

A SURROGATE MEASURE OF CUSTOMER SATISFACTION IN THE  
MANUFACTURE OF PRINTED WIRING BOARDS

by

ADAM Y. MAAMOUN  
B.S. Zagazic University, 1987  
M.S. University Central Florida, 2001

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Major Professors: Linda Malone  
Co Advisor: Ahmad Elshennawy

## **ABSTRACT**

The objective of this research is to determine and develop a model that is capable of accurately measuring customer satisfaction for different industries and in particular for the Printed Wiring Boards (PWB) Manufacturers. The new model will incorporate data not being collected or utilized by the survey method of determining customer satisfaction.

The method used is a weighted average of satisfaction among several researched categories with percentages that accurately represent the relative importance of multiple facets of the PWB manufacturers customer satisfaction.

A very common term in quality assurance is that “What is not measured accurately can not be evaluated or managed correctly,” thus customer satisfaction is a very important aspect of any business, industry, or government. A satisfied customer will do more business and recommend it to other potential customers. Thus the business will grow and more revenues result. On the other hand, an unsatisfied customer will abandon the business and encourage more customers not to get involved with the same business so the business may decline and lose its market share and profitability. The categories that contribute to PWB customer satisfaction will be determined by conducting surveys among the leaders and best in the business of the PWB industry in addition to discovery of related articles that define the categories of the customer satisfaction for the PWB manufacturers.

Once the categories are determined, the research concentrates on the weighting of the categories that most contribute to the PWB customer’s satisfaction and a measure of satisfaction is derived. The model is easily applied to any other kind of PWB business or service industry.

The model is based on empirical methods that will give an accurate measurement for the PWB customer’s satisfaction. This in turn allows organizations the opportunity for improving

customer satisfaction and increasing market share. The algorithm is based on characteristics deemed important by customers. Thus the customer satisfaction index can be computed and monitored on a regular basis without costly surveys.

The major difference between this new model and the standard methods of determining customer satisfaction using the surveys is that this model will utilize data available with the proposals, sales, shipping, receiving, quality, engineering, manufacturing, and purchasing departments. The developed method to measure customer satisfaction utilizing internal data can be more cost effective, more accurate, can provide individual customer satisfaction scores, can measure whether or not these individual scores are statistically lower than the majority, and can provide satisfaction measures in real time none of which can be supplied by the survey method.

To my Mother, in Memory of my Dad and to all my Friends

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## **CHAPTER ONE: INTRODUCTION**

### **Introduction to Customer Satisfaction Measurements**

Customer satisfaction is the true underlying measure of organization success to the PWB manufacturers as well as other manufacturers. Since the 1990s major organizations have embarked on methods to measure their customer satisfaction. Thus customer satisfaction measurement studies evolved and have focused solely on measuring customer satisfaction through conducting surveys. However, other factors that may contribute to customer satisfaction in the PWB industry have been ignored or overlooked. The mass distribution of customer surveys has been the most common method to gather the PWB customers' input and to measure their level of satisfaction. It is believed that increased customer satisfaction has direct correlation to organizational profitability (Vavara, 2002). Thus accurately measuring customer satisfaction will indicate how much a PWB manufacturer needs to improve its customer satisfaction to increase its profitability. Professor David Larcker of the Wharton Business School determined that companies in the top quartile of customer satisfaction experienced a higher appreciation in stock values than did the overall S&P 500 (Vavara, 2002). Even more compelling, the top 10 companies in foods, personal care, PWB Manufacturers, and tobacco in the America Customer Satisfaction Index (ACSI) model gained an impressive 15 percent in the same period -August 1994 to February 1995 (Fierman, 1995).

When a PWB customer is satisfied with a purchase or service, he/she will be retained. Not only will that PWB customer be retained but also he/she will recommend the product or service to other potential PWB customers. Therefore building a satisfied PWB customer base is very important to any organization in order to grow and become prosperous. Every dollar that a

business invests should have the objective of enhancing customer satisfaction (Hanan and Karp, 1989).

### **Research Objectives**

A customer satisfaction measurement index is developed specifically targeting the PWB manufacturers which attempts to incorporate generic (non Product Specifics) characteristics of quality that have some numerical measures associated with them such as customer returns, warranties, servicing, cost, etc. The relative importance of these characteristics was determined by customer surveys to determine an appropriate weight that should be assigned to each of them.

Once the weights have been established, a PWB customer satisfaction index can be determined monthly (if desired) from a PWB company existing database using a weighted average. Since the kinds of measures are generic, the surveys should be less biased than product specific surveys. This also allows a specific PWB company an opportunity at continuous improvement of its satisfaction index which is now not possible. Since the current survey methods for determining customer satisfaction are costly and time consuming and cannot be accomplished often.

Additionally, the process for determining a PWB industry specific index was incorporated into a software tool so that any company could duplicate the procedure to produce this proposed new satisfaction index.

Customer satisfaction is an indicator of a PWB organization's prosperity and thus usually PWB organization business plans are built around retaining and expanding the PWB customer's base. Customer satisfaction measurement is an important tool to determine how a PWB manufacturer can position itself in a global market. Customer surveys are currently the only

method to measure PWB customer satisfaction and are being used by other industry organizations in such areas as education, hospitality, health care, service, and utilities because it is the simplest and easiest tool to utilize. Other inputs are not being utilized or are simply ignored but they contribute directly to customer satisfaction. Thus the main objectives of the research was (1) to determine what other variables or inputs have a direct influence on PWB customer satisfaction, (2) to utilize these factors to accurately establish a systematic, empirical method, to measure PWB customer satisfaction, and (3) to construct the measure from factors which are generic and do not require customer input. The research shall concentrate on the customer satisfaction measurement on the PWB manufacturing industry. Questions, which may naturally arise, are: How important is it to accurately measure customer satisfaction? Is the degree of customer satisfaction an important indicator of a business' decline or rise? What factors influence PWB customer satisfaction? Is the currently used customer survey a reliable tool to measure PWB customer's satisfaction?

To answer these questions, the following steps were under taken:

- 1) Determine what variables are correlated with a PWB customer's satisfaction
- 2) Determine how to utilize these variables and inputs to measure a PWB customer's satisfaction.
- 3) Study other alternatives to the customer survey as a method to measure PWB customer's satisfaction.

### **Research Preponderancy and Influence**

The main goal for an organization is not to produce quality product or service, or to provide superior customer service. The main goal is to produce a satisfied and loyal customer

that shall stay with the organization over and over again (Gerson, 1993). A satisfied customer will not only bring in more business to the organization but also more likely he/she will recommend the product or service to more potential customers. The reasons for assuring customer satisfaction include the following: (Naumann and Geil, 1995):

- 1) Improvement of the relationship between the customer and the organization.
- 2) Customer needs are determined so that their expectation from a product or service standpoint is known.
- 3) Measurement of continuous improvement from the customers' point of view.
- 4) Soliciting the customer for product/ process improvement.
- 5) Determining the attributes that affect the customer's decision- making process and post purchase evaluation of the product, service, and image areas.

In a recent study to measure customer loyalty in a banking system (Jones and Farquhar, 2003), 10,482 surveys were sent out to customers and a response rate of 21.4 per cent was obtained. One question that arises from such a response rate is whether or not the results are representative of the customer loyalty for the banking industry.

## **CHAPTER TWO: LITERATURE REVIEW**

### **History of Customer Satisfaction Measurements**

After World War II, Japan tried to sell its products to the world but because of poor product quality, customers were unsatisfied and were reluctant to purchase Japanese goods. In 1960, Professor Shigeru Mizuno and Yoji Akao founded Quality Deployment Function (QFD) (Kolarik, 1988). Their main goal was to design customer satisfaction into the product prior to its manufacture. Customer satisfaction surveys were used to collect customer satisfaction. Because the return was minimal, Professor Shigeru Mizuno and Yoji Akao had little effect on the Japanese manufacturing cultures.

In 1993, Dr. W. Edwards Deming wrote that the entire quality improvement process is rooted in customer information and feedback (Vavara, 2002), and hence organizations must devote resources to collect and utilize this customer information. It is evident that customer satisfaction surveys cannot collect all the customers' input and their dissatisfaction with a product or services. Terry Vavara showed that collecting customers' feedback was essential to improve product quality and features. Thus it is imperative to gather as much data as possible from the customers to understand their attitudes toward the product or service provide. The return rate for a customer satisfaction averages about 20 percent, so it is difficult to accurately measure the customers input. The current research model does not depend on customers satisfaction survey return rate since it will utilize available data.

The early investigation of customer satisfaction and its correlation to marketing was conducted by Cardozo in 1965, who was one of the first marketing academics to investigate the effect of customer satisfaction on organizations' profits and market share. Cardozo imagined that customer irritation and contention could be aroused in sales that have high

involvement and a lot of effort. This means that if customers invest a lot of effort to purchase a product they will try to minimize the difference between their actual experience with a product or service and their prior expectation. Thus Cardozo concluded that there is a direct correlation between customer satisfaction and his/her past experience with the product/service they purchase.

Customer's loyalty has been researched for its relationship on customer satisfaction for loyal and non-loyal customers (Youjae and Suna, 2004). One of the research objectives was to determine if there was relationship between customer satisfaction and the repurchase intention. Another objective of the research was to compare customer's processing of consumption experiences between high-loyalty and low-loyalty customers. The research examined how loyal customers have an impact on customer satisfaction and the repurchase intent. A survey method was used to measure the customer satisfaction where four questions were utilized and seven-point scales for these questioned were anchored. The respondents of the customer surveys were divided into two groups, loyal and high loyal groups based on the repeat purchase. To determine the customer's loyalty a loyalty survey was conducted with a questioner anchored on two questions. The first question measured the purchase of a category in a certain period of time and the other question was based on measuring the proportion of purchases of the same brand in a certain time frame. To validate the study, the groups' means were compared on several dimensions; prior expectations, subjective knowledge, and confidence in expectation. The validation method showed that there is a significant difference in prior expectations across groups. For a reliability check, the researchers used Cronbach's alpha to measure the reliability of measures for high and low loyalty customers. The reliability checks produced a satisfactory level of reliability. After collecting the data



from the surveys, the research proved customer satisfaction has a direct link between repeat purchasing for high loyal customers while it does not for low loyal customers.

The current model in comparison to the previous research will utilize data that are not collected by the survey method to measure either loyalty or customer satisfaction. The previous research relied totally on customer surveys to collect the data to measure the loyalty and customer satisfaction and ignored the data from the sales, re ordering to replenish stocks and other data that were available to the researchers.

According to Sheth and Howard (1969), their model of consumer behaviors founded the pillars of customer satisfaction models, in which they concluded that customer satisfaction contributes directly to repurchasing.

### **Socratic and Heuristic Approaches**

The most common method for measuring customer satisfaction has been conducting surveys. In 1981 J. D Power and Associates initiated multiple automotive customer satisfaction indices utilizing the method of sending out surveys and collecting the returned data, later the company expanded its customer satisfaction indices to include telecommunication, home building, and travel.

Another index, which is worthy of noting, is the American Customer Satisfaction Index (ACSI). It was established in 1994 in partnership with University of Michigan Business School, the American Society for Quality (ASQ), and the international consulting firm, CFI Group. The American Customer Satisfaction Index tracks most industries in the United States of America. The methodology it uses is the same as the rest of the customer satisfaction measurement tools, sending out surveys and analyzing the returned data. In 1999, the European government

emulated the American Society of Quality by introducing the European customer satisfaction index and created a government foundation by the name of “International Foundation for Customer Focus” solely for that purpose. The European Customer Satisfaction Index (ECSI) was developed with the following objectives:

- Support the different European companies, public services, consumers, investors, regulators and the European policy makers with an annual customer satisfaction index, and its effect and causes on loyalty.
- Provide the European companies and public services that were surveyed with the means to discover their customers perceptions and to compare them with the perceptions of customers of other companies and public services at different levels
- Introduce the index as an economic indicator measuring the performance of the National and European economies and companies”

(Source: “International Foundation for Customer Focus” [IFFCF]).

The IFFCF measures the European customer satisfaction by conducting telephone surveys among European countries and surveying the consumers about their level of satisfaction for the common products and services they utilize. Then a level of customer satisfaction is developed for each of the industries for every European country involved in the survey (Figure 1 and Figure 2).

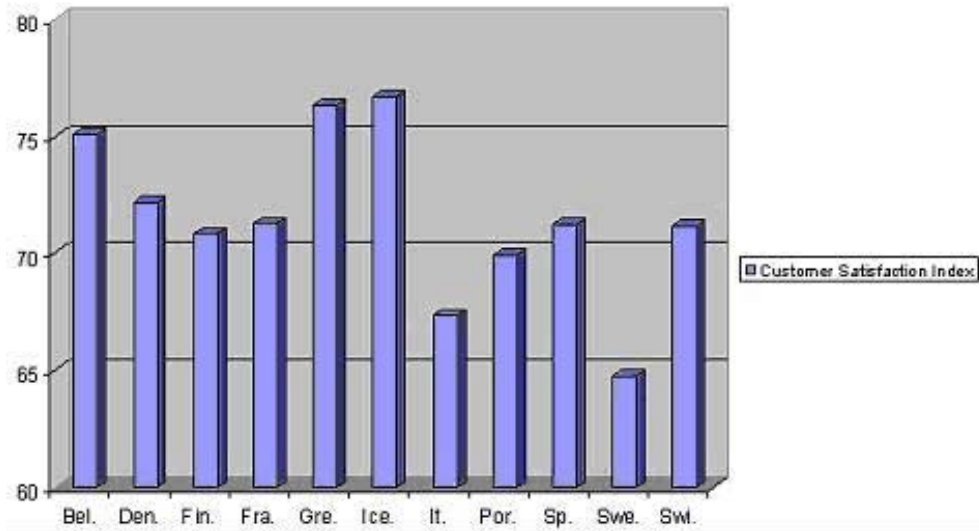


Figure 1: Retail Banking Customer Satisfaction Index (source: International Foundation for Customer Focus <http://www.ifcf.org/pressInfo.asp>)

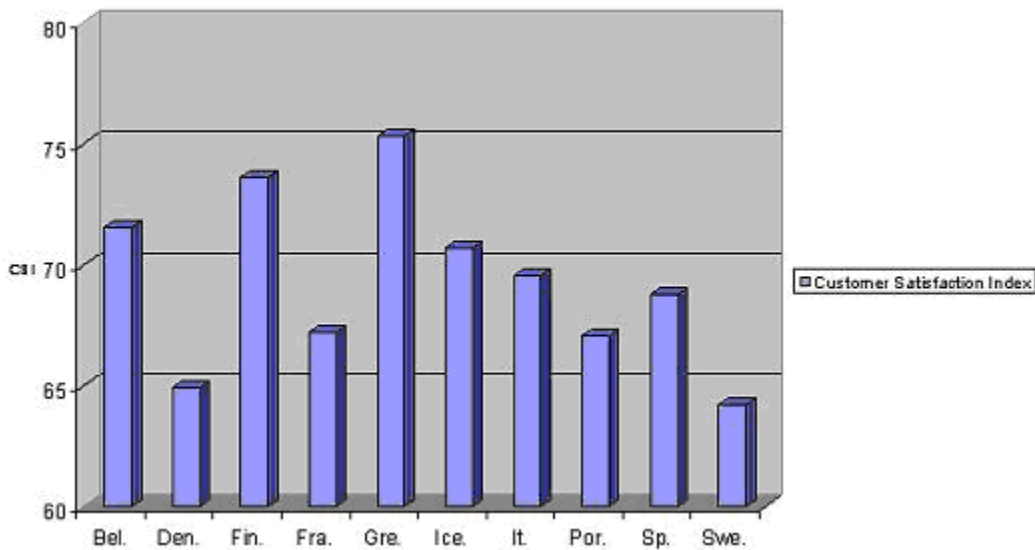


Figure 2: Mobile Phone Customer Satisfaction Index (source: International Foundation for Customer Focus <http://www.ifcf.org/pressInfo.asp>)

In the service industry such as hotels or retail stores, surveys in the form of customer comment cards are left in the lobbies or handed to the customers in the hope that they will be returned. The questions on the cards are an attempt to discern how the customer perceives the

service rendered. In the service industry customer satisfaction is essential to the success of the business. Robert (1983) concluded from his studies that 90 percent of the hotel industries are utilizing the customer comment cards to gain and understand the customer needs, expectation, and perception of the service rendered. The cards are collected and analyzed to understand where improvements are required or service must be sustained to keep the customers satisfied.

The US Federal Government has also acknowledged how customer satisfaction may affect government service. This was emphasized by Executive Order number 12862, signed by President Clinton on September 11<sup>th</sup> 1993, which defined the customer and the “Best in the Business” terms in order to direct government agencies to make their customer both satisfied (the citizens of the USA) and their top priority. Other local Governments have also adopted customer satisfaction definitions and have made a commitment to improve it.

### **Different Methods of Measuring Customer Satisfaction**

Customer satisfaction in the last 20 years has been a cornerstone for management decisions. Popular business tools such as Malcolm Baldrige Award and the European Foundation of Quality Management put considerable emphasis on the significance of both assessing customer satisfaction and using sound assessment methodology for such task (Athanasopoulos and Iliakopoulos, 2003).

The objective of Athanasopoulos and Iliakopoulos research was to assess the effect of multiple transactions by the survey method. The industry they measured customer satisfaction for was the communication industry and in particular the customers satisfaction with the land based phone line service. The researchers used surveys, direct customer contact, and monitoring customer behavior change measurements. Since the researchers were not employed by any of the

telecommunication companies and they didn't have access to the internal companies data, they were unable to obtain data that can influence customer satisfaction as this research has proposed. Athanassopoulos and Iliakopoulos used an external service to contact 2,900 line-based customers (400 interviews were used to validate the questionnaire) and 65% of the contacted customers had some sort of feedback to the survey method. The surveyed customers were asked to rate the company for the service provided by the directory inquiries, billing, branch network, corporate image, fault repair, service provisions, personnel, perceived performance, and speed of service. From customer responses and the researchers came up with a hypothesis about the combination of factors that influence customer satisfaction. The conclusion of their research was that customer interaction with the telecommunication companies during fault repair is the most influential aspect of customer satisfaction in the telecommunication industry.

Most of the work done on measuring customer satisfaction for different industries has been concentrated on utilizing surveys that are given to a respondent who completes a questionnaire addressing topics that are related to the industry being surveyed. Then the organization that handed out the surveys analyzes the results and tries to pin point the areas that need improvement. Different industries have been on the forefront of measuring their customer satisfaction. There are many reasons customer satisfaction measurement is essential to the existence of businesses and organizations. In 1994, the Juran Institute conducted a survey and concluded that 90 percent of top managers of more than 200 companies agreed with the statement, "Maximizing customer satisfaction will maximize profitability and market share" (Fay, 1994).

Many different industries have established a tool or a system to measure their customer satisfaction and a modeling technique was introduced to measure the scale of satisfaction. One

such model is “Affective Response to Consumption using Rasch Model”, (Ganglmair and Lawson, 2002). This model utilized Rasch modeling techniques (Rasch 1960/1980) developed by Georg Rasch (who is a mathematician and a statistician) to determine a scale for a range of 13 emotional satisfaction states. These 13 emotional states have not been tested and applied to different industries to determine if they were applicable. On page 206 of the paper “Affective Response to Consumption using Rasch Model,” the author acknowledges that the paper cannot be generalized to measure expressions and customer satisfaction for different industries. There are many other studies that concentrated on scale development, the best known of which are Delighted-Terrible Scale (D-T) (Andrew and Withery, 1976), and Satisfied and Pleased (Richard, Rust and Vakri, 1997). These studies were on scaling measurements and not on the actual customer satisfaction of the different industries. Thus it is imperative to develop a scale and a measurement technique that can measure and scale customer satisfaction attributes for different industries. Any of these scales may be utilized after the development of the method to measure the customer satisfaction. Since these scales are statistically proven to be consistent with the level of customer satisfaction, they can be used in this research but only for scaling the index of emotional satisfaction. Another important point is that measuring affective customer response will always require a sample and thus can become expensive.

Customer satisfaction in the service industry is an antecedent of repurchases intent, word of mouth, customer loyalty, and ultimately long- term profitability of a firm (Wirtz and Meng, 2003). Most of the literature on customer satisfaction in the service industry is based on George Rasch’s statistical model. This model mapped the change of the cumulative raw score obtained by a subject across items, or by an item across subjects to a linear continuous measure of ability (for subjects) and difficulty (for items) (Tesio, 2003).

Since customer satisfaction has a direct impact on profitability, it is necessary to accurately measure customer satisfaction. There are several research papers on customer satisfaction measurement in the service industry; most are concentrated on utilizing only customer surveys to collect data on customer satisfaction.

Customer Satisfaction in the service industry has been modeled as a form of attitude that is the consequence of the comparison of expectation with performance (Cronin and Taylor, 1992; Parasuraman et al., 1985). In the service literature, strong emphasis is placed on the importance of service quality perception and the relationship between customer satisfaction and service quality (Naser and Jamal, 2003).

Customer satisfaction in the banking system has been the focus of many studies. Customer surveys are the only tool used to collect data on the customer perception of the service rendered with no regard to collecting data on any other factors that influence the customers' satisfaction in the banking system. Future studies were recommended to measure customer satisfaction based on the factors discovered in the surveys. Parasuraman et al. describes these service quality factors as; tangible, responsive, assurance and empathy.

The banking system customer satisfaction is based on multiple interactions between the bank and the customer (Levesque and McDougall, 1996). Thus to measure customer satisfaction in such an industry, one must determine the interactions that occur between the customers and the bank. Levesque and McDougall identified these factors. A later study by Jamal and Nasser to determine which of these factors is significant utilized design of experiments which included convenience of branch locations, convenient opening hours, offers complete range of services, offers easily understood statements, getting into and out of the bank quickly, tells exactly when the service will be performed, employees are consistently courteous, and the employees are

always ready to help. It is important to recognize the halo effect on customer satisfaction variables. The halo effect is defined as the excess correlation caused by outside intervention such as surveys which is over and above the true correlation between factors attributes (Murphy and Jako, 1989). The halo effect inflates the measurement but does not really reflect customer satisfaction. Although, there are methods to determine and reduce the halo effect on the factors that contribute to customer satisfaction measurements, true correlations between the various attributes that effect customer satisfaction are impossible to be determined (Wirtz, 2003).

In 2003 Wirtz utilized design of experiments to test the factors that effect customer satisfaction while holding other attributes constant. He determined that there should be zero correlation between the satisfaction measures of the manipulated and the non-manipulated attributes. Hence a correlation between the attribute factors can be caused by halo. As such, the amount of halo induced via the proposed methods could be determined, (Wirtz, 2003).

### **Linkage between Customer Satisfaction and Company Success**

One of the questions that always arise among organizations is what benefits and return on investment are gained by accurately measuring Customer Satisfaction? The answer to this question is a complex mixture of many variables and conditions that affect the organizations' growth and profits. Organizations must understand the relationship between their customer's level of satisfaction and their growth or loss in either their business or profit. It is sometimes difficult to translate this correlation into practice, since customer satisfaction is intangible. Satisfaction levels cannot be captured on a balance sheet for upper level management to



understand, thus dedicating resources to improve the customer satisfaction and retention has been treated as a cost rather than an investment

On the average, organizations lose between 10 % and 20% of their customers a year. Why are these customers lost? How can the organizations retain their customer base? Where were they lost? Who is the competitor they went to? What do the competitors offer that the losing organization does not offer? How much profit or business has been lost due to the loss of the customers? How much would it cost to retain a customer? It is extremely important for organizations to understand and accurately measure their customer's satisfaction levels. There are numerous methods to measure customer satisfaction available but many of them rely solely on gathering the customer satisfaction or dissatisfaction by the survey approach. These methods are inaccurate methods because the sample size is not correlated to the customer base and the return on the surveys from the customers may not constitute a representative sample and thus may be not predictive. Also, these methods do not take into account or capture information on the other variables that influence customer such as customer returns, complaints, or quality. The proposed research shall take into account quantitative variables that are significant and contribute to customer satisfaction. In other words this research shall take into consideration a different set of variables that are quantitative in nature and do not require customer surveys to obtain. It is important to note however that to measure affective customer response will always require a sample and thus can become a continuing recurring expense.

### **Comparison of Customer Satisfaction Measurement Methodologies**

The national average return on customer satisfaction surveys is around 15 percent. This research proposes using surrogate measures (of satisfaction) to measure customer satisfaction.

This should increase the accuracy of the measurement, be less costly, provide more timely customer satisfaction data and be more traceable. This proposed methodology will be available for any organization to use to help determine accurately their level of customer satisfaction.

A company interested in determining its satisfaction index incurs a high cost for this service and its customer satisfaction index (as measured by the American Society for Quality (ASQ)) has no value to the company except knowing that its satisfaction index is whatever the ASQ gives them. That is, the ASQ index fails to segregate the factors or variables that contribute to a lower satisfaction index, thus the companies are helpless to understand their customers' level of satisfaction or to rectify their processes/products that contribute to a lower index.

Furthermore, the customer satisfaction index introduced by ASQ has not been proven to actually measure customer satisfaction but at this point there are no alternatives.

The proposed customer satisfaction index will not be costly to determine and it will be statistically proven to be correlated with customer satisfaction. Also it will pin point for the companies the variables or factors that require improvement to increase their satisfaction index.

Customer satisfaction has been proven to have direct correlation with companies' profits and growth. The American Society of Quality uses customer surveys to track customer satisfaction for most US industries. By comparing and analyzing these surveys, it is hypothesized that companies with the highest indices for customer satisfaction will have the highest stock growth, and the companies with the lowest customer satisfaction indices will have the lowest stock growth.

If a customer satisfaction measurement can be shown to provide a prediction of companies' performances and their profit projection management, a variety of different industries can use it as a business tool to achieve a competitive business advantage and to predict

stock value. Additionally, expenditures in quality could be justified and linked to measuring customer satisfaction. This new customer satisfaction index identifies quality characteristics so that a company would have the opportunity to improve these and thereby increase its customer's satisfaction.

## **CHAPTER THREE: RESEARCH BENEFIT, METHODOLOGY, AND PROCEDURE**

### **Introduction**

The research method and procedure will be presented in this chapter with explanations of what process and methodology were used. The procedure is illustrated in the PWB industry. This chapter also explains the reason, the method, the types of customers, and the tools that will be used to measure PWB customer satisfaction. The methodology that was used to collect and analyze the data is also discussed in this chapter.

### **Research Benefits**

The survival and growth of organizations worldwide are dependent on customer satisfaction with their products and services, thus a more reliable and action-oriented customer satisfaction measurement tool is needed to determine how to best satisfy customers. The proposed research will measure the customer satisfaction of a PWB company and define the quality characteristics that constitute the index. Further, the characteristics, or their surrogate measures, will not require continued administration of customer satisfaction surveys.

The links between customer satisfaction, customer loyalty and an organization's profits have been demonstrated by a number of researchers (Anderson et al., 1994; Banwarri and Lassar, 1998; Buzzell and Gale, 1987; Heskett et al., 1994; Rapert and Wren, 1998; Rust and Zahorik, 1993; Rust et al., 1995; Taylor and Baker, 1994; Zeithaml, 2000), which suggests that an organization's image and reputation interacts positively with increased customer satisfaction.

Successful customer complaint management has a positive effect on customer retention rates, minimizes the spread of damaging word of mouth, and improves the organization's

performance (Fornell and Wernerfelt, 1987; Kelley, Hoffman, and Davis, 1993; McCollough and Bharadwaj, 1992; Reichheld, 1993). Resolution of customer complaints is linked closely to customer satisfaction, trust, and commitment (Achrol, 1991; Morgan and Hunt, 1994). The proposed PWB satisfaction measurement will capture these complaints and other complaints that are reported throughout the entire PWB organization. An example might be a billing department of a PWB manufacturing company. Customer complaints regarding the refund or billing process should be tabulated and eventually aggregated into a satisfaction weighting average. Thus, if any noticeable satisfaction index change occurs for the billing department, the managers in charge can devise preventative action to resolve the process deficiency on a timely basis.

Another example of customer satisfaction or lack thereof may be PWB customer returns. An increase of PWB customer returns in a PWB manufacturing industry may be indicative of customer dissatisfaction with either the PWB's quality, ease of use, steep price, or the company's poor reputation. If customer returns are being used as a variable in measuring the PWB customer satisfaction index, any increase or decrease in circuit board returns will affect the overall PWB customer satisfaction. Evaluating the reasons for the board's return could indicate the area for corrective action. These variables or quality characteristics and their fluctuations are not captured in the current PWB survey methods.

The PWB customer satisfaction measurement index contained herein supports the PWB organization by providing the opportunity to increase the bottom line; this will be accomplished by indicating the variables that can affect lower customer satisfaction and thereby targeting them for improvement by management. This approach seems feasible since there are several studies suggesting that improvement in customer loyalty and satisfaction increases the organization's

bottom line (Rucci et al., 1998; Bernhardt et al., 2000; Edvardsson et al., 2000; Kristensen et al., 2002; Eskildsen et al., 2003; Juhl et al., 2002).

The research will be a multidimensional measurement tool, in which many of the factors that influence PWB customer satisfaction are aggregated into a single measurement tool. This process ties business success, development, and progress tightly to the PWB customers' level of satisfaction without using customer satisfaction surveys.

### **Research Methodology**

The research methodology consists of two phases, the first phase is the analytical approach where statistics, design of experiments, management and information system tools and surveys are utilized to identify and rank the most relevant variables that affect PWB customer PWB customers' satisfaction are identified by sending surveys to customers who order and assemble PWBs. The survey (Figure 1) requested customers (sales personnel and the PWB users) to identify those variables that have a direct and an indirect affect on their satisfaction. The surveyed PWB customers were from the Institute of Interconnecting and Packaging Electronic Circuits (IPC) organization, of which the researcher is an active member. The IPC/PWB association is a worldwide organization, with headquarters in Bannockburn, Illinois. The IPC organization is dedicated to the competitive and financial excellence of more than 2,200 member companies, which represent all facets of the PWB industry, including design, printed circuit board manufacturing, and electronics assembly (IPC website <http://www.ipc.org/MemLink.aspx?memtype=ems&pageid=4.4.7>).

The number of survey responses produced a statistically valid representation of the PWB industry (a list of the PWB manufacturers and assemblers with their contacts had been obtained).

To prove that the survey responses were statistically valid, the final model factors were sent in a survey to PWB customers to validate that these factors were critical to their customer satisfaction.

Quality tools and literature reviews were also used to construct the surveys in order to help the PWB customers identify the initial and relevant variables. It is to be noted that some of the customer satisfaction variables data were collected from available data that were not being utilized or measured in the survey methods, such as the time taken to obtain a quote or purchase order, time to ship the PWB to the customer, or the time taken to obtain a return authorization.

Some of the indirect variables that could affect customer satisfaction are the bid to order acceptance, customer returns versus shipments shipped, and number of PWBs delivered on time versus PWBs delivered late. It is important to note that this study proposal to accurately and more economically measure customer satisfaction and to include more correlated variables that were not taken into account in the survey method of measuring customer satisfaction.

Relevant customer satisfaction variables within the same industry should be the same. The following are some variables found in the literature review in the PWB service and manufacturing industry (Sureshchandar, Chandrasekharan and Kamalanabhan, 2001):

- 1) Dependability of managing customer service (wait time, or how long the customer waited from the time he/she requested the service until he/she actually ordered it).
- 2) Providing service at the scheduled time (how many minutes/hours late).
- 3) Ensuring employees have the knowledge to answer the customers' questions (this can be achieved and measured by testing the knowledge of the employees with the PWB specification and characteristics. This test usually is taken after the employees have been trained; higher scoring employees can be stationed to answer customers' questions).

- 4) The service cost compared to other organizations.
- 5) Ensuring the customers feel safe in their transactions with the company (This can be achieved by benchmarking and comparing other companies' customer transactions to the company that is measuring its customer satisfaction).
- 6) The service warranty period and cost.
- 7) The wait time after requesting a warranty repair or replacement.
- 8) Quality of the PWB received (this can be measured by the number of defects in a PWB that is being shipped. Defects do not constitute a PWB to be defective; in the PWB industry it is customary to ship PWBs that meet the minimum customer quality requirements since there are more than 90 processes to manufacture a single PWB). We can measure the quality of the PWB by the percentage of known or suspected defects shipping.
- 9) On-time delivery of the PWB shipped.
- 10) Price of the PWB or service rendered.
- 11) Lead time of manufacturing the PWB.

Other factors that are related to the service and PWB manufacturing industry (Levesque and McDougall, 1996) are: convenience to the location (internet access, availability of servers to download the Gerber files that will help the manufacturer building the PWB, shipping access, and distance of the manufacturer from the metropolitan areas) or ability to contact with ease (this can be achieved by having undercover employees pose as customers attempting to contact the company and determining how many were successful in reaching or getting responses to their questions or concerns), the service provider, employees' skills in explaining the issues and method of repairs (conduct a routine PWB knowledge test and grade their skills), the time taken



to complete the service, PWB thickness, layers registrations, hole thickness, copper plating thickness, lead plating thickness, circuit line width, solder mask thickness, etch anomalies, blind and buried vias capability.

Additional factors are employee courtesy and follow-up calls to ensure that quality service was provided. (Courtesy can be measured by employees impersonating customers calling the company then rating the level of employee courtesy, e.g., very polite to rude).

To ensure that the obtained variables are the most relevant, a matrix will be developed to first analyze the variables that affect satisfaction from a wide variety of organizations within the same industry, then to combine, rank and select the variables that affect the customer satisfaction (Yilum and MacLean, 2004). Yilum Yang and Richard MacLean developed this method to obtain the relevant variables that affect corporate performance in the stock market.

The principal goal of this research was to establish a method of determining customer satisfaction using variables that are easily obtained from the PWB company in question. This method provides a company with the means to have monthly satisfaction scores (or weekly if desired) without requiring a customer survey.

Answers to the question why is this desirable?

- 1) Presumably, profits correlate positively with customer satisfaction.
- 2) Tracking surveys is expensive monetarily.
- 3) There is a lag time in getting information from surveys.
- 4) Customers will be annoyed if surveys are conducted too often and their response rate will decrease, thus yielding even fewer responses and less accurate information.

- 5) With “Quantities” variables, companies will be able to identify the number of corrective actions, and using the weights derived from the study, they will know which corrective actions will be most important to pursue.
- 6) The ability to utilize data the companies already have which have not been used in the past to measure the customer satisfaction.

A customer satisfaction measurement was established using the variables that the PWB customers identified from the surveys received. Thus the variables chosen were correlated to the PWB customer satisfaction. The customer satisfaction variables were not proposed by the researcher but were identified by the literature, users, and purchasers of the PWBs and they can be measured in real time.

Some of the researchers had some input and developed conceptual models for the service organizations, Zeithaml researched service quality and developed a conceptual model based on surveying executives; the survey method was divided into the service characteristics of intangibility, heterogeneity, and inseparability (Zeithaml, 2000). The survey had four questions, what do managers of service companies perceive to be the key attribute of service quality? What do consumers perceive to be the key attribute of quality in services? Are there discrepancies between perceptions of consumers and service marketers? Can consumer and marketer perceptions be combined in a general model that explains service quality from the consumer’s standpoint? These questions were the basis of the surveys conducted with the executives. The research concluded from the survey that there are ten dimensions that consumers use in forming expectations and perceptions of services: access, communication, courtesy, creditability, reliability, responsiveness, security, tangibles, and understanding and knowing the customer. The research concluded that the service firm executives may not always understand what features

connote high quality to consumers in advance, what features a service must have in order to meet consumer needs and expectations, and finally, what levels of performance of those features are needed to deliver high quality service.

### **Methodology Verification and Validation**

When the variables were identified, the researcher determined any indirect variables that might have had an effect on the variable that the PWB customers had proposed and included them in the measurement.

Another verification method to ensure that the proposed variables are measuring customer satisfaction was to conduct the customer satisfaction measurement with the identified variables and cross check the satisfaction measurement with one organization that builds/assembles PWBs to another organization and determine which had more satisfied customers (This can be achieved by observing/monitoring the quarterly advertised profit reports from publicly traded PWB companies and whether or not it agrees with the ASQ's assessment. (It is assumed that profits are correlated to customer satisfaction for the PWB industry). Since customer satisfaction has proven to be directly correlated to organizational profit, a high satisfaction measurement with the proposed variables can be verified by comparing the profits of the examined organizations. (The profits can be determined either from the organizations' public profit disclosure or by the researcher's own accounting department).

To insure the proposed variables were significant and have a direct effect on customer satisfaction the research utilized subject expert matter and the customers input. For example, the researcher conducted an analysis on the variables chosen and their significance, such as the warranty variable in the PWB service agreement to determine if an increase or decrease in its

values would have a direct effect on the customers' satisfaction. The increase of customer satisfaction should yield an increase of either business or profits.

The PWB customers determined the weights of the PWB customer satisfaction variables that the researcher used. The weighting mechanism was conducted in two phases. In phase one, the weights were obtained, and in phase two, the weight assignment was validated. The first phase was to send a web-based survey (Figure 1) with the obtained variables to the PWB industry customers. The questions were stated in a manner that requests the customers to identify/rank those variables most relevant to their satisfaction.

There were 25 variables in the survey sent for ranking; each variable will be assigned a percentage/ranking to help the PWB customers' rank the variables (Figure 1). Once the weights are obtained, they will be validated, the researcher will use a portion of the responses to obtain the most relevant factors, and their appropriate weights and the rest of the responses will be used to validate the model and the assigned weights. The second phase was to validate that the weights assigned are representative as to the degree of importance to the PWB customer industry.

Validity of the research is the degree to which a test instrument can measure the research concept (Litwin, 1995). The validity stems from a wide range of experts accepting that the research concept is valid and can be proven to obtain the desired results (Litwin , 1995). To validate the proposed measurement method of customer satisfaction, the research implemented the proposed method and model in the author's PWB assembly organization. After implementing the proposed method of measuring the customer satisfaction, the data was collected and entered in a proposed model and then compared to the current method of measuring customer satisfaction.

This validation method confirmed that the variables identified were significant and a change in their value will affect customer satisfaction. The proposed concept was also sent to other organizations that were participating in the research to validate the newly proposed method of measuring customer satisfaction. Validation can be achieved by sending the concept of measuring customer satisfaction to PWB manufacturers and to other PWB facilities in which the researcher is employed, and requesting them to conduct the measurement with the instrument created and then compare the results for two consecutive quarters after the variables have been improved. There could be a competition between the facilities in the researcher's organization to improve their customer satisfaction. The results could be compared to the facility/organization performance and profitability. The organizations will determine the variables that exhibit the lowest rating and implement plans to improve them. Another test was conducted to validate that the improvements in the variables values increased customer satisfaction and the intent to purchase from the same organization. The research also validated the results of the measurement by comparing it with the organization's profit statement that is publicly released every quarter.

**CUSTOMER SATISFACTION FACTORS DETERMINATION SURVEY**

**PLEASE CHOOSE THE FACTORS THAT CONTRIBUTE TO YOUR PRINTED WIRING BOARD (PWB) CUSTOMER SATISFACTION AND RATE THEIR IMPORTANCE**

If you select "contributes", then select your level of "importance" of the factor to your customer satisfaction where: 1 = very unimportant; 2 = unimportant; 3 = neutral; 4 = important; 5 = very important.

The data gathered from this survey is anonymous. Your participation is voluntary, and is greatly appreciated. Your participation is anonymous, so please answer all questions with complete candor.

Factor	Contributes	Does Not Contribute	Importance (Please Rank 1-5)
Number of Days it Took to Receive the PWB After Ordering	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
PWB Pricing	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Quality Department Response to your Needs	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Warranty on the PWB	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Days it Takes to Obtain a Return Material Authorization	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Days to Obtain Credit for the Returned PWBs	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Days to Resolve Technical Issues	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Days to Access Technical Support	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Days to Access Customer Support	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Days to Receive a Quote Response	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
PWB Thickness	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of PWB Pass Through Hole Registrations	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of PWB Pass Solder Mask Adhesion	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of PWB Pass Blind / Buried Vias registrations	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of PWB Material Types	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of PWB Pass Test (Net Test, Through Hole Test, Bread Board Test) Manufacturer Capabilities	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Shipping Methods Available	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Shipping Packaging Availability	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Capabilities / Servers for Downloading the Gerber Files	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Capabilities to Manufacture PWB Large Volume	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of Capabilities to Manufacture PWB Quick Turn	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of PWB Pass Copper Thickness Meeting Requirements	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of PWB Manufacturer Etch Capability	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Number of PWB Meeting Line Spacing Width Requirements	<input type="radio"/>	<input type="radio"/>	<input type="text" value="5"/>
Please select what industry you are from			<input type="text" value="5"/>

Please add any other factors that may contribute to your customer satisfaction:

Your Email Address:

Figure 3: Research Customer Satisfaction Survey (<http://adamcustomersurvey.kiswa.com/>)

## **CHAPTER FOUR: SURVEY CONSTRUCTION AND ANALYSIS PLAN**

### **Introduction**

This chapter presents how the survey was constructed to extract the important and significant factors that contribute to the PWB customer's satisfaction and the analysis of the data. A comprehensive analysis was done on the responses of the customers who utilize, assemble, and buy PWB. The participants' responses were analyzed and examined using frequency, percentage, mean, and standard deviation (Furterer, El Shennawy, 2004) to determine the ranks of the factors. The factors relevance to each other and whether they contributed to the PWB users' customer satisfaction was studied using multiple regression, statistics, measuring of variation, and correlation statistics. Factor analysis was also used to investigate the above factors (Alasiri Mohamoud, El Shennawy, 2004). The factors were then inserted into a model to predict the PWB customers' satisfaction. This helped the PWB manufacturers to identify the factors that they needed to enhance their customer satisfaction and to pinpoint the factors that have the most fluctuation.

The PWB customer satisfaction variables determination survey consisted of 24 factors; it was developed to determine the most important factors that contribute to PWB users' customer satisfaction. The factors that influence the PWB customer satisfaction were determined by listing all the features and factors of the PWB that have a direct influence on customer satisfaction.

The author, who has 15 years of PWB manufacturing and assembly experience, developed the draft questionnaires using his past experience in the PWB manufacturing and production processes. The questionnaires and a copy of the dissertation proposal were sent to two quality engineers, who have more than 45 years of PWB assembly and manufacturing experience, to review and validate and to determine if the questions were well chosen to

determine the factors that would affect the PWB customer satisfaction. This process was to ensure that the questionnaire represented the concept that the author wanted to measure (Litwin, 1995). The experts suggested some modifications to the survey structure and suggested including an additional question that would request the respondents to suggest any additional factors that may have an influence on the PWB customer satisfaction that were missed in the questionnaire. This added question ensured that the experts and the author included the factors that have an influence on the PWB customer satisfaction.

The author's survey requested the PWB users input and perception for their satisfaction with the PWB purchase, warranty, price, number of days it took to receive the PWB after ordering, quality department response to their needs, number of days it takes to obtain a return material authorization, number of days to obtain credit for the returned PWBs, number of days to resolve technical issues, number of days to access technical support, number of days to access customer support, number of days to receive a quote response, PWB thickness, number of PWB pass through hole registrations, number of PWB pass solder mask adhesions, number of PWB pass blind / buried Vias registrations, number of PWB material types, number of PWB pass test (net test, through hole test, bread board test) manufacturer capabilities, number of shipping methods available, number of shipping packaging availability, number of capabilities / servers for downloading the Gerber files, number of capabilities to manufacture PWB large volume, number of capabilities to manufacture PWB quick turn, number of PWB pass copper thickness meeting requirements, number of PWB manufacturer etch capability, number of PWB meeting circuit line width meeting requirements, number of PWB meeting line spacing width requirements. The PWB life cycle is from the moment the PWB customer places his quote to purchase the PWB. The major PWB process is outlined in Figure 4.



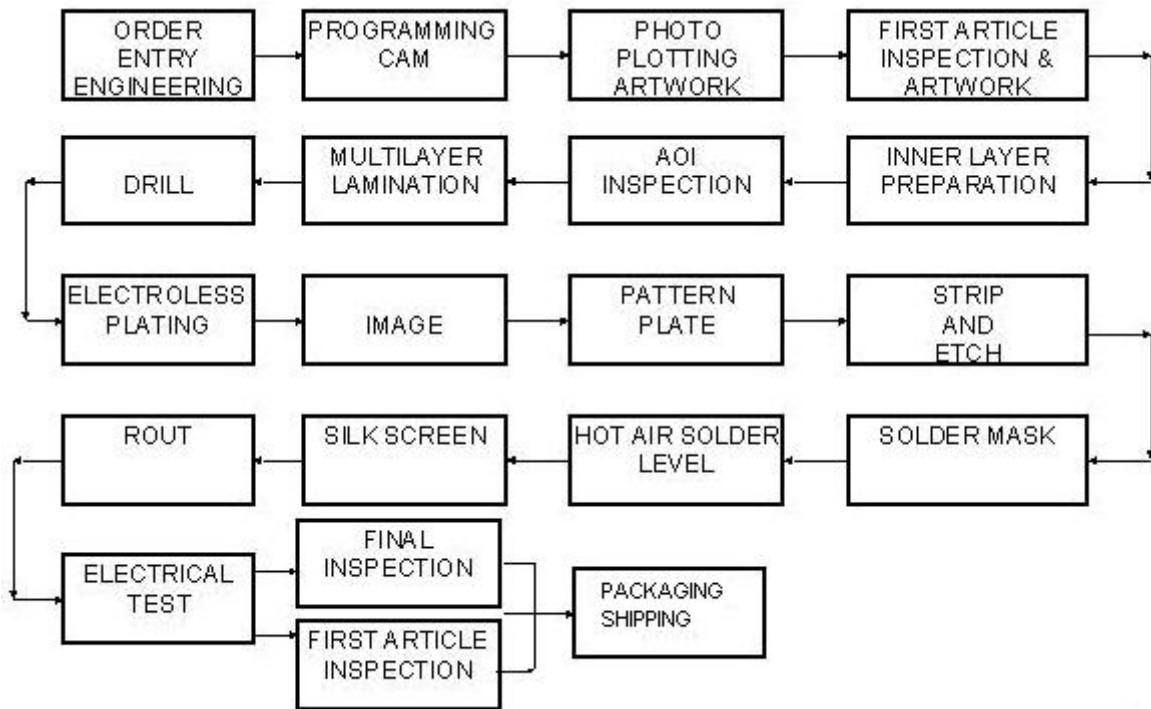


Figure 4: PWB Manufacturing Process

Question 1 of the survey requested from the respondents whether the number of days to receive the PWBs after ordering them had an affect on their customer satisfaction. The question was constructed to determine if the time an order of the PWB had been put in and the time the customer received PWB had an influence on the customer satisfaction or not. The method to measure this variable internally by the PWB manufacturer if the respondent selected it is to determine the number of days it took to get the PWB to the customer after he/she put in the purchase order. To determine the day the customer received the PWB one can enter the shipper tracking number in the shipper site and the date will be displayed or the PWB manufacturer can request the shipper to send a confirmation of delivery day.

Question 2 of the survey was to determine if the PWB price had an affect on the customer satisfaction. This variable can be determined internally and its data gathered by requesting the

PWB purchaser to answer a question after the quote had been entered if the price was compatible with other PWB manufacturers. Nine out ten of PWB purchasers will respond to this question to encourage the PWB manufacture to match or lower the PWB price. The PWB sales employees usually collect this data to discuss it with their managers to gain the PWB customer business. It is also important to ask the PWB customer about value and what is most important for them in order to focus on providing this value better than any other PWB manufacturer (Bigelow, 2007)

Question 3 was constructed to determine if the quality department response to the PWB users needs have an affect on their customer satisfaction or not. When PWB customers receive their PWBs, more likely they will contact the PWB manufacturer quality engineers to determine the PWB specifications, issues, and/or tolerance to environmental factors. The time it takes the PWB manufacturer engineer to respond to the PWB user may be crucial to the customer satisfaction to order more PWB or to place another order with the same PWB manufacturer (Figure 5). The data of this variable can be easily collected by either the receptionist who takes the phone calls or by the quality engineer when he originally receives the message to contact the PWB customer.

In 1999, Marl Wattles in his research concluded that it is crucial to respond to the customer needs and his feedback in a timely manner and, if possible, to request feedback regarding the timely response. Also, Positive customer feedback has a direct correlation to increasing an organization's profit (Wattles, 1999).

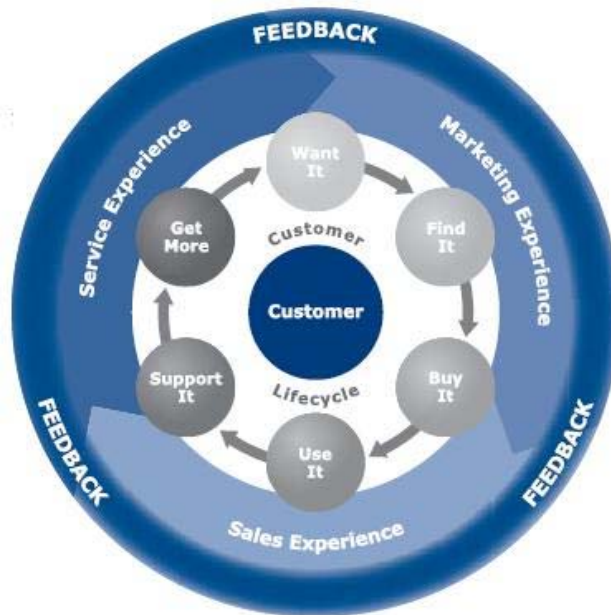


Figure 5: Customer Feedback Lifecycle (<http://www.rightnow.com/products/telco.html>)

Question 4 was to determine if the PWB warranty and time of usage before it fails or breaks down (reliability) has an affect on the customer satisfaction or not. The PWB warranty could be an important factor to the PWB customers, where warranty is a contractual agreement between the manufacturer and the purchaser that requires the manufacturer to either rectify items failures or compensate the purchaser for failures that occur within the warranty period subsequent to its sale, (Murthy and Blischke, 2006). PWB customers want to ensure that the PWB will perform according the requirements given during the life of the PWB. PWB manufacturers need to provide the assurance that the PWB will operate according to the supplied drawings, customer specifications, and purchase order requirements and more important, to ensure the customer satisfaction. There is cost associated with the warranty that may accrue to the manufacturer; it usually ranges from 1% to 10% (Murthy and Blischke, 2006) of the total PWB sale that accounts for the service associated with the PWB warranty. This added cost is

important to ensure a satisfied customer, without this warranty the PWB manufacturer survival in a competitive global market would be extremely difficult.

The data of this variable can be collected and simply measured by the PWB test department where they conduct destructive testing on one PWB board of every single lot passed into the production area. It also can be measured by the time the customer received and populated his PWB and the time the PWB broke down due to measling, delamination, or break out in circuit. The PWB customer usually requests a replacement for his PWB if it fails, so the time between the original order that was taken and the time the PWB customer called to report a defective PWB could be measured to understand the affect of reliability of the PWB to the customer satisfaction.

For Question 5 on the survey, the respondents were asked to select if the number of days it takes to obtain a return material authorization to return their defective PWBs has an affect on their customer satisfaction or not. This question is a double-sword question because some PWB customers may use return material authorizations as means to reduce their inventory or to write off excess inventory. From a PWB manufacturer side, it can be financially detrimental to satisfy all PWB customers if some of them would use this variable as leverage for their satisfaction while some others uses for their financial benefits. The author during his 15 years of experience with PWBs observed that some PWB customers would request return authorizations for entire lots of purchased PWBs from the PWB manufacturers at the end of the quarters or fiscal year so they could return the PWBs and be able to write the price and inventory off their accounting books. Some PWB manufactures tend to authorize a debt to their accounts after the PWB customer sends a defective PWB for evaluation. If the PWB is deemed to be defective by the PWB manufacture, the company may authorize to return the affected lots for

testing/replacement. The evaluation and testing may take time before the determination that the PWB is authorized to be returned for credit or replacement.

Successful fulfillment of an order does not end once the order ships by outbound carrier. Returns processing and account credit is a key concern for almost every customer who places an order (Feare and Seldak, 2002).

The time it takes to authorize the PWB return and the time the customer called to report the defective PWB can be measured by the PWB manufacturer sales employees who receive the PWB customer notification of the defective PWB and the time the PWB are returned to the PWB manufacturer for retesting or replacement.

Question 6 of the survey was to determine if the number of days it takes to obtain credit to the PWB customer account for the returned defective PWB has an affect on the PWB customer satisfaction or not when the customer encounters issues with his PWB. When customers receive products that do not conform to their requirements or expectations, they want to be able to return the product and obtain either credit or replacement as quickly as possible (Tom Feare and Seldak, 2002). The data for this variable can be collected and determined by the time the PWB sales employees receive the shipment when the PWBs are returned and their authorization to accounting to debit the PWB customer with the PWB cost.

Question 7 was to determine if the time it takes to resolve technical issues by the quality or tooling department have an affect on the PWB customer satisfaction or not. Often the PWB manufacturer-tooling department has issues with the PWB specification and how they can build the PWB to meet the customer requirements. Also, the PWB customer builds the PWB on paper/electronically and has limited knowledge of the PWB manufacturing process, thus he/she may design the PWB with requirements that cannot be met during the manufacturing process.

The time it takes to resolve all of these issues before building the PWB is important to the customer in order to receive the PWB on time. Also, after the PWB is delivered to the customer some technical problems may arise and the time taken to resolve these issues is important to the customer. The data for this variable can be collected by PWB manufacturer since the sales employee can log the time it takes to resolve the problems.

Question 7 to the respondents was to seek their opinion if the time it takes them to gain access to the technical support has an affect on their customer satisfaction or not. This question differs from Question 6 because the current question does not specify if the technical issue has been resolved or not; this question targets the PWB manufacturer commitment to respond to the PWB customer's technical issues. The data of this variable can be measured by determining the number of days it takes the PWB technical assistance (whether someone from the tooling or quality department) to contact the PWB customer after his initial call requesting technical assistant support.

Question 8 of the survey was to request from the respondents whether if the number of days to access customer support has an affect on their customer satisfaction or not. The access to the customer support differs from the access to technical support in the previous question where the customer support does not relate to any technical issues with the PWB rather than with the access to information regarding the delivery time the replacements boards will arrive, questions to accounting, questions regarding the quote or purchase order or any other non-technical question. The data for this variable can easily be collected by documenting the time the PWB customer placed the call or e-mail to request customer support, and the time it took to get back with him/her.

Question 9 was to determine if the number of days it took the manufacturer to respond to a PWB customer quote has an affect on the customer satisfaction or not. This variable can be measured by documenting the time the PWB customer called the PWB manufacturing sales employee to place the quote and the time it took to respond back to the customer with his/her quote by either e-mail or mail.

Question 10 was to determine if the PWB thickness has an affect on the PWB customer's satisfaction or not. The data of this variable is measured and collected on every PWB inspected by the quality department of the PWB manufacturer. The PWB final inspection process is to inspect the PWB attributes and ensure its compliance with the customer drawings and purchase order, thus it is a requirement from the quality department to measure the PWB thickness, hence the data of this variable can be used to measure the customer satisfaction and if the customer selected this variable what effect it has on his/her satisfaction with the PWB purchase. It is imperative to note that a micrometer is used to measure the PWB thickness and the tolerance of the PWB will be specified on the customer drawings. To measure the PWB thickness, the micrometer must measure the thickness of the PWB, including the solder mask that protects the PWB, if specified. The PWB thickness may be important to the PWB assembly organization or the final user, but may not be important to the service organization whose sole responsibility is to rework the PWB if it is defective. The user or assembly organization may have to fit the PWB in a tight compartment, thus the PWB thickness becomes crucial to their needs.

Question 11 was to ask the respondent if the number of PWBs that passes through hole registration requirements have an affect on their customer satisfaction or not. PWB though hole registration is the accuracy of the drilled hole into the PWB in relation to the annular ring of the copper that surrounds the hole. If the drilled hole is shifted either to the left or right this causes a

possible breakout of the circuitry. This can be an important variable to military application customers but it is not as important to commercial application customers. The hole registration is measured by a beta scope, high-powered scope, or a micro view machine. The distance between the hole edge and the end of the copper material that surrounds the hole is measured and determined if it meets the customer drawing requirements or not. This data is recorded and collected by the quality department on every PWB lot inspected; measurements are kept on file as evidence that the PWB passed the inspection; this data can be used to measure the customer satisfaction if the PWB customers determined that this variable has an affect on their customer satisfaction.

Question 12 was to determine if the number of PWB passes solder mask adhesion has an affect on the PWB customer's satisfaction or not. Using a special tape that conforms to standard IPC-TM-650 and has adhesion on one of its sides tests PWB solder mask adhesion. The test method requires a roll of pressure sensitive self-adhesive film tape 1.3 cm (0.5 in) wide exhibiting an adhesive strength of at least 44 N/100 mm (40 oz-force/in) but no more than 66 N/100 mm (60 oz-force/in). The test determines the adhesion of solder resists (masks) used over solder plated and re-flowed solder PWB both prior to and after soldering, non-melting metals, and PWB substrates.

The tape is placed on the PWB solder mask and with a 90-degree angle the tape is pulled apart from the PWB. If solder mask came out with residue on the tape, this would indicate that the solder mask adhesion had failed the test and the probability that the solder mask will come apart from the PWB during assembly or during its normal operation is high. Also, if the solder mask comes apart from the PWB this will induce a major problem during the reflow of solder on a PWB that is populated with many components where it is needed to be heated at a certain



temperature that will melt the solder, but not damage its heat sensitive components (Higashi and Tsubone, 2006). The data for this variable can be collected during the final inspection of the PWB before it ships to the customer. A quality inspector must inspect the solder mask adhesion to the PWB to meet the customer drawing requirements and the inspector document the pass/fail on the inspection sheet.

Question 13 was to determine if the number of PWBs that pass the blind / buried vias registrations has an affect on the PWB user's customer satisfaction or not. Blind vias are the holes that are made in the PWB to electrically connect the multiple layers. Blind vias usually can be seen under the solder mask on the outer layers of the PWB. Buried vias do not necessarily puncture the entire PWB; they can be holes to electrically connect the outer layers of the PWB with the first or second layer below it. Buried vias are not seen from the outer layers of the PWB. These vias are imbedded inside the inner layers of the PWB. Buried vias electrically connect the internal layers of multilayer PWB according the PWB customer drawing and specification. Blind vias registration can be measured from the outer layers of the PWB while buried vias can only be measured during the inner layer PWB building process. To measure buried vias at final inspection, a destructive test must be done and a cross section must be taken to measure the buried vias registration by a high-powered scope. Measurements of the registration of either the blind or buried vias are documented on the final inspection sheet for every multi layer PWB built in order to ensure its functionality.

Question 14 was to measure if the PWB manufacturer has capabilities to build PWB with different material types. It is important for some PWB users to select a PWB manufacturer that can build PWBs according to their specific needs; the material with which the PWB is fabricated determines its dielectric constant, where the dielectric constant in turn determines the time in

which electrical signals propagate over the PWB (electrical propagation velocity). Table 1 depicts the PWB material types of electrical propagation

Table 1: PWB Material Types of Electrical

PWB Characteristics		
	Propagation velocity	Permittivity
Material Type	$V_p$	$E_r$
Teflon	212mm/ns	2
Polyimide	173mm/ns	3
FR4 Outer trace	141 - 179mm/ns	2.8 - 4.5
FR4 Inner trace	141mm/nS	4.5
Rogers 4003	N/A	3.38
PTFE	N/A	
GETEK	N/A	3.8 - 4.2
Nelco 4000-8000	N/A	3.5 - 4.4

The PWB material types are dependent on the permittivity (dielectric constant), which is the measure of the ability of the PWB to support an electrostatic field related to its capacitance.  $E_r$  is measured in units of farads/meter. PWB  $E_r$  usually is lower for top traces on the surface of the PWB while it is higher for traces embedded within the PWB material. The signal velocity can be measured by the following formula, Signal Velocity  $[V_p] = C / [E_r]^{1/2}$ , where “C” is a constant at 30cm/ns. Figure 6 depicts how the PWB board material's permittivity and the circuit's rise time affect the maximum allowable trace length. The blue vertical line assumes a rise time of 1.1nS, while the horizontal lines assume a particular board material (orange for FR4, and purple for polyimide).

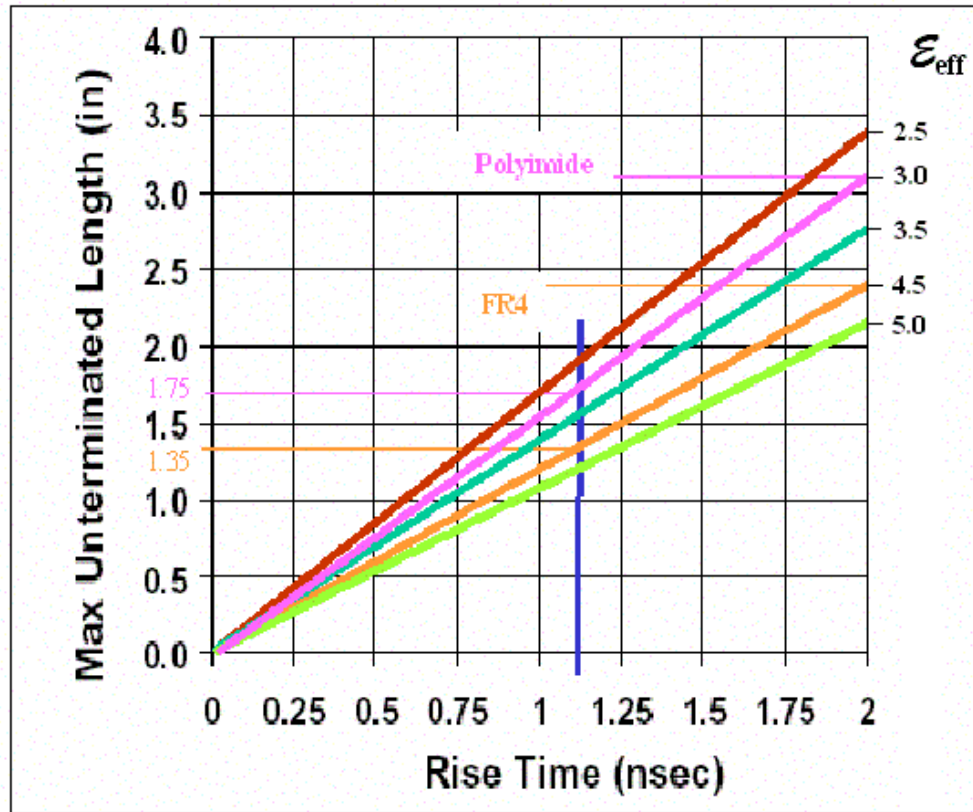


Figure 6: PWB Board Material Permittivity (<http://www.interfacebus.com>)

This variable can be measured by determining the number of materials the PWB manufacturer is capable of using to build PWBs for the PWB customer.

Question 15 was to determine if the PWB Pass Test (Net Test, Through Hole Test, Bread Board Test) Manufacturer Capabilities has an effect on customer satisfaction or not. There are three types of tests that can be performed on the PWB to ensure their connectivity is per the customer requirements. The first type is called comparison test, this is the least expensive type of test that can be performed on a PWB. It is not as reliable as the other two tests types. The comparison test is done by laying the PWB on a table of needles. A software engineer will program the test machine to read every possible connection of the PWB. Once the machine is

programmed with this master PWB, the remaining PWBs in the lot are tested and compared to this PWB. The reason this method is not reliable is that if the master PWB is defective per the customer requirements then the rest of the PWBs will be compared with a defective PWB (Seyama and Yoneda , 2002).

The second method to test the PWB is by reading the Gerber files of the PWB by a software engineer who will generate in turn a specific software program for the test machine to read the PWB connections per the customer's original Gerber files. This kind of test is more reliable and ensures that the PWB conforms to the customer requirements; this test is more expensive than the comparison test. The third PWB test capability is the flying probe test. Flying probe test refers to a method of testing the PWB whereby the circuits are tested for opens and shorts by a tester that uses a moving test probe that is guided to specific X and Y locations on the PWB surface. This test is the slowest test that can be performed on a PWB because the test fixture has all points of contact with the PWB being made simultaneously while a flying probe tester has each point of contact being made consecutively. The flying probe test is characterized by its quick and easy setup and cost savings when testing circuit boards since there is no test fixture that must be designed and manufactured to lay the PWB on as them with the needles. The PWB designers will ensure highest current conductivity intensity on the circuit lines (conductors) to pass electrical tests. It is important to note that the current intensity on the conductors is larger close to the conductor surface due to phenomena called skin effect, (Riazi, 2007). To reduce the skin effect losses the designer may use gold plating instead of solder plating.

The data for this variable can be collected from the sales department while taking customer quotes to manufacture the PWB. If the customer makes a request to test his/her PWB with a test method that is not available, the manufacturer will either have to subcontract the test

of the PWB to another company or will lose the bid to manufacture the PWB. The manufacturer will determine how many quotes per month have been lost due to not having the testing capability that will meet the customer requirements.

Question 16 was to determine if the number of shipping methods available to the PWB manufacturer will have an effect on the customer satisfaction. There are numerous types of shipping methods, FED X, United States postal parcels, DHL, UPS, drop off shipment or by directly shipping the product via air transportation. The ability of a manufacturer to use the different types of shipping methods gives an advantage over other manufacturers. For quick turn delivery, it is imperative for the manufacturer to deliver the product with the fastest delivery method to meet the customer delivery deadline. In most cases, the PWB customer pays a premium for having the PWB delivered to him/her in a matter of days after placing the purchase order for the PWB. Other high volume PWB customers have an account with a specific delivery service and he/she prefers to have his PWB shipped by that carrier. If the PWB manufacturer does not have an account with this carrier, the PWB customer may look at alternative companies from which to purchase the PWB. Some other PWB manufacturers have their own delivery service where their own carriers ship the PWB to the customer, thus they eliminate exorbitant shipping and handling costs to deliver the PWB to the customers. The data for this variable will be collected during the quote period when the PWB customer places his quote to purchase the PWB. The PWB manufacturer sales employee makes a note of the shipping method preferred by the PWB customer. To measure this variable, if the preferred customer shipping method is available to the PWB manufacturer the entire percentage of the allocated weight will be awarded, if the preferred shipping method is not available to the PWB manufacturer, it will result in a deduction of the allocated weight to this variable.

Question 17 was to determine if the number of shipping packaging available to the PWB manufacturer can have an affect on the PWB customer's satisfaction. There are numerous types of PWB packaging, ESD (Electrostatic Discharge) packaging, vacuum seal packaging, bubble wrap packaging, ESD bubble wrap packaging, regular plastic bags, heat seal, desiccant and humidity indicator heat seal and ESD foam. The ability of the PWB manufacture to provide the PWB customer with the packaging that meets his/her requirements may have an affect on customer satisfaction. Also, the ability of the PWB manufacturer to meet the IPC J-STD-033 standard requirements for PWB packaging is an important aspect of his/her customer satisfaction in relation to the PWB packaging. High volume PWB customers would like their PWB shipped in vacuum-sealed bags so that they can store them for long periods of time, while space applications PWB customers would like to have their PWB packaged in heat-sealed ESD bags to prevent humidity seepage into the PWBs' layers.

The data for this variable can be measured during the customer quote phase; the PWB manufacturer's sales employee would take note of the packaging requirement, and if not available to the PWB manufacture a percentage of the customer satisfaction may be deducted.

Question 18 of the survey was to determine if the number of capabilities / servers for downloading the PWB customer's Gerber files have an affect on customer satisfaction or not. The PWB customer sends his drawings, Gerber files, and purchase order to the PWB manufacturer via mail or electronically. The ability to receive these data electronically on the PWB manufacturer's servers may have an affect on the overall PWB customer satisfaction. One of the benefits of sending the Gerber files electronically to the PWB manufacturer is reducing possible errors when the PWB manufacturer converts the files received by mail. The time to send Gerber files electronically is much faster than by regular mail, and finally, the Gerber files will

be intact when received electronically. If this variable is selected by the PWB customers to have an affect on their customer satisfaction, its data can be measured when the PWB manufacturer's sales employee takes the customer quote. If the customer requests to send the Gerber files electronically and the PWB manufacturer does not offer this option, then a percentage of the customer satisfaction may be deducted. On the other hand, if the PWB customer requests to send the Gerber files electronically and the PWB manufacturer has the capability of receiving these electronically, a positive customer satisfaction percentage will be awarded to the PWB manufacturer.

Question 19 was to determine if the capabilities of the PWB manufacturer to produce PWB large volume may have an effect on the PWB customers' satisfaction or not. Some PWB customers are not interested in spending the extra money to produce their PWB in a quick turnaround. Thus, this variable may not be of importance to them. PWB customers often may purchase large quantities of PWBs to reduce the cost of manufacturing especially if they will use the same product over and over again. The data for this variable will be obtained when the customer places his quote to purchase the PWBs.

Question 20 was to determine if the manufacturer's ability to produce PWB quickly affects customer satisfaction. Some PWB customers will pay a premium to receive their PWBs in a matter of days of placing the purchase order. The PWB manufacture processes must be set up to produce and manufacture quick turnaround PWBs. In a quick turn PWB facility, equipment operates in a 24-hour shift, no waste of time is permitted and every minute is counted into the PWB fabrication. Some large volume PWB manufacturers cannot produce concurrently quick turn PWBs because the nature of the equipment set up. On the other hand the quick turn PWB manufacturers can produce high volume PWBs. The survey will determine whether or not the

ability of a PWB manufacturer to produce and manufacture quick turn PWBs has a positive correlation to the PWB customer's satisfaction. The data for this variable, which is if the customer requests manufacturing his PWB in either high volume or quick turn will be collected in the initial phase of the quote process. If the PWB customer requests the PWB to be built in quick turn and the PWB manufacturer has the ability to produce PWB in quick turn, a positive impact on customer satisfaction will occur.

Question 21 was to determine if PWB copper thickness is an important factor to the customer satisfaction. Copper thickness plays an important role in the PWB manufacturing processes. It is common that entire lots of PWB are scrapped or thrown away because they do not meet the minimum customer requirements for copper thickness. Copper thickness in the PWB manufacturing processes can be characterized in two segments; one is plated copper and the other is the actual copper thickness of the internal layers. PWB in process inspections measure the amount of copper that is plated on top of the original layers to meet the customer requirements. Final PWB copper thickness (Figure 7) can be in the range of  $35\mu + 70\mu$  of an inch.



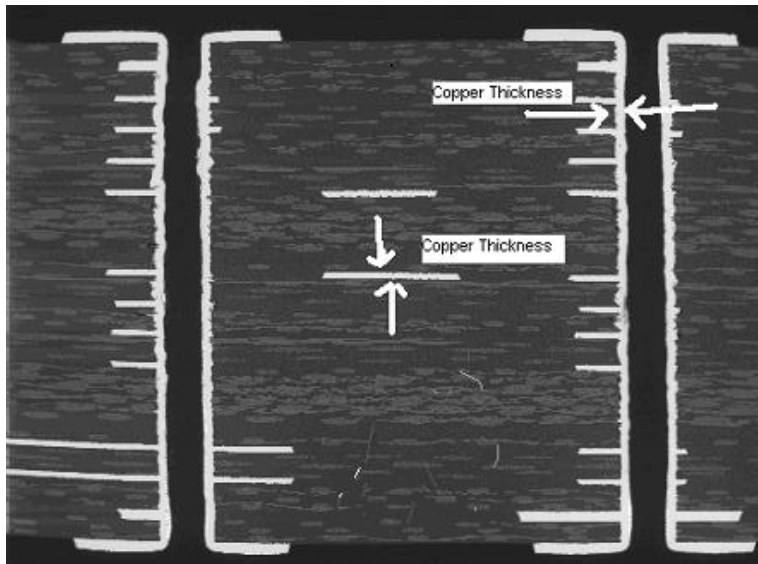


Figure 7: PWB Copper Thickness

At final inspection, a high-powered microscope is used to ensure the PWB's compliance with the minimum copper thickness required by the customer. Copper thickness is not as important for PWB customers who order single or double side PWBs since the copper thickness will not effect affect the functionality of the PWB. On the other hand, copper thickness is crucial for multilayer and space application PWBs. The ability of the PWB manufacturer to meet the copper thickness requirements vary from one PWB customer to the other depending upon the customer's application. The data for this variable will be measured at final inspection and recorded on data sheets. If the manufactured PWBs do not meet the minimum requirements of the copper thickness a negative impact on the customer satisfaction may occur, while a positive impact may occur for meeting the copper thickness requirements.

Question 22 was to determine if the etch capability of a PWB manufacturer has an effect on the PWB customers' satisfaction. Etching is one of the most important processes in the PWB manufacturing business. Circuit paths are created during the etching process. The PWB layers

are made of a dielectric (epoxy and resin) encapsulated between two copper sheetings. Circuit lines on the PWB are developed by applying a photo-resist layer on top of the copper foil. The PWB layers are then exposed to a UV tool to flood specific areas of the photo resist with UV light and with the help of the mask, which determines the pattern of copper on the PWB layer (Figure 8).

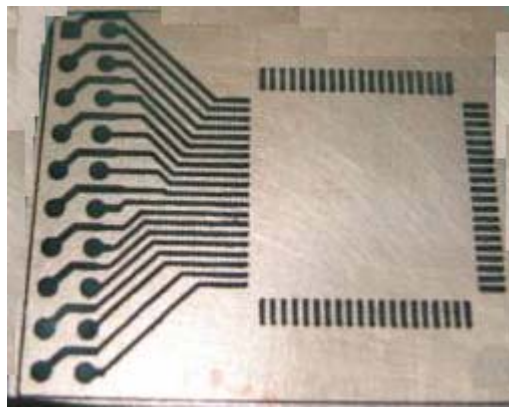


Figure 8: Photo Resist Applied to Copper Layers

The exposing process is the photo process of transferring the circuit image, which is on the UV machine on to the PWB layer. The photo light causes the resist to harden (polymerize) and be retained during the next processes. The PWB layer is moved to be developed chemically to remove the remaining resist that was not exposed to the light source.

The PWB layer is then moved into an etch tank (Ferric Chloride) to etch away the excess copper from the PWB layer (Figure 9).

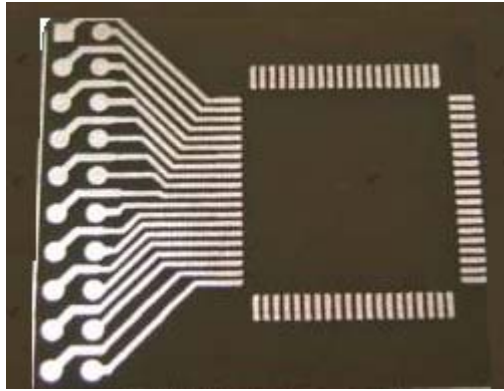


Figure 9: Copper Etched from Copper Layer

After the etching process is completed, the PWB circuit pattern will be visible to be inspected for any open or shorts then coated with black/red oxide to protect the circuit (Figure 10).

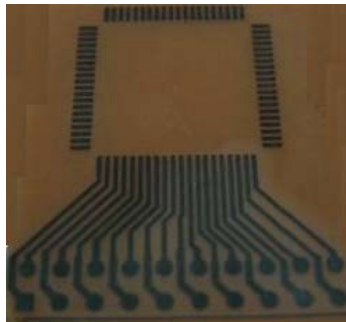


Figure 10: PWB Copper Etched and Covered with Black/Red Oxide

The etching process data will be measured by determining the number of defects found during the AOI inspection (Automatic Optical Inspection). Where the AOI inspection process for the etched PWB layers are performed by scanning and identifying components that appear different from the reference “golden board” (Hecht and Dishon, 1990). Only those components in question are brought to the operator’s attention and are individually displayed at a high-resolution 10x magnification. The PWB inspector is prompted to review the questionable items

by using a set of specifically designed software tools. AOI gives the PWB inspectors the ability to identify components that appear different from what they are assumed to be.

Question 23 was to determine if the PWB circuit line width factor would have an effect on the customer satisfaction. PWB line width requirements for customers that order single or double sided PWB is not as important as PWB line width for PWB customers who order multi layer or space application PWBs. PWB line width is measured by beta scopes and measurements are logged in inspection sheets.

PWB conductor width, spacing, and annular ring must meet the minimum requirements set by the IPC A-600 standard. PWBs are classified into three types in IPC-A-600 standard for inspection. Conductor width requirements and acceptance criteria for PWBs Class 2 and 3 are 20 percent permissible reduction of line width and an additional 20 percent reduction for isolated areas. Requirements for Class 3 PWB permits line width reduction of up to 30 percent of the original line width. The data of this variable will be collected during the final inspection processes. Circuit line width is measured for every PWB that passed final inspection where it is necessary to ensure that the circuits are not close to the edges of the PWB in order to prevent emission of signals (Archambeault, 2008). If the Circuit line width meets the minimum customer or minimum standard IPC-600A requirements for manufacturing PWBs, the PWB manufacturer will get the lowest customer satisfaction percentage allocated for this variable. If all PWB boards in the lot fail to meet the minimum line width requirements, the PWB manufacturer would not get any percentage towards his customer satisfaction (Figure 11).

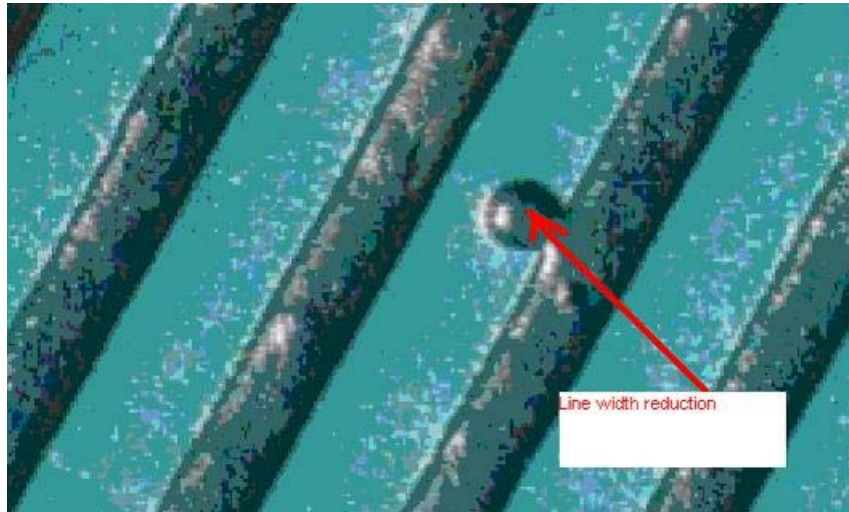


Figure 11: Line Width Requirements

Question 24 was to determine if the requirements of the line spacing between the PWB conductors have an affect on the PWB customers' satisfaction. PWBs (as mentioned above) are classified into 3 classes, the conductor spacing for class 3 in (Figure 12) per the IPC-600 is acceptable as long as the spacing is not reduced to 20 percent.

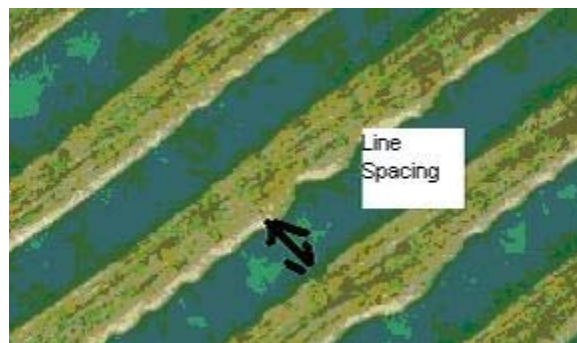


Figure 12: IPC-600 Class 3 Conductor Spacing

As for class 1 and 2 the IPC-600 standard requirement is more lenient where the spacing can be reduced up to 30 percent per Figure 13. The data for this variable will be collected during

final inspection when the inspectors inspect the PWBs. A sample is taken, the conductor spacing is verified and logged into inspection sheets.

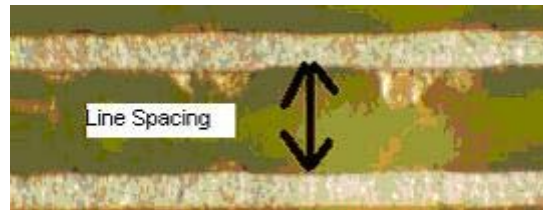


Figure 13: Class 1 and 2 Conductor Spacing

Question 25 was to determine which industry is the respondent from. The survey also requested from the respondents to classify their business type: assembly, service, or users. This will determine if the customer satisfaction model will be applicable to all the PWB organizations. The PWB assembly organizations typically receive the PWB directly from the PWB manufacturer, rather than receiving it from the actual users. On occasion, the PWB user will receive the PWBs then forward them directly to the assembly organization. To ensure that this study is valid to all world customers, the survey was sent to Asian, European, South American, and North American PWB Customers.

### **Validity of the Survey**

To validate that the survey questions adequately rank and determine the factors that have an impact on the PWB customer's satisfaction and to ensure that the survey represents what the authors need to measure (Babbie, 1973) the survey was evaluated for its content by experts in the PWB business with more than 45 years of combined experience. The survey questions would most likely be an accurate measure if the experts approved the content of the survey and if they both agreed that the content covers the factors that are tangible between the PWB and the users

and the factors that may have an impact on the customer satisfaction (Wentland and Smith, 1993).

### **Survey Dry Run Test**

Prior to sending the survey to the PWB customers, a survey dry run test was done to ensure that the survey adequately represented the factors (Al Asiri and El Shennawy, 2004) that influence the PWB customer satisfaction and to determine if there are any improvements needed to the survey.

The survey was first submitted to the author's university Institutional Review Board (IRB) to ensure its compliance with the regulations regarding research involving human participants. The IRB reviewed the survey and suggested some modifications to ensure the confidentiality and anonymity of the participants. A cover letter with an Informed Consent notification to the participants, along with the survey was also reviewed by the IRB. After the IRB approved the survey content and the letter of consent (Appendix A) the author posted the IRB approved survey to a web site to which the participants were directed to visit to post responses. To validate the survey and the consent letter, the survey dry run test was conducted by sending a letter of invitation to participate in the study along with the letter of consent to the engineers and PWB users within the author's organization, which were PWB users and customers. The author's organization's engineers and users were encouraged to submit comments and critique the survey and letter of invitation in order to improve the research. Comments and valuable input were submitted to the author and some were included into the final survey and letter of invitation.

The final survey was posted on the internet and a cover letter with a consent form explaining the importance and purpose of the study was sent by either e-mail or by fax and mail to the PWB users and customers requesting them to participate in the study. A telephone call follow up was conducted throughout the duration of the research to encourage the participant's involvement in the study.

To illustrate the validity of the survey, a case study will be conducted by studying a company that uses PWB after the PWB users and customers respond to the survey. The data will be extracted from the company files and records then the PWB customers' satisfaction will be measured with the proposed method and compared to the PWB customer satisfaction survey method. If the two measurements are equal then this adds creditability to the proposed methodology. The case study will utilize data that are made available by a quality engineer who works for the company and will be generically described because of a non-disclosure agreement. Once important problems factors are identified, quality engineers then will conduct a failure mode and effect analysis to reduce the negative effect of these variables during the design process (Benbow, Berger, Elshennawy, and Walker, 2002).



## **CHAPTER FIVE: RESULTS AND ANALYSIS**

### **Introduction**

This chapter explains the surveys results and how the factors were analyzed to determine the final model for the empirical method to measure the PWB customer satisfaction. The factors will be analyzed over all of the surveys and the entire spectrum of the respondents.

The surveys were conducted via email and mail, 150 surveys were sent to engineers and managers of companies that assemble, use, and service PWBs in Asia, Europe, South America, and North America.

The survey had 25 questions, and all questions can be rated on a 5-point Likert scale (Asiri, El Shennawy, 2004) that ranges from 1 to 5. 1 for very unimportant, 2 for unimportant, 3 for neutral, 4 for important, and 5 for very important. The overall survey result is delivered as a ranking outcome that ranks the factors that influence the PWB from 0 to 100 percent, with 100 percent being the highest level of contribution to the PWB customer satisfaction.

There were 85 respondents representing a 56.6 % response rate. This high rate may be due to the fact that the author promised the respondents a free copy of the empirical method to measure customer satisfaction. Participants were asked to select the factors that contribute to their PWB customer satisfaction and to rank them on a 1 to 5 scale and to include any other factors or features that they think might need to be included in the survey, in addition, they were asked to select their type of industry as to whether it was an assembly, service, or user of the PWBs.

The results of the last question categorized the participating PWB companies into three different categories. Participants were asked to provide information about their organization's sectors. Assembly constituted the largest portion of respondents with 69

responses out of the 85 respondents, which equates to 81.1 percent return rate for the assembly service industry. PWB users had 11 responses, which equates to 12.9 percent. The service industry respondents were only five, which constituted 5.9 percent. These percentages reflect the current trend of the PWB users and manufacturing. The PWB customers most likely will not manufacture or assemble the PWB but would rather subcontract the manufacturing and assembly to another organization to cut operating costs and employee benefits. Instead of designing and assembling the PWBs, the PWB users or customer's would shift their product to the subcontractor who actually assembles the PWB and is faced with all its issues. From the author's past experience, most of the time the PWB users or customers subcontract the entire assembly and manufacturing process to one organization to receive a discount price on the package; this reflects the high percentage of the assembly organizations respondents to the customer satisfaction determination survey.

The service industry, which constituted a 5.9 percent response, is the PWB industry that is specialized in reworking damaged or defective PWB either assembled or not. This industry does not purchase the PWBs but are subcontracted by the PWB purchasers or users to rework PWBs that surpassed the warranty period. Some of these organizations are also subcontracted by the assembly organizations to rework PWBs that are damaged during the assembly process. The service organization would then contact the PWB manufacturer to determine the kinds of material or specifications that are used to manufacture the PWB in which it is needed to be put in consideration while reworking the PWB such as the type of solder mask, the minimum required circuit width, or the required conductors spacing. The PWB users are the actual purchasers of the PWBs; they are the ones that design PWBs to perform specific tasks. PWBs can be found in every electronic device that we use in our daily life, from digital watches, computers, cameras,

cars, trains, planes, missiles, rockets, smart bombs, ships, submarines, radios, to TVs and calculators. The PWB users design the PWBs and subcontract the assembly and the manufacturing process to other organizations. Some PWB users design and manufacture their own PWBs. There were 11 such organizations who responded to the survey, which equates to 12.9 percent of the respondents.

To measure the variations between the three PWB groups and to test any significant differences between them or between the variables, chi-square test was used. Chi Square will be used as a general test to check whether there are significant differences between groups where the data are nominal. The difference is considered significant if the P value for the test is less than or equal to 0.05. A Chi - Square test for significant differences reveals that there is a significant difference among the frequency of the responses of the PWB respondent's sectors that uses PWBs. (Chi Square value =240.903, df = 48 , p = 0.000 < .01).

Despite the fact that PWBs are used in the service and in end product users sectors, the assembly sector represents the largest portion of respondents, with 74.3 percent of respondents. One possible reason for this is that assembly company respondents are involved in assembling electronic and hardware components onto PWB and they are the first to experience any issues, complaints, or satisfaction with the PWB. Another possible reason is that the users or service respondents had all the issues and complaints about the PWB resolved prior to them receiving the PWBs by the assembly respondents. A detailed analysis of the customers' responses was conducted to rank and determine the weights of the factors to be included in the empirical method to measure the customer satisfaction. The model will include and consider all the 25 variables (Table 2). Regression or factor analyses could not be performed on these variables since they were qualitative in nature (Franklin and Malone, 1983). One

hundred and fifty surveys were sent out to PWB customers by email, fax, and letters of invitation along with the letter of consent. One hundred and ten surveys were emailed, thirty-two were faxed and 8 eight were mailed by the United States postal service. Table 3 depicts the frequency, percentage, and standard deviation of the responses.

Table 2: Factors Affecting PWB Customer Satisfaction with Highest Average Ratings

Items	Contributes Frequency	Does not Contribute Frequency	Average Rating	Percentage	Standard Deviation
Quality Department Response to your Needs	79	6	4.28	92.94%	1.33
Number of Days it Took to Receive the PWB After Ordering	80	5	4.27	94.12%	1.22
Number of Days to Access Technical Support	85	0	4.27	100.00%	0.61
Number of Days to Resolve Technical Issues	78	7	4.24	91.76%	1.4
Number of Days to Receive a Quote Response	74	11	3.75	87.06%	1.61
Number of Days to Access Customer Support	80	5	3.72	94.12%	1.22
Number of PWB Meeting Circuit Line Width Meeting Requirements	78	7	3.69	91.76%	1.31
Number of Capabilities to Manufacture PWB Quick Turn	72	13	3.52	84.71%	1.45
Number of Days it Takes to Obtain a Return Material Authorization	79	6	3.44	92.94%	1.2
PWB Thickness	73	12	3.3	85.88%	1.51
Number of PWB Manufacturer Etch Capability	74	11	3.27	87.06%	1.45
Number of Capabilities to Manufacture PWB Large Volume	74	11	3.24	87.06%	1.09
Number of Days to Obtain Credit for the Returned PWBs	74	11	3.22	87.06%	1.4
Number of PWB Meeting Line Spacing Width Requirements	77	8	3.2	90.59%	1.33
Warranty on the PWB	76	9	3.18	89.41%	1.22
PWB Pricing	63	22	3.05	74.12%	2
Number of PWB Pass Solder Mask Adhesion	75	10	3.04	88.24%	1.4
Number of PWB Pass Copper Thickness Meeting Requirements	64	21	2.88	75.29%	1.83
Number of PWB Pass Through Hole Registrations	67	18	2.85	78.82%	1.57
Number of PWB Pass Test (Net Test, Through Hole Test, Bread Board Test) Manufacturer Capabilities	55	30	2.3	64.71%	1.81
Number of Shipping Methods Available	56	29	2.23	65.88%	1.75
Number of Capabilities / Servers for Downloading the Gerber Files	51	34	2.07	60.00%	1.81
Number of PWB Pass Blind / Buried Vias registrations	55	30	1.85	64.71%	1.55
Number of PWB Material Types	40	45	1.44	47.06%	1.71
Number of Shipping Packaging Availability	36	49	1.22	42.35%	1.42

Scale: 1=very unimportant, 2= unimportant, 3= Neutral important, 4= important, 5 very important

Table 3: Frequency, Percentage, and Standard Deviation of Responses

Organization	Frequency	Percent	Standard Deviation
Assembly	69	81.2	1.623
Service	5	5.9	1.403
Users	11	12.9	1.391
Total	85	100	

**Survey Analysis and Model Approach**

Survey response rate was eighty-five responses; sixty-nine responses (81%) were from the PWB assembly customers; eleven (13%) were from the PWB users, and five (6%) from PWB service industries (Figure 14). Most of the responses were from PWB assemblers; this may be because most of the PWB users and designers subcontract the PWB manufacturing, assembly and testing to other facilities instead of assuming the operating cost of these facilities and the product they are marketing may be unique and may not need to be remanufactured. Few other PWB users and designers have their own facilities to manufacture PWB, especially for military or space-related use.

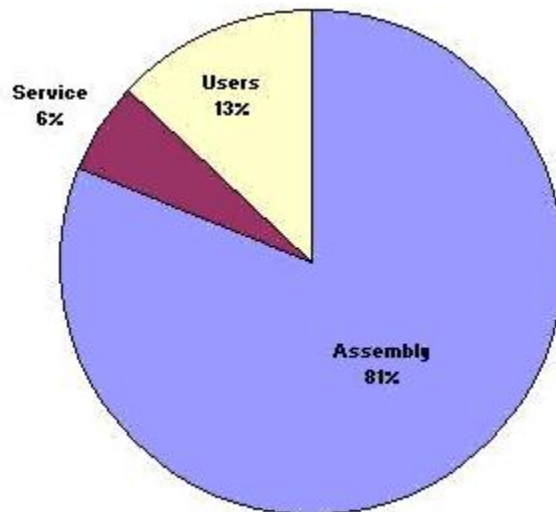


Figure 14: Percentage of PWB Customer Response to Survey Response

### Variable One Analysis

The response rate for the first factor, which was the number of days it took to receive the PWB after ordering, was eighty customers with 94.12% of the customers agreeing that this factor contributes to the PWB customer satisfaction with an 85.41% contribution level. The assembly and users sectors were 81% and 13% respectively (Figure 15). This factor was the second most significant to the PWB customers with an average contribution of 4.27 and a standard deviation of 1.22.

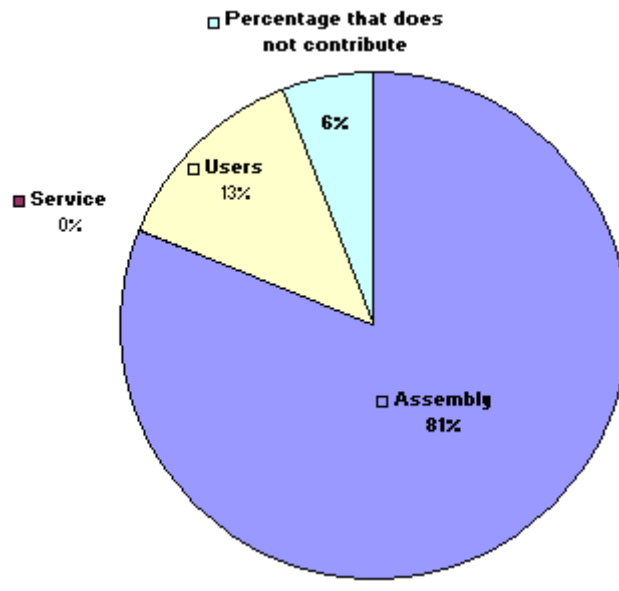


Figure 15: Number of Days to Receive PWB after Ordering Response

Examining the customers' response segments reveals that 100% of the customers that assemble the PWBs, along with the customers that use them forcefully agree that this factor contributes to their customer satisfaction while none of the customers that repair or rework the PWBs believe that this factor contributes to their satisfaction. It is clear that this factor is

extremely important to the customers that assemble the boards then forward the assembled PWB back to the original customers.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that the 47 (85.5%) PWB customers responded that this factor is very important to their customer satisfaction, 29 (34.1%) PWB customers responded that this factor is important, four (4.7%) customers responded that this factor is neutral, and five (5.88%) customers responded that it does not contribute to their customer satisfaction (Figure 16).

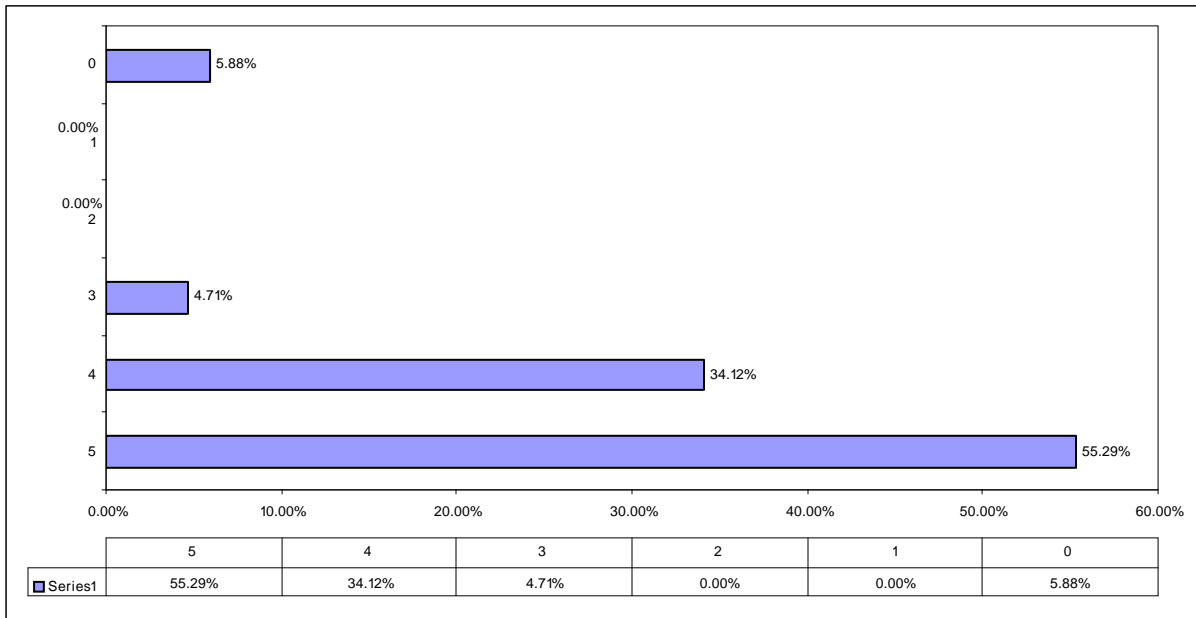


Figure 16: Variable Contribution Frequency Distribution

The PWB repair and rework customers’ response does not indicate that this variable is significant to them since they are involved with the PWB after they have been purchased or assembled. The PWB service organizations are only reworking the PWB or repairing it after the PWB user or assemblers already purchased the PWB. PWB assemblers and users indicated that



receiving the PWB quickly after ordering them contributes to their customer satisfaction with an average of 93.62% contribution level and 72.73% respectively. PWB assemblers are interested in receiving the PWB as soon as possible to populate them and send on to the PWB user so they can be reimbursed for the cost of assembling them. Any delay in receiving the PWB from the PWB manufacturer has an effect on the PWB assemblers who run many product lines and have their lines ready and the parts kitted for assembly. Any delay may cause interruption to the product lines and may cause financial constraint to the PWB assemblers. The PWB users may not have the same concerns with the delivery time, but it is still an important factor to them.

### **Variable Two Analyses**

The response rate for the PWB pricing factor and whether the PWB low cost or comparable cost contributes to the customer satisfaction was a total of sixty-three customers out of eighty five with 74.12% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 61.18% contribution level (Figure 17)

This factor was the nineteenth most significant to the PWB customers with an average contribution of 3.05 and a standard deviation of 2. Examining the variable contribution rate indicates that 60% assembly customers, 1% service customers, and 12.94% users customers believe that this variable contributes to the customer satisfaction.

Examining the customers' distribution response segments reveals that 73.91 % of the customers that assemble the PWBs, 100 % of the customers that use PWBs, and 20% of the customers that service them agree that this factor contributes to their customer satisfaction with a contribution level of 59.42%, 89.09% and 24% respectively.

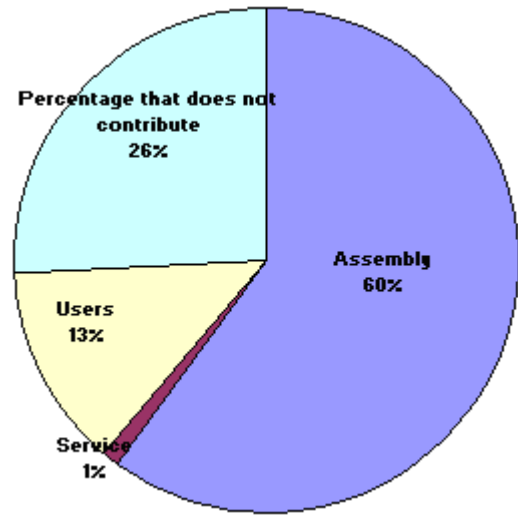


Figure 17: PWB Pricing Response

It is clear that the users of the PWBs have a significant interest in purchasing the PWB with a low or comparable price. PWB users usually shop around for the best price to manufacture the PWBs. For military PWB users, this is not as important since the U.S. government is paying for the purchase, but it may increase the PWB profit margin if they were able to purchase the PWB with low or comparable cost. As for the service organizations, their interest may be in the cost of the PWB if during the rework or repair, the PWBs are damaged or became useless and they may have to repurchase or replace them for the PWB manufacturer.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that the 27 PWB customers responded that this factor is very important to their customer satisfaction, 23 PWB customers responded that this factor is important, nine customers responded that this factor is neutral, one customer responded that it is unimportant, and four customers responded that it is very unimportant, and 21 customers responded that it does not contribute to their customer satisfaction (Figure 18).

The PWB assembly interest in purchasing the PWB would be if the assemblers misplaced some of the components on the PWB or damaged the PWBs during the assembly process and they may have to replace the PWBs for their customers. In some instances the PWB users will subcontract the assemblers' with the entire package of purchasing the PWB and assembling them. In this case, the entire PWB process responsibility lies in the assemblers hands. Another important factor is that the assemblers may bid on the entire order of manufacturing the PWB and assembling them for the PWB users. In this case, the PWB price plays an important factor on winning the bid if the PWB assemblers' organizations are capable of purchasing the PWB with a low or comparable cost. PWB low cost may also increase the PWB assemblers' profit margin if they were to bid on the entire order of assembling and subcontracting the manufacturing of the PWBs.

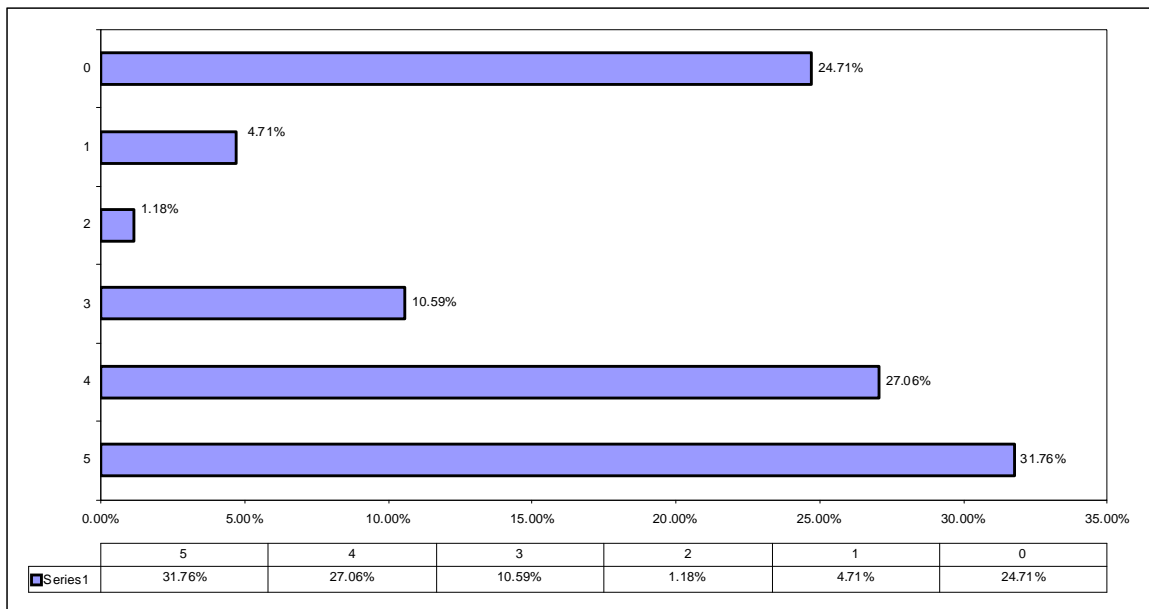


Figure 18: PWB Pricing Frequency of Distribution

### Variable Three Analysis

The response rate for the quality department speed in responding to PWB customers' needs factor was seventy-nine customers out of eighty-five with 93% of the customers agreeing that this factor contributes to the PWB customer satisfaction with an average of 85.65% contribution level.

Examining the variable contribution rate indicates that 81% assembly customers, 1% service customers, and 11% users customers believe that this variable contributes to the customer satisfaction (Figure 19). This factor was the fourth most significant to the PWB customers with an average contribution of 4.28 and a standard deviation of 1.33. Examining the customers response segments reveals that 100 % of the customers that assemble the PWBs, 81.82 % of customers that use them, and 12% of the customers that service the PWBs believe that this factor contributes to their satisfaction with a contribution level of 93.04%, 72.73% and 12% respectively.

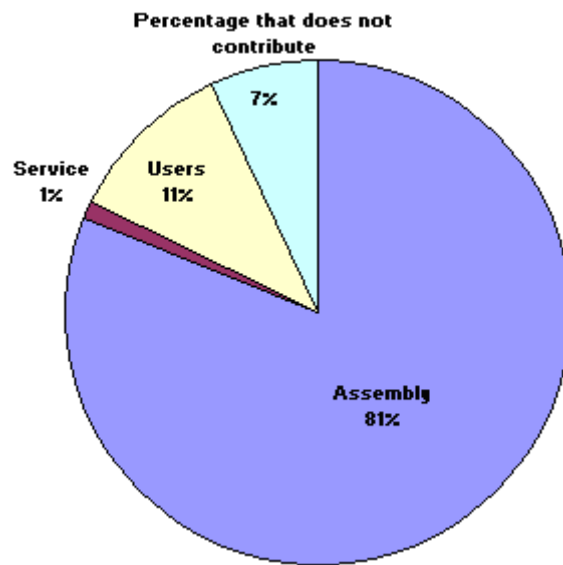


Figure 19: Quality Department Response to Customer Needs

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that no PWB customers responded that this factor is very important to their customer satisfaction (Figure 20), 19 PWB customers responded that this factor is important, six customers responded that this factor is neutral, fifty four customers responded that it is unimportant, no customers responded that it is very unimportant, and six customers responded that it does not contribute to their customer satisfaction. The PWB assemblers indicated receiving support from the PWB manufacture quality department is relatively significant for them. This overwhelming support to this factor from the PWB assemblers indicates that the assemblers may need the PWB manufacturer quality department to resolve issues that pertain to the assembling process. Some of these issues may be the PWB thickness requirements and whether it passes through the wave soldering equipment or if the PWB fails the test after it has been assembled.

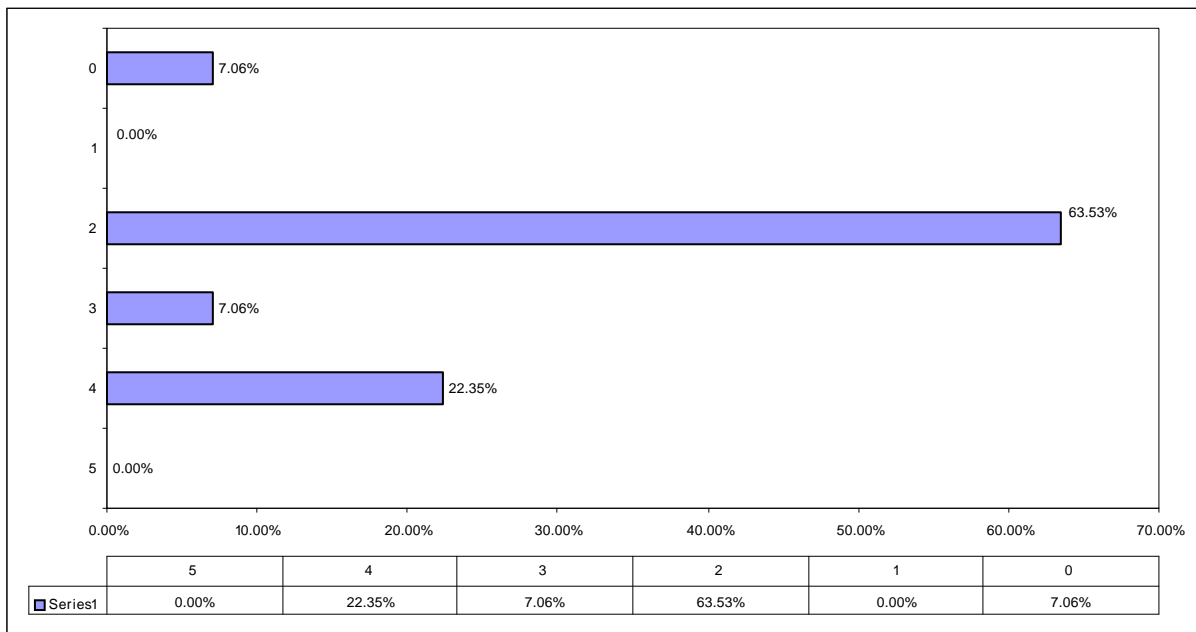


Figure 20: Quality Department Response to Customer Needs Frequency Distribution

Other issues may arise from the assembling process such as measling, or delamination of the PWBs after being assembled. These later issues may occur only after the PWB have been assembled due to the exposure of excessive heat to the PWB during the assembling process. The PWB assemblers may need to contact the PWB manufacturer to determine the heat requirements of the PWBs from which the PWB material have been built. PWB users also have an interest in this factor but when examining the contribution of this factor we notice that the PWB users have less interest than the PWB assemblers in rectifying that this factor has an influence on their satisfaction. The speed of the PWB manufacturer quality department in responding to the PWB users or assemblers concerns regarding any of the PWB characteristics or any related issue with the manufactured PWB is extremely important to the PWB customers.

The PWB service organizations have a limited interest in this factor; only one organization certified that this factor is significant enough to them to contribute to the customer satisfaction.

#### **Variable Four Analysis**

The response rate for the warranty on the PWB factor and whether or not the PWB warranty contributes to the customer satisfaction was seventy-six customers out of eighty-five with 89.4% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 63.76% contribution level. This factor was the ninth most significant to the PWB customers with an average contribution of 3.18 and a standard deviation of 1.22.

Examining the variable contribution rate indicates that 77% of assembly customers and 12 % users customers believe that this variable contributes to the customer satisfaction (Figure 21). Examining the customers' response segments indicates that 95.65% of the customers that

assemble the PWBs, 90.91% of the customers that use PWBs, and 0% of the customers that service them agree that this factor contributes to their customer satisfaction with a contribution level of 68.7%, 61.82% and 0% respectively.

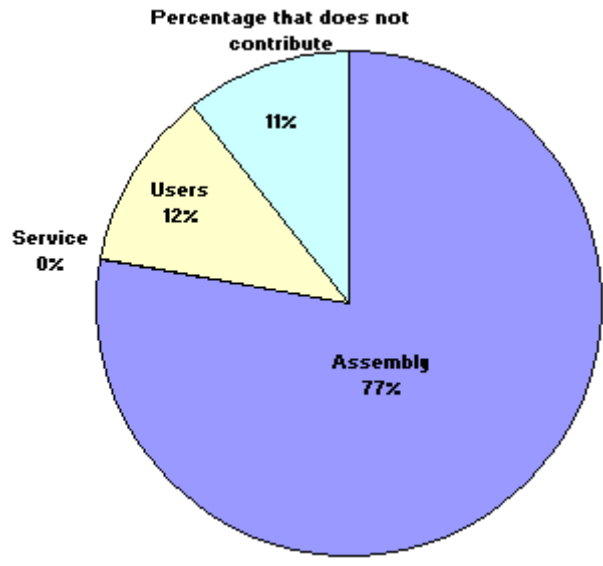


Figure 21: PWB Warranty Response

It is apparent that the PWB service organizations agree that this factor does not contribute to their customer satisfaction since any rework or repair done on the PWB will invalidate the PWB warranty. On the other hand, 90.91 percent of the PWB users believe that this factor contributes to their customer satisfaction. Most, if not all, of the U.S. military PWB customers and users have a mandated seven years PWB warranty in their contract and some space use PWB boards have 15 years mandatory PWB warranty. This U.S. government requirement sometimes places a burden on the PWB manufacturer and assemblers to retain and keep all the test results and documentation for this long period of time.

Examining the variable contribution rate indicated that none of the PWB customers believed that this factor is very important to their customer satisfaction (Figure 22), 45 PWB customers responded that this factor is important, 29 customers responded that this factor is neutral, two customers responded that it is unimportant, no customers responded that it is very unimportant, and nine customers responded that it does not contribute to their customer satisfaction. Thus the PWB warranty is an extremely important factor for the PWB users and assemblers. From the U.S. government perspective this factor is important since the PWB may be installed on aircraft, navy destroyers and ships, satellites, rockets, missiles, and tanks and may have a life threatening impact if any issue arises from a PWB failure in any U.S. military application. The U.S. government wants to ensure that all PWB manufactured and installed in the rest of the application do not have the same issue and are warranted to be replaced if they share the same failure. Also, one malfunctioning PWB may cause extreme financial loss to the PWB users. Any malfunctioning PWB installed on aircrafts or space satellites that are not designed in redundancy can cause the loss of millions of dollars.



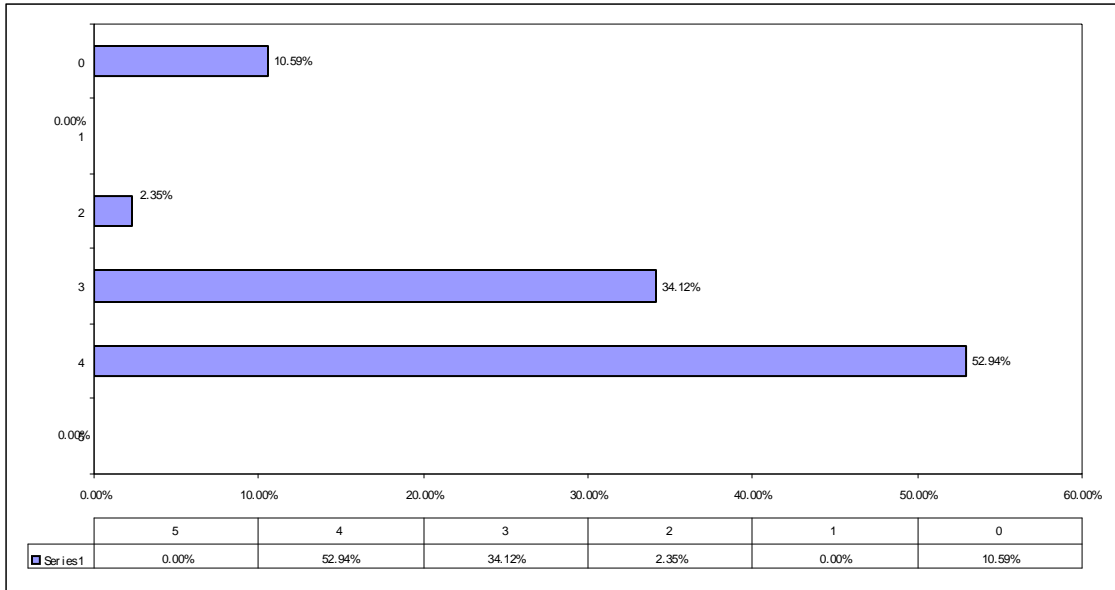


Figure 22: PWB Warranty Frequency Distribution

### Variable Five Analysis

The response rate for whether or not the number of days it takes to obtain a return material authorization from the PWB manufacturer to return the defective PWBs contributes to the customer satisfaction was 79 customers of 85 with 93% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 70.59% contribution level.

Examining the variable contribution rate indicates that 80% of assembly customers and 13% users customers believe that this variable contributes to the customer satisfaction (Figure 23). This factor was the fifth most significant to the PWB customers with an average contribution of 3.44 and a standard deviation of 1.2.

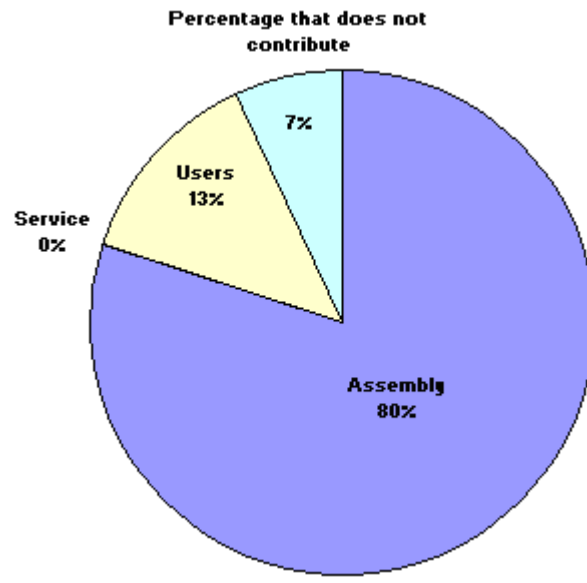


Figure 23: Number of Days to Obtain a Return Material Authorization Response

Examining the customers' response segments indicates that 98.5% of the customers that assemble the PWBs, and 100% of the customers that use PWBs agree that this factor contributes to their customer satisfaction with a contribution level of 71.3%, and 98.1% respectively. The PWB service organizations, along with the PWB users, concluded that the ability to obtain a PWB return authorization is significant to their customer satisfaction. On the other hand, the PWB service organization does not believe that this factor is significant enough to contribute to their customer satisfaction. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that the 14 PWB customers responded that this factor is very important to their customer satisfaction, 35 PWB customers responded that this factor is important, 30 customers responded that this factor is neutral, no customer responded that it is unimportant (Figure 24), no customers responded that it is very unimportant, and six customers responded that it does not contribute to their customer satisfaction.

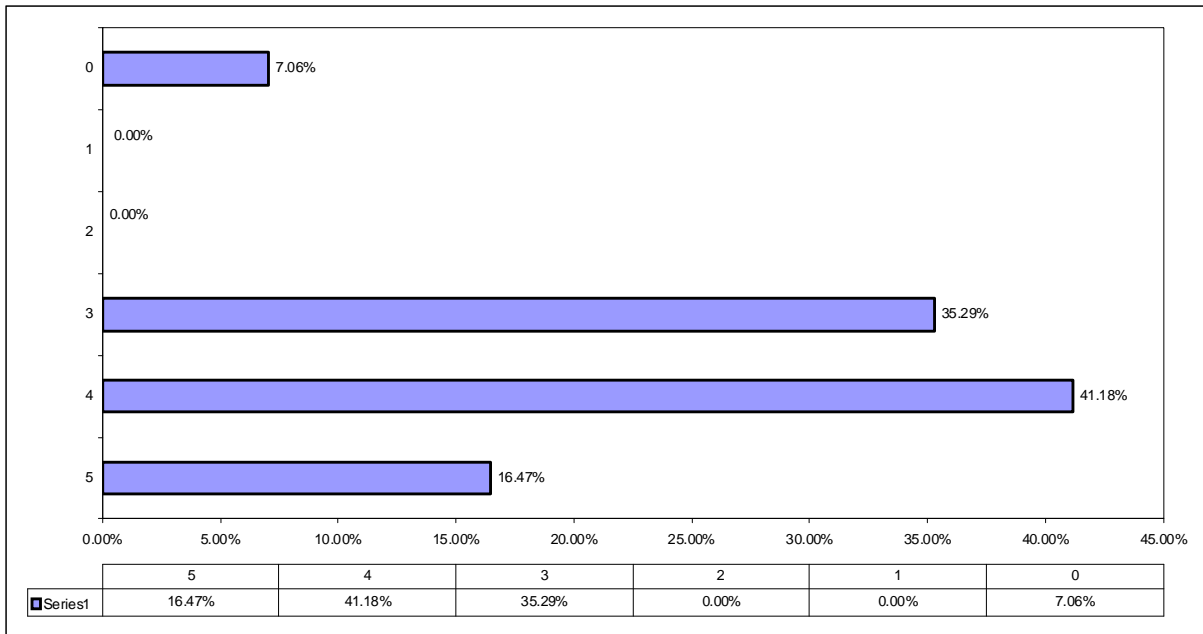


Figure 24: Number of Days to Obtain a Return Material Authorization Frequency Distribution

The PWB service organization deals mostly with PWB that have been already assembled or have defects that cannot be reworked by either the PWB users or the PWB assemblers. In this case the PWB will not be returned to the original manufacturer if they are touched by the PWB service industry. The PWB users would first try to return the PWB to the manufacturer if any defects were found prior to assembling them; once the PWB are assembled any defects caused by the assembling process may not be returned to the original manufacturer for replacement or rework. Thus the PWB service industries would not be able to return the PWB to the manufacturer; this is a predicament for the PWB assembly and users organizations since the damaged PWB cannot be returned to the PWB manufacturers for replacement.

The ability to obtain a return authorization from the manufacturer may be important to the organization because some PWB may have already been either assembled or have been shipped to the end user with PWB that may have a defect, thus it is extremely important to

determine if the defective PWB is a random defect or it is consistent with the entire lot. This helps the organization to either offer a recall of all their PWBs, or at a minimum, inform their customers of the potential issues that may affect their PWBs.

### Variable Six Analysis

The response rate for whether or not the number of days it takes to obtain credit for the returned PWBs factor from the PWB manufacturer to return the defective PWBs contribute to the customer satisfaction was seventy four customers out of eighty-five with 87.06% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 64.71% contribution level.

Examining the variable contribution rate indicates that 72% assembly customers, 2% service customers, and 13% users customers believe that this variable contributes to the customer satisfaction (Figure 25). This factor was the fourteenth most significant to the PWB customers with an average contribution of 3.22 and a standard deviation of 1.4.

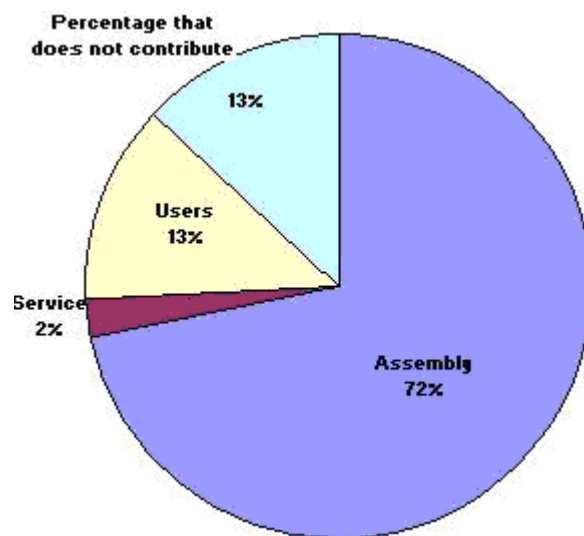


Figure 25: Number of Days to Obtain Credit for Returned PWBs Response

Examining the customers' response segments indicates that 88.41% of the customers that assemble the PWBs, 100% of the customers that use PWBs, and 40 % of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 63.1%, 94.55%, and 20% respectively.

We notice that all the customer users agree that debiting their accounts with the price of the defected PWBs is very significant to their customer satisfaction. It is also financially beneficial to the PWB users to obtain credit for the defective PWBs as soon as they are determined not applicable for usage. This gives the PWB user a leverage to either request to rebuild the PWB or to find another PWB manufacturer that would build the PWB to his/her specifications. On the other hand, the PWB assemblers would like to replace the defective PWB as soon as possible so they can deliver them to the PWB users. One less PWB to the PWB assemblers is less profit from the PWB user.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that eight PWB customers responded that this is factor is very important to their customer satisfaction, 38 PWB customers responded that this factor is important, 27 customers responded that this factor is neutral, one customer responded that this variable is unimportant (Figure 26), no customers responded that it is very unimportant, and 11 customers responded that it does not contribute to their customer satisfaction. Thus the PWB assemblers mostly would like to replace the defective PWB from the PWB manufacturer if it was found that the PWB was defective. This last argument indicates the contribution level of this factor from the assemblers point of view is 63.1%, while for the PWB users who would like to receive an immediate credit for the defective PWB is contribution level of 94.55%. For the PWB service organization it is apparent that this

factor is not as important for them as the other factors with only one customer acknowledging that this factor is an important one to him/her.

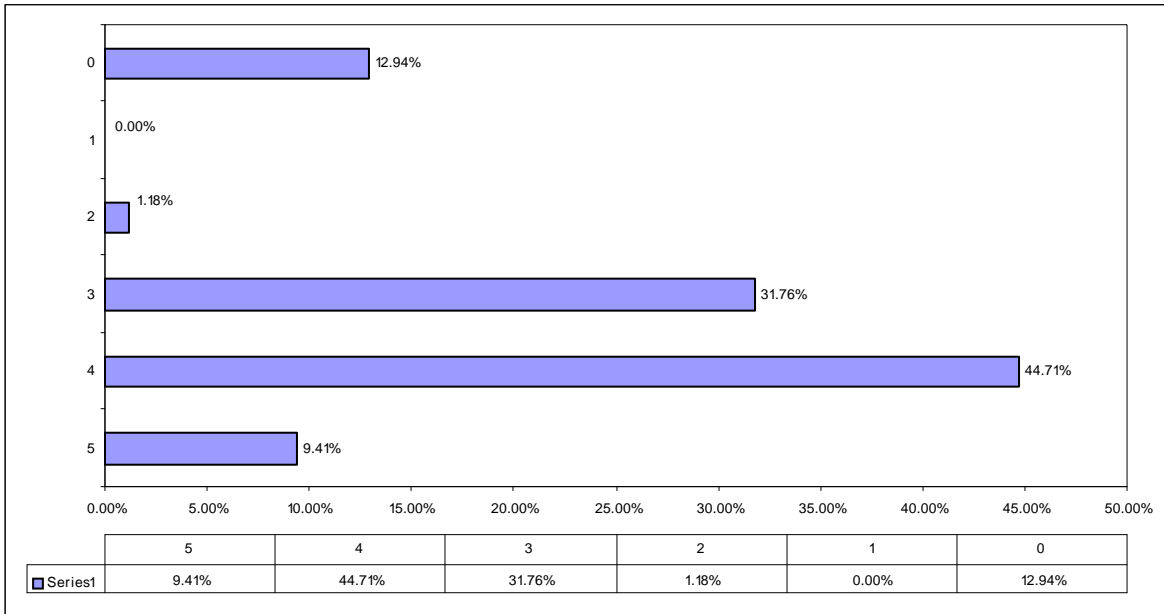


Figure 26: Number of Days to Obtain Credit for Returned PWBs Frequency of Distribution

### Variable Seven Analysis

The response rate for whether or not the number of days to resolve technical Issues with the PWBs contributes to the customer satisfaction was seventy-eight customers out of eighty-five customers with 92% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 84.94% contribution level.

Examining the variable contribution rate indicates that 77% of assembly customers, 2% service customers, and 13% users' customers believe that this variable contributes to the customer satisfaction (Figure 27). This factor was the sixth most significant to the PWB customers with an average contribution of 4.24 and a standard deviation of 1.4.

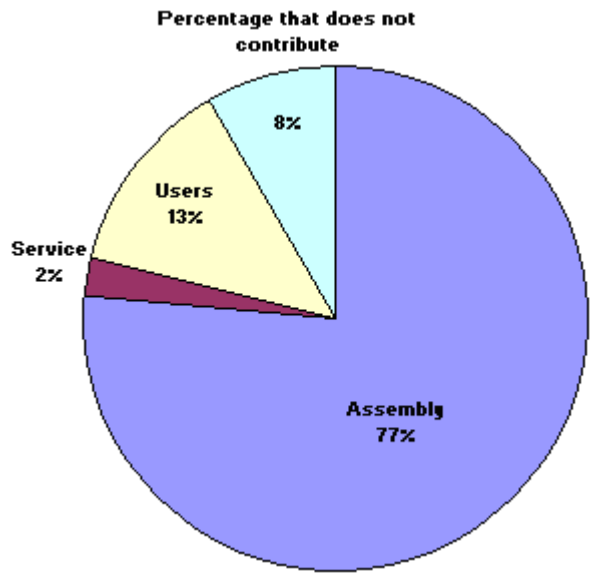


Figure 27: Number of Days to Resolve Technical Issues Response

Examining the customers' response segments indicates that 94.2% of the customers that assemble the PWBs, 100% of the customers that use PWBs, and 40% of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 87.54%, 90.91%, and 63% respectively. Number of days to resolve technical issues are very important to the PWB users. Technical issues may arise from poor design that the PWB had included in their requirements but were manufactured correctly by the PWB manufacturers. PWB assemblers also indicated that this factor is important to them since there are implications that the PWB designers may have not factored it during their PWB design for the assembly processes.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 54 PWB customers responded that this factor is very important to their customer satisfaction, 19 PWB customers responded that this factor is important, five customers responded that this factor is neutral, no customer responded that it is unimportant, no customers responded

that it is very unimportant, and seven customers responded that it does not contribute to their customer satisfaction (Figure 28).

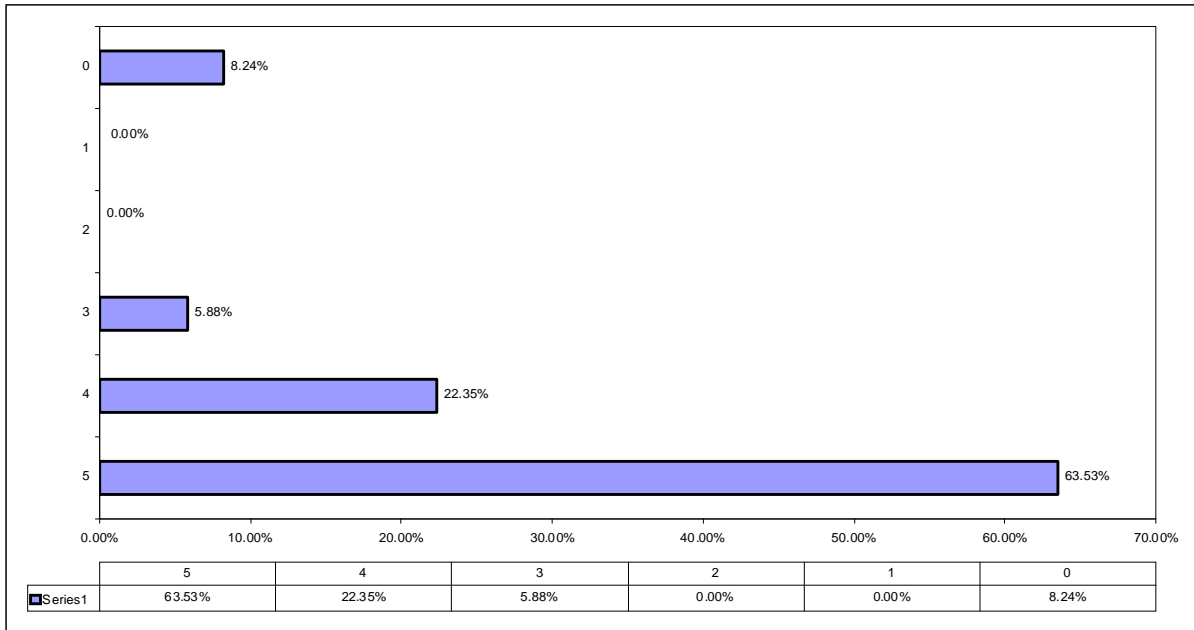


Figure 28: Number of Days to Resolve Technical Issues Frequency Distribution

### Variable Eight Analysis

The response rate for whether or not the number of days it takes to access the PWB manufacturer technical support contributes to the customer satisfaction was eighty-five customers with 100% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 85.41% contribution level.

Examining the variable contribution rate indicates that 81% of assembly customers, 6% service customers, and 13% users customers believe that this variable contributes to the customer satisfaction (Figure 29). This factor was chosen by the PWB customers to be the most significant factor with an average weight of 4.27 and a standard deviation of 0.61.



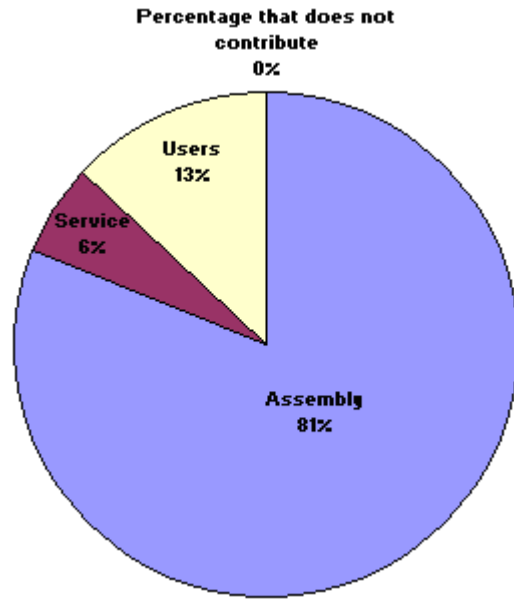


Figure 29: Number of Days to Access Technical Support Response

Examining the customers' response segments indicates that 100% of the customers that assemble the PWBs, 100% of the customers that use PWBs, and 100 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 85.8%, 89.09%, and 72% respectively. Accessing technical support from the PWB manufacturer is important to the PWB assemblers when issues arise from the assembling process. One hundred percent of the PWB assemblers indicated that this is an important factor that contributed to their customer satisfaction. Also one hundred percent of the PWB users also indicated that this factor is important to them. Technical issues with the PWB can occur after the PWB have been installed on the systems and occasionally the PWB will be functional individually but when coupled with other PWB they may fail, thus accessing technical assistance from the PWB manufacturers is important to both the PWB assemblers and the PWB users organizations. The PWB service industry also indicated that this factor is important to them; the fact that the PWB service organizations rework or service PWBs means they may have to be

familiar with the characteristics of the PWB, thus receiving technical assistance and technical information related to the PWB is of a high importance to them.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 30 PWB customers responded that this factor is very important to their customer satisfaction (Figure 30), 48 PWB customers responded that this factor is important, seven customers responded that this factor is neutral, no customer responded that it is unimportant, no customers responded that it is very unimportant, and no customers responded that it does not contribute to their customer satisfaction.

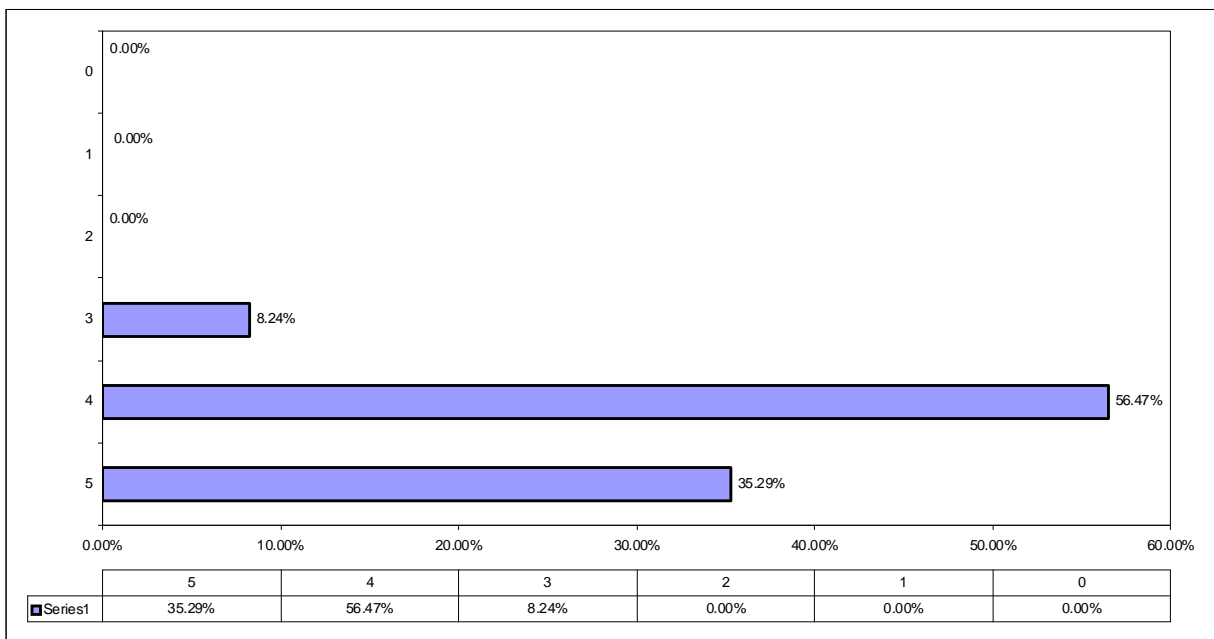


Figure 30: Number of Days to Access Technical Support Frequency Distribution

### Variable Nine Analysis

The response rate for whether or not the number of days to access customer support contributes to the customer satisfaction was eighty customers with 94.12% agreeing that this

factor contributes to the PWB customer satisfaction with a total average of 74.59% contribution level. This factor was the third most significant to the PWB customers with an average contribution of 3.72 and a standard deviation of 1.61.

Examining the variable contribution rate indicates that 76% assembly customers, 5% service customers, and 13% users customers believe that this variable contributes to the customer satisfaction (Figure 31). Examining the customer's response segments indicates that 94.2% of the customers that assemble the PWBs, 100% of the customers that use PWBs, and 80 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 74.2%, 87.27%, and 48% respectively.

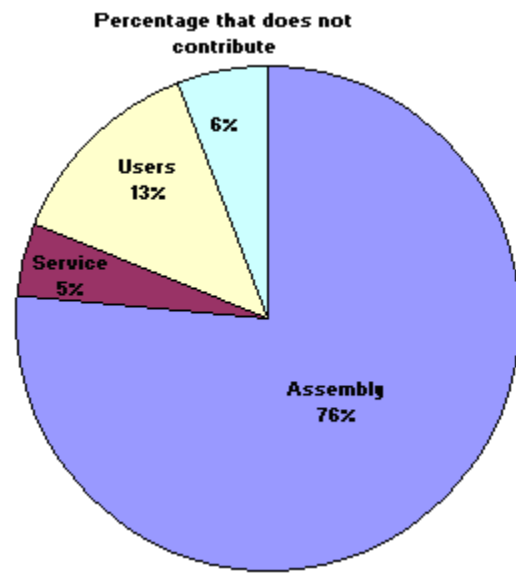


Figure 31: Number of Days to Access Customer Support Response

Accessing customer support can be important to the PWB users in many cases where close contact with the PWB manufacturer is required. Thus the survey indicated that one hundred percent of the PWB have considered that the close customer support is an important aspect of

their customer satisfaction. PWB assemblers also indicated that the response to their needs is extremely important to them.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 23 PWB customers responded that this factor is very important to their customer satisfaction (Figure 32), 31 PWB customers responded that this factor is important, 25 customers responded that this factor is neutral, one customer responded that it is unimportant, no customers responded that it is very unimportant, and five customers responded that it does not contribute to their customer satisfaction.

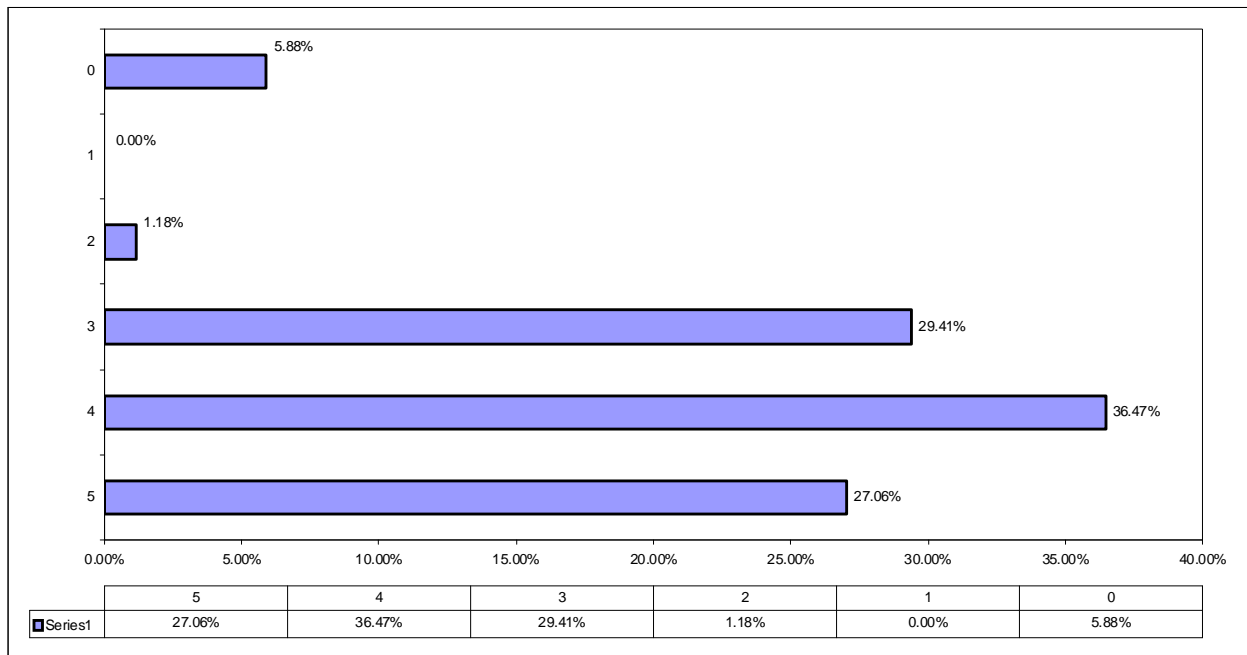


Figure 32: Number of Days to Access Customer Support Frequency Distribution

### Variable Ten Analysis

The response rate for whether or not the number of days to receive a quote response from the PWB manufacturer contributes to the customer satisfaction was seventy-four customers with

87.06% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 75.06% contribution level.

Examining the variable contribution rate indicates that 73% assembly customers, 1% service customers, and 13% users customers believe that this variable contributes to the customer satisfaction (Figure 33). This factor was the eleventh most significant to the PWB customers with an average contribution of 3.75 and a standard deviation of 1.61.

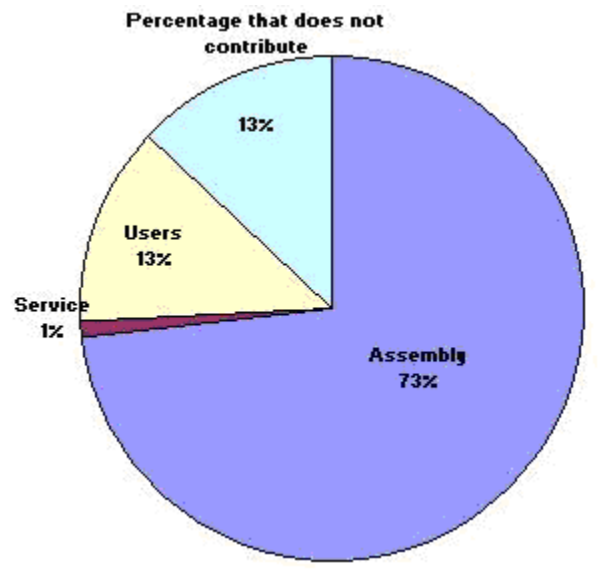


Figure 33: Number of Days to Receive a Quote Response

Examining the customers' response segments indicates that 89.86% of the customers that assemble the PWBs, 100% of the customers that use PWBs, and 20 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 77.10%, 92.73%, and 8.00% respectively.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 34 PWB customers responded that this factor is very important to their customer

satisfaction, 30 PWB customers responded that this factor is important (Figure 34), nine customers responded that this factor is neutral, one customer responded that it is unimportant, no customers responded that it is very unimportant, and 11 customers responded that it does not contribute to their customer satisfaction.

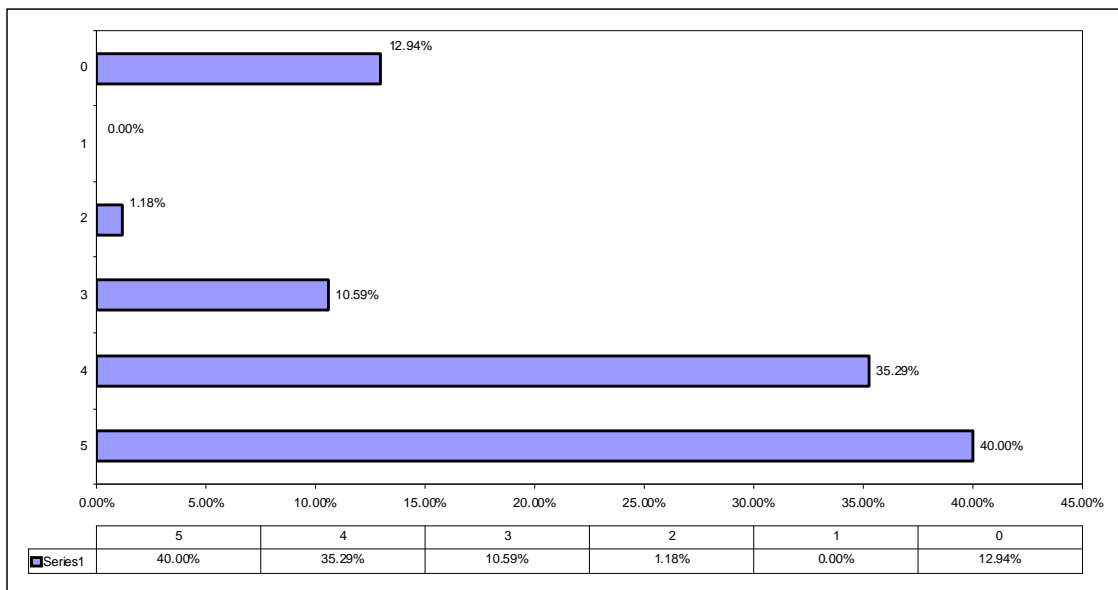


Figure 34: Number of Days to Receive a Quote Response Frequency Distribution

### Variable Eleven Analysis

The response rate for whether or not the PWB Thickness contributes to the customer satisfaction was seventy-three customers with 85.88% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 66.12% contribution level.

Examining the variable contribution rate indicates that 74% assembly customers, 1% service customers, and 11% users customers believe that this variable contributes to the customer satisfaction (Figure 35). This factor was the fifteenth most significant to the PWB customers with an average contribution of 3.3 and a standard deviation of 1.51.

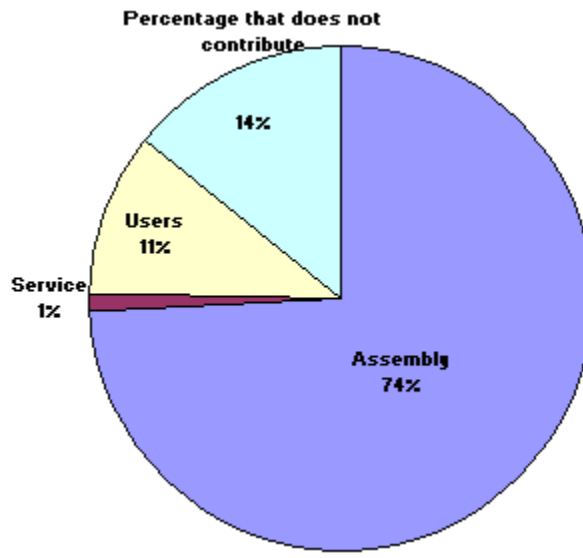


Figure 35: PWB Thickness Response

Examining the customers' response segments indicates that 91.3% of the customers that assemble the PWBs, 81.82% of the customers that use PWBs, and 20 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 70.43%, 63.64%, and 12.00% respectively. PWB assemblers mostly indicated that the PWB thickness is an important factor and receiving PWB with consistent PWB thickness contributes to their customer satisfaction. This is mainly due to the way the assembly machines are set up, where inconsistent PWB thickness may cause the PWB to stop production and adjust the equipment to accommodate the variation that inhibits the PWBs. Thus Inconsistent PWB thickness may cause loss in production and loss of time, which in turn is translated to some financial loss to the PWB assemblers. PWB users were less inclined to support the factor that contributes to their satisfaction and this is mostly due to the fact that most of the PWB users subcontract the assembly process to the PWB assemblers. It was still a concern for some of the PWB users that the PWB thickness factor may influence their satisfaction, this was because after

being assembled, the PWB may need to be installed in enclosures or in boxes and they need to fit precisely.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 13 PWB customers responded that this factor is important to their customer satisfaction (Figure 36), 38 PWB customers responded that this factor is important, 20 customers responded that this factor is neutral, two customer responded that it is unimportant, no customers responded that it is very unimportant, and 12 customers responded that it does not contribute to their customer satisfaction. The PWB service industry showed no interest in this factor since they cannot rework any issues with PWB thickness. It is to be noted that the PWB thickness consist of one or many copper layers and between each layer there is pre preg layer (epoxy resin) that helps bond the layers. The copper layers along with the pre preg layers are pressed together under heat for a period of time that is needed to melt the resin and bond the layers.

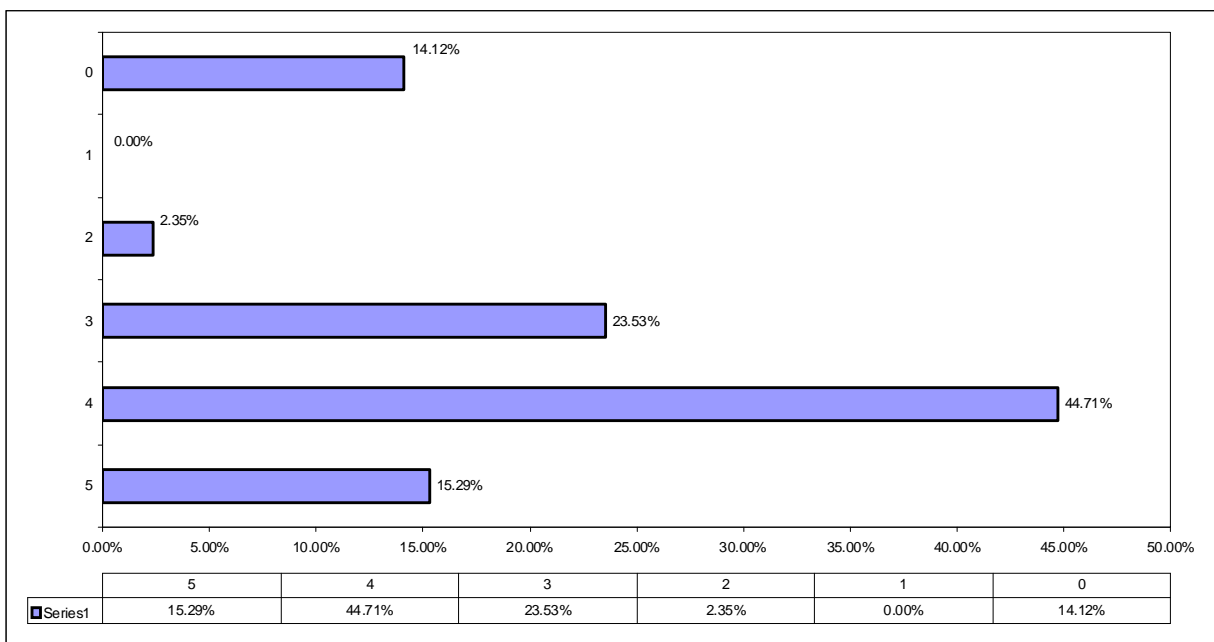


Figure 36: PWB Thickness Frequency Distribution



### Variable Twelve Analysis

The response rate for whether or not the number of PWB passes through hole registrations requirements contributes to the customer satisfaction was 67 customers with 78.82% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 57.18% contribution level.

Examining the variable contribution rate indicates that 63% assembly customers, 5% service customers, and 11% users customers believe that this variable contributes to the customer satisfaction (Figure 37). This factor was the seventeenth most significant to the PWB customers with an average contribution of 2.85 and a standard deviation of 1.57.

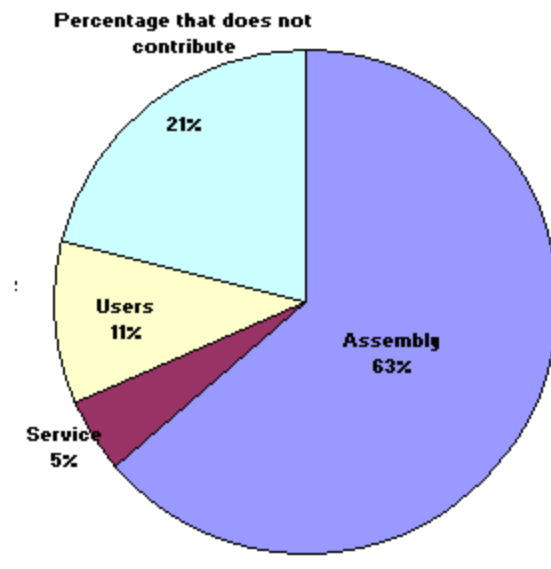


Figure 37: Number of PWB Pass Through Hole Registration Response

Examining the customers' response segments indicates that 78.26% of the customers that assemble the PWBs, 81.82% of the customers that use PWBs, and 80 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level

of 56.81%, 60%, and 56% respectively. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that two PWB customers responded that this factor is very important to their customer satisfaction, 38 PWB customers responded that this factor is important (Figure 38), 27 customers responded that this factor is neutral, no customer responded that it is unimportant, no customers responded that it is very unimportant, and 18 customers responded that it does not contribute to their customer satisfaction.

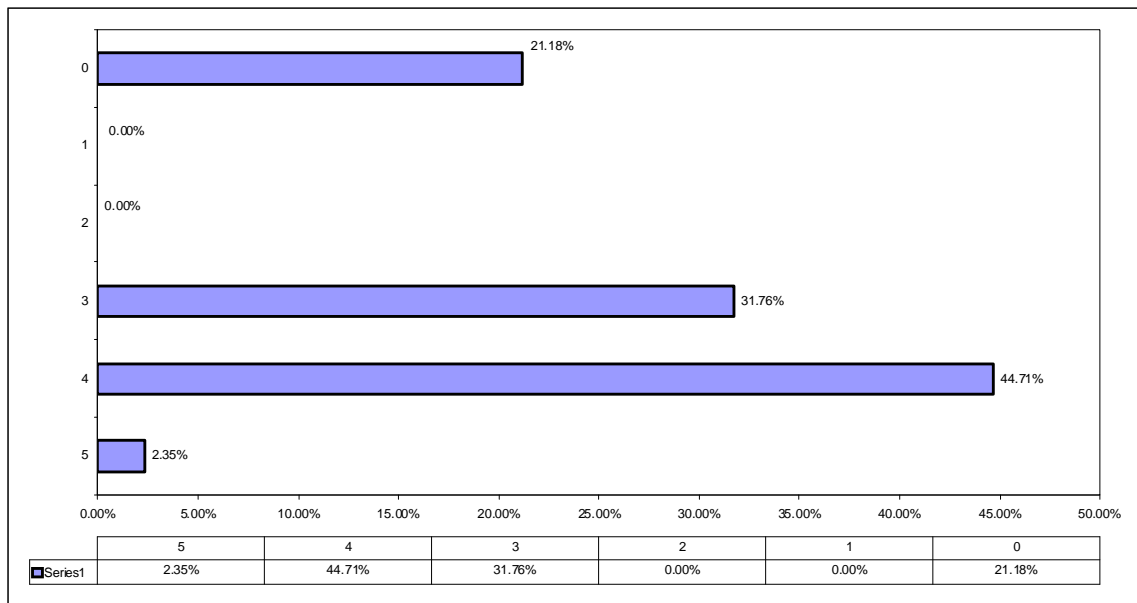


Figure 38: Number of PWB Pass Through Hole Registration Frequency Distribution

### Variable Thirteen Analysis

The response rate for whether or not the number of PWB Pass Solder Mask Adhesion contributes to the customer satisfaction was sixty-seven customers with 78.82% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 57.18% contribution level.

Examining the variable contribution rate indicates that 71.75% assembly customers, 3.5% service customers, and 12.94% users customers believe that this variable contributes to the customer satisfaction (Figure 39).

This factor was the tenth most significant to the PWB customers with an average contribution of 3.04 and a standard deviation of 1.4.

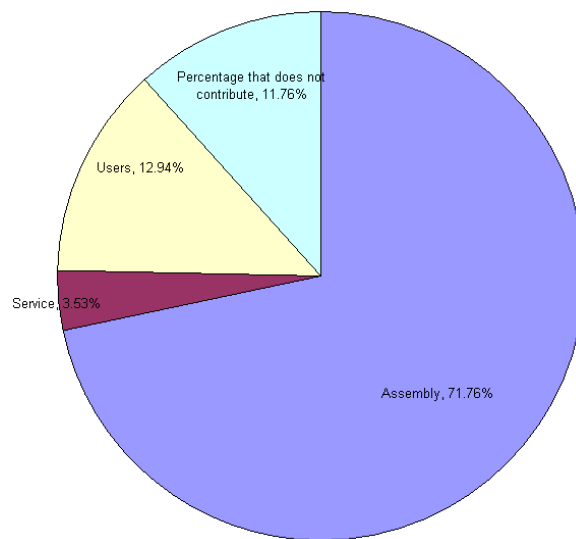


Figure 39: Number of Pass Solder Mask Adhesion Response

Examining the customers' response segments indicates that 78.26% of the customers that assemble the PWBs, 81.82% of the customers that use PWBs, and 80 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 56.81%, 60%, and 56% respectively. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that eight PWB customers responded that this factor is very important to their customer satisfaction, 30 PWB customers responded that this factor is important (Figure 40), 25 customers responded that this factor is neutral, 12 customers responded

that it is unimportant, no customers responded that it is very unimportant, and 10 customers responded that it does not contribute to their customer satisfaction.

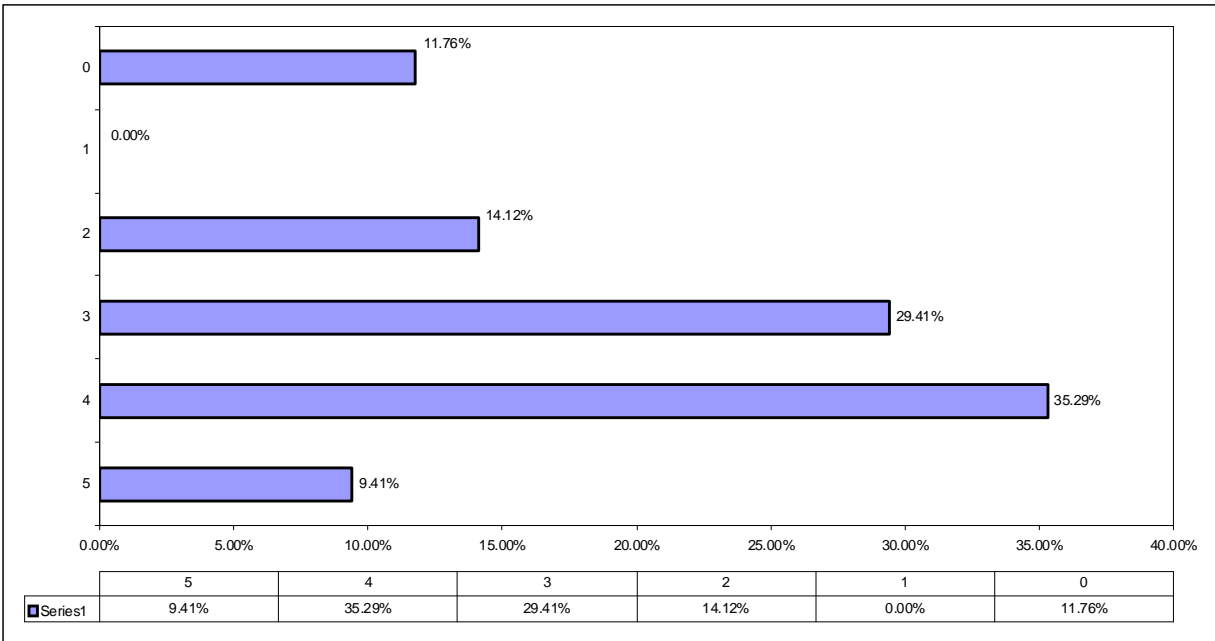


Figure 40: Number of Pass Solder Mask Adhesion Frequency Distribution

### Variable Fourteen Analysis

The response rate for whether or not the number of PWB passes Blind / Buried Vias registrations requirements contributes to the customer satisfaction was fifty-five customers with 64.71% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 37.18% contribution level.

Examining the variable contribution rate indicates that 51% assembly customers, 1% service customers, and 13% users customers believe that this variable contributes to the customer satisfaction (Figure 41). This factor was the twenty-second most significant to the PWB customers with an average contribution of 1.85 and a standard deviation of 1.55.

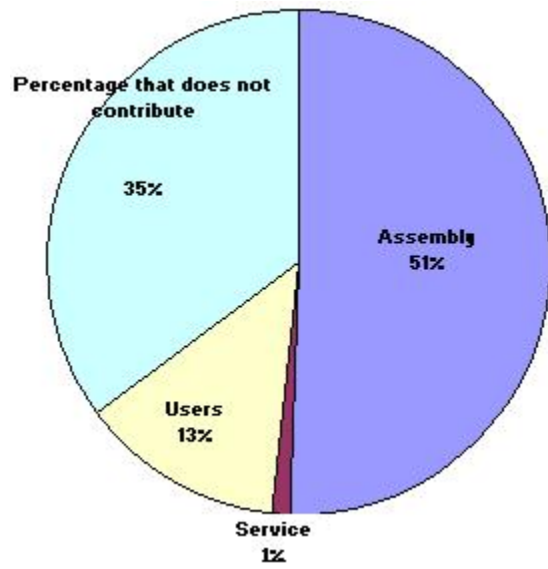


Figure 41: PWB Passes Blind/Buried Vias Registrations Response

Examining the customers' response segments indicates that 62.32% of the customers that assemble the PWBs, 100% of the customers that use PWBs, and 20 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 33.91%, 70.91%, and 8% respectively. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that one PWB customers responded that this factor is very important to their customer satisfaction, 12 PWB customers responded that this factor is important (Figure 42), 23 customers responded that this factor is neutral, 18 customers responded that it is unimportant, no customers responded that it is very unimportant, and 31 customers responded that it does not contribute to their customer satisfaction

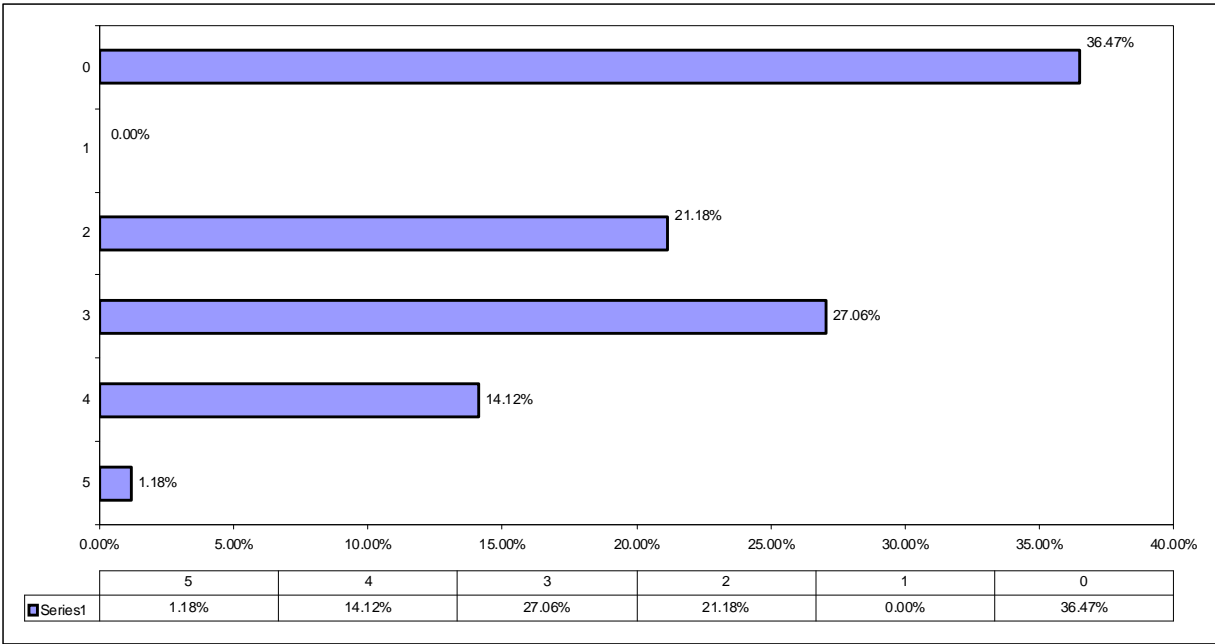


Figure 42: PWB Passes Blind/Buried Vias Registrations Frequency Distribution

### Variable Fifteen Analysis

The response rate for whether or not the number of PWB material types that the PWB manufacturer stocks in his inventory or can use to build the PWB contributes to the customer satisfaction was forty customers with 47.06% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 28.94% contribution level.

Examining the variable contribution rate indicates that 33% of assembly customers, 1% service customers, and 13% users customers believe that this variable contributes to the customer satisfaction (Figure 43). This factor was the twenty-fourth most significant to the PWB customers with an average contribution of 1.44 and a standard deviation of 1.71.

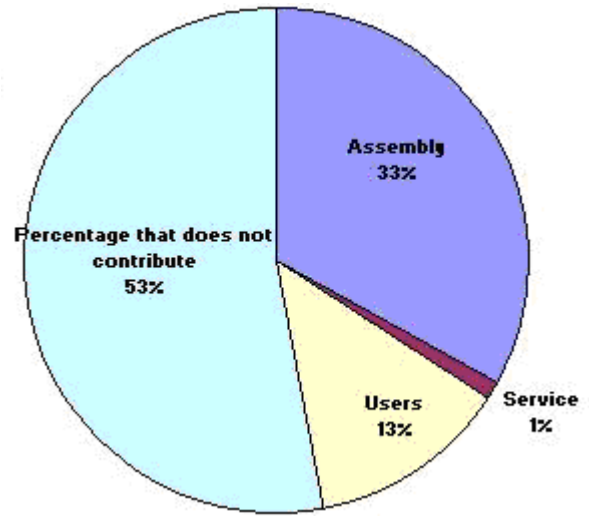


Figure 43: PWB Material Types Response

Examining the customers' response segments indicates that 40.58% of the customers that assemble the PWBs, 100% of the customers that use PWBs, and 20 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 20.58%, 90.91%, and 8% respectively. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that six PWB customers responded that this factor is very important to their customer satisfaction (Figure 44), seven PWB customers responded that this factor is important, 11 customers responded that this factor is neutral, 16 customers responded that it is unimportant, no customers responded that it is very unimportant, and 45 customers responded that it does not contribute to their customer satisfaction.

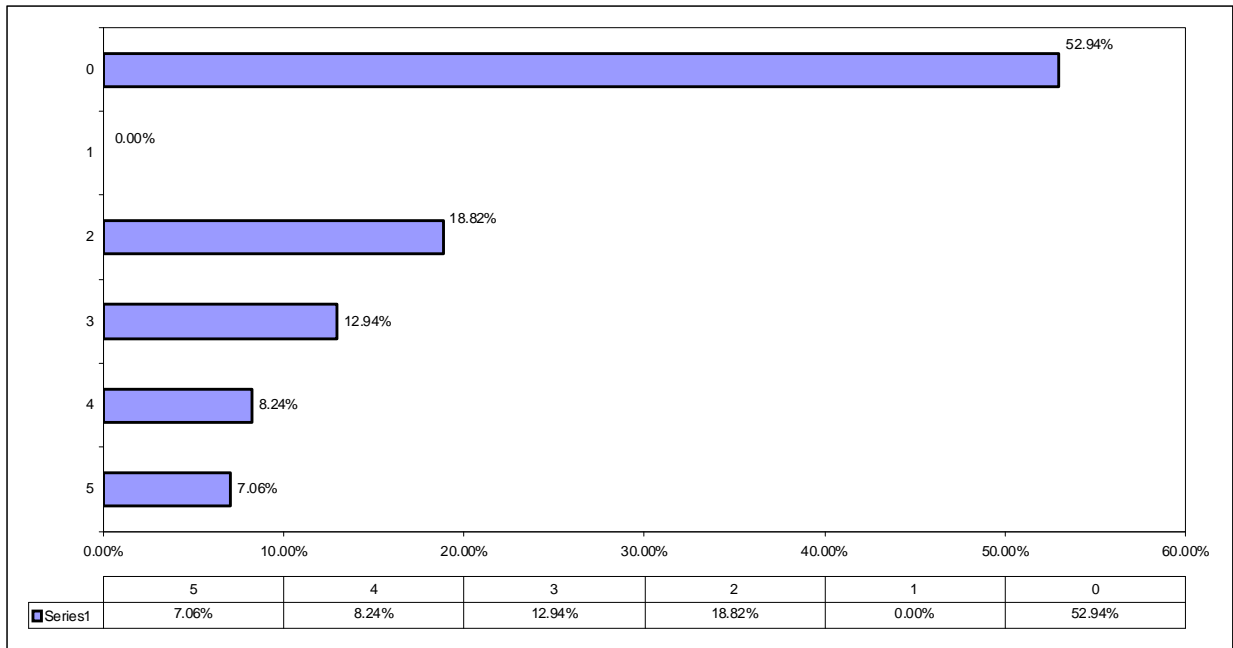


Figure 44: PWB Material Types Frequency Distribution

### Variable Sixteen Analysis

The response rate for whether or not the number of PWB passes the electrical test and if the PWB manufacturer has different types of testing capabilities that contribute to the customer satisfaction was fifty-five customers with 64.71% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 46.12% contribution level.

Examining the variable contribution rate indicates that 55% assembly customers, 1% service customers, and 9% users customers believe that this variable contributes to the customer satisfaction (Figure 45). This factor was the twenty-first most significant to the PWB customers with an average contribution of 2.3 and a standard deviation of 1.81.



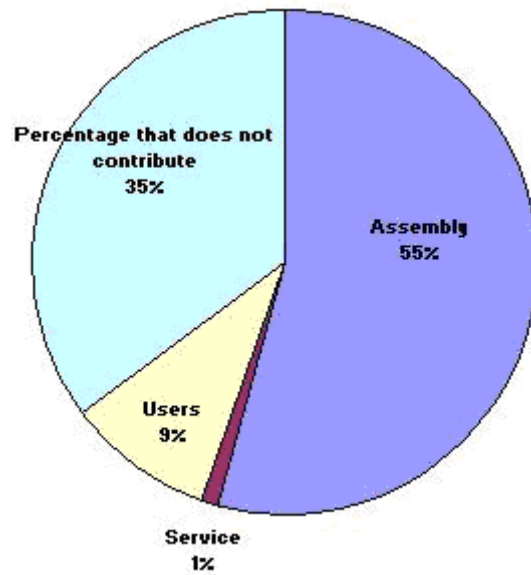


Figure 45: PWB Passes Electrical Test and if PWB Manufacturer Has Different Types of Testing Response

Examining the customers' response segments indicates that 44.35% of the customers that assemble the PWBs, 72.73% of the customers that use PWBs, and 20% percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 44.35%, 72.73%, and 12% respectively. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that seven PWB customers responded that this factor is very important to their customer satisfaction (Figure 46), 21 PWB customers responded that this factor is important, 21 customers responded that this factor is neutral, seven customer responded that it is unimportant, no customers responded that it is very unimportant, and 29 customers responded that it does not contribute to their customer satisfaction.

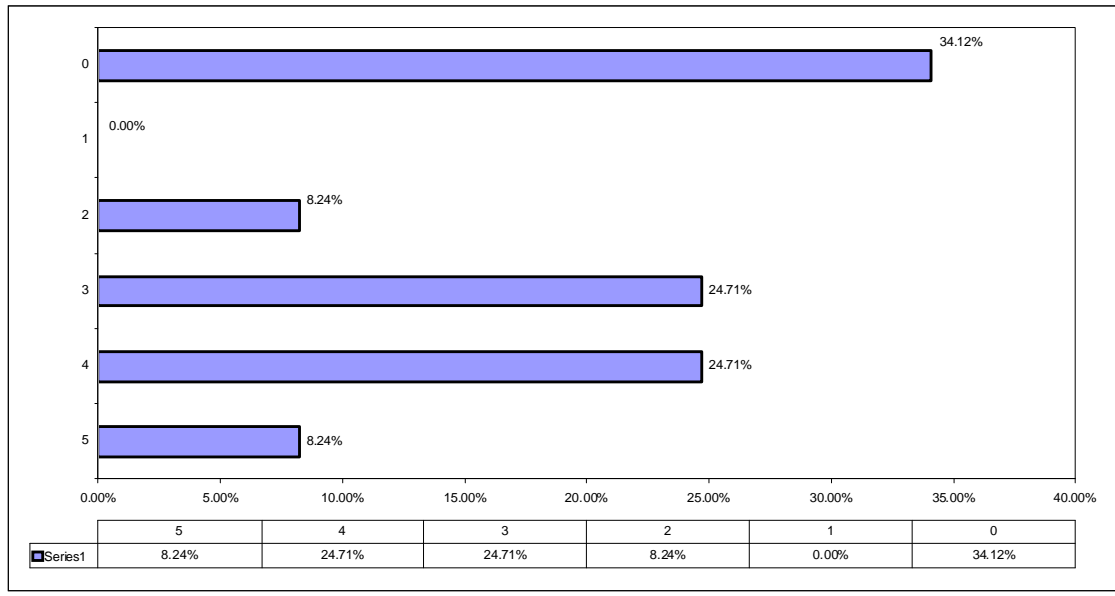


Figure 46 : PWB Passes Electrical Test and if PWB Manufacturer Has Different Types of Testing Frequency Distribution

### Variable Seventeen Analysis

The response rate for whether or not the number of shipping methods the PWB manufacturer offers to the customers contributes to the customer satisfaction was fifty-six customers with 65.88% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 44.71% contribution level.

Examining the variable contribution rate indicates that 59% of assembly customers and 7% users customers believe that this variable contributes to the customer satisfaction (Figure 47).

This factor was the twentieth most significant to the PWB customers with an average contribution of 2.23 and a standard deviation of 1.75.

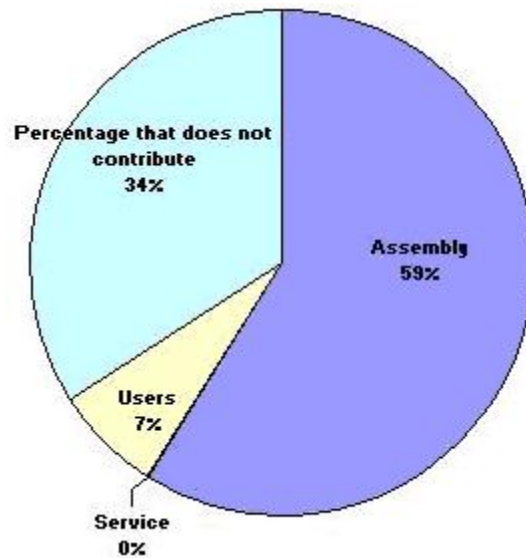


Figure 47: Number of Shipping Methods Available Response

Examining the customers' response segments indicates that 72.46% of the customers that assemble the PWBs, 54.55% of the customers that use PWBs agree that this factor contributes to their customer satisfaction with a contribution level of 48.12%, and 43.64% respectively.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that five PWB customers responded that this factor is very important to their customer satisfaction, 19 PWB customers responded that this factor is important, 25 customers responded that this factor is neutral, seven customers responded that it is unimportant, no customers responded that it is very unimportant (Figure 48), and 29 customers responded that it does not contribute to their customer satisfaction.

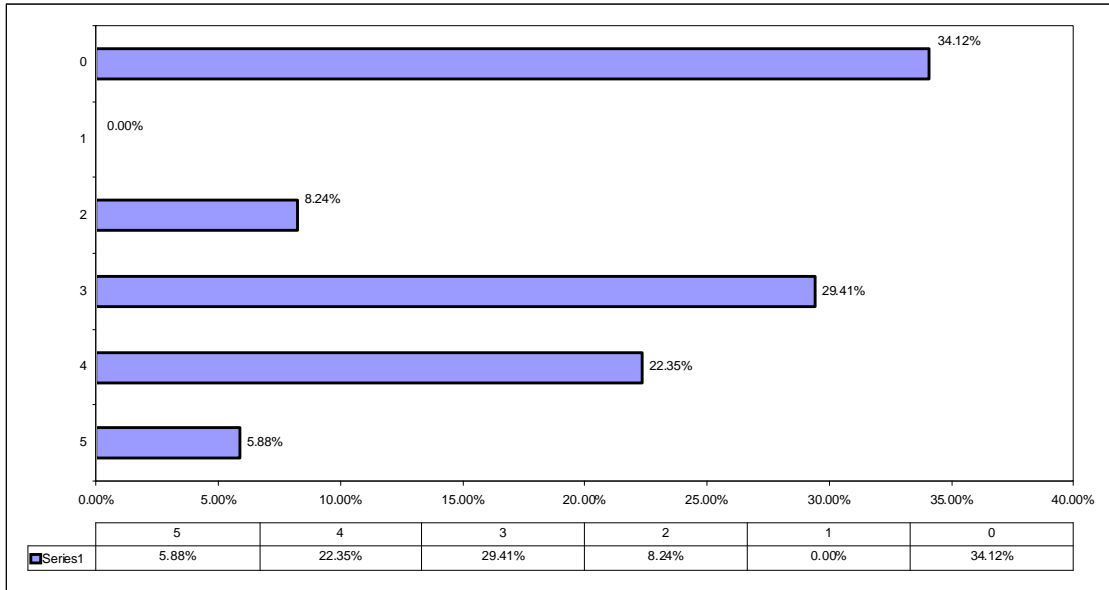


Figure 48: Number of Shipping Methods Available Frequency Distribution

### Variable Eighteen Analysis

The response rate for whether or not the number of shipping packaging the PWB manufacturer offers to the customers contributes to the customer satisfaction was thirty-six customers with 42.34% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 24.47% contribution level.

Examining the variable contribution rate indicates that 29% assembly customers and 13% users customers believe that this variable contributes to the customer satisfaction (Figure 49). This factor was the twenty-fifth and least significant to the PWB customers with an average contribution of 1.22 and a standard deviation of 1.42.

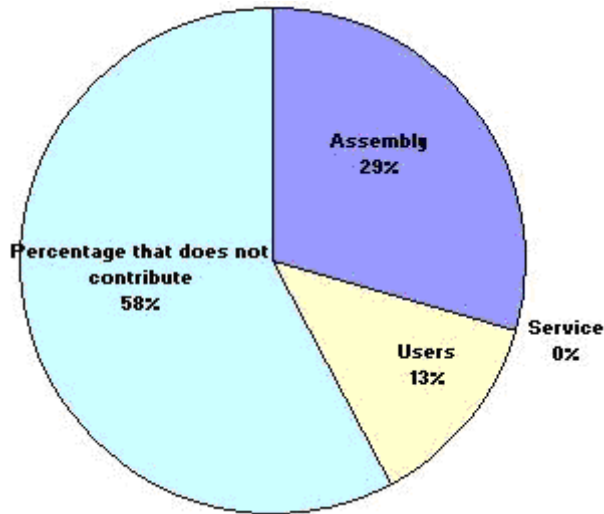


Figure 49: Number of Shipping Packaging Available

Examining the customers' response segments indicates that 36.23% of the customers that assemble the PWBs, and 100% of the customers that use PWBs agree that this factor contributes to their customer satisfaction with a contribution level of 20.29%, and 61.82% respectively. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that no PWB customers responded that this factor is very important to their customer satisfaction, two PWB customers responded that this factor is important, 25 customers responded that this factor is neutral, nine customers responded that it is unimportant (Figure 50), three customers responded that it is very unimportant, and 46 customers responded that it does not contribute to their customer satisfaction.

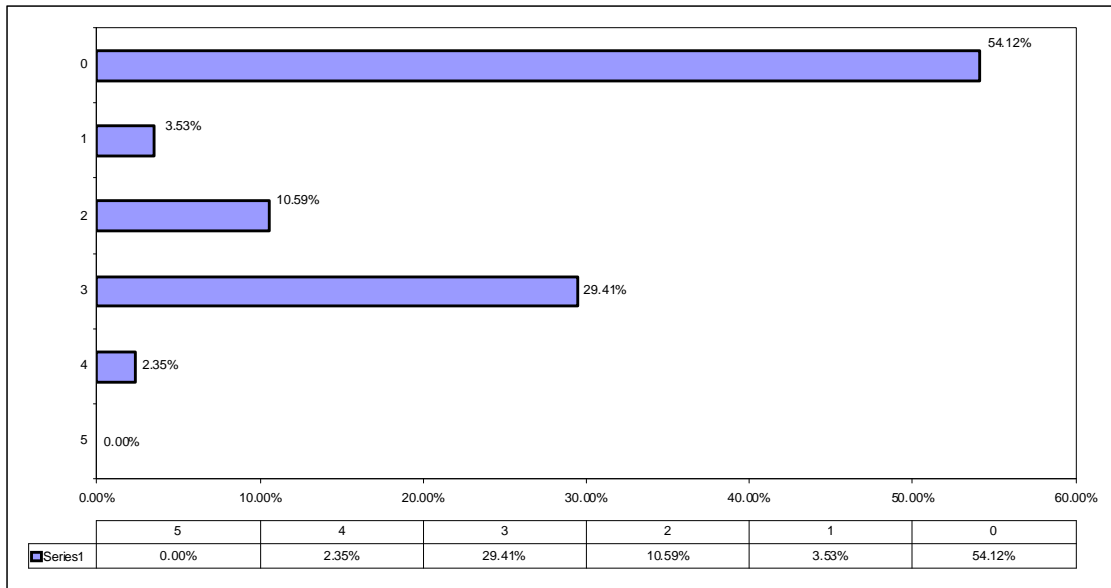


Figure 50: Number of Shipping Packaging Available Frequency Distribution

### Variable Nineteen Analysis

The response rate for whether or not the PWB manufacturer poses more than one capability / servers to download PWB customers' Gerber files that contribute to the customer satisfaction was fifty-one customers with 60% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 41.41% contribution level.

Examining the variable contribution rate indicates that 49% of assembly customers and 11% users customers believe that this variable contributes to the customer satisfaction (Figure 51). This factor was the twenty-third most significant to the PWB customers with an average contribution of 2.07 and a standard deviation of 1.81.

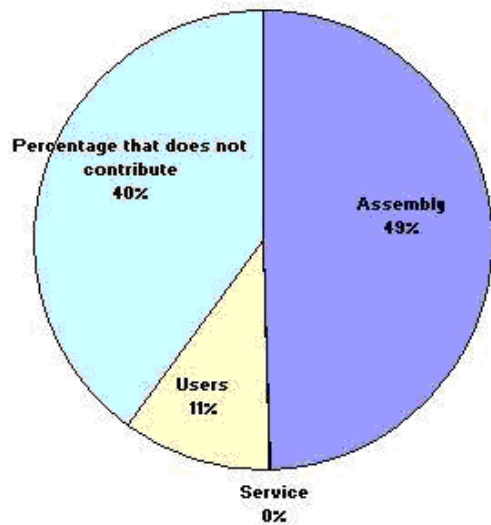


Figure 51: Number of Capabilities/Servers for Downloading Gerber Files Response

Examining the customers' response segments indicates that 60.87% of the customers that assemble the PWBs, and 81.82% of the customers that use PWBs agree that this factor contributes to their customer satisfaction with a contribution level of 39.71%, and 70.91% respectively.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that six PWB customers responded that this factor is very important to their customer satisfaction, 19 PWB customers responded that this factor is important (Figure 52), 21 customers responded that this factor is neutral, six customers responded that it is unimportant, no customers responded that it is very unimportant, and 33 customers responded that it does not contribute to their customer satisfaction.

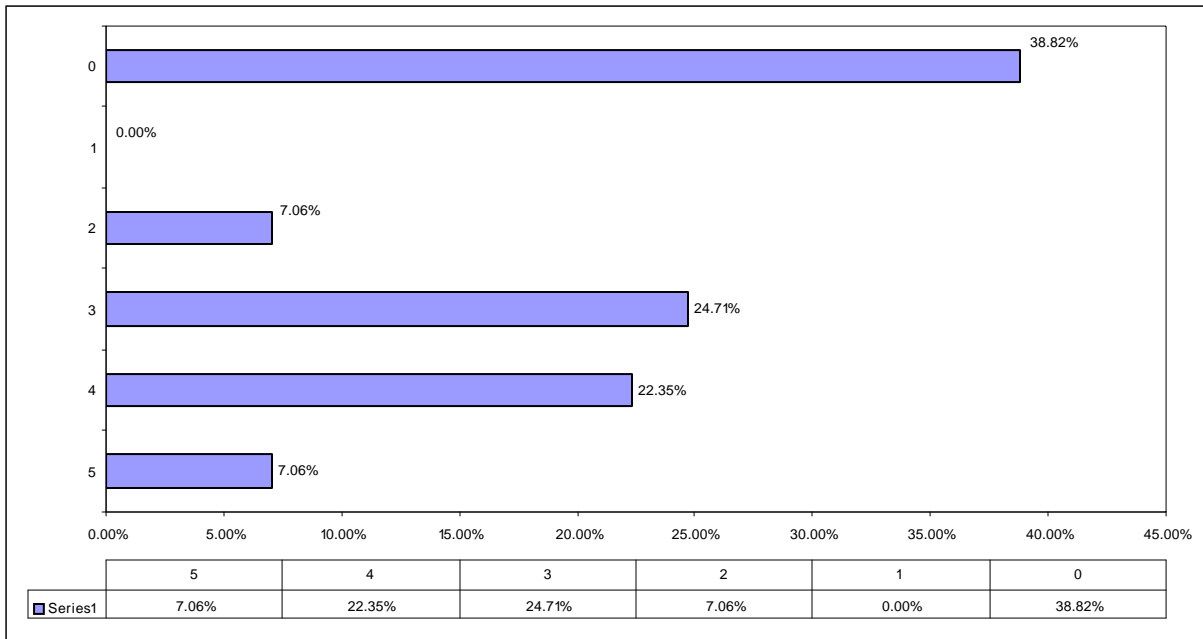


Figure 52: Number of Capabilities/Servers for Downloading Gerber Files Frequency Distribution

### Variable Twenty Analysis

The response rate for whether or not the ability of the PWB manufacturer to produce large PWB volume contributes to the customer satisfaction was seventy-four customers with 87.06% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 64.94% contribution level.

Examining the variable contribution rate indicates that 71% assembly customers, 5% service customers, and 11% users customers believe that this variable contributes to the customer satisfaction (Figure 53). This factor was the thirteenth most significant to the PWB customers with an average contribution of 3.24 and a standard deviation of 1.09.



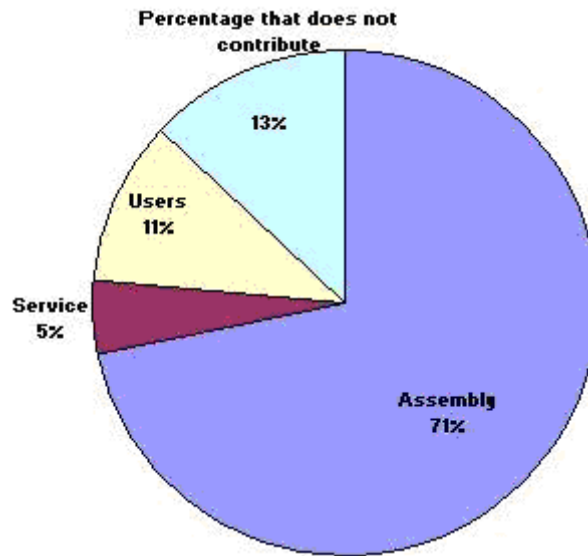


Figure 53: Number of Capabilities to Manufacture PWB Large Volume Response

Examining the customers' response segments indicates that 88.41% of the customers that assemble the PWBs, 81.82% of the customers that use PWBs, and 80 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 64.06%, 78.18%, and 48% respectively.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 5 PWB customers responded that this factor is very important to their customer satisfaction (Figure 54), 35 PWB customers responded that this factor is important, 33 customers responded that this factor is neutral, one customer responded that it is unimportant, 10 customers responded that it is very unimportant, and one customer responded that it does not contribute to their customer satisfaction.

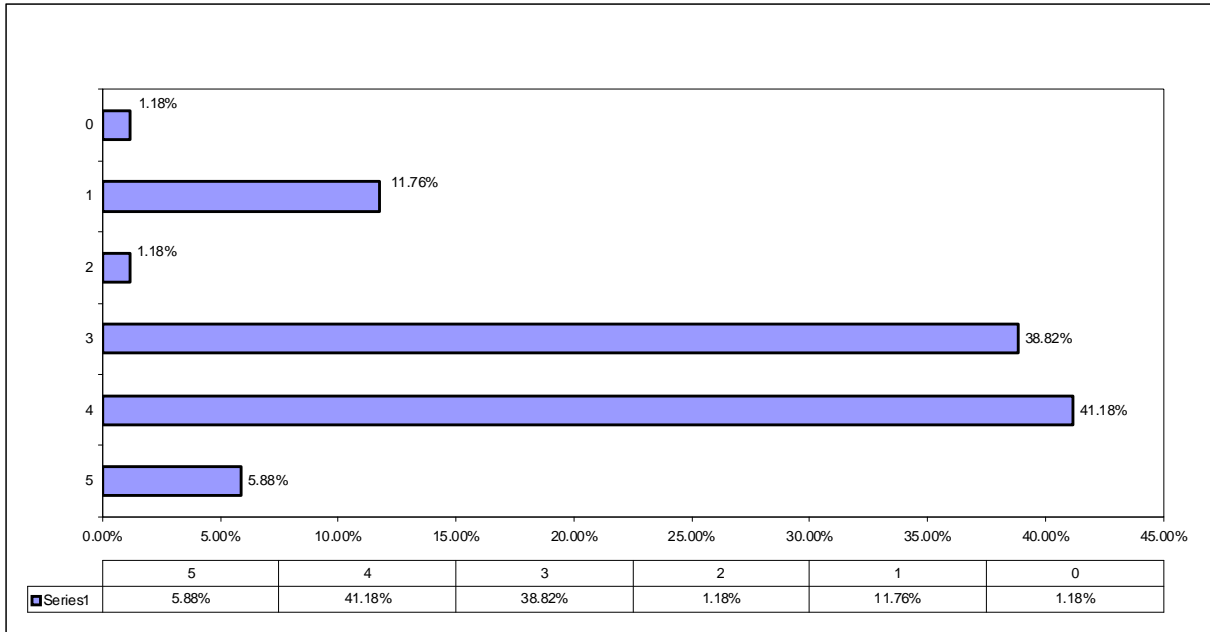


Figure 54: Number of Capabilities to Manufacture PWB Large Volume Frequency Distribution

### Variable Twenty One Analysis

The response rate for whether or not the ability of the PWB manufacturer to produce “Quick Turn” PWB contributes to the PWB customers’ satisfaction was 72 customers with 84.71% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 70.59% contribution level.

Examining the variable contribution rate indicates that 73% of assembly customers, 1% service customers, and 11% users customers believe that this variable contributes to the customer satisfaction (Figure 55). This factor was the sixteenth most significant to the PWB customers with an average contribution of 3.52 and a standard deviation of 1.45.

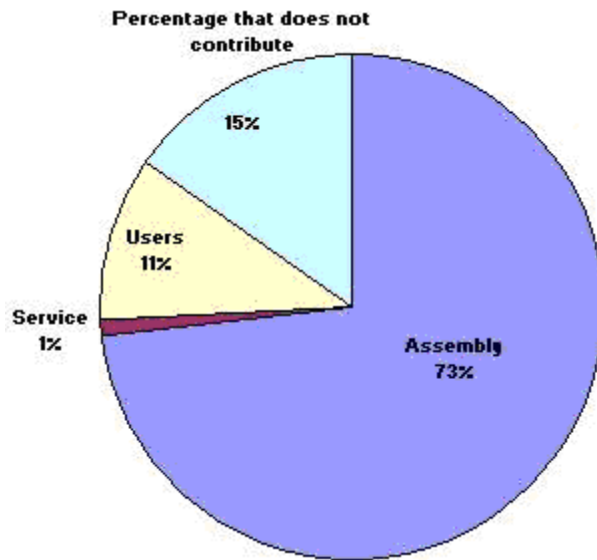


Figure 55: Number of Capabilities to Manufacture PWB Quick Turn Response

Examining the customers' response segments indicates that 89.86% of the customers that assemble the PWBs, 81.82% of the customers that use PWBs, and 20% of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 73.91%, 78.18%, and 8% respectively. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 22 PWB customers responded that this factor is very important to their customer satisfaction, 36 PWB customers responded that this factor is important (Figure 56), nine customers responded that this factor is neutral, five customers responded that it is unimportant, nine customers responded that it is very unimportant, and four customers responded that it does not contribute to their customer satisfaction.

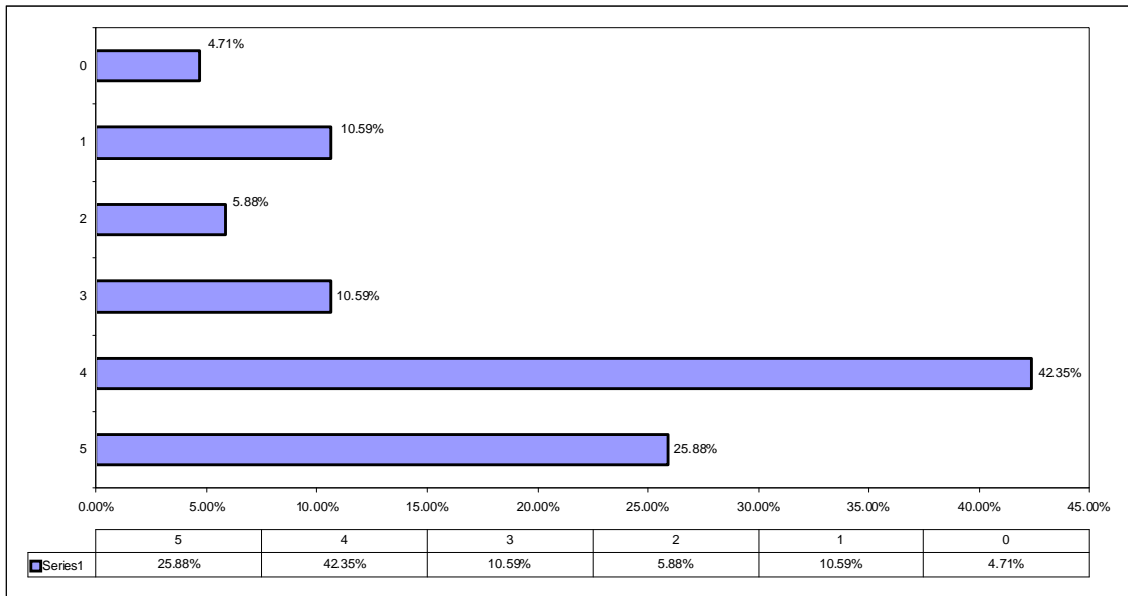


Figure 56: Number of Capabilities to Manufacture PWB Quick Turn Frequency Distribution

### Variable Twenty Two Analysis

The response rate for whether or not the number of PWB that were manufactured by the PWB manufacturer meets the copper thickness requirements contributes to the PWB customers' satisfaction was seventy-two customers with 75.29% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 57.65% contribution level.

Examining the variable contribution rate indicates that 66% assembly customers, 1% service customers, and 8% users customers believe that this variable contributes to the customer satisfaction (Figure 57). This factor was the eighteenth most significant to the PWB customers with an average contribution of 2.88 and a standard deviation of 1.83.

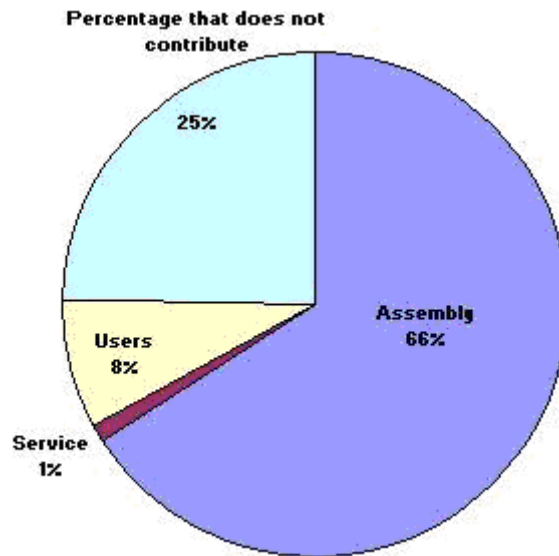


Figure 57: Number of PWB Pass Copper Thickness Requirements Response

Examining the customers' response segments indicates that 81.16% of the customers that assemble the PWBs, 63.64% of the customers that use PWBs, and 20 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 62.61%, 49.09%, and 8% respectively. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 14 PWB customers responded that this factor is very important to their customer satisfaction, 30 PWB customers responded that this factor is important (Figure 58), 16 customers responded that this factor is neutral, three customers responded that it is unimportant, one customer responded that it is very unimportant, and 21 customers responded that it does not contribute to their customer satisfaction.

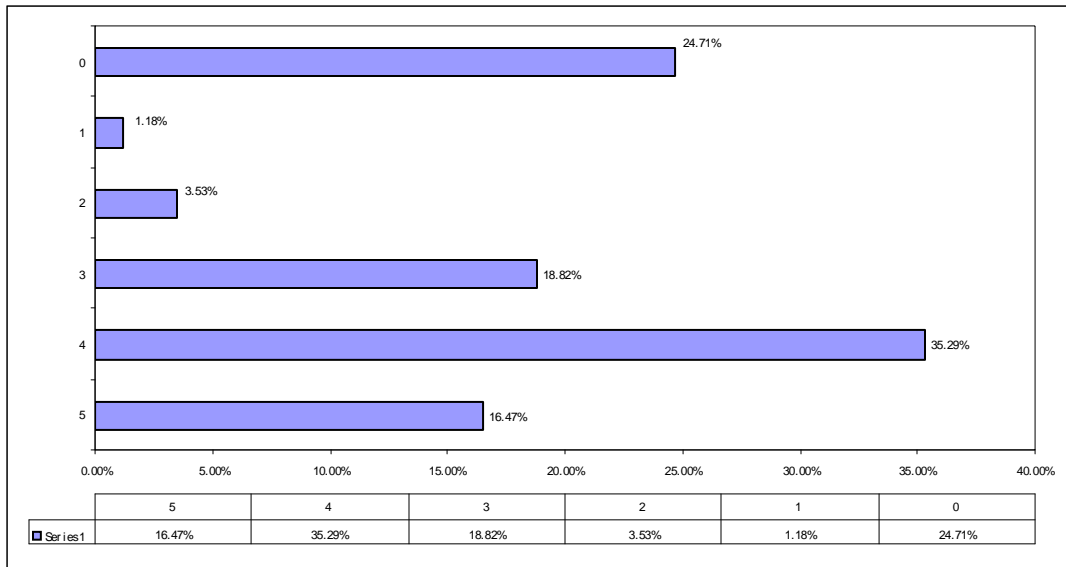


Figure 58: Number of PWB Pass Copper Thickness Requirements Frequency Distribution

### Variable Twenty Three Analysis

The response rate for whether or not the number of PWB manufacturer etch capability contributes to the PWB customers' satisfaction was seventy-two customers with 87.06% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 65.41% contribution level.

Examining the variable contribution rate indicates that 74% of assembly customers, 2% service customers, and 11% users customers believe that this variable contributes to the customer satisfaction (Figure 59). This factor was the twelfth most significant to the PWB customers with an average contribution of 3.27 and a standard deviation of 1.45.

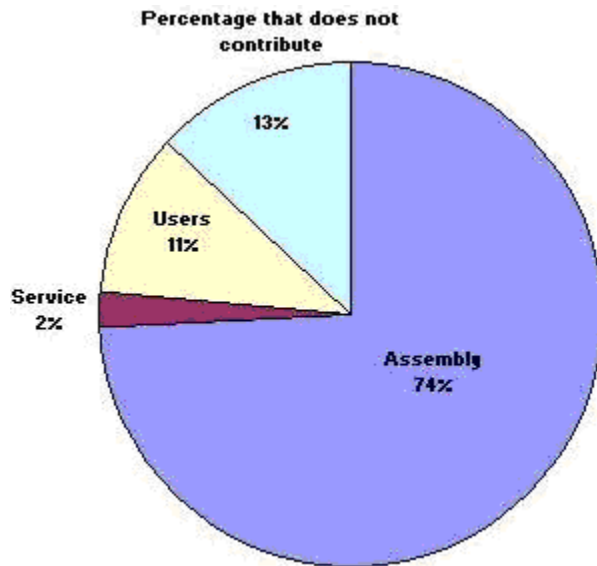


Figure 59: Number of PWB Manufacturer Etch Capabilities

Examining the customers' response segments indicates that 91.3% of the customers that assemble the PWBs, 81.82% of the customers that use PWBs, and 40 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 67.25%, 74.55%, and 20% respectively. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 10 PWB customers responded that this factor is very important to their customer satisfaction, 40 PWB customers responded that this factor is important (Figure 60), 20 customers responded that this factor is neutral, four customers responded that it is unimportant, no customers responded that it is very unimportant, and 11 customers responded that it does not contribute to their customer satisfaction.

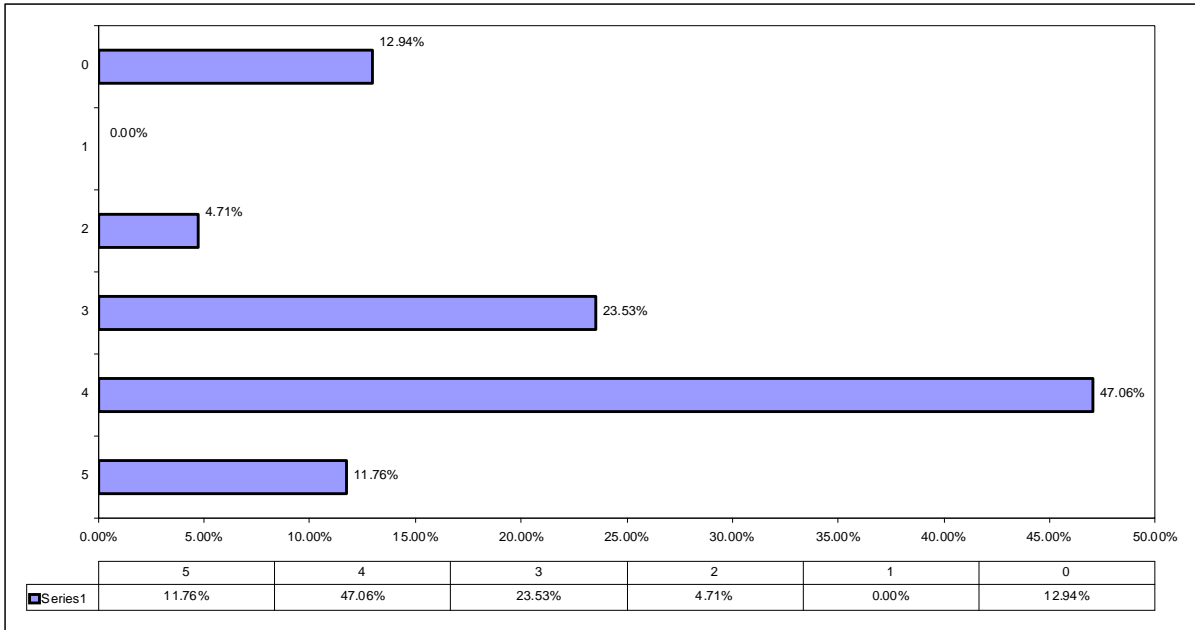


Figure 60: Number of PWB Manufacturer Etch Frequency Distribution

### Variable Twenty Four Analysis

The response rate for whether or not the number of PWB manufactured by the PWB manufacturer meet the circuit line width requirements contributes to the PWB customers' satisfaction was seventy-eight customers with 91.76% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 73.88% contribution level.

Examining the variable contribution rate indicates that 78% assembly customers, 2% service customers, and 12% users customers believe that this variable contributes to the customer satisfaction (Figure 61). This factor was the seventh most significant to the PWB customers with an average contribution of 3.69 and a standard deviation of 1.31.



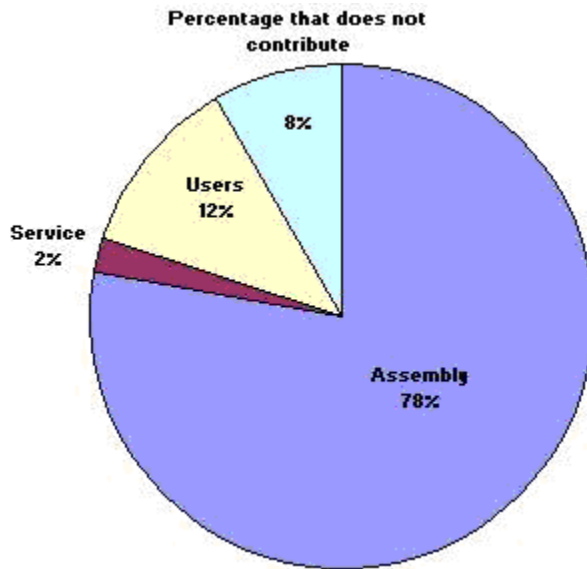


Figure 61: Number of PWB Meeting Circuit Line Width Requirements Response

Examining the customers' response segments indicates that 95.65% of the customers that assemble the PWBs, 90.91% of the customers that use PWBs, and 40 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 79.42%, 65.45%, and 73.88% respectively.

The PWB circuit line width factor is one of the most important characteristics of the PWB. PWB users acknowledged from their responses that this is an important factor in the manufacturing process of the PWB that contributes to their customer satisfaction. The reason is that the circuit line width requirement contributes to the life cycle of the PWB and it has a major effect on the operation of the PWB. Either reduced PWB circuit line width or oversized line width causes a major breakdown in the operation of the PWB. PWB designers and users specify their operational requirement to the PWB manufacturer.

Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 19 PWB customers responded that this factor is very important to their customer

satisfaction, 44 PWB customers responded that this factor is important (Figure 62), 13 customers responded that this factor is neutral, two customer responded that it is unimportant, no customers responded that it is very unimportant, and seven customers responded that it does not contribute to their customer satisfaction.

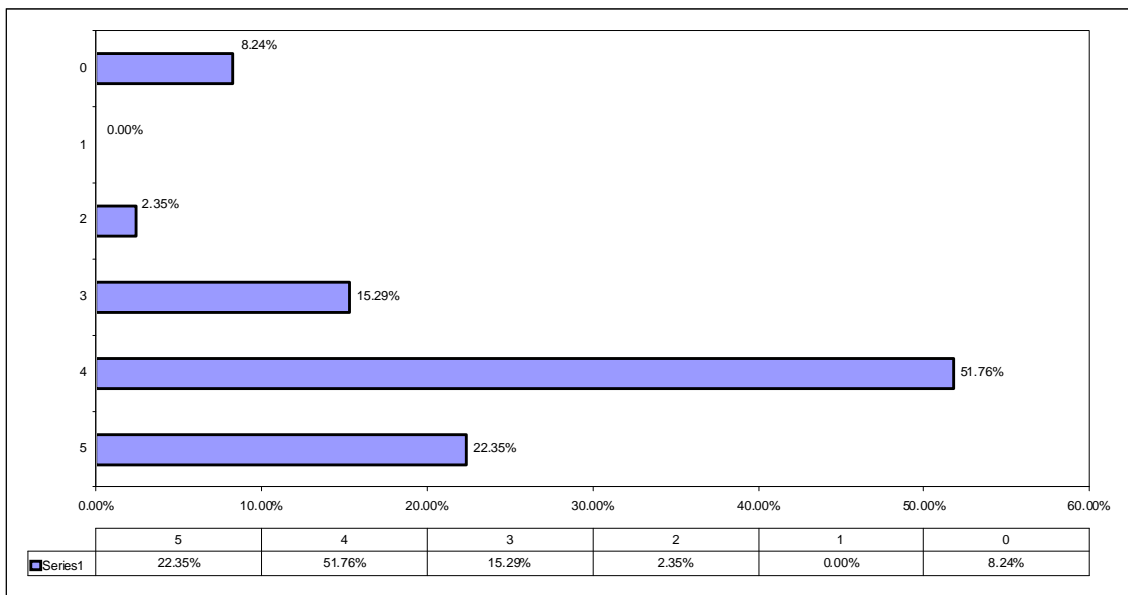


Figure 62: Number of PWB Meeting Circuit Line Width Requirements Frequency Distribution

Reduced PWB circuit line width is caused by many factors, one is in the PWB manufacturer tooling department where the designers do not include in their design the amount which will be reduced during etching, or the break down in the resist while it was being etched, or simply by handling when the PWB panels are transported from one department to the other. Ninety percent of the PWB users with a contribution level of sixty five percent to this factor have indicated that this is an important factor that contributes to their satisfaction. Also, it is to be noted that some of the PWB service organizations indicated that this factor contributes to their satisfaction. Over ninety percent of the PWB assemblers showed interest that this factor

contributes to their customer satisfaction with more than seventy-nine percent level of contribution. Any break-down to the PWB during the assembly process causes scheduling and financial havoc for the PWB assemblers who are obliged to assemble the PWB for the users in a constrained time domain. This is most likely the reason that this factor is of great importance to the PWB assemblers as well as to the PWB users.

### **Variable Twenty Five Analysis**

The response rate for whether or not the number of PWB manufactured by the PWB manufacturer meet the conductor line spacing width requirements contributes to the PWB customers' satisfaction was seventy-seven customers with 90.59% agreeing that this factor contributes to the PWB customer satisfaction with a total average of 64% contribution level.

Examining the variable contribution rate indicates that 77% of assembly customers, 1% service customers, and 13% users customers believe that this variable contributes to the customer satisfaction (Figure 63). This factor was the eighth most significant to the PWB customers with an average contribution of 1.33 and a standard deviation of 3.2. Examining the customers' response segments indicates that 94.2% of the customers that assemble the PWBs, 100% of the customers that use PWBs, and 20 percent of the PWB service industries agree that this factor contributes to their customer satisfaction with a contribution level of 67.25%, 67.27%, and 12% respectively. The PWB users and assemblers have a common interest to receive PWB with no defects. Conductor line spacing requirement is very important to the PWB users and especially for military application users.

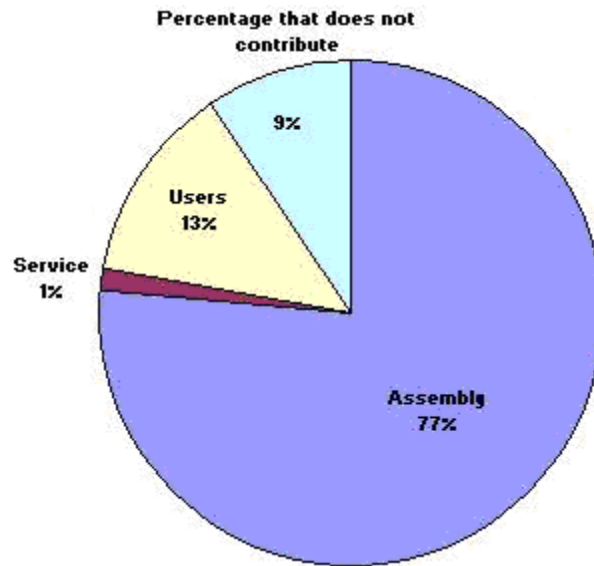


Figure 63: Number of PWB Meeting Line Spacing Width Requirements Response

Meeting the minimum requirement for conductor line spacing is not recommended for PWBs. Conductors line spacing has two major implications; one is caused by the thickness of the conductor and the other is caused by the spacing between the conductors. Conductors line spacing is caused by either improper etching or by failure in the resist coating process prior to the etch process where more cross sectional areas of the conductors are covered by the resist film, which in turn is to not allow it to be etched away. Examining the frequency of contribution for this factor to the PWB customer satisfaction shows that 12 PWB customers responded that this factor is very important to their customer satisfaction, 24 PWB customers responded that this factor is important, 35 customers responded that this factor is neutral (Figure 64), five customers responded that it is unimportant, one customer responded that it is very unimportant, and eight customers responded that it does not contribute to their customer satisfaction. If the conductor line is too thick, this will cause the conductor temperature to rise with respect to the conductor

cross-sectional area, thus the wider the conductors the more heat is generated and the more stress on the assembled parts in respect to meeting its operating temperature requirements.

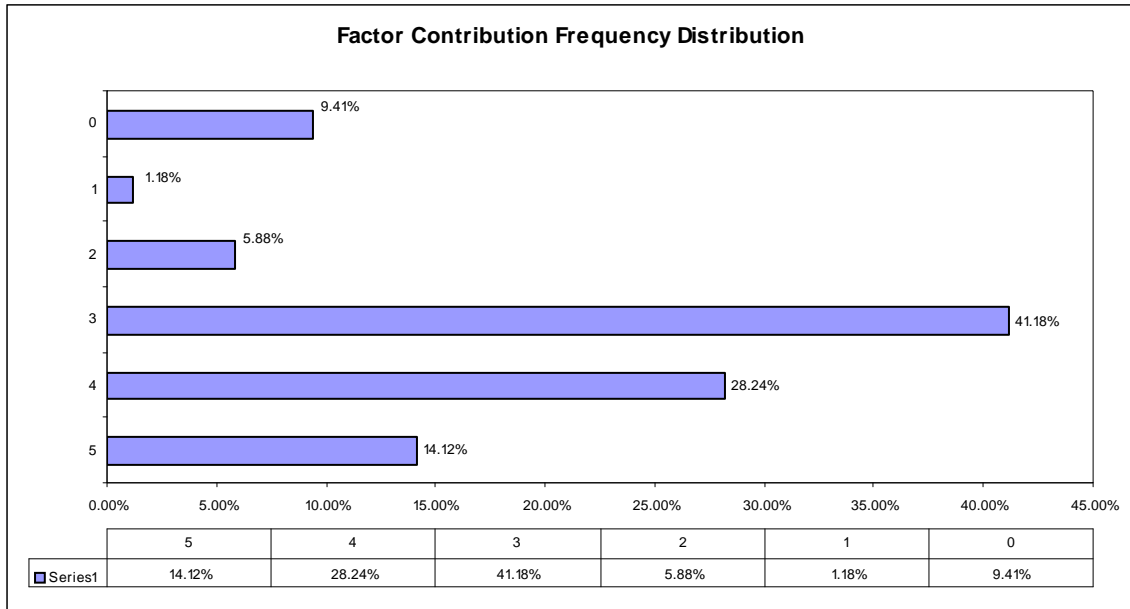


Figure 64: Number of PWB Meeting Line Spacing Width Requirements Frequency Distribution

If the conductors are overheated because of their thickness they may break down by causing an opening in the PWB circuits and the entire PWB will fail to operate. It is important to note that the process of causing the conductor line to fail and open due to an over heated conductor is used by the test department to clear a short in the circuit by inducing a high current to the conductor line, which causes it to break open from excessive heat. The other failure of the conductor line spacing is caused by the reduced space between the conductors because of the over-thickness of the conductor line. The reduced space between the conductors may cause an electric arc between the circuits, which causes shorts in the PWBs and the entire PWB would fail while in operation. Also, there is a concern of electromagnetic interference, which is induced by

not meeting the circuit line spacing requirements where cross electromagnetic fields are generated in the circuits that are close to each other, which may induce severe communication or radio transmittal interference. PWB service organizations are not very concerned with this factor since it may generate more business for them. In other words, the PWB service industries would mainly benefit financially from this factor when the PWB do not meet the customer requirements since they may be asked to repair at an additional cost to rework the PWB. The most significant factors have been organized in Table 4, where the first significant variable is accessing the PWB technical service, the second most significant was the number of days it takes to receive the PWBs, the third is the number of days it takes to contact the customer service department, the fourth most significant was the number of days it takes the QA department to respond to their customers concerns.

#### **PWB Customers Perception Regarding Customer Satisfaction**

The analysis of the surveys showed that the PWB Customers had different perceptions of customer satisfaction depending on their line of business. For example, the PWB service customers were not interested in the “Number of Days it Took to Receive the PWB After Ordering” variable and none of the PWB service customers thought it was an important factor that would influence their customer satisfaction. This is due to the fact that the PWB service customers receive the PWB after it has been assembled and purchased and their only concern is reworking any defects or non-conformity that appear in the PWB. On the other hand, this variable is more important to the PWB users customers or the PWB assembler customers. The PWB price variable, along with quality department response to the customer needs variable, warranty on the PWB variable, number of days it takes to obtain a return material authorization

variable, number of days to receive a quote response variable, PWB thickness variable, number of PWB pass blind / buried Vias registrations variable, number of PWB material types variable, number of PWB pass test (net test, through hole test, bread board test) manufacturer capabilities variable, number of shipping methods available variable, number of shipping packaging availability variable, number of capabilities / servers for downloading the Gerber files variable, number of capabilities to manufacture PWB quick turn variable, number of PWB pass copper thickness meeting requirements variable, number of PWB manufacturer etch capability variable, and number of PWB meeting line spacing width requirements variable were not very important to the PWB service industry but were very importance to the PWB users and PWB assemblers customers.

The result of the Chi-Square testing showed that there is a significant difference between the variables among the three PWB customers groups (Chi-Square value =276, df =48, P=. 001). Since some variables were also less or more important than each other depending on their relevance of importance to the PWB customers line of business, it was imperative to develop a model that represented each of the PWB customers' industry.

Table 4: Most Significant Questions

Questions	Percentage	Standard Deviation	In Xs
# of Days to Access TS	100.00%	0.61	X8
# of Days to Receive PWB	94.12%	1.22	X1
# of Days to Access CS	94.12%	1.22	X9
QA Department Response	92.94%	1.33	X3
# of Days to obtain RMA	92.94%	1.2	X7
# Days to Resolve TI	91.76%	1.4	X24
#r of PWB Meeting CLW requirement	91.76%	1.31	X5
# of PWB Meeting LSW Requirements	90.59%	1.33	X25
Warranty on the PWB	89.41%	1.22	X4
# of PWB Pass SMA	88.24%	1.4	X13
# of Days to Receive Quote	87.06%	1.61	X6
# of PWB Manufacturer Etch Capability	87.06%	1.45	X10
# Number of Capabilities to Manufacture PWB LV	87.06%	1.09	X20
# of Days to Obtain Credit for returned PWB	87.06%	1.4	X23
PWB Thickness	85.88%	1.51	X11
# of Capabilities to Manufacture PWB QT	84.71%	1.45	X21
Number of PWB Pass Through Hole Registrations	78.82%	1.57	X12
# of PWB Pass CT requirements	75.29%	1.83	X22
PWB Pricing	74.12%	2	X2
# of Shipping Methods	65.88%	1.75	X17
# Manufacturer Test Capabilities	64.71%	1.81	X14
# of PWB Pass BBV registrations	64.71%	1.55	X16
# of Capabilities / Servers for receive GF	60.00%	1.81	X19
# of PWB Material Types	47.06%	1.71	X15
# of Shipping Packaging Availability	42.35%	1.42	X18

### **An Overall PWB Customer Satisfaction Model**

In this section an overall customer satisfaction model to measure the PWB customers satisfaction will be introduced along with three alternative models that will measure PWB customers satisfaction based on their line of business and whether they are PWB assembly, PWB



users, or PWB service customers. Finally, a unique model that would measure the individual PWB customer satisfaction based on his/her power of purchase will be introduced.

The overall customer satisfaction model utilizes the survey results that were given out to the PWB customers to determine the items that have a significant effect on their customer satisfaction and their level of contribution. For the PWB customers, the average weight for the level of contributions for each variable was calculated and that was the standardized weight for each item. The over all customer satisfaction model includes all the PWB customers that responded to the surveys regardless of the type of PWB customers. The model uses the average weight of all the items that were surveyed (Table 5).

Table 5: Overall PWB Customer Satisfaction Model

<b>PWB Overall Satisfaction</b>				
<b>Column A</b> <b>Averages</b>	<b>Column B</b>	<b>Column C</b> <b>Maximum</b>	<b>Column D</b> <b>Database</b>	<b>Column E</b> <b>Calculated Weight</b>
4.27	X1	5	5	21.35
3.06	X2	5	4	12.24
4.28	X3	5	5	21.41
3.19	X4	5	4	12.75
3.53	X5	5	5	17.65
3.24	X6	5	5	16.18
4.25	X7	5	5	21.24
4.27	X8	5	5	21.35
3.72	X9	5	4	14.87
3.75	X10	5	5	18.76
3.31	X11	5	4	13.22
2.86	X12	5	5	14.29
3.05	X13	5	4	12.19
1.86	X14	5	5	9.29
1.45	X15	5	5	7.24
2.31	X16	5	4	9.22
2.24	X17	5	5	11.18
1.22	X18	5	4	4.89
2.10	X19	5	4	8.38
3.25	X20	5	3	9.74
3.53	X21	5	1	3.53
2.88	X22	5	4	11.53
3.27	X23	5	4	13.08
3.69	X24	5	4	14.78
3.20	X25	5	5	16.00
		<b>388.77</b>	<b>Database</b>	<b>336.37</b>
			<b>Satisfaction</b>	<b>86.52%</b>

The overall customer satisfaction model integrates all PWB customers based on all the surveys responses. Assume the variables are designated X01 through X25 (Table 5), where X1 is the number of days it took to receive the PWB after ordering it from the manufacturer; X2 is the PWB price relative to other PWB manufactures; X3 is the number of days it took the PWB manufacturer quality department to respond to the PWB customer needs; X4 is the conditions of

the warranty offered and available for the purchased PWB; X5 is the number of PWB that meet the nominal circuit line width customer or standard requirements; X6 is the number of days it takes to receive a quote response from the PWB manufacturer; X7 is the number of days it takes to obtain a return material authorization from the PWB manufacturer; X8 is the number of days it takes the PWB customer to access the PWB manufacturer technical support; X9 is the number of days it takes to access the PWB manufacturer customer support; X10 is the number of PWB manufacturer etch capability; X11 is the number of PWB with nominal thickness delivered to the PWB customers; X12 is the number of PWB that passes the nominal through hole registrations; X13 is the number of PWB that passes solder mask adhesion test; X14 is the number of PWB that passes Test (net test, through hole test, bread board test) and manufacturer test capabilities; X15 is the number of PWB material types that the PWB manufacturer offer to the PWB customers; X16 is the number of PWB that passes blind / buried vias registrations; X17 is the number of shipping methods that the PWB manufacturer offer to the PWB customers; X18 is the number of shipping packaging that the PWB manufacturer offers and make available to the PWB customers; X19 is the number of capabilities/servers available to the PWB customer to download their Gerber files; X20 is the capability of the PWB manufacturer to manufacture large PWB volume; X21 is the capability of the manufacturer to manufacture PWB Quick Turn; X22 is the number of PWB that passes nominal copper thickness requirements; X23 is the number of days it takes to obtain credit for the returned PWBs; X24 is the number of days it takes to resolve technical issues; X25 is the number of PWB that meet the nominal line spacing width requirements. The overall model will utilize the average weights for each of the items that were obtained from the survey responses, where the average weights for each of the items surveyed is in Column A of Table 3. The overall customer satisfaction model is the sum of the product of column A and column D (results in E)

divided by the sum of product of column A by column C, where column C is the max weight assigned to every item, column A is the average weight obtained from the surveys results for each item. Column D is the measured weight from the PWB manufacturer database. In the example above the overall customer satisfaction is  $(336.37/388.7)*100$ , which is 86.52.

The customer satisfaction model for the overall PWB customer industry will be calculated by the following formula,  $CS = (4.27 X1 + 3.06X2 + 4.28 X3 + 3.19 X4 + 3.53 X5 + 3.24 X6 + 4.25X7 + 4.27 X8 + 3.72 X9 + 3.75 X10 + 3.31 X11 + 2.86 X12 + 3.05 X13 + 1.86 X14 + 1.45 X15 + 2.31 X16 + 2.24 X17 + 1.22 X18 + 2.10 X19 + 3.25 X20 + 3.53 X21 + 2.88 X22 + 3.27 X23 + 3.69 X24 + 3.20 X25) / 4.27 Y1 + 3.06Y2 + 4.28 Y3 + 3.19 Y4 + 3.53 Y5 + 3.24 Y6 + 4.25Y7 + 4.27 Y8 + 3.72 Y9 + 3.75 Y10 + 3.31 Y11 + 2.86 Y12 + 3.05 Y13 + 1.86 Y14 + 1.45 Y 5 + 2.31 Y16 + 2.24 Y17 + 1.22 Y18 + 2.10 Y19 + 3.25 Y20 + 3.53 Y21 + 2.88 Y22 + 3.27 Y23 + 3.69 Y24 + 3.20 Y25)$ , Where X1 through X25 in the numerator are defined in Table 5. X1 through X25 are the overall customers' variables ratings obtained from the database, while Y1 through Y25 in the denominator are the maximum rating allowed for each of the variables from a scale (1-5). The denominator for overall PWB customer industry is 388.7.

### **Alternative Customer Satisfaction Models**

In this section, three alternative customer satisfaction models will be introduced based on the PWB customers' line of business and whether they are PWB assembly customers, PWB users customers or PWB service customers.

The first alternative customer satisfaction model is for the PWB assembly customers, which is based on the PWB assembly survey responses taking into account the different variables weights. Assume the variables are as designated X01 through X25 in Table 6. The analysis of the

survey results for the PWB assembly customers is in Table 7. The PWB assembly customers' satisfaction model is calculated by the same technique as explained in the previous section except for the PWB assembly customers only.

Table 6: Variables Assigned to the Items

Item	Variable
Number of Days it Took to Receive the PWB After Ordering	X01
PWB Pricing	X02
Quality Department Response to your Needs	X03
Warranty on the PWB	X04
Number of PWB Meeting Circuit Line Width Meeting Requirements	X05
Number of Days to Receive a Quote Response	X06
Number of Days it Takes to Obtain a Return Material Authorization	X07
Number of Days to Access Technical Support	X08
Number of Days to Access Customer Support	X09
Number of PWB Manufacturer Etch Capability	X10
PWB Thickness	X11
Number of PWB Pass Through Hole Registrations	X12
Number of PWB Pass Solder Mask Adhesion	X13
Number of PWB Pass Test (Net Test, Through Hole Test, Bread Board Test)	X14
Manufacturer Capabilities	
Number of PWB Material Types	X15
Number of PWB Pass Blind / Buried Vias registrations	X16
Number of Shipping Methods Available	X17
Number of Shipping Packaging Availability	X18
Number of Capabilities / Servers for Downloading the Gerber Files	X19
Number of Capabilities to Manufacture PWB Large Volume	X20
Number of Capabilities to Manufacture PWB Quick Turn	X21
Number of PWB Pass Copper Thickness Meeting Requirements	X22
Number of Days to Obtain Credit for the Returned PWBs	X23
Number of Days to Resolve Technical Issues	X24
Number of PWB Meeting Line Spacing Width Requirements	X25

The customer satisfaction model for the PWB customer assembly industry will be calculated by the following formula,  $CS = (4.68 X1 + 2.97 X2 + 4.65 X3 + 3.43 X4 + 3.57 X5 +$

$3.16 X_6 + 4.38 X_7 + 4.29 X_8 + 3.71 X_9 + 3.86 X_{10} + 3.52 X_{11} + 2.84 X_{12} + 2.90 X_{13} + 1.70 X_{14} + 1.03 X_{15} + 2.22 X_{16} + 2.41 X_{17} + 1.01 X_{18} + 1.99 X_{19} + 3.20 X_{20} + 3.70 X_{21} + 3.13 X_{22} + 3.36 X_{23} + 3.97 X_{24} + 3.36 X_{25}$

) / 395.1, where in the numerator X1 through X25 are defined in Table 5, X1 through X25 are the assembly customers' variables ratings obtained from the database, the denominator is the maximum allowed ratings on a scale (1-5) for the variables multiplied by the coefficients of the Xs in the numerator.

Table 7: PWB Assembly Customer Satisfaction Model Determination

<b>PWB Assembly Customers satisfaction</b>				
<b>Column A</b>	<b>Column B</b>	<b>Column C</b>	<b>Column D</b>	<b>Column E</b>
<b>Averages</b>		<b>Maximum</b>	<b>Database</b>	<b>Calculated Weight</b>
4.68	X1	5	5	23.41
2.97	X2	5	4	11.88
4.65	X3	5	5	23.26
3.43	X4	5	4	13.74
3.57	X5	5	5	17.83
3.16	X6	5	5	15.80
4.38	X7	5	5	21.88
4.29	X8	5	5	21.45
3.71	X9	5	4	14.84
3.86	X10	5	5	19.28
3.52	X11	5	4	14.09
2.84	X12	5	5	14.20
2.90	X13	5	4	11.59
1.70	X14	5	5	8.48
1.03	X15	5	5	5.14
2.22	X16	5	4	8.87
2.41	X17	5	5	12.03
1.01	X18	5	4	4.06
1.99	X19	5	4	7.94
3.20	X20	5	3	9.61
3.70	X21	5	1	3.70
3.13	X22	5	4	12.52
3.36	X23	5	4	13.45
3.97	X24	5	4	15.88
3.36	X25	5	5	16.81
<b>Average</b>		395.14493	Database	341.74
			<b>Satisfactor</b>	<b>86.48%</b>

The second alternative model to be introduced is for the PWB users customers where the satisfaction index will be determined by utilizing the same procedure that was used to determine the PWB assembly customer satisfaction index but instead the weights used in this model will be the weights determined by the PWB users' surveys. The satisfaction model for the PWB users customers will be determined by calculating the average of each of the 25 item weights from the survey result in column A, then multiplying this weight in column A by the item weight obtained from the PWB Manufacture database in column D. The PWB users' customer satisfaction index is calculated by adding all the calculated items weight in column E and divided by the total maximum weight assigned to the items in column C. The customer satisfaction model for the PWB customer users (Table 8), industry will be calculated by the following formula,  $CS = (3.64 X_1 + 4.45 X_2 + 3.64 X_2 + 3.09 X_3 + 4.91 X_4 + 4.73 X_5 + 4.55 X_6 + 4.45 X_7 + 4.36 X_8 + 4.64 X_9 + 3.18 X_{10} + 3.00 X_{11} + 4.73 X_{12} + 3.55 X_{13} + 4.55 X_{14} + 3.64 X_{15} + 2.18 X_{16} + 3.09 X_{17} + 3.90 X_{18} + 3.91 X_{20} + 3.91 X_{21} + 2.45 X_{22} + 3.73 X_{23} + 3.27 X_{24} + 3.36 X_{25}) / 474.5$ , where X1 through X25 are defined in Table 5, X1 through X25 in the numerator are the users customers' variables ratings obtained from the database, while the denominator is the maximum allowed ratings on a (scale 1-5) for the variables multiplied by the coefficients of the Xs .

The third alternative model to be introduced is for the PWB service customers (Table 9), that utilizes the same procedure that was used to determine the PWB Assembly and the PWB user customer satisfaction index but instead the weights used will be the weights determined by the PWB services surveys where their satisfaction index is determined by calculating the average of each of the 25 item weights from the survey result in column A, then multiplying this weight in column A by the item weight obtained from the PWB Manufacture database in column D. The customer satisfaction model for the PWB customer service industry will be calculated by the

following formula,  $CS = (1.2X_2 + 0.6X_3 + X_6 + 1.8X_7 + 3.6X_8 + 2.4X_9 + 0.4X_{10} + 0.6X_{11} + 2.8X_{12} + 1.4X_{13} + 0.4X_{14} + 0.4X_{15} + 0.6X_{16} + 2.4X_{20} + 0.4X_{21} + 0.4X_{22} + X_{23} + 0.8X_{24} + 0.6X_{25}) / 114$  where  $X_1$  through  $X_{25}$  are defined in Table 4,  $X_1$  through  $X_{25}$  are the customers' service variables ratings obtained from the database, the denominator is the maximum allowed ratings on a scale (1-5) for the variables multiplied by the coefficients of the  $X_s$  in the numerator.

Table 8: PWB Users Customer Satisfaction Model Determination

PWB User satisfaction				
Column A	Column B	Column C	Column D	Column E
Averages		Maximum	Database	Calculated Weight
3.64	X1	5	2	7.27
4.45	X2	5	4	17.82
3.64	X3	5	3	10.91
3.09	X4	5	4	12.36
4.91	X5	5	2	9.82
4.73	X6	5	5	23.64
4.55	X7	5	5	22.73
4.45	X8	5	5	22.27
4.36	X9	5	4	17.45
4.64	X10	5	5	23.18
3.18	X11	5	4	12.73
3.00	X12	5	5	15.00
4.73	X13	5	4	18.91
3.55	X14	5	3	10.64
4.55	X15	5	5	22.73
3.64	X16	5	4	14.55
2.18	X17	5	5	10.91
3.09	X18	5	4	12.36
3.90	X19	5	4	15.60
3.91	X20	5	2	7.82
3.91	X21	5	3	11.73
2.45	X22	5	4	9.82
3.73	X23	5	3	11.18
3.27	X24	5	4	13.09
3.36	X25	5	3	10.09
		474.5	Database	364.60
			Satisfaction	76.84%



Table 9: PWB Service Customer Satisfaction Model Determination

<b>PWB Service Satisfaction</b>				
<b>Column A</b>	<b>Column B</b>	<b>Column C</b>	<b>Column D</b>	<b>Column E</b>
<b>Averages</b>		<b>Maximum</b>	<b>Database</b>	<b>Calculated Weight</b>
0	X1	0	5	0.00
1.20	X2	5	4	4.80
0.60	X3	5	5	3.00
0.00	X4	0	4	0.00
0	X5	0	5	0.00
1	X6	5	5	5.00
1.8	X7	5	5	9.00
3.6	X8	5	5	18.00
2.4	X9	5	4	9.60
0.4	X10	5	5	2.00
0.6	X11	5	4	2.40
2.8	X12	5	5	14.00
1.4	X13	5	4	5.60
0.4	X14	5	5	2.00
0.4	X15	5	5	2.00
0.6	X16	5	4	2.40
0	X17	0	5	0.00
0	X18	0	4	0.00
0	X19	0	4	0.00
2.4	X20	5	3	7.20
0.4	X21	5	1	0.40
0.4	X22	5	4	1.60
1	X23	5	4	4.00
0.8	X24	5	4	3.20
0.6	X25	5	5	3.00
		<b>114</b>	<b>Database</b>	<b>99.20</b>
			<b>Satisfaction</b>	<b>87.02%</b>

### Individual Customer Satisfaction Model

In this section a unique method to measure an individual PWB customer satisfaction will be introduced and a control chart to monitor the individual PWB customer satisfaction will be demonstrated. Tracking individual customers' satisfaction is an important tool to monitor in real time any customer dissatisfaction either with a service or a product and promptly rectify the compromised issue. This also would involve contacting the customer to establish a feed back process in which it demonstrate to the PWB customer that the PWB manufacturer is actively

pursuing his satisfaction and that the PWB manufacture monitor their product or service compliance to the customer requirements.

The individual PWB customer satisfaction standardized weights for the items can be obtained by two different ways, either at the beginning of the quoting process where a survey to identify the important items that contributes to the PWB customer satisfaction and their assigned weights is sent out along with the quote to the PWB customer to complete, or by identifying the PWB customer line of business type and using the standardized weights obtained from the surveys responses. Once the standardized items weights are known, an individual customer satisfaction model can be constructed.

To measure the individual customer satisfaction with this model, the PWB manufacturer will calculate the individual PWB customer's satisfaction by monitoring each order the customers will make. The standard weights can be either obtained at the beginning of the contact during the quoting process or by utilizing the standard weight obtained from the surveys depending on the PWB customer type of organizations. The individual customer satisfaction model is calculated by multiplying the standard weights obtained from the survey by the maximum allocated weight for the variables, and then adding the results this would be the denominator. The numerator of the formula is calculated by multiplying the weights obtained from the database for each order with the standard weights obtained from the survey (Table 10). This would track the individual customer satisfaction score, example is shown in (Table 11). An advantage of computing the individual customer satisfaction scores is that they can be used on a control chart to monitor any out of control customer satisfaction (Figure 55). Note that it is always possible to compute the satisfaction score for an individual by using the weights previously determined and the current company data. The average overall customer satisfaction

will be the average of all individual customer satisfaction results. The customer satisfaction model for the individual PWB customer will have two variables X and Y and it will be calculated by the following formula,  $CS = (Y_1X_1 + Y_2X_2 + Y_3X_3 + Y_4X_4 + Y_5X_5 + Y_6X_6 + Y_7X_7 + Y_8X_8 + Y_9X_9 + Y_{10}X_{10} + Y_{11}X_{11} + Y_{12}X_{12} + Y_{13}X_{13} + Y_{14}X_{14} + Y_{15}X_{15} + Y_{16}X_{16} + Y_{17}X_{17} + Y_{18}X_{18} + Y_{19}X_{19} + Y_{20}X_{20} + Y_{21}X_{21} + Y_{22}X_{22} + Y_{23}X_{23} + Y_{24}X_{24} + Y_{25}X_{25}) / 5 (Y_1 + Y_2 + Y_3 + \dots + Y_{25})$  where X1 through X25 are defined in Table 4, X1 through X25 are the individual customer variables ratings obtained from the database, Y1 through Y25 are the standardized weights obtained from the survey given to the PWB customer at the quoting process. Since some PWB customers purchase more PWBs from a PWB manufacturer than other customers, the manufacturer may want to pay more attention to their larger customers. Hence, the manufacturer may want to take into consideration the power of purchase. From a manufacturer's point of view, when a customer purchases more PWBs, his/her power of purchase should become a factor in the customer satisfaction measurement. Once again, we can calculate the individual's satisfaction score incorporating purchasing power or we can calculate the overall customer satisfaction score for the company.

Table 10: Individual Customer Satisfaction Determination

<b>PWB individual Satisfaction</b>				
<b>Column A</b>	<b>Column B</b>	<b>Column C</b>	<b>Column D</b>	<b>Column E</b>
<b>Averages</b>		<b>Maximum</b>	<b>Database</b>	<b>Calculated Weight</b>
4.68	X1	5	5	23.41
2.97	X2	5	4	11.88
4.65	X3	5	5	23.26
3.43	X4	5	4	13.74
3.57	X5	5	5	17.83
3.16	X6	5	5	15.8
4.38	X7	5	5	21.88
4.29	X8	5	5	21.45
3.71	X9	5	4	14.84
3.86	X10	5	5	19.28
3.52	X11	5	4	14.09
2.84	X12	5	5	14.2
2.9	X13	5	4	11.59
1.7	X14	5	5	8.48
1.03	X15	5	5	5.14
2.22	X16	5	4	8.87
2.41	X17	5	5	12.03
1.01	X18	5	4	4.06
1.99	X19	5	4	7.94
3.2	X20	5	3	9.61
3.7	X21	5	1	3.7
3.13	X22	5	4	12.52
3.36	X23	5	4	13.45
3.97	X24	5	4	15.88
3.36	X25	5	5	16.81
<b>Average</b>		395.14493	Database	341.74
			<b>Satisfaction</b>	<b>86.48%</b>

Table 11: Individual Customer Satisfaction Determination with Power of Purchase Factor

	From Survey	Customer 1	Customer 2	Customer 3
	Weights	1	2	3
X1	5	2	5 5	5 5
X2	5	3	3 5	4 5
X3	4	2	5 5	5 5
X4	3	5	4 5	0 5
X5	3	1	4 4	3 5
X6	4	5	3 5	3 5
X7	4	5	4 5	4 5
X8	4	5	4 5	4 5
X9	4	5	3 5	4 5
X10	5	5	5 5	0 0
X11	3	5	4 5	4 5
X12	3	2	4 5	0 5
X13	4	3	3 5	4 5
X14	0	0	2 5	0 0
X15	0	0	0 0	3 5
X16	3	4	3 5	0 0
X17	2	4	3 5	0 0
X18	2	4	2 5	0 0
X19	3	5	4 5	0 0
X20	3	5	4 5	3 5
X21	4	5	4 5	5 5
X22	0	0	5 5	0 5
X23	4	5	2 5	4 5
X24	4	4	4 5	5 5
X25	3	4	3 5	3 5
	395	315	435 431	315 315
	Max Score	Corp Score		
	Specific Customer Satisfaction	79.75%	99.08%	100.00%
	UCL	89.88%	89.88%	89.88%
	LCL	73.12%	73.13%	73.13%
	Standard Deviation	8.38%		
	Average	81.51%	81.51%	81.51%
	Customer Purchases	\$190,000	\$220,000	\$30,000
	Customer Weights	5.351%	6.195%	0.845%
	Total sales	\$3,551,005		
		Corporate Customer satisfaction 86.087%		

To calculate the company's overall customer satisfaction taking into consideration the purchasing power weight, the individual customer purchasing power weight will be calculated by

dividing the individual customer sales by the total company sales, then multiplying the results by the individual customer satisfaction score. The overall company customer satisfaction will be calculated by adding the individual customer satisfaction scores.

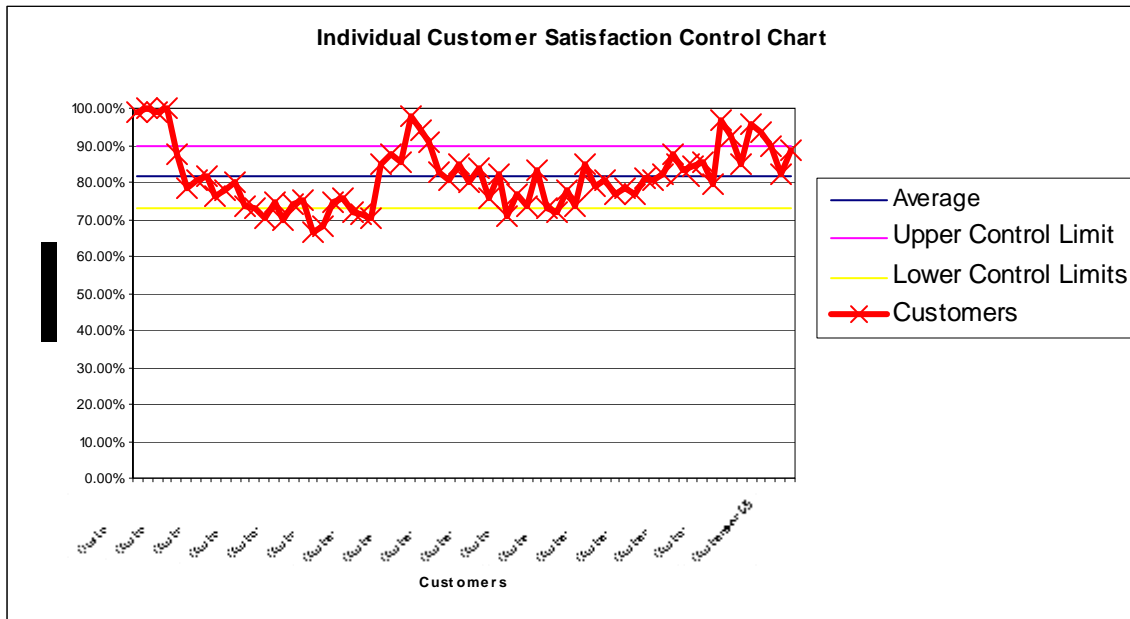


Figure 65: Individual Customer Satisfaction Control Chart

### Case Study

The researcher utilized the first model to measure the customer satisfaction for one customer then compared it to the actual customer satisfaction survey obtained from the customer after the customer received his/her PWBs and closed the purchase order. The data used were from the company database (Table 11) and since the PWB customer already existed in the database and he/she didn't complete a survey to determine his/her preferred variables weights the researcher utilized were the research weights that were concluded from this study. The twenty-five variables data were obtained from the database as follows:

- 1) Quality department response to the customer needs: During the course of the order, the quality department received four requests from the quality department by phone, the quality engineer responded on the same day in three instances and on the fourth, he responded in 2 days to review the standards to which the PWB was built since it conflicted with the customer's requirements. The rating for this variable will be 75 percent of the weight assigned to this variable since the quality engineer did not respond in the same day.
- 2) Number of days it took to receive the PWB after ordering: The database showed that the customer received the PWB 10 days after the purchase order was received. The current standard number of days to have the PWB manufactured and shipped to the customer is approximately two weeks. Since the customer received the PWB on time this variable weight will be assigned 100%.
- 3) Number of days to access technical support: The database showed that the customer contacted the tooling department three times in response to questions from the PWB manufacturer engineering department. The engineering department responded in the following day in each of the cases. From a scale of 1 to 5, if the engineering department responded instantly then they would have been awarded 5. Since the response was in a day then the rating will be 4 (80 percent), if they had responded in 2 days the rating would have been 3, and if was in 3 days it would have been a 2, and 4 days would have been 1.
- 4) Number of days to resolve technical Issues: The records show that customer did not contact any of the departments with any technical issue, thus this variable will be zero and will not be counted in the final customer satisfaction index.

- 5) Number of days to receive a quote response: The data for variables were measured from the day the customer sent an e-mail request for a quote and the day the quote was sent by e-mail to the customer. The database showed that the quote was delivered to the customer after three days because manufacturing engineering, along with the tooling department had to quote this order. The PWB industry average response quote is two-business days. Since the PWB manufacturer didn't respond immediately to the quote request the score 3 (60%) will be given. If the quote was sent in the same day, a score of five would have been given, if the quote was delivered in 2 days; a score of 4 would have been given.
- 6) Number of days to access customer support: The data showed that the customer contacted the sales department three times either by e-mails or phone. The sales department responded to one e-mail in the same day and responded a day later to both the other phone call and the email request. The first response will get a score of 5 and the other two responses will get a score of 4 with an average total score of 4.5 (90 %).
- 7) Number of PWB meeting circuit line width meeting requirements: the quality department database records showed that 80 percent of the PWB met the exact line width requirement, but 10 percent were meeting the minimum PWB standard requirement. A score of 5 will be given to the 90% of the PWBs delivered and a score of 2 will be given to the 10 percent of the PWB that met the minimum PWB standard requirement, (since the customer may argue whether or not the PWB meets the requirement of the PWB standard, score of 2 is given), Thus the total score for this variable is 4.7 (94%).
- 8) Number of capabilities to manufacture PWB quick turn: The PWB facility in this study was capable of manufacturing both quick turn and large volume PWBs. A score of 5 (100%) will be given to both factors.



- 9) Number of days it takes to obtain a return material authorization: There was no data for this variable in the database since there were no PWB returns on this order.
- 10) PWB thickness: the quality department database records showed that 75 percent of the PWB met the exact PWB thickness requirement and 25 percent met the minimum/maximum PWB customer requirement for PWB thickness. A score of 5 will be given to the 75% of the PWBs delivered and a score of 2 will be given to the 25 percent of the PWB that met the minimum/maximum PWB customer requirement, (since the customer may argue if the PWB minimum passes the PWB standard equipment, score of 2 is given). Thus the total score for this variable is 3.85 (77%).
- 11) Number of PWB manufacturer etch capabilities: the manufacturing and the micro-section inspection department database records showed all the PWBs met the minimum/maximum etch requirements. This variable score will be 5 (100%).
- 12) Number of capabilities to manufacture PWB large volume: The PWB facility in this study was capable of manufacturing large volume PWBs. A score of 5 (100%) will be given to this factor.
- 13) Number of days to obtain credit for the returned PWBs: There was no data for this variable in the database since there was no credit on any PWB on this order. A score of 0 will be given to this factor.
- 14) Number of PWB meeting line spacing width requirements: the quality and etch department database records showed that the 95 percent of the PWB met the line spacing requirement, but 5 percent were meeting the minimum or maximum PWB standard and customer requirements. A score of 5 will be given to all the PWBs delivered since the 5

percent of the lot was not delivered and went into inventory. Thus, the total score for this variable is 5 (100%).

15) Warranty on the PWB: For this particular order, there is extra PWB in inventory to replace any defective PWBs that the customer may have. Also, the PWB manufacturer warranties its PWB to be free of defect for three years. Thus, the total score for this variable will be 5 (100%).

16) PWB Pricing: The sales and marketing department concluded that the PWB manufacturer prices are a little above average, this is due to the fact manufacturer capability and quality requirements are above average. The sales department quotes and markets all PWB sold approximately 10 percent above average. Thus, this variable score will be 90 percent of 5, which is 4.5 (90%).

17) Number of PWB Pass Solder Mask Adhesion: The solder mask and the quality department records showed that the applied LPI (Liquid Photo-imageable) solder mask was consistent with the IPC-TM-650 Adhesion Test Method paragraph 2.4.28.1 and it passed the tape pull test utilizing a pressure sensitive self-adhesive film that is .3 cm (0.5 in) wide with an adhesive strength of at least 44 N/100 mm (40 oz-force/in) but no more than 66 N/100 mm (60 oz-force/in). All PWB shipped and in inventory passed this tape test and the score given will be 5 (100%)

18) Number of PWB Pass Copper Thickness Meeting Requirements: The plating, microsection, and quality department's records showed that there was enough plated copper on the PWB to meet the customer requirements. Thus this variable will be awarded a score of 5 (100%).

- 19) Number of PWB Pass Through Hole Registrations: The plating, microsection, and quality department's records showed that there was enough plated copper on the PWB to meet the customer requirements. Thus, this variable will be awarded a score of 5 (100%).
- 20) Number of PWB Pass Test (Net Test, Through Hole Test, Bread Board Test (s): the test department records showed that all PWBs passed electrical test. (Net Test administered). The PWB manufacturer had the capabilities to test the PWB per the customer requirements. Thus, this variable will be awarded a score of 5 (100%).
- 21) Number of Shipping Methods Available: The shipping department records showed that the PWBs shipped by United Parcel Service per the customer requirements. Thus, this variable score will be a 5 (100 %).
- 22) Number of Capabilities / Servers for Downloading the Gerber Files: The engineering department records showed that the customer sent the Gerber data by mail, thus this variable will be awarded a zero score since it was not utilized.
- 23) Number of PWB Pass Blind / Buried Vias registrations: The plating, microsection, and quality department's records showed that there was enough plated copper on the PWB to meet the customer requirements. Thus this variable will be awarded a score of 5 (100%).
- 24) Number of PWB Material Types: The engineering department records showed that the PWB manufacturer didn't stock the material (polyimide) and it had to be ordered. The PWB manufacturer was capable of manufacturing the PWB per the material customer requirements. Thus, this variable score will 5 (100%), although the PWB manufacturer had to order the material.

25) Number of Shipping Packaging Availability: The shipping department records showed that the PWB manufacturer had shipped the PWB utilizing the shipping packaging (ESD) per the customer requirement, thus this variable will be awarded a score of 5 (100%).

By analyzing the results to determine the customer satisfaction, the measured total database customer satisfaction weight is 56.88; this will be divided by the total basic weight obtained from the research surveys results 79.04 (nominal weights), which results in a customer satisfaction of 72%.

Table 12: Case Study Customer Satisfaction

Items	Assigned weight from the survey	Percentage received from database	Weight Awarded	In Xs
# of Days to Receive PWB	4.68	100%	4.58	X01
PWB Pricing	2.97	90%	2.67	X02
QA Department Response	4.65	75%	3.49	X03
Warranty on the PWB	3.43	100%	3.43	X04
# of PWB Meeting CLW requirement	3.57	94%		X05
# of Days to Receive Quote	3.16	60%	1.89	X06
# of Days to obtain RMA	4.38	0%	0	X07
# of Days to Access TS	4.29	80%	3.43	X08
# of Days to Access CS	3.71	90%	3.33	X09
# of PWB Manufacturer Etch Capability	3.86	100%	3.86	X10
PWB Thickness	3.52	77%	2.7	X11
Number of PWB Pass Through Hole Registrations	2.84	100%	2.84	X12
# of PWB Pass SMA	2.9	100%	2.9	X13
# Manufacturer Test Capabilities	1.7	100%	1.7	X14
# of PWB Material Types	1.03	100%	1.03	X15
# of PWB Pass BBV registrations	2.22	100%	2.22	X16
# of Shipping Methods	2.41	100%	2.41	X17
# of Shipping Packaging Availability	1.01	100%	1.01	X18
# of Capabilities / Servers for receive GF	1.99	0%	0	X19
# Number of Capabilities to Manufacture PWB LV	3.2	100%	3.2	X20
# of Capabilities to Manufacture PWB QT	3.7	100%	3.7	X21
# of PWB Pass CT requirements	3.13	100%	3.13	X22
# of Days to Obtain Credit for returned PWB	3.36	0%	0	X23
# Days to Resolve TI	3.97	0%	0	X24
# of PWB Meeting LSW Requirements	3.36	100%	3.36	X25

In this chapter a detailed analysis of the surveys questions was performed to develop a model to measure customer satisfaction. The analysis showed that there are three types of PWB customers, each type had different perception about their customer satisfaction, and thus it was important to determine a unique model for each type of the PWB customers industries.

A unique model to measure individual customer satisfaction was also developed. The model would be able to track individual customers' satisfaction which helps monitor in real time the customers' satisfaction with the product or services of a PWB manufacturer. The individual customer scores were also plotted on a control chart to locate individuals to target for improved customer relations. The control chart will also track in real time any out of control customer unhappiness with a single service or a product.

Finally, a customer satisfaction model that incorporates the PWB customer's power of purchase was also introduced. The customer power of purchase was an important addition to the customer satisfaction model because a PWB manufacturer can first address satisfying their largest customers. In addition, the satisfaction model will be a real time measurement of the customer satisfaction and it will be a more realistic measurement of the customer input and activity. In contrast to survey reactive methodology to measure customer satisfaction or dissatisfaction, the developed methodology is a proactive process, where any negative or positive customer satisfaction is measured in real time. The introduced methodology differs from the survey method in measuring customer satisfaction in that it allows the identification and tracking of customer's satisfaction results by individual customers and/or takes into consideration the purchasing power of the individual customer. The introduced methodology also has the capability to track customer satisfaction using control charts to identify any customer whose satisfaction has significantly fallen so that corrective action can be taken on their respective customer satisfaction scores.

Another contrast between the introduced methodology and the survey methodology to measure customer satisfaction is that the survey method always has an inherent bias by nature, order, and wording of the question on paper, and if the surveys are taken by phone, the

surveyors' gender, speaking voice and intonation can bias the results. In addition the survey method to measure customer satisfaction has a low response rate by comparison to the introduced method in which the customer satisfaction will be measured continuously by order and/or by shipment. Another contrast between the survey method to measure customer satisfaction and the introduced method is that the survey method is dependent upon spacing the mailings of the surveys to the customers over a wide length of time in order not to pester or antagonize the customer. On the other hand, the introduced method does not require the customer to complete multiple surveys to measure his/her satisfaction, but instead utilizes the data collected internally. Finally, the PWB manufacturer can save money in the long term by using the developed method instead of the survey method by eliminating the associated cost that is inherent in sending surveys such as: mail delivery cost, envelopes, paper, printers, printer ink, return of surveys delivery cost, labor to accumulate and sort the survey data, labor to send the survey by mail, the cost of incentives such as free gifts or free vouchers to the customers to get a survey response back, the cost of sending the incentives ( gifts or free vouchers) by mail to the customers, and the labor it takes to extract the customers addresses and contacts.

The survey-associated costs can mount, especially if the incentives to receive more responses require a separate mailing to the customers, but the developed method's only associated cost is in the labor cost that will initially be required to set up the reporting process internally and the routine labor cost to collect the data. Since the PWB manufacturers electronically track the variables data, the data can be dumped in spreadsheets to be tallied or imported directly to the spreadsheet or to the developed computer software. The cost of pulling the data and utilizing it for the developed model in the case study was approximately ten minutes per month (to extract the data and import it into the database). In comparison to the survey

method, the cost of sending a survey or interviewing a customer to get his/her satisfaction response and tallying the data would amount to far more than ten minutes.

In conclusion, the developed method to measure customer satisfaction utilizing internal data can be more cost effective, more accurate, can provide individual customer satisfaction scores, can measure whether or not these individual scores are statistically lower than the majority, and can provide satisfaction measures in real time none of which can be supplied by the survey method.



## **CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH**

### **Introduction**

This chapter will discuss conclusions to the research and provide recommendations for future research that is based on the same theory of utilizing existing data within organizations in order to develop a model to measure, in real time, customer satisfaction. The first section presents conclusions of the study. The second section provides recommendations for future research.

As the final model to empirically measure the PWB customer satisfaction has been developed, there are many conclusions that can be drawn from this new method that is based on findings and the PWB customer's input. As these findings are uncovered and validated, a model to measure the PWB customer satisfaction using data that are available to the PWB manufacturer has laid the ground rules to further studies to develop models to measure other organizations' customer satisfaction in real time. The model developed has used available data that can be updated in real time in which it measures the PWB customer satisfaction in a proactive manner where any deviation from the normal can be immediately observed and corrective action taken. As an example, if the PWB manufacturer noticed that the PWB customer satisfaction indicator had dipped because of PWB pricing, this indicates that the PWB prices on the full spectrum among the PWB organizations may have dipped and the manufacturer has not followed suit to adjust its prices to match the other organizations. There are several conclusions that the study and the author concluded for the research and the model that has been developed.

- 1) Customer satisfaction can be measured in real time with data available from the PWB manufacturers to determine their customers' level of satisfaction

- 2) Surveys are not the only method available to measure customer satisfaction; survey input can be used to at least partially validate the proposed method to measure customer satisfaction, (Surveys have their own inherent problems for accurately measuring customer satisfaction).
- 3) There is data available to the PWB organizations that are not being utilized efficiently.
- 4) Surveys do not include all the factors that measure customer satisfaction and there are no methods developed to validate the survey outcome.
- 5) The model developed measures the customer satisfaction based on real time data that are being collected by the organization from feedback from the customer either in writing, verbally or by his/her activity.
- 6) The PWB satisfaction model actively measures the customer in a reactive process where any deviation can be instantly recognized.
- 7) There is a contrast between the model developed and the survey method to measure customer satisfaction, one is that the survey has to be mailed to the PWB customers and wait for a response in order to determine any issues or negative activity from the PWB's customers, while the developed model, on the other hand, is measured and it fluctuates in real time to bring attention to any problems negatively affecting customer satisfaction.
- 8) The approach to the model development can be easily integrated into any organization regardless of whether it is in the PWB business or not. The actual developed model is compatible with all different types of businesses that use assembly service and manufacture PWB.

- 9) The model developed was based on factors which were deemed important by the literature, subject matter experts, or PWB customers in influencing PWB customer satisfaction.
- 10) Data is gathered by the PWB manufacturer employees which provide a measurement tool for organizing and mobilizing the manufacturer's different departments into one goal, which is improving the overall manufacturer customer satisfaction.
- 11) The developed method of measuring the PWB manufacturer customer satisfaction generates ownership of the process and the participation of all the organization employees into measuring their customer level of satisfaction.
- 12) PWB customers from the assembly and users organizations tend to be more involved in the PWB manufacturing process than the service organizations which rework assembled PWBs.
- 13) The more the PWB manufacturer employees will be involved in measuring their customer satisfaction, the more likely customer satisfaction will improve.
- 14) It was observed that the overall PWB customer satisfaction rating and final score is highly correlated to the fluctuation of any factor that is in the PWB customer satisfaction model.
- 15) It was observed that the overall PWB customer satisfaction rating and final score is highly correlated to the fluctuation of any factor that is in the PWB customer satisfaction model.

In conclusion, to successfully measure PWB customer satisfaction the customer input, the employees' participation, the data collection and the developed satisfaction model have to all have been dealt with in a synchronous motion. If one process is not implemented the entire

system will fail. All the processes are dependent on each other to accurately measure the PWB manufacturer's customer satisfaction.

### **Future Areas of Research and Discussion**

For future research it is recommended to apply this approach or process theory for determining customer satisfaction models for different types of organizations that are involved in the production of different types of products. The factors that will influence the customer satisfaction that pertains to the particular product will need to be determined and a new model will need to be developed.

This study was limited to the PWB customers that use, assemble, and service PWBs. The study could also be expanded to include the entire systems assembly, including the hardware and software that will be used on the PWBs to assemble the entire system to measure the customer satisfaction of the end item.

The analysis and validity of the study was based on 85 respondents from a total of 150 surveys that were sent out to PWB customers. Thus the model which was developed can be more reliable by expanding the sample size to include more organizations, which will assist in narrowing the broader factors that were included in the original model. This will affect the customer satisfaction measurement in that it will be more refined and accurate. Further studies should also be conducted to determine the root cause of the fluctuation and differences of the customer satisfaction rating between the assembly, service, and users organizations.

Organizations that have multiple manufacturing sites for the same product may test the validity of the selected variables by monitoring their profit and by setting the variables to either their highest or lowest economical levels (to maintain profitability) in one facility/organization

and compare it with the other participating facilities / organizations. It would be interesting to note those that have differing ratings on satisfaction and then observe their profitability, their individual or composite customer ratings, and their position relative in the industry.

## **APPENDIX A: LETTER OF CONSENT**

----- Original Message -----

From: adam maamoun

To: dougwoodworth@mindspring.com

Sent: 2/4/2008 12:54:32 AM

Subject: Can you help in completing a survey for my Dissertation in the PhD Program at UCF, Adam Maamoun

Dear Manager/Engineer

My name is Adam Maamoun and I am a PhD candidate in the Department of Industrial Engineering and Management Systems at the University of Central Florida. I would very much appreciate it if you could take approximately 5 minutes of your time to participate in a survey to determine the factors that contribute to the Printed Wiring Board customer's satisfaction and hence to help me determine an empirical method to measure Printed Wiring Board customer's satisfaction.

The study is completely anonymous. The following is a link to the survey that is posted on the Internet at <http://adamcustomersurvey.kiswa.com/>. Please feel free to visit this site and select the factors that you may think are related to a printed wiring board customer's satisfaction. The results will be sent to my email address anonymously. You must be a Printed Wiring Board user or purchaser, at least 18 years old and complete the survey in three weeks from the time you receive this email or letter. There is no payment or compensation for your participation; it is completely voluntary. My advisers for the doctoral research are Dr. Linda Malone and Dr. Ahmad El Shennawy. If you have any questions, comments, or concerns, they can be reached by phone or by email at (407) 823-2204 or (407) 823.5742 or at [lmalone@mail.ucf.edu](mailto:lmalone@mail.ucf.edu) , <http://iems.ucf.edu/faculty/malone.htm> or [ahmade@mail.ucf.edu](mailto:ahmade@mail.ucf.edu) , <http://iems.ucf.edu/faculty/elshennawy.htm> , respectively

P.S The survey is only to determine the factors that have an impact on customer satisfaction for the PWB industry.

Thank you so much for your support in this study

Sincerely,

P.S The survey is only to determine the factors that have an impact on customer satisfaction for the PWB industry. Also, if you would like a copy of my dissertation I will be glad to send it to you after the graduation to utilize it to measure your company customer satisfaction with data already at your disposal without having to send out customer surveys.

Thank you

Adam Maamoun

Quality Assurance Engineer

70 Ready Avenue

Fort Walton Beach, Florida 32548

Phone # (850)-664-6070 Ext 6737

Fax # (850)-664-6007

<http://www.mtifwb.com/>

<http://www.avcom.mtifwb.com/>

## **APPENDIX B: UCF IRB APPROVAL**





University of Central Florida Institutional Review Board  
Office of Research & Commercialization  
12201 Research Parkway, Suite 501  
Orlando, Florida 32826-3246  
Telephone: 407-823-2901, 407-882-2012 or 407-882-2276  
[www.research.ucf.edu/compliance/irb.html](http://www.research.ucf.edu/compliance/irb.html)

### Notice of Exempt Review Status

From: UCF Institutional Review Board  
FWA00000351, Exp. 5/07/10, IRB00001138

To: Adam Maamoun

Date: December 05, 2007

IRB Number: SBE-07-05318

Study Title: **PRINTED WIRING BOARD (PWB) CUSTOMERS SATISFACTION SUREVY IN FULLFILMENT OF THE PHD DESSERTATION REQUIRMENTS TO SURVEY PWB CUSTOMERS TO DETERMINE THE FACTORS THAT CONTRIBUTE TO THEIR SATISFACTION,**

Dear Researcher:

Your research protocol was reviewed by the IRB Chair on 12/03/2007. Per federal regulations, 45 CFR 46.101, your study has been determined to be **minimal risk for human subjects and exempt** from 45 CFR 46 federal regulations and further IRB review or renewal unless you later wish to add the use of identifiers or change the protocol procedures in a way that might increase risk to participants. Before making any changes to your study, call the IRB office to discuss the changes. **A change which incorporates the use of identifiers may mean the study is no longer exempt, thus requiring the submission of a new application to change the classification to expedited if the risk is still minimal.** Please submit the Termination/Final Report form when the study has been completed. All forms may be completed and submitted online at <https://iris.research.ucf.edu>.

The category for which exempt status has been determined for this protocol is as follows:

2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey or interview procedures, or the observation of public behavior, so long as confidentiality is maintained.
  - (i) Information obtained is recorded in such a manner that the subject cannot be identified, directly or through identifiers linked to the subject, **and/or**
  - (ii) Subject's responses, if known outside the research would not reasonably place the subject at risk of criminal or civil liability or be damaging to the subject's financial standing or employability or reputation.

A **waiver of documentation of consent** has been approved for all subjects. Participants do not have to sign a consent form, but the IRB requires that you give participants a copy of the IRB-approved consent form, letter, information sheet, or statement of voluntary consent at the top of the survey.

All data, which may include signed consent form documents, must be retained in a locked file cabinet for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

On behalf of Tracy Dietz, Ph.D., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 12/05/2007 09:15:01 AM EST

IRB Coordinator

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