.9	4	0.125	6.25	0.81
Total		50			8.88

Degree of freedom = K – 1 = 7; Desired significant level, $\alpha = 0.05$

$\chi^2_{7,\,0.05} = 14.067$

$\chi^2_{calc} = 8.88$

Since $\chi^2_{calc} < \chi^2_{7,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1\text{-}e^{-\alpha k}) - (1\text{-}e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	2300 – 2399.9	5	0.000372	0.0155	0.6200	30.9426
2	2400 – 2499.9	4	0.000372	0.0149	0.4768	26.0338
3	2500 – 2599.9	7	0.000372	0.0144	0.8064	47.5703
4	2600 – 2699.9	11	0.000372	0.0139	1.2232	78.1441
5	2700 – 2799.9	10	0.000372	0.0134	1.0720	74.3556
6	2800 – 2899.9	5	0.000372	0.0129	0.5160	38.9656
7	2900 – 2999.9	4	0.000372	0.0124	0.3968	32.7194
8	3000 – 3099.9	4	0.000372	0.0119	0.3808	34.3976
Total		50				363.1290

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 363.1290$

Since $\chi^2_{calc} > \chi^2_{6,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	2300 – 2399.9	5	0.0483	1.9320	4.8720
2	2400 – 2499.9	4	0.0983	3.1456	0.2321
3	2500 – 2599.9	7	0.1563	8.7528	0.3510
4	2600 – 2699.9	11	0.1943	17.0984	2.1751
5	2700 – 2799.9	10	0.1887	15.0960	1.7203
6	2800 – 2899.9	5	0.1433	5.7320	0.0935
7	2900 – 2999.9	4	0.0851	2.7232	0.5986
8	3000 – 3099.9	4	0.0394	1.2608	5.9512
Total		50			15.9938

Degree of freedom = K – 3 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 15.9938$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

APPENDIX G5

Chi-Square Test Calculation For Sanding II Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n - 1$
1	2638.5	293.4	86083.56	1756.807347
2	2388.4	43.3	1874.89	38.26306122
3	2164.1	-181	32761	668.5918367
4	2565.3	220.2	48488.04	989.5518367
5	2117.9	-227.2	51619.84	1053.466122
6	2209.4	-135.7	18414.49	375.8059184
7	2436.8	91.7	8408.89	171.61
8	2695.0	349.9	122430.01	2498.571633
9	2383.5	38.4	1474.56	30.09306122
10	2411.4	66.3	4395.69	89.70795918
11	2087.6	-257.5	66306.25	1353.188776
12	2107.3	-237.8	56548.84	1154.057959
13	2317.9	-27.2	739.84	15.09877551
14	2017.4	-327.7	107387.29	2191.577347
15	2380.7	35.6	1267.36	25.8644898
16	2277.3	-67.8	4596.84	93.81306122
17	2693.1	348	121104	2471.510204
18	2361.2	16.1	259.21	5.29
19	2187.7	-157.4	24774.76	505.6073469
20	2453.8	108.7	11815.69	241.1365306
21	2266.2	-78.9	6225.21	127.045102
22	2046.8	-298.3	88982.89	1815.977347
23	2653.0	307.9	94802.41	1934.743061
24	2173.2	-171.9	29549.61	603.0532653
25	2511.8	166.7	27788.89	567.1202041
26	2263.9	-81.2	6593.44	134.56
27	2069.2	-275.9	76120.81	1553.485918
28	2576.8	231.7	53684.89	1095.61
29	2662.1	317	100489	2050.795918
30	2212.5	-132.6	17582.76	358.8318367
31	2345.7	0.6	0.36	0.007346939
32	2165.2	-179.9	32364.01	660.49
33	2088.4	-256.7	65894.89	1344.793673
34	2359.0	13.9	193.21	3.943061224
35	2239.9	-105.2	11067.04	225.8579592
36	2543.1	198	39204	800.0816327
37	2418.2	73.1	5343.61	109.0532653
38	2611.2	266.1	70809.21	1445.085918
39	2436.7	91.6	8390.56	171.2359184

40	2254.3	-90.8	8244.64	168.2579592
41	2043.2	-301.9	91143.61	1860.073673
42	2460.7	115.6	13363.36	272.7216327
43	2139.6	-205.5	42230.25	861.8418367
44	2453.9	108.8	11837.44	241.5804082
45	2634.7	289.6	83868.16	1711.595102
46	2581.1	236	55696	1136.653061
47	2065.3	-279.8	78288.04	1597.715102
48	2394.0	48.9	2391.21	48.80020408
49	2506.7	161.6	26114.56	532.9502041
50	2184.3	-160.8	25856.64	527.6865306
	2345.1			39691.26041

Mean, μ = 2345.1

Standard Deviation, $\sigma = \sqrt{39691.26041}$

$= 199.2266559$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	2000 – 2099.9	7	0.1429	7.145	0.0029
2	2100 – 2199.9	8	0.1429	7.145	0.1023
3	2200 – 2299.9	7	0.1429	7.145	0.0029
4	2300 – 2399.9	8	0.1429	7.145	0.1023
5	2400 – 2499.9	7	0.1429	7.145	0.0029
6	2500 – 2599.9	6	0.1429	7.145	0.1835
7	2600 – 2699.9	7	0.1429	7.145	0.0029
Total		50			0.3997

Degree of freedom = K – 1 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 0.3997$

Since $\chi^2_{calc} < \chi^2_{6,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	2000 – 2099.9	7	0.000426	0.0178	0.8722	43.0520
2	2100 – 2199.9	8	0.000426	0.0170	0.9520	52.1789
3	2200 – 2299.9	7	0.000426	0.0163	0.7987	48.1484
4	2300 – 2399.9	8	0.000426	0.0156	0.8736	58.1337
5	2400 – 2499.9	7	0.000426	0.0150	0.7350	53.4017
6	2500 – 2599.9	6	0.000426	0.0144	0.6048	48.1286
7	2600 – 2699.9	7	0.000426	0.0138	0.6762	59.1399
Total		50				362.1832

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\, 0.05} = 11.070$

$\chi^2_{calc} = 362.1832$

Since $\chi^2_{calc} > \chi^2_{5,\, 0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	2000 – 2099.9	7	0.0676	3.3124	4.1053
2	2100 – 2199.9	8	0.1238	6.9328	0.1643
3	2200 – 2299.9	7	0.1771	8.6779	0.3244
4	2300 – 2399.9	8	0.1979	11.0824	0.8573
5	2400 – 2499.9	7	0.1729	8.4721	0.2558
6	2500 – 2599.9	6	0.1180	4.9560	0.2199
7	2600 – 2699.9	7	0.0629	3.0821	4.9804
Total		50			10.9074

Degree of freedom = K – 3 = 4; Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\, 0.05} = 9.488$

$\chi^2_{calc} = 10.9074$

Since $\chi^2_{calc} > \chi^2_{4,\, 0.05}$; **Reject**

APPENDIX G6

Chi-Square Test Calculation For Drilling / Boring Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	1966.9	-138.274	19119.69908	390.1979403
2	1897.4	-207.774	43170.03508	881.021124
3	2343.2	238.026	56656.37668	1156.252585
4	2202.1	96.926	9394.649476	191.7275403
5	2013.8	-91.374	8349.207876	170.3919975
6	2117.9	12.726	161.951076	3.305124
7	1923.7	-181.474	32932.81268	672.0982179
8	1886.0	-219.174	48037.24228	980.3518832
9	1920.7	-184.474	34030.65668	694.5031975
10	2017.9	-87.274	7616.751076	155.4438995
11	2260.7	155.526	24188.33668	493.639524
12	1987.5	-117.674	13847.17028	282.5953118
13	2483.2	378.026	142903.6567	2916.401157
14	1837.6	-267.574	71595.84548	1461.139704
15	1712.4	-392.774	154271.4151	3148.396226
16	2138.0	32.826	1077.546276	21.99074033
17	2087.0	-18.174	330.294276	6.74069951
18	2312.8	207.626	43108.55588	879.7664464
19	1940.8	-164.374	27018.81188	551.404324
20	2411.3	306.126	93713.12788	1912.512814
21	2093.1	-12.074	145.781476	2.975132163
22	1806.9	-298.274	88967.37908	1815.660797
23	2125.7	20.526	421.316676	8.59829951
24	1752.4	-352.774	124449.4951	2539.785614
25	2367.8	262.626	68972.41588	1407.600324
26	2174.1	68.926	4750.793476	96.9549689
27	2207.4	102.226	10450.15508	213.2684709
28	2430.2	325.026	105641.9007	2155.957157
29	2134.2	29.026	842.508676	17.19405461
30	2073.1	-32.074	1028.741476	20.994724
31	2388.6	283.426	80330.29748	1639.393826
32	1864.6	-240.574	57875.84948	1181.139785
33	2190.4	85.226	7263.471076	148.2341036
34	1768.9	-336.274	113080.2031	2307.759246
35	1933.8	-171.374	29369.04788	599.368324
36	2283.1	177.926	31657.66148	646.074724
37	2094.6	-10.574	111.809476	2.281826041
38	2473.3	368.126	135516.7519	2765.647997
39	2176.0	70.826	5016.322276	102.373924

40	2041.9	-63.274	4003.599076	81.70610359
41	2134.9	29.726	883.635076	18.0333689
42	2287.3	182.126	33169.87988	676.936324
43	1749.0	-356.174	126859.9183	2588.977924
44	2284.1	178.926	32014.51348	653.3574179
45	2050.6	-54.574	2978.321476	60.78207094
46	2451.1	345.926	119664.7975	2442.138724
47	2111.5	6.326	40.018276	0.81669951
48	1977.3	-127.874	16351.75988	333.7093852
49	2108.9	3.726	13.883076	0.283328082
50	2263.0	157.826	24909.04628	508.3478832
Total				42006.23298

Mean, μ = 2105.174

Standard Deviation, $\sigma = \sqrt{42006.23298}$

$= 204.9542217$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1700 – 1799.9	4	0.125	6.25	0.81
2	1800 – 1899.9	5	0.125	6.25	0.25
3	1900 – 1999.9	7	0.125	6.25	0.09
4	2000 – 2099.9	8	0.125	6.25	0.49
5	2100 – 2199.9	10	0.125	6.25	2.25
6	2200 – 2299.9	7	0.125	6.25	0.09
7	2300 – 2399.9	4	0.125	6.25	0.81
8	2400 – 2499.9	5	0.125	6.25	0.25
Total		50			5.04

Degree of freedom = K – 1 = 7; Desired significant level, $\alpha = 0.05$

$\chi^2_{7,\,0.05} = 14.067$

$\chi^2_{calc} = 5.04$

Since $\chi^2_{calc} < \chi^2_{7,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1700 – 1799.9	4	0.000475	0.0207	0.6624	16.8170
2	1800 – 1899.9	5	0.000475	0.0197	0.7780	22.5139
3	1900 – 1999.9	7	0.000475	0.0188	1.0528	33.5954
4	2000 – 2099.9	8	0.000475	0.0179	1.1456	41.0115
5	2100 – 2199.9	10	0.000475	0.0171	1.3680	54.4674
6	2200 – 2299.9	7	0.000475	0.0163	0.9128	40.5938
7	2300 – 2399.9	4	0.000475	0.0155	0.4960	24.7541
8	2400 – 2499.9	5	0.000475	0.0148	0.5920	32.8217
Total		50				266.5748

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 266.5748$

Since $\chi^2_{calc} > \chi^2_{6,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1700 – 1799.9	4	0.0442	1.4144	4.7266
2	1800 – 1899.9	5	0.0900	3.6000	0.5444
3	1900 – 1999.9	7	0.1454	8.1424	0.1603
4	2000 – 2099.9	8	0.1858	11.8912	1.2733
5	2100 – 2199.9	10	0.1881	15.0480	1.6934
6	2200 – 2299.9	7	0.1508	8.4448	0.2472
7	2300 – 2399.9	4	0.0957	3.0624	0.2871
8	2400 – 2499.9	5	0.0481	1.9240	4.9178
Total		50			13.8501

Degree of freedom = K – 3 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 13.8501$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

APPENDIX G7

Chi-Square Test Calculation For Sanding III Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	1896.8	-215.314	46360.1186	946.1248693
2	1997.0	-115.114	13251.233	270.4333264
3	2018.3	-93.814	8801.066596	179.613604
4	1974.1	-138.014	19047.8642	388.7319224
5	2301.4	189.286	35829.1898	731.207955
6	2313.1	200.986	40395.3722	824.3953509
7	2014.0	-98.114	9626.356996	196.4562652
8	2115.5	3.386	11.464996	0.23397951
9	1949.5	-162.614	26443.313	539.6594489
10	1896.7	-215.414	46403.1914	947.003906
11	2017.0	-95.114	9046.672996	184.6259795
12	2210.6	98.486	9699.492196	197.9488203
13	2012.7	-99.414	9883.143396	201.696804
14	2168.9	56.786	3224.649796	65.80917951
15	2483.7	371.586	138076.1554	2817.880722
16	2053.2	-58.914	3470.859396	70.83386522
17	1811.2	-300.914	90549.2354	1847.94358
18	2107.0	-5.114	26.152996	0.533734612
19	2315.4	203.286	41325.1978	843.3713836
20	2140.8	28.686	822.886596	16.793604
21	1844.5	-267.614	71617.253	1461.576592
22	2084.1	-28.014	784.784196	16.016004
23	1966.0	-146.114	21349.301	435.7000203
24	2289.4	177.286	31430.3258	641.4352203
25	2160.1	47.986	2302.656196	46.99298359
26	1832.6	-279.514	78128.0762	1594.450535
27	2380.5	268.386	72031.045	1470.021326
28	2110.2	-1.914	3.663396	0.074763184
29	1994.3	-117.814	13880.1386	283.2681346
30	2455.6	343.486	117982.6322	2407.80882
31	2180.3	68.186	4649.330596	94.88429788
32	2278.9	166.786	27817.5698	567.705506
33	1987.6	-124.514	15503.7362	316.4027795
34	1874.3	-237.814	56555.4986	1154.193849
35	2250.0	137.886	19012.549	388.011204
36	2431.4	319.286	101943.5498	2080.480608
37	2296.1	183.986	33850.8482	690.8336367
38	2245.2	133.086	17711.8834	361.4670081
39	1943.2	-168.914	28531.9394	582.2844775

40	2134.8	22.686	514.654596	10.50315502
41	1892.6	-219.514	48186.3962	983.3958407
42	2007.6	-104.514	10923.1762	222.9219632
43	2349.2	237.086	56209.7714	1147.138192
44	2412.9	300.786	90472.2178	1846.371792
45	2144.8	32.686	1068.374596	21.80356318
46	1972.5	-139.614	19492.069	397.7973264
47	2267.8	155.686	24238.1306	494.6557264
48	1832.1	-280.014	78407.8402	1600.160004
49	2142.9	30.786	947.777796	19.342404
50	2047.3	-64.814	4200.854596	85.73172645
Total				32694.72776

Mean, $\mu = 2112.114$

Standard Deviation, $\sigma = \sqrt{32694.72776}$

$= 180.8168348$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1800 – 1899.9	8	0.1429	7.145	0.1023
2	1900 – 1999.9	8	0.1429	7.145	0.1023
3	2000 – 2099.9	8	0.1429	7.145	0.1023
4	2100 – 2199.9	10	0.1429	7.145	1.1408
5	2200 – 2299.9	7	0.1429	7.145	0.0029
6	2300 – 2399.9	5	0.1429	7.145	0.6440
7	2400 – 2499.9	4	0.1429	7.145	1.3843
Total		50			3.4789

Degree of freedom = K – 1 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\,0.05} = 12.592$

$\chi^2_{calc} = 3.4789$

Since $\chi^2_{calc} < \chi^2_{6,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1800 – 1899.9	8	0.000473	0.0197	1.1023	43.1163
2	1900 – 1999.9	8	0.000473	0.0188	1.0528	45.8431
3	2000 – 2099.9	8	0.000473	0.0179	1.0024	48.8492
4	2100 – 2199.9	10	0.000473	0.0171	1.1970	64.7392
5	2200 – 2299.9	7	0.000473	0.0163	0.7987	48.1484
6	2300 – 2399.9	5	0.000473	0.0156	0.5460	36.3335
7	2400 – 2499.9	4	0.000473	0.0148	0.4144	31.0244
Total		50				318.0541

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 318.0541$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1800 – 1899.9	8	0.0781	4.3736	3.0069
2	1900 – 1999.9	8	0.1471	8.2376	0.0069
3	2000 – 2099.9	8	0.2055	11.5080	1.0693
4	2100 – 2199.9	10	0.2130	14.9100	1.6169
5	2200 – 2299.9	7	0.1640	8.0360	0.1336
6	2300 – 2399.9	5	0.0936	3.2760	0.9073
7	2400 – 2499.9	4	0.0397	1.1116	7.5053
Total		50			14.2462

Degree of freedom = K – 3 = 4; Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\,0.05} = 9.488$

$\chi^2_{calc} = 14.2462$

Since $\chi^2_{calc} > \chi^2_{4,\,0.05}$; **Reject**

APPENDIX G8

Chi-Square Test Calculation For Brushing Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n-1$
1	1967.7	-235.09	55267.3081	1127.904247
2	2134.3	-68.49	4690.8801	95.73224694
3	2385.6	182.81	33419.4961	682.0305327
4	1927.5	-275.29	75784.5841	1546.624165
5	2302.7	99.91	9982.0081	203.714451
6	1964.0	-238.79	57020.6641	1163.687022
7	2311.7	108.91	11861.3881	242.0691449
8	2012.3	-190.49	36286.4401	740.5395939
9	2114.9	-87.89	7724.6521	157.6459612
10	1976.4	-226.39	51252.4321	1045.968002
11	2037.8	-164.99	27221.7001	555.5449
12	2241.6	38.81	1506.2161	30.73910408
13	2483.6	280.81	78854.2561	1609.270533
14	2155.6	-47.19	2226.8961	45.44685918
15	2271.1	68.31	4666.2561	95.22971633
16	1911.7	-291.09	84733.3881	1729.252818
17	2134.9	-67.89	4609.0521	94.06228776
18	2350.5	147.71	21818.2441	445.2702878
19	2206.8	4.01	16.0801	0.328165306
20	2185.6	-17.19	295.4961	6.030532653
21	2463.1	260.31	67761.2961	1382.883594
22	2234.8	32.01	1024.6401	20.91102245
23	2028.5	-174.29	30377.0041	619.9388592
24	2268.8	66.01	4357.3201	88.9249
25	2407.2	204.41	41783.4481	852.7234306
26	2166.7	-36.09	1302.4881	26.5813898
27	1946.8	-255.99	65530.8801	1337.3649
28	2386.7	183.91	33822.8881	690.2630224
29	2412.9	210.11	44146.2121	900.9431041
30	2134.6	-68.19	4649.8761	94.89543061
31	2308.9	106.11	11259.3321	229.7822878
32	2208.7	5.91	34.9281	0.712818367
33	2183.5	-19.29	372.1041	7.593961224
34	2345.7	142.91	20423.2681	416.8013898
35	1967.8	-234.99	55220.3001	1126.9449
36	2148.0	-54.79	3001.9441	61.26416531
37	2273.2	70.41	4957.5681	101.1748592
38	2435.0	232.21	53921.4841	1100.438451
39	2361.1	158.31	25062.0561	511.4705327

40	2215.5	12.71	161.5441	3.296818367
41	1988.9	-213.89	45748.9321	933.6516755
42	2377.6	174.81	30558.5361	623.6435939
43	2289.3	86.51	7483.9801	152.7342878
44	2095.4	-107.39	11532.6121	235.3594306
45	2433.7	230.91	53319.4281	1088.151594
46	2329.8	127.01	16131.5401	329.2151041
47	2178.0	-24.79	614.5441	12.54171633
48	2263.8	61.01	3722.2201	75.96367551
49	2190.7	-12.09	146.1681	2.983022449
50	2018.5	-184.29	33962.8041	693.118451
Total				25339.36296

Mean, $\mu = 2202.79$

Standard Deviation, $\sigma = \sqrt{25339.36296}$

$= 159.1834255$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1900 – 1999.9	8	0.1667	8.333	0.0133
2	2000 – 2099.9	5	0.1667	8.333	1.3331
3	2100 – 2199.9	11	0.1667	8.333	0.8536
4	2200 – 2299.9	10	0.1667	8.333	0.3335
5	2300 – 2399.9	10	0.1667	8.333	0.3335
6	2400 – 2499.9	6	0.1667	8.333	0.6532
Total		50			3.5202

Degree of freedom = K – 1 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 3.5202$

Since $\chi^2_{calc} < \chi^2_{5,\,0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1900 – 1999.9	8	0.000454	0.0187	0.8976	56.1988
2	2000 – 2099.9	5	0.000454	0.0179	0.5370	37.0919
3	2100 – 2199.9	11	0.000454	0.0171	1.1286	86.3411
4	2200 – 2299.9	10	0.000454	0.0163	0.9780	83.2275
5	2300 – 2399.9	10	0.000454	0.0156	0.9360	87.7736
6	2400 – 2499.9	6	0.000454	0.0149	0.5364	55.6505
Total		50				406.2834

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 4; Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\,0.05} = 9.488$

$\chi^2_{calc} = 406.2834$

Since $\chi^2_{calc} > \chi^2_{4,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1900 – 1999.9	8	0.0727	3.4896	5.8298
2	2000 – 2099.9	5	0.1577	4.7310	0.0153
3	2100 – 2199.9	11	0.2335	15.4110	1.2625
4	2200 – 2299.9	10	0.2361	14.1660	1.2252
5	2300 – 2399.9	10	0.1629	9.7740	0.0052
6	2400 – 2499.9	6	0.0767	2.7612	3.7990
Total		50			12.1370

Degree of freedom = K – 3 = 3; Desired significant level, $\alpha = 0.05$

$\chi^2_{3,\,0.05} = 7.815$

$\chi^2_{calc} = 12.1370$

Since $\chi^2_{calc} > \chi^2_{3,\,0.05}$; **Reject**

APPENDIX G9

Chi-Square Test Calculation For Assembly Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n - 1$
1	1896.7	-146.63	21500.3569	438.7827939
2	2045.3	1.97	3.8809	0.079202041
3	2013.7	-29.63	877.9369	17.91707959
4	2384.0	340.67	116056.0489	2368.490794
5	2352.1	308.77	95338.9129	1945.6921
6	1865.7	-177.63	31552.4169	643.9268755
7	1977.6	-65.73	4320.4329	88.1721
8	1998.2	-45.13	2036.7169	41.56565102
9	2009.3	-34.03	1158.0409	23.63348776
10	2111.4	68.07	4633.5249	94.56173265
11	1710.4	-332.93	110842.3849	2262.089488
12	2070.5	27.17	738.2089	15.06548776
13	2204.7	161.37	26040.2769	531.4342224
14	1833.2	-210.13	44154.6169	901.1146306
15	2376.4	333.07	110935.6249	2263.992345
16	1946.8	-96.53	9318.0409	190.1641
17	1728.9	-314.43	98866.2249	2017.678059
18	2112.8	69.47	4826.0809	98.49144694
19	1843.2	-200.13	40052.0169	817.3881
20	2284.3	240.97	58066.5409	1185.031447
21	2074.3	30.97	959.1409	19.57430408
22	2197.0	153.67	23614.4689	481.9279367
23	1904.5	-138.83	19273.7689	393.3422224
24	2365.9	322.57	104051.4049	2123.498059
25	2166.8	123.47	15244.8409	311.119202
26	1780.6	-262.73	69027.0529	1408.715365
27	2267.4	224.07	50207.3649	1024.6401
28	1846.9	-196.43	38584.7449	787.4437735
29	2186.5	143.17	20497.6489	418.3193653
30	1764.0	-279.33	78025.2489	1592.352018
31	2041.0	-2.33	5.4289	0.110793878
32	1807.5	-235.83	55615.7889	1135.0161
33	2284.3	240.97	58066.5409	1185.031447
34	1933.2	-110.13	12128.6169	247.5227939
35	2301.2	257.87	66496.9369	1357.080345
36	2145.7	102.37	10479.6169	213.8697327
37	2044.2	0.87	0.7569	0.015446939
38	1745.5	-297.83	88702.7089	1810.259365
39	1930.7	-112.63	12685.5169	258.8881

40	2034.9	-8.43	71.0649	1.450304082
41	2243.1	199.77	39908.0529	814.4500592
42	1936.6	-106.73	11391.2929	232.4753653
43	1768.9	-274.43	75311.8249	1536.976018
44	2096.4	53.07	2816.4249	57.47805918
45	2341.8	298.47	89084.3409	1818.047773
46	2077.8	34.47	1188.1809	24.2485898
47	1955.4	-87.93	7731.6849	157.7894878
48	1733.8	-309.53	95808.8209	1955.282059
49	2231.1	187.77	35257.5729	719.5423041
50	2194.3	150.97	22791.9409	465.141651
	2043.33			38496.87929

Mean, μ = 2043.33

Standard Deviation, $\sigma = \sqrt{38496.87929}$

$= 196.2062162$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1700 – 1799.9	7	0.1429	7.145	0.0029
2	1800 – 1899.9	6	0.1429	7.145	0.1835
3	1900 – 1999.9	8	0.1429	7.145	0.1023
4	2000 – 2099.9	10	0.1429	7.145	1.1408
5	2100 – 2199.9	7	0.1429	7.145	0.0029
6	2200 – 2299.9	6	0.1429	7.145	0.1835
7	2300 – 2399.9	6	0.1429	7.145	0.1835
Total		50			1.7994

Degree of freedom = K – 1 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\ 0.05} = 12.592$

$\chi^2_{calc} = 1.7994$

Since $\chi^2_{calc} < \chi^2_{6,\ 0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^1/_\mu$	$(1\text{-}e^{-\alpha k}) - (1\text{-}e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1700 – 1799.9	7	0.000489	0.0208	1.0192	35.0961
2	1800 – 1899.9	6	0.000489	0.0198	0.8316	32.1216
3	1900 – 1999.9	8	0.000489	0.0188	1.0528	45.8431
4	2000 – 2099.9	10	0.000489	0.0179	1.2530	61.0615
5	2100 – 2199.9	7	0.000489	0.0169	0.8281	45.9997
6	2200 – 2299.9	6	0.000489	0.0163	0.6846	41.2701
7	2300 – 2399.9	6	0.000489	0.0155	0.6510	43.9505
Total		50				305.3426

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\,0.05} = 11.070$

$\chi^2_{calc} = 305.3426$

Since $\chi^2_{calc} > \chi^2_{5,\,0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1700 – 1799.9	7	0.0673	3.2977	4.1565
2	1800 – 1899.9	6	0.1249	5.2458	0.1084
3	1900 – 1999.9	8	0.1799	10.0744	0.4271
4	2000 – 2099.9	10	0.2008	14.0560	1.1704
5	2100 – 2199.9	7	0.1739	8.5211	0.2715
6	2200 – 2299.9	6	0.1168	4.9056	0.2442
7	2300 – 2399.9	6	0.0608	2.5536	4.6513
Total		50			11.0294

Degree of freedom = K – 3 = 4; Desired significant level, $\alpha = 0.05$

$\chi^2_{4,\,0.05} = 9.488$

$\chi^2_{calc} = 11.0294$

Since $\chi^2_{calc} > \chi^2_{4,\,0.05}$; **Reject**

APPENDIX G10

Chi-Square Test Calculation For Finishing Process

i	X_i	$X_i - \bar{X}$	$(X_i - \bar{X})^2$	$(X_i - \bar{X})^2/n - 1$
1	2194.4	-18.798	353.364804	7.211526612
2	2038.4	-174.798	30554.3408	623.5579756
3	1987.4	-225.798	50984.7368	1040.504833
4	1921.1	-292.098	85321.2416	1741.249829
5	2133.2	-79.998	6399.680004	130.6057144
6	2246.0	32.802	1075.971204	21.958596
7	2383.5	170.302	29002.7712	591.8932899
8	2017.4	-195.798	38336.8568	782.3848327
9	1985.5	-227.698	51846.3792	1058.089372
10	2333.2	120.002	14400.48	293.887347
11	2108.6	-104.598	10940.7416	223.2804409
12	1808.7	-404.498	163618.632	3339.155755
13	2284.1	70.902	5027.093604	102.593747
14	2010.6	-202.598	41045.9496	837.6724409
15	2580.5	367.302	134910.7592	2753.2808
16	2290.7	77.502	6006.560004	122.5828572
17	2309.2	96.002	9216.384004	188.0894695
18	1950.8	-262.398	68852.7104	1405.157355
19	2414.5	201.302	40522.4952	826.989698
20	2384.1	170.902	29207.4936	596.071298
21	2107.8	-105.398	11108.7384	226.708947
22	2534.8	321.602	103427.8464	2110.772376
23	2256.7	43.502	1892.424004	38.62089804
24	2346.1	132.902	17662.9416	360.468196
25	2145.6	-67.598	4569.489604	93.25488988
26	1836.7	-376.498	141750.744	2892.872327
27	2260.8	47.602	2265.950404	46.2438858
28	2463.1	249.902	62451.0096	1274.5104
29	2137.9	-75.298	5669.788804	115.7099756
30	2513.7	300.502	90301.452	1842.886776
31	2281.0	67.802	4597.111204	93.818596
32	2118.6	-94.598	8948.781604	182.628196
33	2438.9	225.702	50941.3928	1039.620261
34	1946.8	-266.398	70967.8944	1448.324376
35	2294.2	81.002	6561.324004	133.9045715
36	2388.6	175.402	30765.8616	627.8747266
37	2155.4	-57.798	3340.608804	68.17568988
38	2506.7	293.502	86143.424	1758.029061
39	2164.4	-48.798	2381.244804	48.59683273

40	2230.7	17.502	306.320004	6.251428653
41	1875.6	-337.598	113972.4096	2325.967543
42	2455.8	242.602	58855.7304	1201.137355
43	2145.5	-67.698	4583.019204	93.53100416
44	2073.6	-139.598	19487.6016	397.7061552
45	2211.2	-1.998	3.992004	0.081469469
46	2566.5	353.302	124822.3032	2547.393943
47	2175.0	-38.198	1459.087204	29.77728988
48	2085.0	-128.198	16434.7272	335.402596
49	2377.3	164.102	26929.4664	549.580947
50	2184.0	-29.198	852.523204	17.39843273
Total				38593.46632

Mean, μ = 2213.198

Standard Deviation, $\sigma = \sqrt{38593.46632}$

$= 196.4521986$

Uniform Distribution

Cell (i)	Interval	Observed Frequency (X_1)	H_o Probability	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1800 – 1899.9	3	0.125	6.25	1.69
2	1900 – 1999.9	5	0.125	6.25	0.25
3	2000 – 2099.9	5	0.125	6.25	0.25
4	2100 – 2199.9	12	0.125	6.25	5.29
5	2200 – 2299.9	9	0.125	6.25	1.21
6	2300 – 2399.9	7	0.125	6.25	0.09
7	2400 – 2499.9	4	0.125	6.25	0.81
8	2500 – 2599.9	5	0.125	6.25	0.25
Total		50			9.84

Degree of freedom = K – 1 = 7; Desired significant level, $\alpha = 0.05$

$\chi^2_{7, 0.05} = 14.067$

$\chi^2_{calc} = 9.84$

Since $\chi^2_{calc} < \chi^2_{7, 0.05}$; **Accept**

Exponential Distribution

Cell (i)	Interval	Observed Frequency (X_1)	$\alpha = {}^{1}/_{\mu}$	$(1-e^{-\alpha k}) - (1-e^{-\alpha j})$	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1800 – 1899.9	3	0.000452	0.0196	0.4704	13.6031
2	1900 – 1999.9	5	0.000452	0.0187	0.7480	24.1705
3	2000 – 2099.9	5	0.000452	0.0179	0.7160	25.6322
4	2100 – 2199.9	12	0.000452	0.0171	1.6416	65.3609
5	2200 – 2299.9	9	0.000452	0.0163	1.1736	52.1920
6	2300 – 2399.9	7	0.000452	0.0156	0.8736	42.9633
7	2400 – 2499.9	4	0.000452	0.0149	0.4768	26.0338
8	2500 – 2599.9	5	0.000452	0.0143	0.5720	34.2783
Total		50				284.2341

j = Class lower boundary; k = Class upper boundary; $\mu = \bar{X}$

Degree of freedom = K – 2 = 6; Desired significant level, $\alpha = 0.05$

$\chi^2_{6,\ 0.05} = 12.592$

$\chi^2_{calc} = 284.2341$

Since $\chi^2_{calc} > \chi^2_{6,\ 0.05}$; **Reject**

Normal Distribution

Cell (i)	Interval	Observed Frequency (X_1)	Area (A_i)	Expected Frequency (X_2)	$\frac{(X_2 - X_1)^2}{X_2}$
1	1800 – 1899.9	3	0.0377	0.9048	4.8517
2	1900 – 1999.9	5	0.0834	3.3360	0.8300
3	2000 – 2099.9	5	0.1432	5.7280	0.0925
4	2100 – 2199.9	12	0.1908	18.3168	2.1784
5	2200 – 2299.9	9	0.1973	14.2056	1.9076
6	2300 – 2399.9	7	0.1583	8.8648	0.3923
7	2400 – 2499.9	4	0.0986	3.1552	0.2262
8	2500 – 2599.9	5	0.0476	1.9040	5.0343
Total		50			15.5130

Degree of freedom = K – 3 = 5; Desired significant level, $\alpha = 0.05$

$\chi^2_{5,\ 0.05} = 11.070$

$\chi^2_{calc} = 15.5130$

Since $\chi^2_{calc} > \chi^2_{5,\ 0.05}$; **Reject**

APPENDIX H

ACTUAL DAILY PRODUCTION OUTPUT DATA

Actual Daily Output Chairs

45	37	41	44	38
40	48	44	40	48
38	40	45	36	44
46	45	44	46	42
41	37	39	39	40
43	40	42	50	41

Average, $\bar{X} = \Sigma \mathrm{X_i}/\mathrm{n}$

$$= 1263/30$$

$$= 42.1$$

$$\approx 42\ units$$