PARAMETRIC COST ESTIMATION MODEL FOR MICROCHANNEL BONDING PROCESS BASED ON ACTIVITY BASED COSTING

by

PANITA SUEBVISAI

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To my mother Kanchana Suebvisai, my father Sorasak Suebvisai,
and my brother Surachet Suebvisai

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Abstract

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Panita Suebvisai, PhD

The University of Texas at Arlington, 2013

Supervising Professor: Dr. John W. Priest

The microchannel bonding process was developed to decrease product size and improve product performance. As the microchannel bonding process has moved from research to industrial manufacturing, it has become increasingly important to create a model to more accurately estimate the costs associated with this process. However, due to problems in project planning and limitations in funding, most microchannel bonding projects appear to have schedule slips and cost overruns.

This dissertation presents a cost estimation model that links activity-based costing with parametric cost estimation. A parametric cost model has been designed to improve decision making in the microchannel bonding process, specifically the eutectic microchannel bonding process developed at CREST lab at the University of Texas, Arlington (UTA). The Activity Based Costing (ABC) breaks down the eutectic microchannel bonding process into specific cost elements in each step of the production process. The Activity Based Costing (ABC) will manage the cost by activity of each process. The cost of each activity will be put into the parametric cost estimation model to calculate the cost of each activity. These specific cost elements can then be used to establish the total manufacturing cost, thereby improving the design and manufacturing process. These specific cost elements can then be used to establish the total manufacturing cost, thereby improving the design and manufacturing process. The results of the parametric cost model will afterward be analyzed by the regression method of analysis, further improving final results in the production process. The results of the regression analysis will be shown in both graph and numerical formula.

Keywords: Cost Estimation, Mirochannel bonding, Cost drivers, Parametric cost estimation, Activity Based Costing (ABC), Regression Analysis

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Chapter 1

Introduction

1.1 Background and Motivation

Cost estimation is one of the most important activities for the manufacturing industry. Moreover, there is a natural requirement in the industry to reduce production cost and increase productivity (Arieh, David Ben; Qian, Li;, 2003). Fundamental to the engineering process and business decisions is cost estimation. Cost estimation is used to estimate the cost of labor, materials, utilities, sales, overhead, time, and other costs related to a specific project. Cost driver data is also part of the cost estimation process. Because cost estimation is used in new manufacturing processes, there is no helpful past data to review (Smith, Alice E; Mason, Anthony K;, 1996) (Tornberg, Katja; JaKmsen, Miikka; Paranko, Jari;, 2002)

The microchannel bonding technique is used to minimize the amount of bonding material necessary to bond other materials together, such as steel, aluminum, glass, and like matter. The technique is not new and has been used to improve the size and weight of the bonding material, which in turn affects the cost of the final product. The materials used in the bonding process necessarily relates to the types of materials to be bonded. As there are different types of bonding processes, including eutectic and aluminum**,** the process used is determined by the final product. To move the microchannel technique from the research stage to the commercial market requires a better understanding of the costs associated with the production process and volumes of material needed for the final product.

The aluminum microchannel bonding technique begins with the initial concept of the final product, followed by design, channel bonding, and testing. Each process includes sub processes which may involve extra cost. The microchannel cost model has been created to examine these different parts of the microchannel bonding process. If each process is made to function to its best ability, then the expense of using the microchannel process in production would decrease, thus allowing for greater returns on investment.

. In recent years, the interest in microchannel bonding process has increased. But the cost of microchannel bonding process remains expensive. Therefore, the cost estimation for microchannel bonding process is important in helping manufacturers make accurate business decisions. Cost estimation can used for generating requests for proposals, scheduling, monitoring and control. Underestimating the cost may result in a management system which exceeds the budget, underdeveloped functions and poor quality, or failure to complete the project on time. Cost overestimation may result in too many resources committed to the project. Accurate cost estimation is important because:

- It can be used to determine what resources should be committed to a project and how well these resources may be used.
- It can help assess the impact of changes and support planning.

- It can help classify and prioritize the development projects with respect to the overall business plan.

The manufacturing industry is a highly competitive environment. The purpose of every business and manufacturer is to lower production costs and increase profit, and to maintain a competitive edge. The cost estimation model is a method to help make strategic decisions related to the production process. Cost estimation is especially important in a competitive environment. Correct estimations can ensure financial success in manufacturing. When considering whether to use the microchannel process, cost estimation can help businesses make decisions related to the manufacturing process over all. Businesses can decide the benefits in tradeoff, cost, and schedule planning in relation to the microchannel process.

1.2 Statement of Problem

The microchannel bonding process is currently moving from research to the commercial market, yet the cost of its use remains a concern. It is difficult to make a good decision for planning and budgeting without understanding the expenses related to the manufacturing process. Moreover, hidden costs can become a secondary burden. These hidden costs often represent the missing or unmeasured factors. Without first uncovering these hidden costs, business planners could not make a good decision between alternative production processes or device development.

Additionally, the cost of the microchannel bonding technique remains high. These costs include numerous variables, such as materials, tools, equipment, and labor. The problem is how to identify and select these variables that can be used to determine the ultimate price of microchannel bonding.

Due to the limitations of research in the area, one of the main problems is the lack of information or data of the microchannel bonding process. The problem is further compounded by the variety of bonding methods, including adhesive, eutectic, and diffusion bonding. Each method creates a different demand in relation to the materials used. Therefore, there is no good historical data from prior research that includes every variable in the bonding process.

1.3 Research Question

The cost estimation of using microchannel bonding in manufacturing is complicated. Due to the lack of information currently available for consumers, businesses do not have a reliable method for estimating costs. Furthermore, the equipment and tools of the microchannel bonding process are expensive. These, then, are a few questions considered in this research.

- What are the factors which make the microchannel bonding process expensive?
- Are there any factors that could be affected to the cost of microchannel bonding process?

- Are there any tools that could give an accurate cost for microchannel bonding process?

1.4 Research Objective

The main objective of this research is to develop an accurate cost estimation model for using the microchannel bonding technique. This research focuses on developing a cost estimation model specifically for predicting the expenses of using microchannel bonding in the manufacturing process. This model will be useful in all phases of the microchannel bonding process, including its use in the manufacturing process and future product development. The objectives of this research also identify three sub-objectives.

1. To develop a parametric cost estimating model for cost estimating of microchannel bonding manufacturing processes. The model development process is illustrated and discussed to the understanding of the model development requirements, methodologies used, and specific development outcomes.
2. To identify and assess the relative importance of the significant microchannel characteristics or parameters to be incorporated into a cost estimating model to improve the model's cost estimating performance in the microchannel bonding process.
3. To identify the result by using statistic method. Regression analysis will be applied to find the relationship between parameters.

1.5 Research Scope

The scope of this research is limited to the development of parametric cost estimation model based on the activity based costing for microchannel bonding process. This research is limited to microchannel bonding process developed by CREST lab, University of Texas at Arlington. The microchannel technique used will be eutectic bonding process. The material type will be aluminum 6061. The cost of materials, tools and equipment will base on data from CREST lab.

Chapter 2

Research Background and Literature Review

2.1 Introduction

Cost management has been the primary concern regarding the financial investment in resources needed to complete a project. The cost management in the machine manufacturing process focuses on cost estimation and cost analysis. Cost estimation is the process of predicting the cost of work activity from the input given through cost analysis. Cost analysis is the process of studying past costs and estimating future costs (Stewart, Rodney D; Wyskida, Richard M; Johannes, James D;, 1995).

Cost estimation is a fundamental factor for companies making business decisions. It is especially important in the design stage and helpful in making decisions pertaining to product structure, materials, and the manufacturing process. The cost of a product can be calculated from the summation of various components such as material, machine hours, labor, and engineering cost (Zhang, Y F; Fuh, J Y H; Chan, W T;, 1996).

As each process of a project is dependent upon the work activity in the preceding process, each process therefore requires different methods to calculate cost estimation and cost analysis. Each process further requires different workers, materials, and equipment.

This chapter presents a comprehensive literature review and a discussion of the microchannel bonding process, parametric cost estimation method, activity based costing, and regression analysis. Section 2.2 discusses the different types of microchannel bonding process. Section 2.3 discusses cost definition. Section 2.4 discusses the cost allocation, or cost classification, method. Section 2.5 presents the identification and selection of input variables, or cost drivers, for cost the estimation model. The principal of cost estimation methodology is discussed in section 2.6. The cost estimation based on functional relationship is presented in section 2.7.

2.2 Types of Microchannel Bonding Process

Though the microchannel bonding process is not a new technology, it has only recently been adopted by the manufacturing industry. The microchannel bonding process affords a wide range of uses in the industry, as there are a wide variety of processes that allow bonding under numerous conditions, including variations in temperature and kinds of materials used. These bonding processes include diffusion bonding, eutectic bonding, adhesive bonding, and laser welding. Table 2-1 presents the types of microchannel bonding process by (Paul, 2011).

Table 2-1: Type of Microchannel Bonding Process (Paul, 2011)

Process	**Capability**
Diffusion brazing	VHP (vendor)
	Shim coating
	DTE fixture
Brazing	Braze dispense
	Braze foil
	Screen printing
	Forming gas oven
	Reflow oven
	Humpback furnace
Soldering	
Adhesive bonding	Adhesive dispense
	Screen printing
Laser welding	
Ultrasonic welding	
Spark plasma bonding	

2.2.1 Diffusion Bonding

Diffusion bonding is the process of joining solid states together. The process works by pressing together two clean, smooth surfaces under an applied force or pressure at high temperatures in vacuum furnace. The heat and pressure causes the atoms from each surface to diffuse across the interface, thereby forming a diffusion bond (Dunkerton, S B; TWI, United Kingdom, 1991). If the temperature of bonding process increases, the rate of diffusion requires a shorter amount of time to complete. During the bonding process, a problem can occur through poor stress distribution and leakage, resulting in a weaker bond (Paul, Brian K; Kwon, Patrick; Subramanian, Ramkumar;, 2006). The diffusion bonding process is applicable to anything from a thin sheets of metal to much larger materials. Diffusion bonding technology is used aerospace-parts manufacturing, including titanium tanks and scaled combustion chambers (Lee, Yoon, & Yoo, 2011)

2.2.2 Eutectic Bonding

Eutectic bonding is used for bonding two substrates which then form a eutectic system. This method is based on the mixture of two materials taking advantage of the specific properties of the individual substances and alloy mixtures. To yield the temperature of the eutectic bonding process, subtract 10°C below the melting point of the mixture. This is the ideal range for eutectic bonding (Yi, S; Trumble, K P; Geskell, D R;, 1999; Yi, S; Trumble, K P; Geskell, D R;, 1999) .

2.2.3 Adhesive Bonding

Adhesive bonding uses to join two surfaces together and relies on evaporation and pressure. This method is used for bonding in temperatures as low as 200° to 400°C. Numerous factors affect the quality of adhesive bonding, including the roughness and cleanliness of the surface of the microchannel plate, and should be carefully monitored prior to bonding to get a good quality bond (Lo, Jeffery C C; Zhang, Rong; Lee, S W W Ricky;, 2011). This joining technique uses glues, epoxies, or various plastic agents. The adhesive bonding process has been used in commercial and military aircraft.

2.2.4 Laser Welding

Laser welding is another type of bonding process. Laser welding is one of the technologies used in high level manufacturing productivity. This process works to join multiple metals with heat emitted by a laser. The cost of laser welding can be lowered by reducing the processing temperature and using the cheaper but higher performance materials. This bonding process is used in joining thin thermoplastic components, such as those employed in the aircraft industry (Katsiropoulos, C., V., Moraitis, G.A., Labeas, G. N., and Pantelakis, S. P., 2009). Laser welding technology is also utilized in the manufacturing of lighter and safer automobiles (Kang, Hee Shin; Suh, Jeong; Kim, Tae Hyun; Cho, Taik Dong;, 2010).

2.3 Cost Definition

(Stewart, Rodney D; Wyskida, Richard M; Johannes, James D;, 1995) described cost is "the amount paid or payable for the acquisition of material, property, or service". A cost driver is any factor which causes a change in the cost of an activity. Therefore, the ultimate cost is affected by the cost driver.

And the cost driver can be either increased or decreased depending on the work activity of each process of a project (Cokins, 2001).

Cost estimation is the process of predicting the cost of a final product, which is important to manufacturing industry for a final estimate on the price of product. Cost estimation can also help predict the profit to be gained by the final product. Cost estimation can break down the cost of manufacturing into the following categories (Stewart, Rodney D; Wyskida, Richard M; Johannes, James D;, 1995):

- Engineering, design, and development cost
- Manufacturing cost
- Equipment and tooling costs
- Material cost
- Supervision cost
- Quality control, reliability, and testing costs
- Receiving and shipping costs
- Packaging cost
- Material handling and inventory costs
- Distribution and marketing costs
- Financing
- Taxes and insurance

- General and administrative expenses
- Plant overhead

There are some cost categories that are associated with the microchannel bonding process. The following are some useful classification concepts of the costs associated with microchannel bonding process cost estimation.

1. Nonrecurring cost is the cost that occurs once during the life cycle of a work activity or work output. This cost will usually occur at the early stages of a work activity. This nonrecurring cost includes of engineering effort in the early design stages, tools, or planning cost.
2. Recurring cost is the cost occurs throughout the life cycle of a work activity. This cost can be increased depending on the work activity.
3. Fixed cost are costs of production that do not change with the volume of manufacturing, such as insurance, depreciation, property tax, and basic utility fees (Stewart, Rodney D; Wyskida, Richard M; Johannes, James D;, 1995). An example of this cost is the cost of a machine.
4. Variable cost is "A cost that changes with the rate of production of goods or the performance of services" (Stewart, Rodney D; Wyskida, Richard M; Johannes, James D;, 1995)

5. Direct cost is a cost that can be identified directly with a project or process, such as a product, service, program, function, or a project. For example, a direct material cost is the cost of all materials that are a part of the final product. Direct labor is the labor cost based on the amount of labor hours consumed by the product.
6. Indirect cost is the cost that is not identified directly from an activity, project, or a process, such as energy costs.
7. Total cost includes the fixed cost and a variable cost.
8. Unit cost means cost per item.

2.4 Types of Cost Allocation Structure

These cost categories require specific types of information, such as labor hours, unit cost, or machine hours. There are many methodologies to define product costs from input data. Therefore, a cost system should provide or manage information that helps minimize waste. These many types of cost allocation structures are used by the machine-parts industry when working with the microchannel bonding processes. Each type of cost allocation methods performs different types of job. Each type of cost allocation has a different level of accuracy.

2.4.1 Work Breakdown Structure (WBS)

The main objective of work breakdown structure is to allocate the project's work activities into segments that control cost, schedule, and technical content. A WBS is developed in the project's development cycle. It defines the project's total work to be performed as well as all subtasks. A work breakdown structure tells what work will be performed. The WBS has some advantages, including providing a basis for developing a project's work schedule, providing a basis for assigning project responsibility, and dividing the work scope into manageable units (Administration., 2010). WBS is applied to many industrial areas. (García-Fornieles, Jose M; Fan, Ip-Sing; Perez, A; Wainwright, C; Sehdev, K;, 2003) presented WBS to manage the work scope in an aircraft modification project. WBS helps in managing all information and separate functions in aircraft modification. (He, 2013) used WBS to estimate the cost for an online production project.

2.4.2 Feature-Based Modeling

Feature-based modeling considers product costs related to the cost estimation model. Feature-based modeling can use in different industries. (Liu, Changqing ; Li, Yingguang; Wang, Wei ; Shen, Weiming ;, 2013) applied the feature-based modeling for the NC estimation of machining time. The machine time estimates process planning and scheduling based on material removal rates. In welding manufacturing, (Chayoukhi, Slah; Bouaziz, Zoubeir; Zghal, Ali;,

2008) applied the feature-based method to estimate the manufacturing cost of welding joints. The feature-based model provides better choices for economic decisions in alternative product design. There are some disadvantages to this method, including associated costs features that cannot be included with the final cost (Feng, Chang Xue; Kusiak, Andrew; Huang, Chun Che;, 1996)

2.4.3 Process-Based Approach

The process-based approach is mostly used in the cost estimation of manufacturing. The process based approach establishes the relationship between product design, material type, process selection, and cost of the process. The cost formulation is formulated based on the production process.

The process-based approach can apply to either the complex production process or for a new technology for production. The process-based approach can predict the cost of a new technology production process without historical data. The process-based method has some disadvantages in that this process is expensive and time consuming to develop. In addition, the process-based approach requires engineering expertise to develop the process and evaluate each part (Huang, 2007) (Leith, Steven D; King, Dale A; Paul, Brian K;, 2010) presented the process based cost model they used to estimate manufacturing costs for the microchannel manufacturing process. They used the process based approach as a method to break down the manufacturing cost into a number of cost elements associated with each step of the production process.

2.4.4 Traditional Cost Accounting Structure

The traditional cost accounting structure will break down the cost production details. The total cost of the product is derived by the summation of all costs of a product during the production cycle, including the costs of material, manufacturing, labor, and overhead. This calculation requires detailed information of the production process. The accuracy of traditional cost accounting structure depends on the availability of the required information.

(Cokins, Implementing Activity-Based Costing, 2006) presented the different between Traditional costing methodology and Activity-Based costing model in Table 2-2 below.

Table 2-2: Traditional Costing VS Activity-Based Costing (ABC) Model

Traditional costing	• Easy to implement for companies that provide one product and straight forward. • Structure-oriented • Assumed that cost objects consume resources • Utilizes volume related allocation bases • Allocates overheads first to the individual departments

Table 2-2 — Continued

Activity-based costing	• More technical and time consuming • Process-oriented • Assumed that cost objects consume activities • Uses drivers at various levels • Assigns over heads to each activity first.

2.4.5 Activity-Based Costing (ABC) Estimating

Activity-based costing (ABC) estimating was introduced by (Cooper, Robin; Kaplan, Robert S;, 1988) as a better alternative method and more accurate than the traditional cost accounting method. ABC develops indirect costs, or overhead costs, from the traditional cost system into direct cost by using activities as a distributor of cost assignment (Tsai, 1996). ABC identifies the activity that generates the cost and matches it to the level bases. The next process is the process of assigning the cost to the product. The ABC is important in the manufacturing process for improving productivity and quality. The production requires some activities, such as the design process, production process, and testing process. Each activity consumes resources that match the level base of activities, encompassing labor, equipment and tools, and electricity (Gunasekaran, A; Sarhadi, M;, 1998). ABC has been applied to many industries, such as parts manufacturing (Arieh, David Ben; Qian, Li;, 2003) (Tsai, 1996), supply chain management (Askarany, Davood ; Yazdifar, Hassan ; Askary, Saeed ;, 2010), and applications in hospitals (Yereli, 2009). The advantages of ABC incorporate providing more details of indirect cost, providing timely cost information, as well as improving accuracy and relation of product costing (Arieh, David Ben; Qian, Li;, 2003).

2.4.5.1 Activity-Based Costing model

The ABC model is a two stage approach model. In the first stage, the cost is assigned to cost pools or cost centers by using the appropriate resource consumption cost drivers. In the second stage, the cost is allocated from the cost pools to the products by using appropriate activity cost drivers (Cooper, Robin; Kaplan, Robert S;, 1988). By using cost drivers in both first and second stages, The ABC provides more accurate measurements for product or service cost. To identify the resource cost for each activity, there are some activity classified methods that incorporate how activities consume resources, entailing

1. Unit – level activity is performed on one unit of product or service at a time, including direct material, direct labor, and drilling a hole. The resource driver and activity driver are the same in unit – level.

2. Batch – level activity is performed on each batch, or group of product or service, at a time, including the setting up of a machine, scheduling production, and handling material.
3. Product – level activity is performed on a specific production of product or service. Designing a product is just one example.
4. Facility – level activity is performed to support operation in general. For example, providing security and safety, managing the plant, and performing machine maintenance.

There are three basic steps required to implement an ABC system:

1. Identify resource cost and activity

The first step of ABC is to analyze an activity to identify resource cost of each activity. The examples of activity resource costs are supplies, purchasing, material handling, warehousing, office expenses, furniture and fixtures, buildings, equipment, utilities, and salaries and benefits.

2. Assign resource costs to activities

ABC uses resource consumption cost drivers to assign resource costs to activities. The resource consumption cost drivers are made up of

- Labor hours for labor activities
- Machine hours for machine repair and maintenance
- Square feet for general maintenance and cleaning activity
- Moves for material handling activities

- Employees for payroll activities

The cost of resources can be assigned to activities by tracing or estimation.

Tracing requires measuring the actual usage of resources by activities. An example would be the power used to operate machine. In this case, power usage can be read by the meter attached to the machine. When the tracing is not available, the estimation is best used to identify the cost of activities.

3. Assign activity costs to cost objects

The final step is to assign the costs of activities to the appropriate cost objects based on the activity consumption of cost drivers. The actual outputs of a cost system are products and services. The activity consumption cost drivers should be able to explain why the costs of a cost object may go up or down.

2.5 Identification and Selection of Input Variables (Cost Drivers)

The accuracy of the activity-based costing method is important for process and project improvement. The accuracy of ABC method depends on the information given to the ABC and the types of cost drivers that will be selected for use in the ABC model.

2.5.1 Input Variables (Cost Drivers)

The input variables of the cost estimation model are called cost drivers. The cost drivers can be any factor that effects the change of performance in organizational costs. The cost drivers will effect the final cost. The cost driver can be related to resources, material, equipment, production process, production plan, performance, maintainability, and activities performed in a life cycle. (Spedding, T A; Sun, G Q;, 1999) presented three types of activity cost drivers in order of increasing accuracy, which are

1. Transaction drivers

   Transaction drivers count each time that activity happened.

2. Duration drivers

   Duration drivers represent the time taken for each activity.

3. Intensity drivers

   Intensity drivers represent the direct cost of the resources that were used in each activity.

2.5.2 Identification and Selection of Cost Drivers

The ABC method requires cost driver selection decisions. At least one cost driver has to be selected from the candidate cost drivers of each activity.

The cost driver selection is presented by

1. Select activity drivers that match with activity
2. Select activity drivers that correlate well with the activity
3. Reduced number of drivers
4. Select the activity drivers that have potential to improve performance
5. Select the activity drivers that have modest cost measurements

6. Minimize activity drivers that require new measurements

2.5.3 Microchannel Machine Part Cost Driver

Cost drivers are important for the development of a cost estimation model. The cost drivers relate to either process or activity. (Porter, J David; Paul, Brian K; Ryuh, Beom Sahng;, 2002) present the cost drivers of microlamination diffusion bonding through raw materials, tooling cost, indirect costs, and labor costs. In the laser welding method of bonding, (Katsiropoulos, Ch V; Moraitis, G A; Labeas, G N; Pantelakis, Sp G;, 2009) present the basic cost drivers which determine each sub process. The cost drivers for laser welding are separated by process

1. Part data

The cost drivers for this process include of part area, weight of the part, number of piles, part parameter, ply thickness, ply area, complexity of the part, welding length, resin specific mass, absorptivity, welding area.

2. Process data

The cost drivers for process data include laser power, distance between material and laser source, welding speed, volume, estimated life of the equipment, and number of maintenances.

3. Material and infrastructure cost data

The cost drivers of this process include of the costs of materials, workers, NDT equipment cost, pressure equipment cost, laser source cost.

4. Equipment cost

The equipment cost include machine costs

5. Maintenance cost

Table 2-3 presents the cost drivers of different bonding processes from different researchers.

Table 2-3: Cost Driver for Bonding Process

Researcher	**Cost drivers**				
(Wasim, Ahmad; Shehab, Essam; Abdalla, Hassan; Ashaab, Ahmed Al; Sulowski, Robert; Alam, Rahman;, 2012)		Material cost	Labor cost		Equipment running cost
(Ye, Jinrui; Zhang, Boming; Qi, Haiming;, 2009)	Equipment cost, Tooling cost	Material cost	Labor cost		
(Chayoukhi, Slah; Bouaziz, Zoubeir; Zghal, Ali;, 2008)	Equipment cost	Material cost	Labor Cost	Energy Cost	
(Masmoudi, F; Bouaziz, Z; Hachicha, W;, 2007)			Labor Cost	Energy Cost (Gas & electric)	Machining cost

2.6 Principal Cost Estimating Model Methodologies

Cost estimating is predetermining the lowest realistic price or cost of an item or activity which will make a normal profit (Bontas, Elena Paslaru; Mochol, Malgorzata;, 2005). There are two major types of cost estimation methods: algorithmic and non-algorithmic. There are two principal cost estimating models: the top down and bottom-up models.

2.6.1 Top-Down or Holistic Models

The top-down cost estimation technique estimates a job or task as either the overall features or a whole project. This technique applies historical data from similar engineering projects. This technique also modifies the original data for size, weight, activity level, and etc. The top-down cost estimation technique estimates the total cost of a complete project. The subcomponent is then assigned by the percentage of the costs. This technique is managed early in the estimation process. The top down model is also called a conceptual estimate. The conceptual estimate is a pre-design estimate. Pre-design estimates work with a limited project, limited engineering information, and no design concept. The conceptual estimate is prepared before the design or engineering process has begun. The information of this stage is usually considered high level information (Phaobunjong, 2002). Table 2-4 presents advantage and disadvantage of top-down or holistic models.

Table 2-4: Advantage and Disadvantage of Top-Down or Holistic Models

Advantage	• Represent the factors that drive cost • Enables comparison of different estimates for the same task/product. • Good for developing initial estimates and sensitivity/impact relatively quickly.
Disadvantage	• Difficult to tune to one's process/set of activities • Varying cost drivers effect on activities

2.6.2 Bottom-Up Model

The bottom-up technique starts with lowest-level cost component and works up to the highest-level for cost estimation. The bottom-up technique attempts to break down the project into smaller, more manageable units, estimated costs, etc. This technique is represented in the form of the Work Breakdown Structure (WBS). This technique considers the cost of each activity separately. The smaller unit costs are added together with other types of costs to obtain overall cost estimation. This technique is used when detailed design is available.

The bottom-up model also calls for a design estimate or post-design estimate. The cost estimation of this stage relies on complete design and engineering data. It is performed once the project design and engineering have been completed. The bottom-up model is more complex and detailed than other methods, requiring all product information included in the project, such as material quantities and unit costs (Phaobunjong, 2002). Table 2-5 presents the advantage and disadvantage of bottom-up model.

Table 2-5: Advantage and Disadvantage of Bottom-Up Model

Advantage	• Can ensure that all activities such as those on the WBS are estimated. • Can reflect varying effects to modify unit costs from base line/past project experience.
Disadvantage	• Sometime difficult to compare the basis of an estimate (driving factors not specifically articulated) • Does not enable a quick/easy comparison with past project experience. • Not good for developing initial estimates or quick sensitivity/impact analysis.

2.7 Cost Estimation Approaches Based on Functional Relationships

Cost estimating is the process of predicting the cost of project activity. The cost estimating methodology is required to analyze and manage the information of the project scope to produce the conceptual cost estimate. The following sections present other methods of cost estimation, including the analogy method, expert judgment, and parametric method.

2.7.1 Analogy Method, or Case Based Reasoning Method

The analogy method, or case based reasoning (CBR) method, estimates the solution based on past cases. This is a qualitative estimation method (Cavalieri, Sergio; Maccarrone, Paolo; Pinto, Roberto;, 2004). The main idea of this methodology is the extrapolation of available data from similar projects to estimate the costs of the proposed project. This method is suitable in situations where the data from previous projects are available and trustworthy and where the date depends on the accuracy in establishing real differences between completed and current projects. This method mostly useful estimating the cost in the first stage of the product development process. The analogy method is often used in software effort estimation. The main focus of analogy based method relies on past cases or pattern mapping. The performance of analogy based method is based on current data or information. Figure 2-1 presents a picture of case based reasoning.

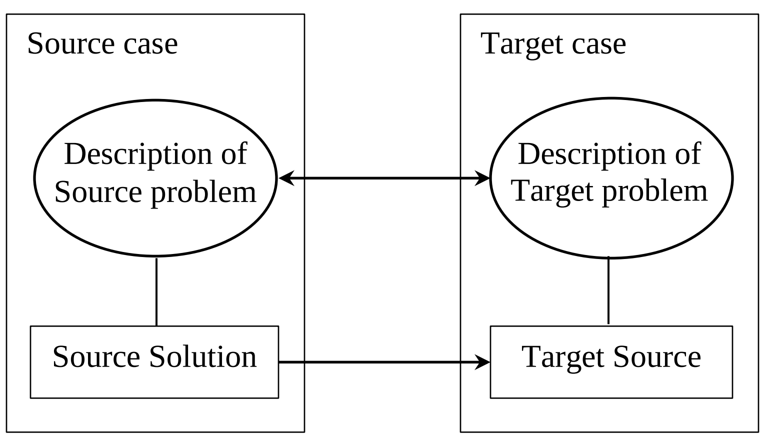

Figure 2-1: Case Base Reasoning

There are some problems of using this method. The following presents the advantage and disadvantage of analogy method. Table 2-6 presents the advantages and disadvantages of analogy or case based reasoning method.

Table 2-6: Advantage and Disadvantage of Analogy Method

Advantage	• Offers chance to learn from past experience • Save time or process quickly • Requires fewer data • Potential to reduce problem with outliers • Potential to reduce problem with calibration • Easy to understand the basis for an estimate • Useful where the domain is difficult to model
Disadvantage	• Difficult to access if the is design changed • Could not identify cost drivers • Accuracy depends on the similarity of data

2.7.2 Expert Judgment

The expert judgment method is based on a knowledge and experience of experts in the area or field. This is done through a structured process for collecting and distilling knowledge from a group of experts by means of a series of questionnaires interspersed with controlled opinion feedback. The cost estimation using this method therefore is a cost prediction of the experts. The experts' predict the cost of a product from their experience gained during the design process. This method has some weakness because the cost estimation comes from expert experience. The result will be no better than the experts' knowledge or experience (Guorong, 2007).

The expert judgment method is predicated by what an expert thinks something should cost for each activity. The experts chosen should have many years of experience to be successful in creating a cost estimation model. The expert judgment method also has some drawbacks and limitations. The advantage and disadvantage of expert judgment are presented by (Rush, Christopher; Rajkumar, Roy;, 2001) and are presented on Table 2-7 as follows:

Table 2-7: Advantage and Disadvantage of Expert Judgment Method

Advantage	• Quick to produce • Requires little resource in terms of time and cost • This method can be as accurate as other more expensive methods
Disadvantage	• Subjective: With the same information, the different experts can be presented different result of cost estimation. • Risky and prone to error • Use of expert judgment is not consistent and an

Table 2-7 — Continued

	unstructured process • Prone to bias: personal experience, political aims, resources, time pressure, memory recall • The reasoning is known only to the owner of the estimate • Estimate reuse and modification is difficult. • Difficult to negotiate effectively with customers • Difficult to quantify and validate the estimates • Estimate depends on level of experience • Experts leave the company – knowledge loss • Difficult to provide an audit trail • Estimates are black box in nature

2.7.3 Parametric Method

This method involves the usage of mathematical equations based on research and historical data from previous projects. The method analyzes main cost drivers of a specific class of projects and their dependencies and uses statistical techniques to refine and customize the corresponding formulas. As in the case of the analogy method the generation of a proved and tested cost model using the parametric method is directly related to the availability of reliable and relevant data to be used in calibrating the initial core model. Table presents advantage and disadvantage of parametric method (International Society of Parametric Analysts , 2008). Table 2-8 presents the advantages and disadvantages of parametric method.

Table 2-8: Advantage and Disadvantage of Parametric Method

Advantage	• Provided a better result of cost estimating • There is a high quality relationship between technical and cost • The activity data is easy to understand in both calibration and validation • It is easy to estimate conceptual design • It is effective to estimate the early cost • Do not required bill of material (BOM) • It is easier to manage when there is some information changed such as scope, technical and performance
Disadvantage	• Provide inaccurate result if not properly calibrated and validated • The model required to be adjusted if it is used with the new cost driver and database system.

2.7.3.1 History of Parametric Estimating

Parametric cost estimation started during World War II. The demand for military aircraft in numbers and models was greater than the aircraft industry had ever manufactured. Out of obvious necessity, they tried to develop techniques for more accurately predicting costs. There was not many cost estimation techniques available besides those used to estimate labor hours and material costs. In 1936, T.P. Wright suggested a type of statistical estimating. Wright provided the equation that could wield the predicted costs of long production runs on airplanes- a theory which came to be called the learning curve. In the early years of World War II, the demand for airplanes exploded; industrial engineers exercised Wright's learning curve to predict the unit cost of each airplane (Brundick, 2002). More recently, the parametric cost estimation method has been applied to estimate the cost of development in many areas. It has been applied to the cost estimation for software development (Boehm, B W; Abts, C; Brown, A W; Chulani, S; Clark, B; Horowitz, E; Madachy, R; Reifer, D J; Steece, B;, 2000), hardware development (PRICE-H, 2002), and system engineering development (Valerdi, 2005).

2.7.3.2 Parametric Estimating Procedure

Parametric cost estimation for microchannel bonding process includes of seven steps. The seven steps of microchannel bonding cost estimation are derived from the activity-based costing procedure is presented in Figure 2-2.

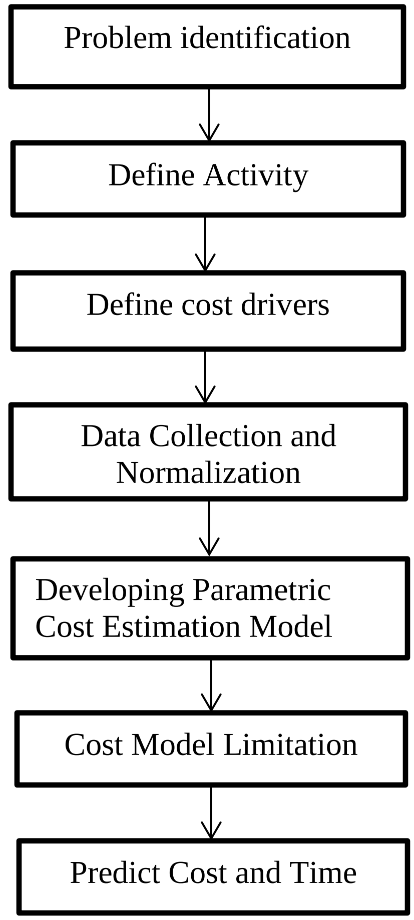

Figure 2-2: Parametric Cost Estimation Based on Activity Based Costing Procedure

The first step is Problem Identification. This process is important for learning the activity process. This process explains the objective and scope of the project.

The second step is to Define Activity. This step helps to classify the activity that may affect the cost of the product manufacturing process. The ABC will focus to the activities that incur the major cost of productions and services.

The third step is to Define Cost Drivers. This step considers the factors that cause change in the cost of activity and in the production process. The cost driver is the parameter that drives the cost. The cost driver should have an indirect relationship to the activities.

The fourth step is Data Collection and Normalization. This step is important to generate the correct output. This step will ensure that all the data have the same unit or the same base before processing the data in the parametric cost estimation model. Normalizing the data means making adjustments for the location, project scope, and system specification. The cost data from historical projects should be adjusted for the current time frame.

The data for the parametric database can be data from either inside or outside the organization. The data of each variable should include of information that relates to each specific variable, such as performance characteristics, quantities, and schedule information (Stewart, Rodney D; Wyskida, Richard M; Johannes, James D;, 1995).

The fifth step is the Developing Cost Estimation Model. The parametric cost estimation uses the Cost Estimating Relationships (CER) with the project characteristics and an algorithm to estimate project cost. CERs are based on cost-to-cost or cost-to-non cost variables (Kwak, Young Hoon; Watson, Rudy J;, 2005).

The sixth step is Cost Model Limitation. This step is the process of documentation of an assumption and limitation of the model. The limitation of data will be in the range of simple algorithms which are one-to-one relationships. The data can have a more complex relationship with the increase of the level of complexity of the algorithm (Kwak, Young Hoon; Watson, Rudy J;, 2005).

The seventh step is to Predict Cost and Time. This step calculates the result from the parametric cost estimation model through inputting the data value. The parametric cost estimation model then calculates the result for the cost of the manufacturing process or bonding process and time of the bonding process.

2.8 Regression Model

Regression analysis is widely used technique in nearly every field of application. The regression analysis is the method perceives the relationship between a dependent variable and other independent variables. Their relationship will be one of cause and effect (Ryan, 1997). The example of research that applies to the regression analysis method includes a building construction project (Phaobunjong, 2002), software cost estimation (Mittas, Nikolaos ; Angelis, Lefteris ;, 2010), light rail transit and metro trackwork (Gunduz, Murat ; Ugur, Latif Onur ; Ozturk, Erhan;, 2011), and sheet metal operations (Verlinden, B; Duflou, J R; Collin, P; Cattrysse, D;, 2008).

2.8.1 General Multiple Linear Regression Model

The general multiple linear regression models can be expressed in the form of

$$Y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_{p-1} x_{i,p-1} + \varepsilon_i$$

Where:

$\beta_0, \beta_1, \ldots, \beta_{p-1}$ are parameters

$x_{i1}, \ldots, x_{i,p-1}$ are known constants

ε_i are independent $N(0, \sigma^2)$

i = 1,…,n

n = Observation number

p = number of regression parameters

2.8.2 Basic Concept Regarding Statistic Test

2.8.2.1 Linearity

To review our MLR model for a reasonable interpretation, we have to check its linearity. The plots of $e_i - x_k$ are used to identify a linear relationship between response variable and each predictor.

2.8.2.2 Constant Variance

To check that the residual has a constant variance, the residual versus the mean response plot ($e_i - \hat{y}$) is used. In this plot, we look for curvature and a funnel shape. If neither structure is present, the result is constant variance.

2.8.2.3 Normality

Normality can be checked by a normal probability plot (NPP). The normal probability plot should be linear. It should not have a long right and left tail. If it has neither, then we can accept the plot represents normality and our findings are good. Figure 2-3 shows the example of normal probability plot.

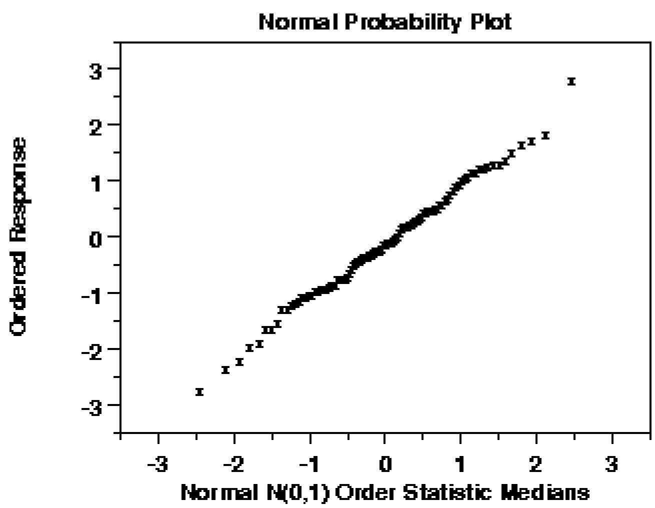

Figure 2-3: Normal Probability Plot

2.8.3 Graphical Technique

2.8.3.1 Histogram

The histogram is a graphical presentation of the distribution of the data by using the bars of different heights. Figure 2-4 is an example of a histogram.

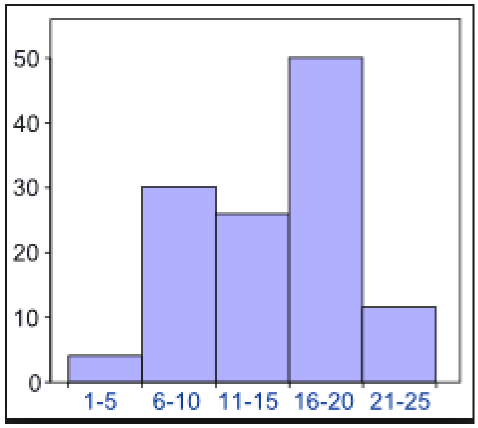

Figure 2-4: Histogram

2.8.3.2 Scatter Plot

A scatter plot is a graph that presents the correlation or relationship between two sets of data. The dot represents that correlation of two data. If the plots on the graph resemble the line, then there is a correlation between two sets of data. There are two types of correlation: positive correlation and negative correlation. Figure 2-5 presents an example of a scatter plot.

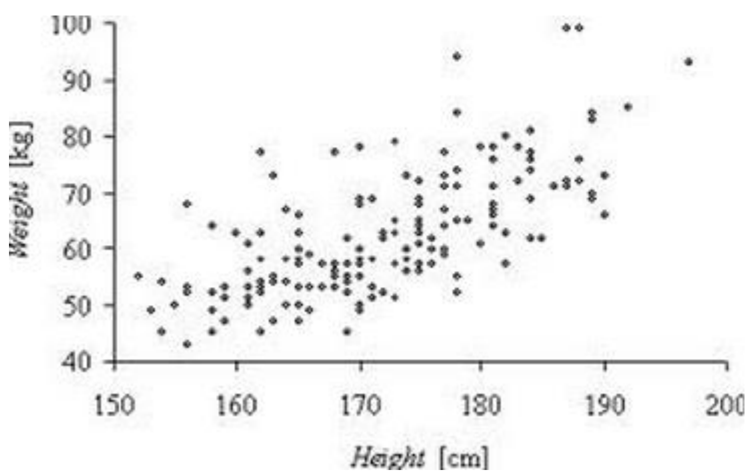

Figure 2-5: Scatter plot

2.8.4 Selecting the Best Model

In multiple regressions, there are many potential predictors to find the best subset. Some methods are better than others in finding the best potential predictor for a model. The following present strategies to find the best subset for a model.

2.8.4.1 Backward Elimination

The backward elimination method is one method used to select the variables. The backward elimination process starts by inputting the date of all available variables. It then finds the worst variable and eliminates it, repeating the process stage by stage. The backward elimination uses F-tests to determine the worst variable that can be cut at each stage (Ryan, 1997).

2.8.4.2 Stepwise Regression

The stepwise regression also starts by entering all variables into the procedure. The procedure then checks to see if any of variables can be deleted. The procedure will terminate or stop when no variables can be added or deleted. The stepwise regression method can be used with many variables (Ryan, 1997).

2.8.4.3 Forward Selection

The forward selection method starts with the fit intercept-only model as a base model. The process of forward selection adds a single variable to the model. It can be called a set of “added-in-order test” for the current model. The first stage considers a one variable model. The second stage evaluates a set of two variable models, and so on. If the variable is deemed significant, it will be added to the model (Muller, Keith E; Fetterman, Bethel A;, 2003).

Chapter 3

Research Methodology

3.1 Introduction

The research area addressed by this dissertation focuses on the cost estimation for the eutectic microchannel bonding process. This bonding process is based on the eutectic bonding process of CREST lab, University of Texas at Arlington. This research presents the relationship of cost drivers and cost characteristics within the microchannel bonding process. This research also demonstrates the data collection process and the cost estimating model development.

Chapter three presents the research methodology for the microchannel process. First, a basic overview of the eutectic microchannel bonding process is presented. This includes data collection, activity based model, and parametric cost estimation model, respectively.

3.2 Microchannel Bonding Process of CREST Lab (UTA)

There are many methods for bonding microchannel plate. This research focuses on the four step processes of bonding: design, machining, bonding, and testing. The picture of microchannel bonding process shows in Figure 3 -1.

Figure 3-1: Microchannel Bonding Process

The first step is in the microchannel bonding process is the design process. This process designs the channel for each microchannel plate and selects the material for bonding. There are five different types of microchannel plate: connection cap, top plate, a plate, b plate, and bottom plate.

The second step in the process is machining. The machining process requires a micro-machine CNC as the main equipment. The machining process cuts the selected material into the predetermined design shape, places the inlet and outlet holes, and channels the plate.

The third step is the bonding process. The bonding process bonds five different plates together by using a hot press machine. The bonding process starts with cleaning each plate. The microchannel plates are then stacked up and placed into the hot press machine.

The final step is the testing process. Water pressure and heating are two methods used to test the microchannel plate bonding.

3.2.1 Microchannel Design Process

The design process includes designing for all five main parts: a connection cap, top cap, a plate, b plate, and bottom plate. These plates are designed by a CAD program and exported as IGES files. This design process decides the material for the microchannel plate. The CREST lab, UTA chose to use the Aluminum Alloy (AL) 6061 T6 as the material for microchannel plate.

3.2.2 Machining or Channel Process

The machining process includes three major actions. First is the placement of each plate separately. A customized jig- a block of stainless steel with holes for mounting to the CNC and two captured flaps on either side- hold the flat aluminum plate in place. Second is machining. A high speed micro machining spindle drills holes into the aluminum plate. Then, the machine channels up to 0.015” deep on both sides of the plate. Next, the edges of each plate are trimmed before the plate is flipped for machining on the reverse side. All five plates must go through the machining process separately as each plate requires different channels.

3.2.3 Laminae Bonding Process

Before starting to bond the microchannel plates, the plates have to be cleaned by degreasing. All channel plates are stacked in order. To straighten each aluminum part, the stack of channel plates are placed in a carver hot press with temperatures of 340° C, 700 lbs of pressure for 6 hours. After straightening the channel plates, their surfaces are cleaned through sanding then washed with acetone. The acetone cleaning is also applied to copper foil. After cleaning both aluminum and copper, the microchannel plates and copper foil are stacked in bonding order on a bonding fixture base. The microchannel bonding fixture is placed in an AVS vacuum hot press with the minimum force ramp of 300 lbs, or the minimum setting allow for each vacuum machine. The pressure is not to exceed 1000 lbs. The vacuum will heat up to 560° C and hold for 30 minutes at a rate of 30° C per minute. After the microchannel fixture cools, the fixture is cleaned with argon and removed from the vacuum press.

3.2.4 Testing Process

The testing process for the microchannel bonding process includes passing pressure through the microchannel model to check for any leaks in the model. This is done by attaching the module to argon tank, verifying all exits are sealed, and connecting the module to a silicon oil bath. The silicon oil is heated up to 275° C and the module pressurized up to 300 PSI. After three hours, if no leakage has been found, the module is considered acceptable.

3.3 Data Collection

Data collection is defined as the process of prepared and collected data for a given sample population for observation. There are five different types of research with different methods of observation (Babbie; Earl, R;, 1992). These five different methods are described below:

1. Experimental Research

   Experimental research includes of taking action upon the research subject and observing the result of that action.

2. Survey Research

   Survey research collects data from asking a select group of specific questions regarding the research subject.

3. Field Research

   Field research is the direct observation of the subject within its natural setting.

4. Unobtrusive Research

   Unobtrusive research involves investigation, without researchers, within the environment of study. It analyzes existing statistics or historical data.

5. Evaluation Research

   Evaluation research involves the evolution of impact of data collected by the experiment method.

Evaluation research requires the data gathered by the experimental research. The microchannel bonding data herein was collected from separate location due to the particulars of the bonding process. The design, bonding, and testing process data was collected from the CREST lab. The channel process data was collected from machine shop. The testing process data was similarly collected from the CREST lab. Other data concerning microchannel bonding was gathered from published research. However, there is very little historical data to rely on. Most of the data was gathered from previous research and experimentation.

3.4 Microchannel Bonding Cost Drivers

The cost driver is the factor that can cause a change in the cost of an activity. An example of a production activity may have the following associated cost drivers: machine parts, power consummation, the quantity of waste, and/or rejected output (Business dictionary, 2012). The cost drivers in the model refer to variables that affect the calculation of the microchannel cost model. Table 3-1 shows data items and informational needs for the microchannel bonding cost model.

Table 3-1: Microchannel Bonding Process Cost Driver

Driver Name	Data Item
Raw Material	Al Alloy, copper, Argon tank
Labor	Labor rate per area
Equipment or Tool support	CNC machine, vacuum hot press
Time	Machining time, bonding time, setup time

3.5 Data Preparation

The historical data for this research derives from previous research and from experimentation. As mentioned above, there are a number of bonding methods and each method requires different materials, time, and equipment and tools. The research and data collected below was limited by the accessibility to those requirements. The data requirements available for this research include the data of raw material cost, labor cost, equipment or tool cost, and time of each activity. Table 3-2 presents the data of microchannel bonding process. The data is shown by requirement of each process.

Table 3-2: Microchannel Bonding Process Data

Design Process	**Machining Process**	**Bonding Process**	**Testing Process**
CAD program	a high speed micro machining spindle	acetone	Argon tank
Aluminum Alloy 6061 T6 0.040” thickness	CNC machine	Vacuum Hot press machine	Labor
Copper 99.99% 0.0005”thickness	Channel up to 0.015” deep	Laser machine	
Labor	Drill the holes	Labor	
	Labor		

3.5.1 Normalization Data

The data normalization is the process of adjusting the data to the same unit or basis of information. This research the labor cost is normalized to the US dollar. The labor effort, or labor hour, is normalized to the hour. The length of channel is normalized to millimeter (mm). The diameters of big and small holes are normalized to the inch. The machine time and setup time are normalized to the minute.

3.6 Activity Based Costing (ABC)

Parametric cost estimation integrated with the activity based costing technique far more exact in the cost estimation results for microchannel bonding process. ABC technique helps to separate the cost of the microchannel process by activity. It makes the cost estimation easier to calculate the cost and is more accurate.

3.6.1 Identify Cost Center and Cost Drivers

The cost centers are the resources that are used to produce the end product or service. The cost centers include human resources, such as a design engineer, a manufacturing engineer, and a student engineer. The cost centers also include equipment and tools, such as a milling machine, a laser cutting machine, and others.

The cost drivers are the expense or cost that is allocated to the end product or service. The cost drivers are determined by number of hours or rate per hours.

3.6.1.1 Design Process

Table 3-3 presents the cost centers and cost drivers of the design process for the microchannel bonding method.

Table 3-3: Design Process Cost Centers and Cost Drivers

Activity	**Cost center used**	**Cost driver**
Design channel plate	Design engineer	Labor hours
Create design	Equipment and tools	Number of software licenses
Create design	Equipment and tools	Number of computers

3.6.1.2 Channel Process

Table 3-4 presents the cost centers and cost drivers for the channel processes for the microchannel bonding method.

Table 3-4: Channel Process Cost Centers and Cost Drivers

Activity	**Cost center used**	**Cost driver**
Cap plate	Mechanical	Labor hours
Top plate	Mechanical	Labor hours
A plate	Mechanical	Labor hours
B plate	Mechanical	Labor hours
Bottom plate	Mechanical	Labor hours

3.6.1.3 Bonding Process

Table 3-5 presents the cost centers and cost drivers of the bonding process for microchannel bonding method.

Table 3-5: Bonding Process Cost Centers and Cost Drivers

Activity	**Cost center used**	**Cost drivers**
Cleaning (Acetone)	Equipment & tools	Portions used
Degreasing	Equipment & tools	Portions used
Sanding paper	Equipment & tools	Portions used
Sanding	Student engineer	Labor hours
Straightening	Student engineer	Labor hours
Laser cutting copper	Student engineer	Labor hours
Assembly	Student engineer	Labor hours
Loading & Bonding	Student engineer	Labor hours
Vacuum hot press machine	Equipment & tools	Numbers used
Electricity used	Equipment & tools	Rates used

3.6.1.4 Testing Process

Table 3-6 presents the cost centers and cost drivers of the testing process for microchannel bonding method.

Table 3-6: Testing Process Cost Centers and Cost Drivers

Activity	**Cost center used**	**Cost drivers**
Argon tank	Equipment & tools	Portions used
Silicon Oil	Equipment & tools	Portions used
Tester	Testing engineer	Labor hours

3.7 Model Assumption

The objective of microchannel bonding cost model is to evaluate the cost of the microchannel bonding process. The parametric cost estimation model is specifically generated for the eutectic microchannel bonding process. This creates some restrictions or limitations on the model that will be described below.

Assumption A1. The cost of the microchannel bonding process cost model includes labor and equipment. The equipment costs are quantified as software and hardware. Also, the cost of labor will be considered in hours. Other overhead costs will not be considered for in the microchannel bonding cost or expense.

Assumption A2. There are four processes in microchannel bonding. These four processes in the microchannel bonding include the design, channel, bonding, and testing process.

Assumption A3. The process of system testing will work in a series. There are four processes in the microchannel bonding process and include the design, channel, bonding, and testing process. All four processes of system testing are performed in sequence. The design process should be performed first and further testing performed in the order of the bonding process.

Assumption A4. The duration time for the microchannel bonding process is considered to be the maximum duration time a worker works in each process.

The duration time of the project is calculated from the summation of the maximum duration time the worker works in each sub process.

Assumption A5. Overhead costs are not considered in this model. The over-head cost is not included in this microchannel bonding cost estimation model. Overhead costs may include the use of indirect labor, indirect material, indirect engineering, and other indirect expense.

Assumption A6. The price lists of raw materials, equipment, and tools are subject to change depending on the market condition.

3.8 Parametric Cost Estimation Model

This section presents the parametric cost analysis integration with the ABC model to obtain easy and accurate computation for the microchannel bonding process. The cost model for the microchannel bonding process has been developed to help in decision making or tradeoff benefits between costs and time required for the microchannel manufacturing process. The function of the manufacturing costs of bonding microchannel plate will be calculated based on the material, machine, tools, and the operational and financial data of each bonding process. The parametric cost estimation obtained from the ABC for the microchannel bonding process is presented below.

3.8.1 Labor Cost

Labor cost represents the rate of labor per hour. The rate of labor will be different for each worker. The rate per hour of each worker is reflected in the worker's skill. L is a set of workers. i is a person or worker in L ($i \in L$). The role process association means the same worker can provide different skills. For example, worker A may work on both the design channel plate and work on the bonding process.

$$C_l = \sum_{i \in L} \sum_{j \in R} C_i T_{ij} \qquad (1)$$

Where :

R = a set of role process association

L = a set of worker or people

C_l = cost of labor

C_i = the cost of person $i \in L$ per hour

T_{ij} = Duration time that person $i \in L$ work on role $j \in R$ unit in work day

3.8.2 Material Cost

The material of each product is selected in product design. Items used to make a product are called direct material. The materials used in the production process, but which do not become part of product, are called indirect material. In the manufacturing industry, the cost of material is determined per product unit.

The estimation of material includes waste, short ends, and other losses (Ostwald, Phillip F; McLaren, Timothy S;, 2004)

The primary cost drivers for the material cost are as follows:

- Material cost
- Length of material
- Width of material
- Thickness of material

The listed price of raw material is available from a sheet metal supplier. The price of raw the material may be different from each supplier for each type of material. The price of raw material can be changed depending on the market situation.

The main materials selected for microchannel bonding process in CREST lab included aluminum (AL) alloy 6061 T6 with 0.040 inch thickness and copper (CU) with 99.99% and 0.0005 inch thickness. The material cost model represents the cost of raw materials and reflect to the size of material. Therefore, the cost of each material is multiplied by the the size or area of the material.

$$CR_m = (W_m * L_m * H_m) * \ C_m \qquad (2)$$

Where:

CR_m = Cost of raw material

W_m = Width of raw material

L_m = Length of raw material

H_m = Thick of raw material

C_m = Cost of raw material

3.8.3 Machine or Equipment cost

The main cost of the cost estimation model is the capital investment in equipment. The main equipment of the microchannel bonding process is the CNC machine and the vacuum hot press. The capital investment cost is calculated by the price of the machine deducted by the salvage cost or the depreciation cost. The total cost of equipment will be the price of equipment after deducting depreciation costs added with the interest.

$$C_{mhe} = (C_{tp} - SV) * (1 + I_r) \quad (3)$$

Where:

C_{mhe} = Cost of equipment or machine

C_{tp} = start up price of equipment

SV = salvage value or depreciation cost of equipment

I_r = interest rate

3.8.4 Software Cost

The main software required for the microchannel bonding process is the CAD program. The CAD program is used to design the channel plates and include all five main parts. The five main parts are connection cap, top plate, a plate, b plate, and bottom plate. The software cost model is calculated by cost of the software per license multiplied by the number of software licenses used.

$$C_{tsw} = \sum_{d=1}^{n} \sum_{p \in P} Csw_d \mathrm{Ns}_{dp} \quad (4)$$

Where:

P = set of process of microchannel bonding

C_{tsw} = total cost of software

Csw_d = the cost of software d per license

NS_{dp} = Number of software license is a constant

3.8.5 Electricity Cost

The cost of electricity focused mainly on the machining, bonding, and testing processes. The cost of electricity during the bonding period is calculated by cost of electricity per unit times the number of unit used. The total cost of electricity is divided by number of part completed.

$$C_e = \frac{C_u * U}{N_c} \quad (5)$$

Where:

C_e = electricity cost

C_u = cost per unit (kw per hour)

U = number of electricity unit used

N_c = number of part completed

3.8.6 Cost of Cutting or Reticle for Machining Process

$$C_{ret} = \frac{C_{mhe}}{N_c} * R_{cplex} \qquad (6)$$

Where

C_{ret} = cost of cutting or reticle

N_c = number of part completed

C_{mhe} = Cost of equipment or machine

R_{cplex} = weight or level of complexity of reticle

Level of complexity is separated into 3 levels which are

Level1 = 1, Level2 = 1.1, Level3 = 1.2

3.8.7 Cost of Bonding

$$C_b = \frac{C_{mhe}}{N_c} \qquad (7)$$

Where

C_b = cost of bonding

N_c = number of part completed

C_{mhe} = Cost of equipment or machine

3.9 Time of Microchannel Bonding Process

3.9.1 Machining Time

Machining time includes cutting, trim, channeling, and setup time. The setup time is the setup time for the machine and for each tool that will be used for the machining process. Table 3-7 presents the setup time for different machines and the setup time for each tool (Ostwald, 1992).

Table 3-7: Machine Setup Time (Ostwald, 1992)

Machine Tools	**Setup Time Machines (minutes)**
Punch in and out, study drawing	12
Turret lathe	
First tool	78
Each additional tool	18
Collect fixture	12
Chuck fixture	6
Milling Machine	
Vise	66
Angle plate	84
Shoulder-cut milling cutter	90
Slot-cut milling center	96
Tight tolerance	30
Drill press	
Jig or fixture	6
Vise	3
Number of numerically controlled turrets	
First turret	15
Additional turrets	1.05

Machine time is calculated by the length of cut divided by the feed rate of the machine

$$T_f = \frac{L_c}{F_m}$$

T_f is machine time in minutes or cutting time

L_c is the length of cut in feed direction in inches

F_m is the feed rate in inches per minute

The length of cut is the total distance traveled by the tool at the feed rate on the work piece plus any pretravel and overtravel for the tool to clean the work piece. That is,

L_c is the length of channel to be machine + pretravel (or approach length) + overtravel

The feed rate is the product of the feed and the rotational rate of the tools. That is, $F_m = f_t * N_r$

F_m = feed rate in inches per minute

f_t = feed rate per revolution

N_r = rotational rate in revolution per minute

Therefore;

$$T_f = \frac{L_c}{f_t * N_r} \quad (8)$$

3.9.2 Time for Drilling

Drilling time is the time to drill two holes on one blank plate. The two blank plates are the top cap and bottom cap. The two holes are the inlet and outlet for the microchannel bonding module.

$N = 12V/\pi D_c$

Therefore;

$$T_d = \frac{\pi D_c L_c}{12V f_t} \qquad (9)$$

Where:

T_d = Time of drilling the hole

V = cutting speed between the tool and the work piece

D_c = diameter of the feature cut

L_c = length of cut in feed direction in inches

f_t = feed rate per revolution

3.9.3 Bonding Time

Bonding time is the time of the bonding process when the microchannel module is placed in the vacuum hot press. The bonding time is calculated by the heat up time plus holding time plus cooling time. The holding time is the time of hold the module is in the hot press with the required temperature.

$$T_b = \frac{Temp_h}{Temp_r} + T_{hold} + T_{cool} \qquad (10)$$

Where:

T_b = Bonding time

$Temp_h$ = Temperature heat

$Temp_r$ = Temperature rate per minute

T_{hold} = holding time

T_{cool} = Cooling time

The cost estimation model is used to predict the cost and process time of the microchannel process. The results from the cost estimation model are analyzed by the regression analysis method. The analysis result is presented in the next chapter.

Chapter 4

Data Analysis and Presentation of Results

4.1 Introduction

A parametric method based on activity based costing involves significant parameters and cost drivers within the microchannel bonding process. The activity based costing method classifies all the microchannel bonding data by activity. Then, the parametric cost estimation model will estimate the cost and time of each activity or each process. The data of the bonding process is analyzed by using the statistic method. This method analyzes the significant cost drivers and establish the relationship of parametric cost estimation parameters.

4.2 Cost Estimation Model

The cost estimation model was developed based on known information of cycle time and equipment driver for the production system. The assumption for the microchannel developing process was made to develop a cost estimation model, which is presented below:

1. The production system produces microchannel plate or microlaminated from aluminum alloy type 6061. The production method used eutectic banding process. The production system operates 8 hours a day, 5 days a week.
2. The microlaminated contains three different lamina patterns. The device will have two endcaps containing inlet and outlet ports.

4.3 Cost Estimation Model by Using Sensitivity Analysis

The cost estimation model was implemented in Microsoft Excel 2010. All the information of the microchannel bonding processes was entered into the cost estimation model to estimate the production unit cost per device.

The microchannel structure includes three different lamina patterns and two endcaps. The size of the lamina has a width of 47.625 mm and a length of 70.644 mm. All lamina have the same thickness but different pattern complexities. Figure 4-1 presents sensitivity analysis of microchannel bonding process.

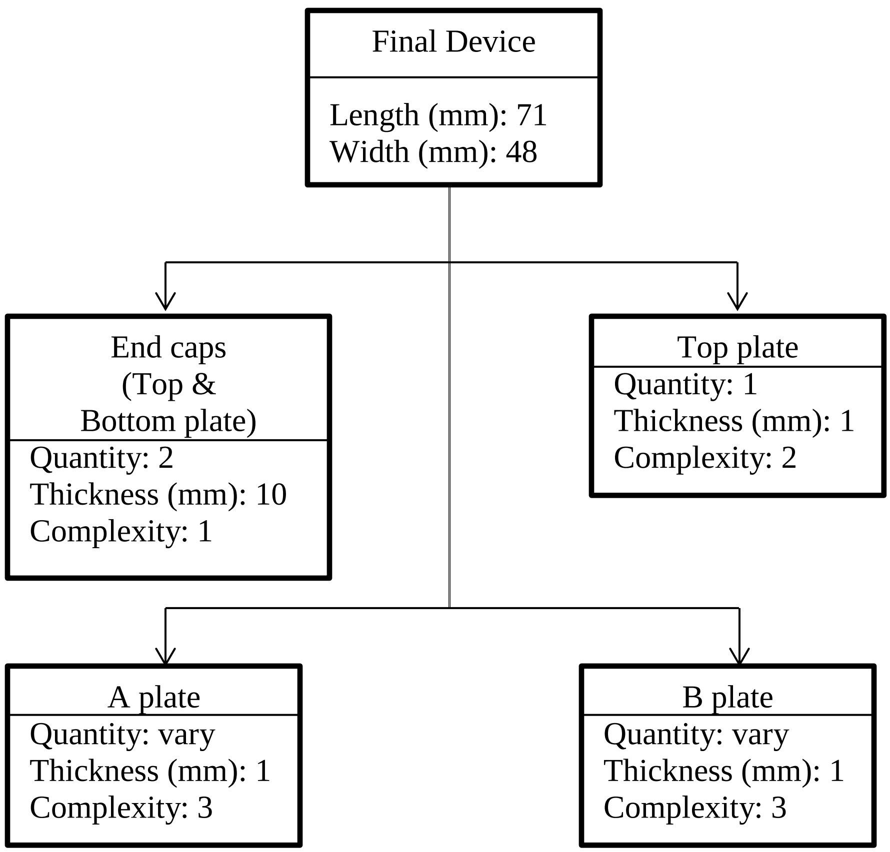

Figure 4-1: Sensitivity Analysis

4.4 Cost Estimation for Capital Investment on Equipment

The main cost driver for the microchannel bonding process cost estimation model is capital investment on equipment. The equipment or machine cost of each process for microchannel bonding process is shown in the table 4-1 below.

Table 4-1: Capital Investment on Equipment

Process	**Machine**	**Capital ($)**	**Amortized (5 years; $/year)**	**Interest rate (8%;$/year)**	**Annual total**
Bonding Process	Vacuum hot press	250,000	50,000	20,000	70,000
Bonding Process	Laser cutting	45,000	9,000	3,600	12,600
Channel Process	Micro CNC machine	37,500	7500	3,000	10,500

The main cost driver for microchannel bonding cost estimation process is the capital investment on equipment. The equipment or machine cost was collected from vendor websites to reflect the recent price of equipment costs. The price of the equipment can change depending on the model and the market price. The estimated cost per vacuum hot press was approximately $250,000. The estimated cost per laser cutter was approximately $45,000. The estimated cost per micro CNC milling machine was approximately $37,500. The capital investment figure was amortized over a 5-year period using an annual interest rate of 8%. The number of equipment needed was allocated as one for each type used in the production system. The annual total cost was the estimated expense cost per year per machine or equipment.

4.5 Cost Estimation Microchannel Bonding Process

This research focus cost estimation for the microchannel eutectic bonding process included four processes, which were design, channel, bonding, and the testing processes. The cost estimation method applied the parametric cost estimation model to calculate the cost of the microchannel. This research separated the cost of microchannel bonding by using the activity based costing method. The cost of microchannel bonding is shown by the activity based costing of each process.

4.5.1 Cost Estimation for Design Process

The design process is the first step in the microchannel bonding process. This process includes of two main cost drivers, which are

1. Worker or labor

   The worker of this process was a design engineer. The design engineer of CREST lab was a research assistant (RA). The RA working rate is 23.08 USD per hour. Research assistants working hours for this project were 20 hours per week for 16 weeks per semester.

2. Equipment or tool

   The equipment used with the design process included of the computer and Auto CAD software.

The design activity included design material for the microchannel plate, design size of microchannel plate, and the design of the channel. All the tasks of the design processes was counted as one activity.

Table 4-2: Activity Cost Analysis for Design Process

Activity	**Cost drivers**	**Rate (USD)**	**Total hours**	**Cost**
Design Part	Design engineer (RA)	23.08	320 (20 hrs/week) (16 week/semester)	7385.60
	Auto CAD software	1500		1500
	Computer	1000		1000
Total				9885.60

Table 4-2 presents the cost estimation for the design process. The cost of the design engineer (TA) was 7,385.60 USD. The cost of Auto CAD software was 1,500 USD. The cost of computer was 1,000 USD. Therefore, the total cost estimation for the design process was 9,885.60 USD. Information from the design engineer's (RA) rate was collected from an interview with the RA of CREST lab. Information about software and computer pricing was collected from vendor websites to reflect the most recent pricing for tooling costs.

4.5.2 Cost Estimation for Channel Process

The channel process is the second process of the microchannel bonding process. The process includes of two main cost drivers which are

1. Worker or labor

   The worker for this channel process was a technician. The technician worked at the machine shop. The technician's rate was 35 USD per hour.

2. Equipment and tools

   The equipment and tools used in the channel process included the micro-machine CNC.

The cost estimation of the process varied for the number produced. There are five different types of microchannel plate, including the

1. Cap

   The cap required two big holes and three small holes. The size of the big hole was 0.00138 inch and the size of the small hole was 0.000398 inch.

2. Top plate

   The top plate required three small holes and channel for one side of channel plate.

3. A plate

   The A plate is required three small holes and channel for both sides of the channel plate.

4. B plate

   The B plate is required three small holes and channel for both sides of the channel plate.

5. Bottom

   The bottom plate is required two big holes and three small holes. Both sets of holes matched the same size diameter of the top plate.

Table 4-3: Activity Cost Analysis for Channel Process

Part name	**Diameter big hole (inch)**	**Diameter small hole (inch)**	**Length (mm)**	**Machine time (min)**	**Setup time (min)**	**Labor cost ($35/hrs.)**
Cap	0.00138	0.000398		0.00475	7.67	4.48
Top		0.000398	1213.7	5.8599	44.67	29.48
A plate		0.000398	2811.95	13.3769	44.67	33.86
B plate		0.000398	2811.95	13.3769	44.67	33.86
Bottom	0.00138	0.000398	1213.7	5.84475	44.67	29.47
Total						131.15

Table 4-3 presents the cost estimation for the channel process. The cost of production of the channel for each microchannel plate depended on the length of channel and diameter of the hole that was required. The production time for each microchannel plate was included the setup time for the machine. The setup time for the machine was presented by (Ostwald, 1992) shown in table 3-3. The production time of each microchannel plate was added to the production time and setup to calculate the cost estimation plate placed in the machine. Information for the technician's rate was collected through an interview at the machine shop at the University of Texas at Arlington (UTA).

4.5.3 Cost Estimation for Bonding or Lamina Process

The bonding process was the third process of the microchannel bonding process. This research included the cost of aluminum as the part of the raw material cost. The main cost drivers of this bonding process considered the

1. Raw material

   The raw material used for this process included the use of aluminum alloy type 6061. The price of aluminum alloy was obtained from vendors for 65.30 USD per sheet. The aluminum alloy sheet size was 36"x36"x0.040".

2. Equipment and tools

   Equipment and tools cost drivers included of the vacuum hot press machine, degreasing, acetone, and sanding paper.

3. Worker or labor

   The worker for this process was the research assistant (RA). The rate of RA's work was 23.08 USD per hour.

4. Other cost

   The other cost reflected in this process included the cost of electricity. The information for the electrical cost of the process was collect from a vender website connected to the Arlington, Texas area. The cost of electricity was 9.4 cents per kilowatt.

Table 4-4: Activity Cost Analysis for Bonding Process

Activity	**Cost drivers**	**Rate (USD)**	**Total hours**	**Cost (USD)**
Cleaning (Acetone)	portion			11
Degreasing	portion			3.50
Sanding paper	portion			19.96
Sanding	Student	23.08	4	92.32
Straightening	Student	23.08	0.75 hrs. or 45 mins	17.31
Laser cutting copper	Student	23.08	6	138.48
Assembly	Student	23.08	1	23.08
Loading & Bonding	Student	23.08	1	23.08
Vacuum hot press machine	Machine cost	70,000	1	70,000
Laser cutting machine	Machine cost	12,600	1	12,600
Electricity used	kW/hrs.	9.4 cents/kW	0.612 kW/piece	5.75
Total				82,934.50

Table 4-4 presents the activity cost analysis for bonding process by activity. The total cost of bonding process for a one time process was $82,934.50.

4.5.4 Cost Estimation Analysis for Testing Process

The testing process is the last process of microchannel bonding process. This process includes the raw material used, which were argon and silicon oil. The argon rate was $0.50 per 100 gram. The silicon oil rate was $36.55 USD for 13 ounces. The tester for this process was a student engineer. The student engineer's rate was $ 23.08 USD.

Table 4-5: Activity Cost Analysis for Testing Process

Activity	**Cost drivers**	**Rate**	**Total use**	**Cost (USD)**
Argon tank		($.50/100 grams)	1000	5
Silicon Oil	ounce	36.55 for 13 oz	26 oz	73.10
Tester	Student	23.08	2 hrs.	46.16
Total				124.26

Table 4-5 presents activity cost analysis for testing process by activity. The total cost for the testing process is $124.26.

4.6 Manufacturing Unit Cost for Different Production Rates

Table 4-6 presents the unit cost for different production rates among four different processes of the microchannel bonding process. The production rates compared the cost of production from 1 up to 100,000 units. The production costs were reduced by increasing the units produced. The cost of the production processes differed from each other due to the requirement of the machine, raw material, and labor.

Table 4-6: Manufacturing Unit Cost for Different Production Rates

	Unit Cost				
Production rate	**Design process**	**Channel process**	**Bonding process**	**Testing process**	**Total cost/piece**
1	9,885.60	10,947.80	82,934.50	124.26	103,892.16
10	988.56	1,497.76	8,594.48	82.716	11,163.516
100	98.856	552.76	1,160.48	78.5616	1,890.658
1,000	9.8856	458.26	417.08	13.2332	898.459
10,000	0.98856	448.81	342.74	6.6542	799.193
100,000	0.098856	447.865	335.306	5.9963	789.267

4.7 Analysis Tools and Statistic Technique

The multiple linear regression (MLR) was used to model the data set. This research explored the relationship between the cost drivers of the microchannel bonding process. The response variable of this formula was the cost of the microchannel plate. The predictor variables included the raw material cost, labor cost, time of process, and machine cost.

The data set was obtained from previous research and the experiments conducted at the CREST LAB, University of Texas at Arlington. Assumptions, diagnostic checks, tests, and tools were used to reach the potentially best model overall.

This model was the tool that helped predict the cost of the microchannel bonding process. This model provided a quick and accurate way to estimate the cost for the bonding process.

4.7.1 Data Set

The data of microchannel bonding process consisted of price per microchannel piece (Y) and fours predictors based on the main cost drivers, which were the raw material cost (USD), labor cost (USD), time of process (second), and machine cost (USD). The data is presented in table 4-7.

Table 4-7: Microchannel Bonding Data Set

The SAS System

Obs	raw	labor	time	machine	cost
1	45.14	18.750	180.0	254800	89.74
2	26.23	4.900	50.4	254800	30.08
3	40.78	14.625	140.4	55300	59.61
4	35.96	7.140	108.0	212800	47.70
5	24.13	25.125	241.2	170800	93.89
6	47.89	4.425	54.0	55300	37.25
7	50.15	19.950	205.2	59500	89.63
8	25.75	49.740	752.4	35140	238.91
9	38.15	35.000	360.0	64400	131.27
10	42.60	5.236	79.2	55714	40.24
11	36.50	15.750	151.2	2500	75.74
12	23.16	19.870	190.8	10500	75.45
13	28.21	8.750	90.0	82600	39.13

4.7.2 Fitting a Preliminary Model

The project explored the multiple linear regression analysis to establish relationships between a response variable and possible predictor variables. The response variable was the cost per piece of microchannel plate. The possible predictor variables were raw material cost, labor cost, time, and machine cost. Table 4-8 presents SAS output for parameter estimates.The estimated regression function between a response variable and predictor variables obtained from the SAS used the Least Square Estimators as shown below.

$$\widehat{Y_h} = -2.64244 + 0.45043x_{i1} + 1.08920x_{i2} + 0.23150x_{i3} + 0.00001631x_{i4} + \varepsilon_i$$

Where:

Y_h = cost per piece (USD)

x_{i1} = raw material cost (USD)

x_{i2} = labor cost (USD)

x_{i3} = time (min)

x_{i4} = machine cost (USD)

Table 4-8: SAS Output for Parameter Estimates

Parameter Estimates							
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Type I SS	Variance Inflation
Intercept	1	-2.64244	7.66530	-0.34	0.7392	84588	0
raw	1	0.45043	0.16667	2.70	0.0270	2007.43253	1.12943
labor	1	1.08920	0.39276	2.77	0.0242	33300	12.34965
time	1	0.23150	0.02790	8.30	<.0001	1784.68299	12.44583
machine	1	0.00001631	0.00001733	0.94	0.3742	23.14760	1.10933

Table 4-9: SAS Output for Analysis of Variance for the Preliminary Model

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	37115	9278.85220	355.07	<.0001
Error	8	209.06214	26.13277		
Corrected Total	12	37324			

Root MSE	5.11202	R-Square	0.9944
Dependent Mean	80.66462	Adj R-Sq	0.9916
Coeff Var	6.33738		

4.7.3 Model Assumption

1. Linearity

Figure 4-2 shows the MLR plot. The plots presented are scattered and no curvature was identified. However, some outliers can be recognized from the plots. In this case, the MLR model form is reasonable for this dataset.

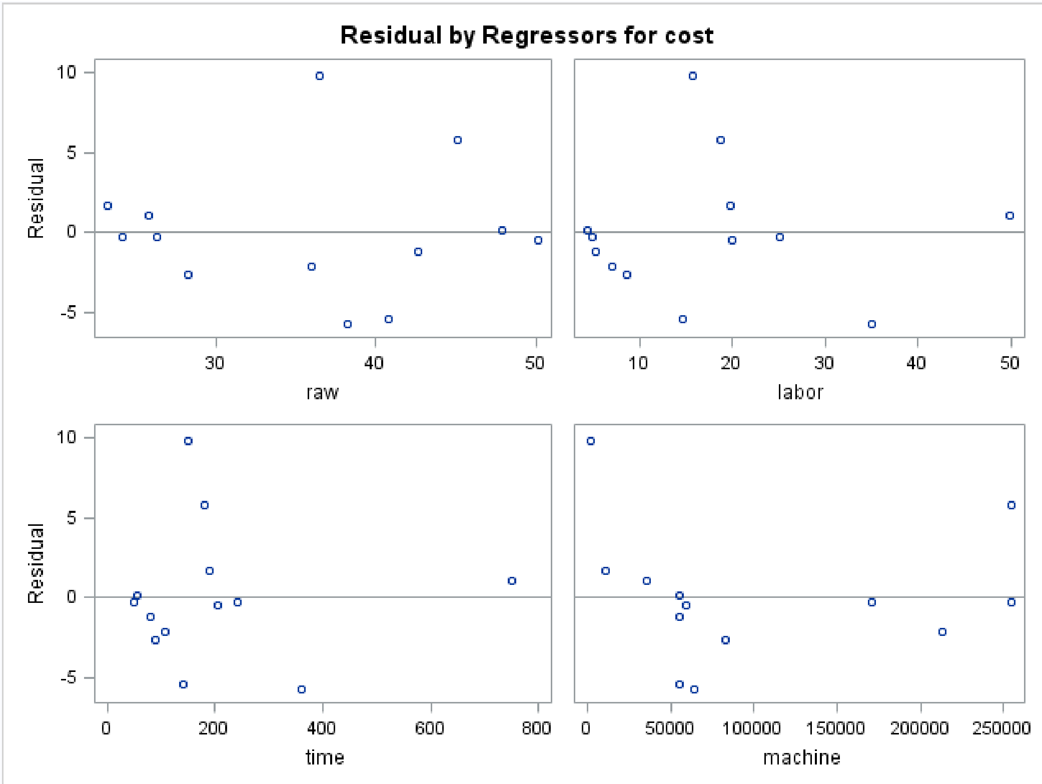

Figure 4-2: The Residual (e) versus x_{ik} Plots of Preliminary Model

2. Constant Variance

In Figure 4-3, no curvature or funnel shape was found. Therefore, the dataset is constant variance.

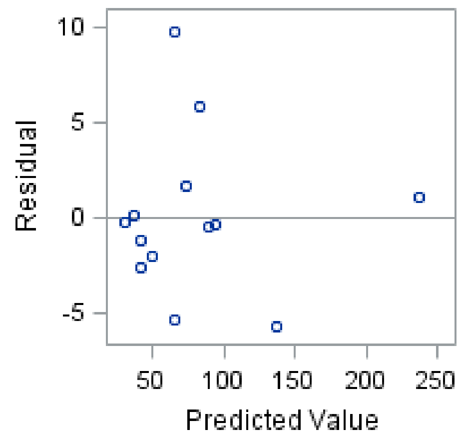

Figure 4-3: Residual versus Mean Response Plot of Preliminary Model

3. Normality

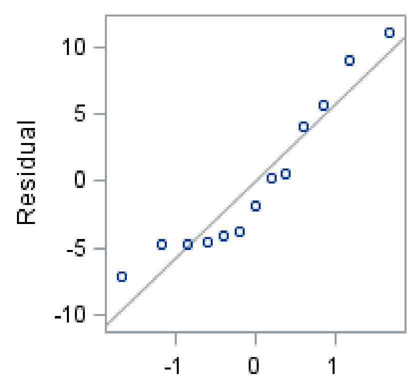

Figure 4-4: The Normal Probability Plot of Preliminary Model

From Figure 4-4 the normal probability plot, the plot has both slightly

shorter

right and left tails, but are mostly linear.

The normality test

H_o = Normality is Ok.

H_1 = Normality is violated.

Assume ∝ = 0.05

C (∝ = 0.05, n=13) = 0.553 from table

The sample correlation r = 0.94917 from Table 4-10

Decision rule: Reject H_o if r < C (∝, n)

Since r = 0.94917 > C (∝ = 0.05, n=13) = 0.553

Conclusion: Fail to reject H_o . Therefore, normality is OK.

The results from the NPP plot and normality test conclude that the residuals have mostly normal distribution.

Table 4-10: Correlation Analysis for the Normality Test

Pearson Correlation Coefficients, N = 13 Prob > |r| under H0: Rho=0		
	e	enrm
e Residual	1.00000	0.94917 <.0001
enrm Normal Scores	0.94917 <.0001	1.00000

4.7.4 Significance of Parameters

4.7.4.1 T-Test for β_1 (Raw Material)

Use α = 0.05

H_0: $\beta_1 = 0$

H_a: $\beta_1 \neq 0$

From Table 4-9, $|t^*|$ = 2.70 and t (0.975, 8) = 2.306

Since, $|t^*|$ > t (0.975, 8), it rejects H_0. The conclusion is 95% confident that the raw the material is not zero (0).

4.7.4.2 T-Test for β_2 (Labor)

Use α = 0.05

H_0: $\beta_2 = 0$

H_a: $\beta_2 \neq 0$

From Table 4-9, $|t^*|$ = 2.77 and t (0.975, 8) = 2.306

Since, $|t^*|$ > t (0.975, 8), it rejectsH_0. The conclusion is 95% confident that labor is not zero (0).

4.7.4.3 T-Test for β_3 (Time)

Use α = 0.05

$H_0: \beta_3 = 0$

$H_a: \beta_3 \neq 0$

From Table 4-9, $|t^*|$ = 8.30 and t (0.975, 8) = 2.306

Since, $|t^*|$ > t (0.975, 8), it rejects H_0. The conclusion is 95% confident that the time for each activity is not zero (0).

4.7.4.4 T-Test for β_4 (Machine)

Use α = 0.05

$H_0: \beta_4 = 0$

$H_a: \beta_4 \neq 0$

From Table 4-6, $|t^*|$ = 0.94 and t (0.975, 8) = 2.306

Since, $|t^*|$ < t (0.975, 8), it fails to rejectH_0. The conclusion is 95% confident the machine is zero (0).

4.7.5 Significance of Predictors

4.7.5.1 Test Whether x_1 (Raw Material) is Significant

Use α = 0.05

$H_0: \beta_0 + \qquad + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} + \varepsilon_i$ (Reduce model)

$H_1: \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} + \varepsilon_i$ (Full model)

Table 4-11: Analysis of Variance: Model Cost = Labor, Time, Machine

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	36925	12308	276.98	<.0001
Error	9	399.93037	44.43671		
Corrected Total	12	37324			

Root MSE	6.66609	R-Square	0.9893
Dependent Mean	80.66462	Adj R-Sq	0.9857
Coeff Var	8.26395		

$$F^* = \frac{SSE(R) - SSE(F)}{df_R - df_F} \div \frac{SSE(F)}{df_F}$$

F^* = 7.30379

F (0.95, 1, 8) = 5.32

Since F^* = 7.30379 > F (0.95, 1, 8) = 5.32

The conclusion is 95% confident that predictor for raw material,x_1 is significant. It cannot be dropped from the model.

4.7.5.2 Test Whether x_2 (Labor) is Significant

Use α = 0.05

$H_0: \beta_0 + \beta_1 x_{i1} + \qquad + \beta_3 x_{i3} + \beta_4 x_{i4} + \varepsilon_i$ (Reduce model)

$H_1: \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} + \varepsilon_i$ (Full model)

Table 4-12: Analysis of Variance: Model Cost = Raw Material, Time, Machine

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	36914	12305	270.08	<.0001
Error	9	410.03707	45.55967		
Corrected Total	12	37324			

Root MSE	6.74979	R-Square	0.9890
Dependent Mean	80.66462	Adj R-Sq	0.9854
Coeff Var	8.36772		

$$F^* = \frac{SSE(R) - SSE(F)}{df_R - df_F} \div \frac{SSE(F)}{df_F}$$

F^* = 7.69053

F (0.95, 1, 8) = 5.32

Since F^* = 7.69053 > F (0.95, 1, 8) = 5.32

The conclusion is 95% confident that predictor labor,x_2 is significant. It cannot be dropped from the model.

4.7.5.3 Test Whether x_3 (Time) is Significant

Use α = 0.05

$H_0: \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \quad + \beta_4 x_{i4} + \varepsilon_i$ (Reduce model)

$H_1: \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} + \varepsilon_i$ (Full model)

Table 4-13: Analysis of Variance: Model Cost = Raw Material, Labor, Machine

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	35317	11772	52.77	<.0001
Error	9	2007.91097	223.10122		
Corrected Total	12	37324			

Root MSE	14.93657	R-Square	0.9462
Dependent Mean	80.66462	Adj R-Sq	0.9283
Coeff Var	18.51688		

$$F^* = \frac{SSE(R) - SSE(F)}{df_R - df_F} \div \frac{SSE(F)}{df_F}$$

F^* = 68.835

F (0.95, 1, 8) = 5.32

Since F^* = 68.835 > F (0.95, 1, 8) = 5.32

The conclusion is 95% confident that the predictor labor,x_3 is significant.

It cannot be dropped from the model.

4.7.5.4 Test Whether x_4 (Machine) is Significant

Use α = 0.05

$H_0: \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \quad + \varepsilon_i$ (Reduce model)

$H_1: \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} + \varepsilon_i$ (Full model)

Table 4-14: Analysis of Variance: Model Cost = Raw Material, Labor, Time

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	37092	12364	479.21	<.0001
Error	9	232.20974	25.80108		
Corrected Total	12	37324			

Root MSE	5.07948	R-Square	0.9938
Dependent Mean	80.66462	Adj R-Sq	0.9917
Coeff Var	6.29703		

$$F^* = \frac{SSE(R) - SSE(F)}{df_R - df_F} \div \frac{SSE(F)}{df_F}$$

F^* = 0.885769

F (0.95, 1, 8) = 5.32

Since F^* = 0.885769 < F (0.95, 1, 8) = 5.32

The conclusion is 95% confident that the predictor of the machine cost,x_4 can be dropped from the model.

4.7.6 Best Subset Regression

To obtain a set of potentially best model, backward method or stepwise method will be used to select the significant variable from preliminary model.

4.7.6.1 Stepwise

From Table 4-15, the potential best model contains labor cost (x_{i2}) and raw material cost (x_{i1}). Therefore, the potential predictors for parametric cost estimation model for microchannel bonding process are raw material cost and labor cost.

Table 4-15: Summary of Stepwise Selection

Summary of Stepwise Selection									
Step	Variable Entered	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	labor		Labor cost	1	0.9372	0.9372	9.1950	164.13	<.0001
2	raw		Raw Material	2	0.0208	0.9580	5.1586	4.96	0.0500

4.7.6.2 The Final Best Model Overall

Table 4-16: Parameter Estimate of the Model: Regress Y (Cost per Piece) on x1 (Raw Material), x2 (Labor Cost)

Parameter Estimates							
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Type I SS	Variance Inflation
Intercept	1	-3.38223	19.11636	-0.18	0.8631	84588	0
raw	1	0.29708	0.45469	0.65	0.5283	2007.43253	1.08916
labor	1	4.16369	0.32404	12.85	<.0001	33300	1.08916

The final best overall model is the model of Y (cost per piece) and x_1(raw material cost), x_2 (labor cost). The parameter estimates and ANOVA table are shown in Table 4-16. The model is shown as:

$$\widehat{Y_i} = -3.8223 + 0.29708x_{i1} + 4.16369x_{i2}$$

Where: Y_i is mean percentage of cost per piece; x_{i1} is raw material cost; x_{i2} is labor cost.

b_0 = - 3.8223 which is an unbiased point estimator forβ_0, and also a y-intercept. It means that the mean percentage of cost per piece will be - 3.8223 when raw material cost and labor cost are zero, which is out of the range of interest and not meaningful for this project. b_1= 0.29708 is the unbiased point estimator forβ_1. It means that the mean percentage of cost per piece will increase by 0.29708 when cost of raw material increase by 1 and labor cost is held constant. b_2= 4.16369 is the unbiased point estimator forβ_2. It means that the mean percentage of cost per piece will increase by 4.16369 while labor cost increases by 1 and raw material cost is held constant.

Chapter 5

Conclusions and Recommendations

5.1 Review of Research Objectives

The main objective of this research is to develop an accurate cost estimation model for microchannel bonding process that can be used in the manufacturing process or used in the estimating or planning for machine part projects.

This research has three objectives, as stated below:

1. To develop a parametric cost estimating model for cost estimating of the microchannel bonding manufacturing process. The model development process is illustrated and discussed for the understanding of the model development requirements, methodologies used, and specific development outcomes.
2. To identify and assess the relative importance of the significant microchannel characteristics or parameters to be incorporated into a cost estimating model to improve the model's cost estimating performance in the microchannel bonding process.
3. To identify the result by using the statistic method. Regression analysis will be applied to find the relationship between parameters.

5.2 Research Conclusions

The conclusions for this research study are:

1. Activity Based Costing (ABC) method

This research selected the activity based costing method to classify the cost of the microchannel bonding process. ABC provides a more accurate view of product cost. ABC determines all the activities that are associated with the production process and allocates the cost for activities. The cost was assigned to activities and then assigned to the products that are associated with these activities. ABC helps to classify the cost of the bonding process easier and faster. This research uses ABC to separate the cost of activities by processes. This research include of four sub processes, which are design, channel, bonding, and testing processes. Each sub process has an activity for each process, which can lead to be cost drivers. Applying the ABC method to the microchannel bonding data yield the cost drivers, including the cost of raw material, labor, time, and machine cost.

2. Development of the parametric cost estimation model for the microchannel bonding process.

From the literature review, the parametric cost estimation method is the proper method to apply with the microchannel bonding cost estimation database. The application of parametric cost estimation for microchannel bonding is to start from data collection, data normalization or data preparation, and data analyses.

The parametric cost estimation for the microchannel process is successful with this model development. The results from this model are satisfied by the objective of this research. The model development data set presents the linear normal probability. The R^2 is a fraction of the total variability explained by the model. It also determines how well the model fits the data. From the model, this research found that the R^2 = 0.9460, which is considerably high. The R_a^2 compares the variances estimate from the regression (MSE) and the sample variance for each response. The difference between R^2 and R_a^2 indicates that one or more variables that do not explain the model well. For this model, the researcher found that R_a^2 = 0.9352, which is not much different from R^2. This concludes that the predictors in the model explain data successfully.

3. Identification of significant microchannel bonding process parameters

To identify significant parameters of the cost estimation model for the microchannel bonding process, this research used the regression technique. This research also used stepwise regression to find the best model for the microchannel bonding cost estimation process. The best model included two significant parameters or variables, which were raw material cost and labor cost. Therefore, the cost estimation for the microchannel bonding process should focus on raw material cost and labor cost. The machine cost raised the cost way too high.

4. Cost estimation tools and development

This research used the SAS statistic program to complete the regression analysis. To analyze the data for the microchannel process, the SAS program selected to analyze the microchannel bonding data because of greater accuracy than other statistical tools. In addition, the SAS program is easy to learn.

5.3 Recommendation for Future Research

There are some recommendations for the future research are as follows:

1. There is a need to identify additional bonding parameters. There many methods for the microchannel bonding or machine-parts manufacturing. Other parameters may be important to other bonding process.
2. To improve the cost estimation performance, the cost estimation model can be improved by using different techniques of the cost estimation formula. The calculation technique can also be improved to make it more accurate and faster calculations.
3. Additional research may be directed to other bonding process methods. The other bonding methods may require different processes, different materials, and different tools or machines.
4. A Graphic User Interface (GUI) could provide users with easier formats for input and output. The next step of this research area is to

develop the tools to help users with this application. This GUI can help users with input into the database. The GUI can also help users by generating and reporting the information.

5. This research method can be applied to other areas of research that require the cost estimation technique.

5.4 Research Contribution

The research focus was to identify the microchannel bonding parameters that significantly influence the cost of the microchannel processes. The development of parametric cost estimating model based on activity based costing methods helped to identify the cost of the microchannel bonding by the activities of each process.

The first contribution from this research was identifying the major parameters for the microchannel bonding process. The significant parameters can serve as cost drivers. The cost drivers are a unit of activities that can change the cost. The major cost drivers of this research included raw material cost, labor cost, time, and machine cost.

The second contribution from this research is developing the parametric cost estimating model based on activity costing. This successful model development presents accurate results of costs that occur from microchannel bonding activities. Furthermore, the parametric cost estimation model also presents the potential application for eutectic microchannel bonding. .

The third contribution was finding the significant parameters that affected the cost of the microchannel bonding process. To check the significant parameters, this research applied the regression analysis method to analyze the significant microchannel bonding data. The regression result was that raw material cost and labor cost affected the microchannel bonding process cost. The knowledge and contributions of this research may serve as a useful guide for future data collection efforts of cost estimation in related areas.

Appendix A

SAS Output

The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: cost

Number of Observations Read	13
Number of Observations Used	13

X'X Inverse, Parameter Estimates, and SSE				
Variable	Intercept	raw	labor	cost
Intercept	1.8118726053	-0.040324499	-0.016651612	-3.382232587
raw	-0.040324499	0.0010250744	0.0002090093	0.29708045
labor	-0.016651612	0.0002090093	0.0005206065	4.163685025
cost	-3.382232587	0.29708045	4.163685025	2016.8927309

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	35308	17654	87.53	<.0001
Error	10	2016.89273	201.68927		
Corrected Total	12	37324			

Root MSE	14.20173	R-Square	0.9460
Dependent Mean	80.66462	Adj R-Sq	0.9352
Coeff Var	17.60590		

Parameter Estimates							
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Type I SS	Variance Inflation
Intercept	1	-3.38223	19.11636	-0.18	0.8631	84588	0
raw	1	0.29708	0.45469	0.65	0.5283	2007.43253	1.08916
labor	1	4.16369	0.32404	12.85	<.0001	33300	1.08916

Figure A 1: The Parameter Estimate of Model: Regress Y (Cost per Piece) on x_1 (Raw Material Cost), x_2 Labor Cost

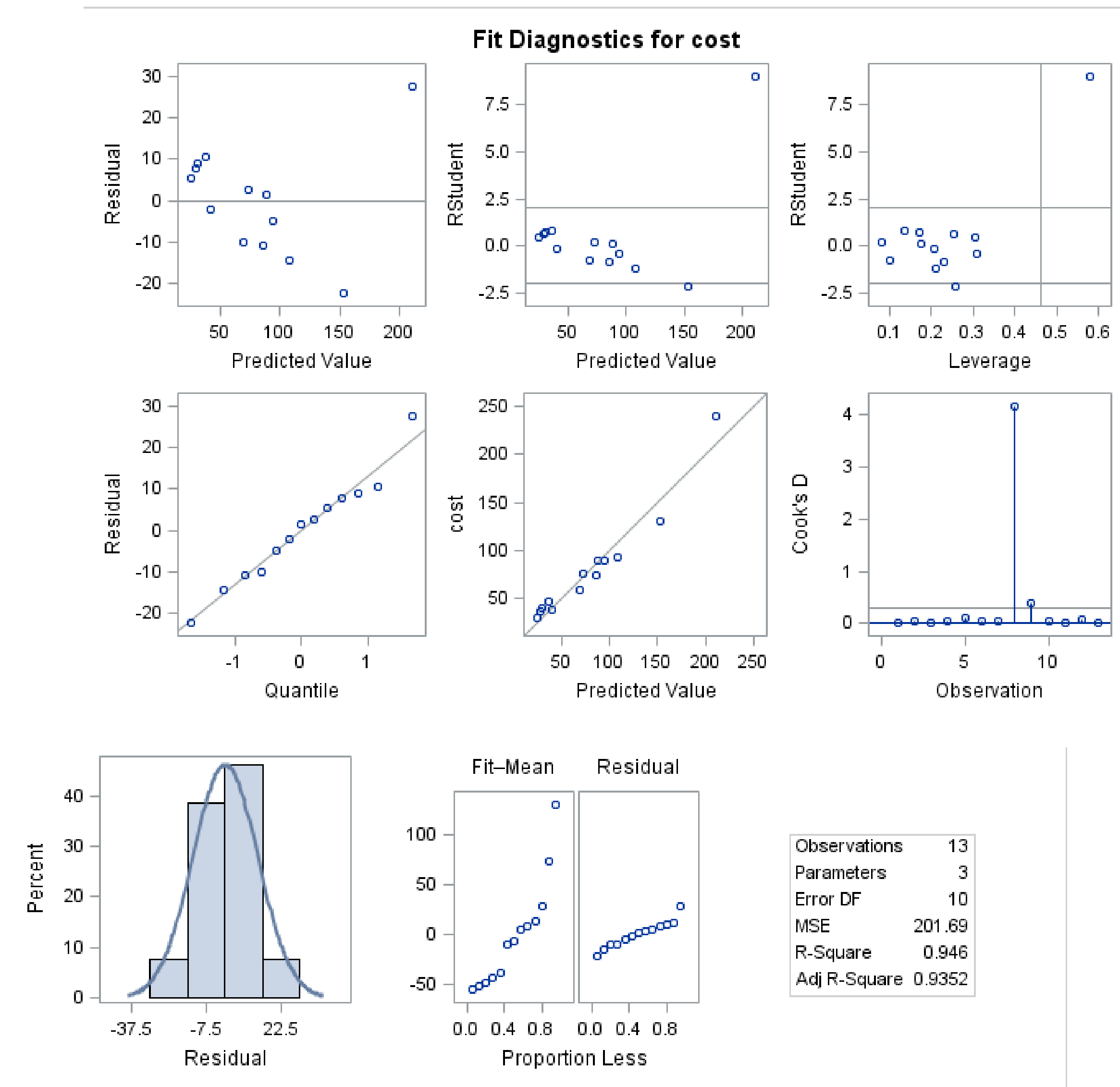

Figure A 2: Fit Diagnostics for Cost

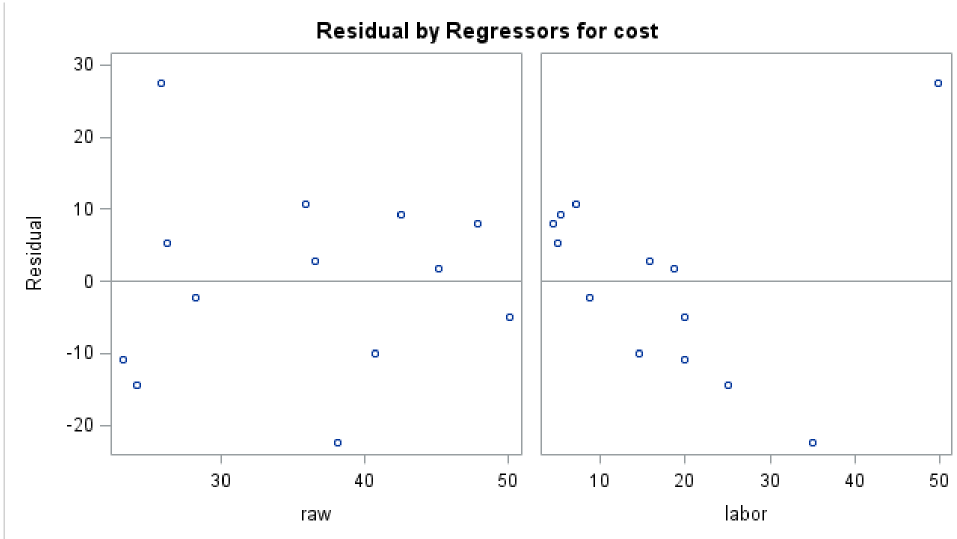

Figure A 3: The Residual (e_i) versus x_i Plots

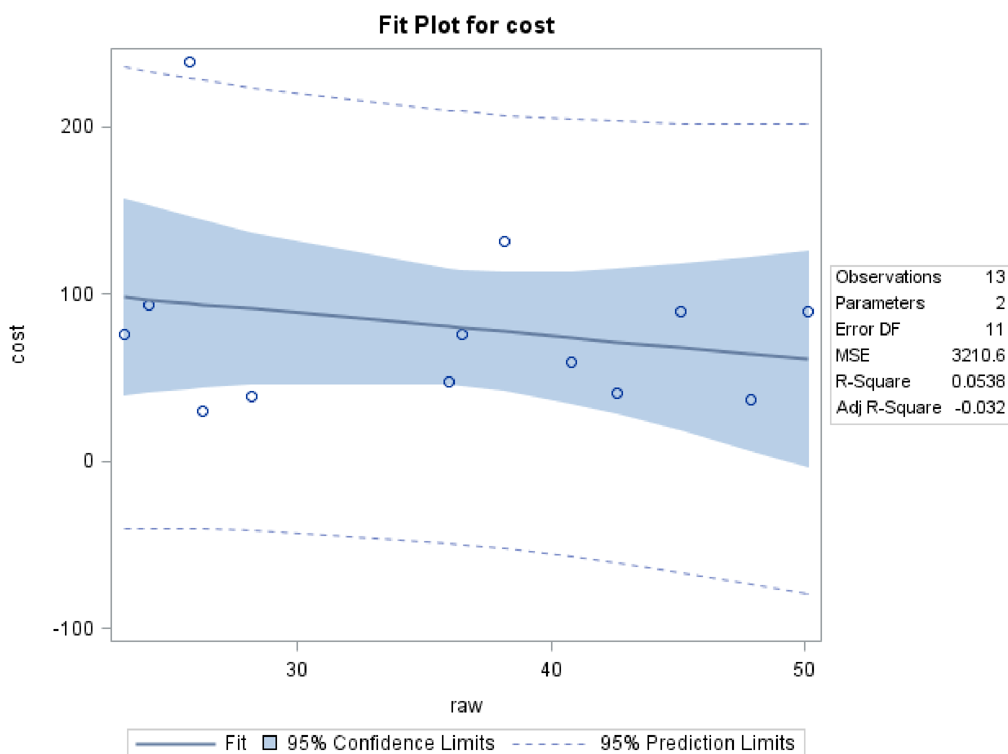

Figure A 4: Fit Plot Cost versus Raw Material Cost

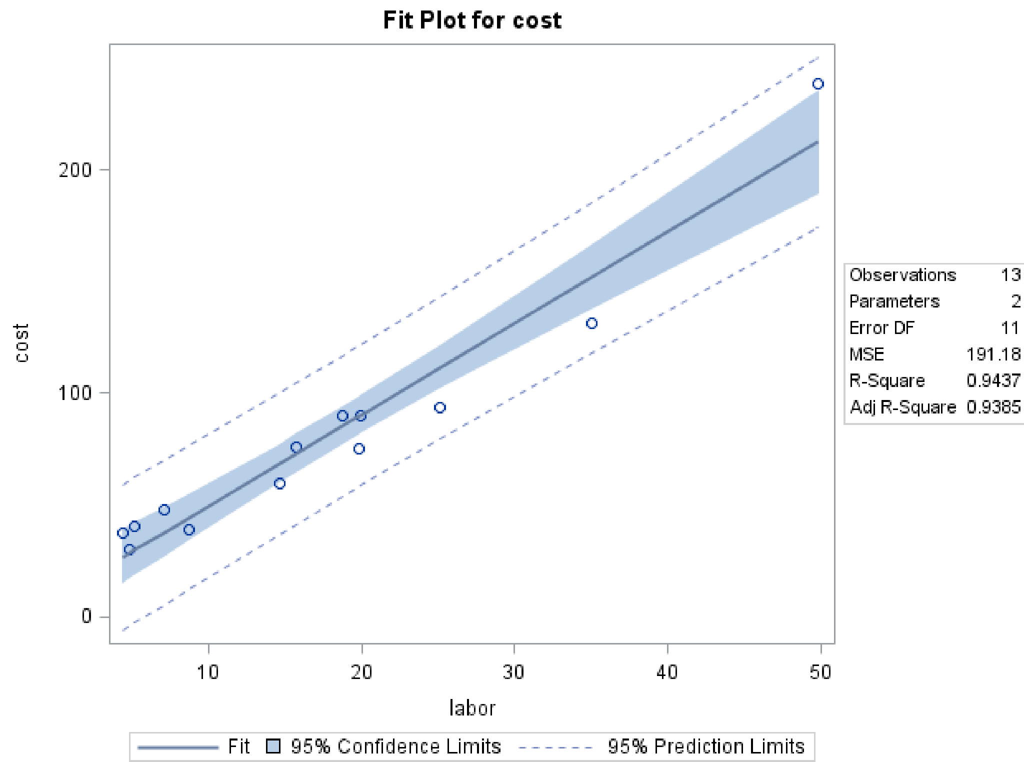

Figure A 5: Fit Plot Cost versus Labor

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Biographical Information

Panita Suebvisai was born in Ratchaburi, Thailand. She received bachelor's degree in Computer Science from Thammasat University, Bangkok, Thailand, in 1997. From July 1997 to August 1999, she worked as a computer programmer at Unilever Thai Holding Co., Ltd. In January 2000, she attended the English Language Institute at University of Florida (UF). She received a Master's degree in Industrial and Manufacturing Systems Engineering at the University of Texas at Arlington (UTA) in 2003. After receiving the master's degree, she entered into the Ph.D. program in Industrial and Manufacturing Systems Engineering at the University of Texas at Arlington. During that time, she was a Research Assistant (RA) and a Teacher Assistant (TA) at Industrial and Manufacturing Systems Engineering department, UTA. Her email address is psuebvisai@hotmail.com.