Designing an Arm Support Model to Minimize UECTD Risk Among Filipino Electronic Technicians Using QFD, KANO Model, TRIZ and Anthropometry

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ABSTRACT

Electronics technicians are prone to develop Upper Extremity Cumulative Trauma Disorder (UECTD) owing to the awkward posture, repetitive motion and static loading associated with the routine tasks of multi-testing, soldering and desoldering. In the Philippines, validation using Rapid Upper-Limb Assessment (RULA) yielded a score of 5.774 requiring intervention as a result of an Action Level 3 classification. A two-phase study approach, Quality Functional Deployment (QFD), KANO model, Theory of Inventive Problem Solving (TRIZ) and Anthropometry results were used as inputs in the design stage. QFD revealed 168 relationships between engineering and customer requirements, and 48 correlations with technical requirements. Six "attractive", five "one-dimensional" and three "indifferent" engineering attributes were generated from the Kano Model analysis. Meanwhile, the determined contradictions during the designing stage were resolved using TRIZ. The resulting engineering attributes based on QFD, KANO and TRIZ were matched with the 5th to 95th percentile upper extremity anthropometric dimensions to determine the best fit and the ensuing optimal attributes were used to construct the design model. This study demonstrated the effectiveness of combining TRIZ, QFD principles, KANO Model Analysis, and Anthropometry in achieving the target ergonomic and functional design objectives tailored after user requirements to mitigate a real-world occupational hazard.

Keywords: Anthropometric Dimensions, Arm Support, Electronic Technician, KANO Model, Quality Functional Deployment (QFD), Rapid Upper-Limb Assessment (RULA), Theory of Inventive Problem Solving (TRIZ), Upper-Extremity Cumulative Trauma Disorder (UECTD)

INTRODUCTION

The Philippines is known as one of the import capital Asian countries of second-hand electrical and electronic equipment (EEE) from developed countries. According to Terazono and Yoshida (2008), Japan has exported 2 million second-hand TVs annually primarily to other Asian countries since 2004. Although the destinations of the said exports vary from year to year, it is estimated that around 400,000 units is exported to the Philippines annually. In terms of general second-hand electronic equipment, Cardenas (2007) estimated that approximately 0.6-1.2 million of these pieces of equipment were imported into the Philippines every year from 2001 to 2005. The growth of second-hand EEE in the Philippines has been characterized with good and bad effects. On the one hand, it opens job opportunities to Filipino electronic technicians. On the other, Terazono and Yoshida (2008) argue that imported TVs are either damaged upon arrival (3%) or malfunctioned (40%). As a result, repair services and technicians are highly needed. Technician and associate professional occupation group are ranked fourth among the jobs with highest workdays lost due to occupational injuries (Bureau of Labor and Employment Statistics (BLES), 2012). The tasks related to multitesting, soldering and desoldering involve repetitive motion, static muscle loading, awkward postures and even vibration. Previous studies have confirmed that repetitive motion, static muscle loading and existence of vibration can lead to UECTD (NIOSH, Armstrong, 1982; Punnet, 1985; Siverstein, 1986). Moreover, during the troubleshooting process, technicians tend to position their arms, shoulder, elbow and wrists in awkward manners. Awkward posture is considered to be the top driver of CTD development (Armstrong, 1982; Putz-Anderson, 1988; Rothflesch, 1978). Arm support is suggested to alleviate the risk of UECTD development. It was found in various studies that arm support helps to reduce the activity of the muscles in the different parts of the upper extremities (Feng et al, 1997; Onyebeke, C. et al, 2013; Stal et al, 2001; Coulson et al, 2010; P.K. Nag et al, 2007; Fernandez, 1998).

Problem Statement

The tasks performed by an electronic technician are highly associated with static muscle loading, repetitive motion and awkward postures which increase the risk of UECTD development. An arm support is deemed necessary to minimize the risk, utilizing industrial engineering and ergonomic principles to meet the functional and ergonomic requirements of the end-user.

Objectives of the Study

In response to the need of having a mechanism that could potentially minimize the risk of UECTD development among Filipino electronic technicians, this paper aims to achieve the following:

- to quantify the UECTD risk level among Filipino electronic technicians while conducting troubleshooting activities such as multitesting, soldering and desoldering;
- to gauge the technician requirements and integrate their voice on the design of the arm support model;
- to systematically resolve the identified design technical contradictions or problems without sacrificing the engineering and user requirements; and
- to develop and design an ergonomic arm support using Theory of Inventive Problem Solving (TRIZ), QFD principles, KANO Model Analysis and anthropometry.

Significance of the Study

In repairing service industries and electronic technician professions, upper extremities and various tools are widely used. Designing an ergonomic arm support model that can minimize the risk of developing UECTD and can promote safety and health in the long run. This paper can provide information to the technicians which among the tasks that can influence the risk of UECTD. Also, the findings of this paper can be used as inputs in formulating job and workplace design for electronic technicians and repairing services industries specially when dealing with Cumulative Trauma Disorder issues. Moreover, this provides a new design approach in achieving the target ergonomic and functional design objectives tailored after user requirements to mitigate a real-world occupational hazard.

Conceptual Framework

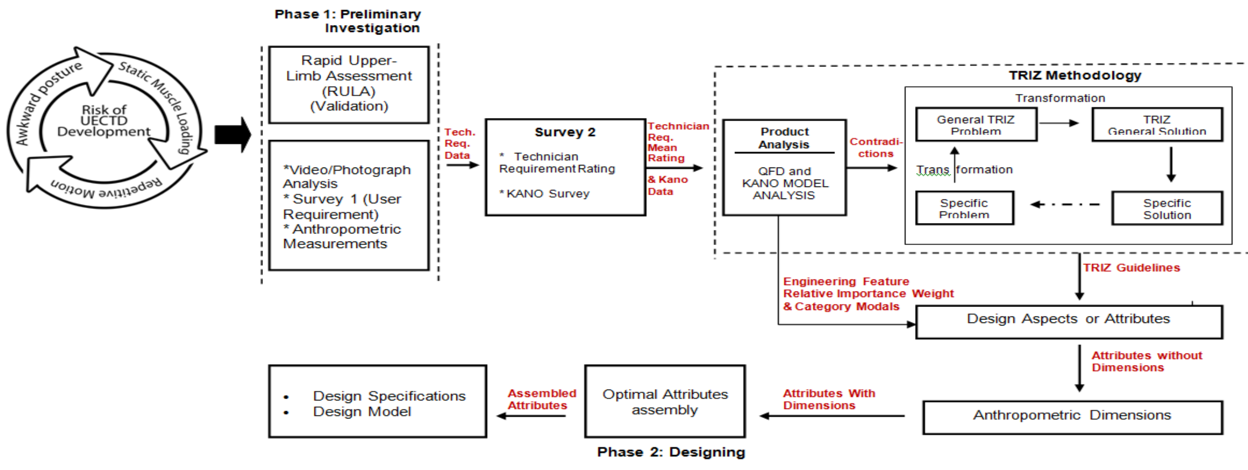


Figure 1. Research Conceptual Framework

The concept of this paper starts with the UECTD risk. The risk of developing Upper Extremities Cumulative Trauma Disorder (UECTD) is caused by three main risk factors namely awkward posture, static muscle loading, and repetitive motion. RULA also suggested that tasks performed by electronic technicians are highly associated with UECTD. Theoretically, arm support reduces the pressure of the neck, trunk and shoulder. To respond to this, an ergonomic arm support model was developed. This study used a two-phase research approach. The first phase focused on the preliminary investigations which included video analysis, interview, RULA analysis and the first survey. During this phase, the concept of arm support was introduced and technicians were asked about the features that an arm support device should have. Also, anthropometric measurements were conducted. The second phase of the study was the designing stage. The second survey was conducted which included technician arm support requirements or features rating and the KANO survey. The customer requirements gathered during the first survey and the feature importance ratings were used as inputs to the Quality Functional Deployment (QFD). Also, QFD were used to measure the relationships among the features. Then, KANO model analysis was employed to gauge the perception of the technicians about the engineering features and their possible effects on satisfaction. These two processes can be described as the product analysis. The results generated from the product analysis suggested various contradictions or problems. Furthermore, the mentioned contradictions were then used as inputs to the Theory of Inventive Problem Solving (TRIZ) methodology. TRIZ analysis, QFD and KANO model results were utilized to come up with the design attributes. These attributes were then matched with the upper extremity anthropometric dimensions to get the best fit. These were then assembled to arrive with the arm support design model. Then, design specifications were generated.

REVIEW OF RELATED LITERATURE

Cumulative Trauma Disorder (CTD)

Work-Related Cumulative Trauma Disorder (WRCTD) or Repetitive Strain Injuries (RSI) or Musculoskeletal Disorder is a term used to describe a soft tissue injury due to series of activities. WRCTDs are defined as those diseases and injuries that affect the musculoskeletal, peripheral nervous, and neurovascular systems that are caused or aggravated by occupational exposure to ergonomic hazard (NIOSH). This disorder is associated with the word cumulative which means that it is developed over a period of time due to repeated activities or tasks that can cause stress to a particular portion of the body. Another term that is associated with this health condition is the word trauma. Trauma refers to the injuries in the body due to stress.

The prevalence of CTD varies from industry to industry. Steelcase Inc (2002) reported that seventy percent of CTD cases include people in the manufacturing, assembly, process and service jobs. Twenty-five percent of the said cases include those who are in the managerial, professional and sales professions. In addition, five percent of the CTD cases include those people who are in the administrative professions. The variation in the number of cases is due to the distinction of the risk factors that could aggravate CTD development. One of the classifications of Cumulative Trauma Disorder is Upper-Extremities CTD. This is also known as Upper limb or Thoracic Musculoskeletal Disorder. It is defined as soft tissue injuries in the shoulder, arm, forearm, wrist, or hand. Usually, this disorder is evident in these parts of the body because they are often used in activities. One of the examples of job that often use hands in carrying out activities is electronic technician profession. In this job, a technician usually uses both hands in carrying out repairing procedures. As a result, this may lead to tissue injuries.

In 1987, the Bureau of Labor Statistics conducted a survey to the 25 states in the U.S and reported that 10,600 of the CTD cases involved the upper extremities. In the UK, this type of CTD is ranked as the second disorder experienced by the employees in various work organization. Melhorn (1996) argues that this illness has been identified by the National Institute for Occupational Safety and Health as one of the ten most significant occupational health problems in the United States, accounting for 56% of all occupational injuries that affect 15% to 20% of all Americans.

Factors Affecting Upper-Extremities Cumulative Trauma Disorder

There have been a significant number of researches performed in the area of Upper-Extremity Cumulative Trauma Disorders. Most of the objectives of these studies are to determine the risk factors associated to the development of UECTD. Some researchers classified these factors as intrinsic and extrinsic. Kummel and Melhorn (2000) reports that intrinsic contributing factors include age, anatomical abnormalities, and metabolic disorders among others. Extrinsic factors include ergonomic factors, repetition, force, posture, vibration, temperature, contact stresses and unaccustomed activities. Other studies suggested that the existence of Upper Extremity Cumulative Trauma Disorder is due to physical, personal and psychosocial factors.

Physical factors are the primary reasons for the development of UECTD (Armstrong, 1982 and Silverstein, 1986). In the area of Ergonomics and Human Factors, physical factors refer to the physical aspect of the environment which mainly refers to force, repetition, vibration, posture/ergonomics, temperature, color, and noise, among others. Usually these physical factors are actually geared with ergonomic hazard that aggravates UECTD. Researchers (Armstrong, 1982; Arndt, 1987; Blair 1987; Punnet, 1985; Rothflesch, 1978; Siverstein, 1986; Stock, 1991) believe that vibrating tools, forceful motions, and motions in awkward or extreme postures are three other important ergonomic hazards proven to cause these disorders. Another ergonomic physical hazard that is associated with physical factors is the physical activity of a person. Bernard (1997) suggested that the lack of physical activity may increase susceptibility to injury, and after injury, the threshold for further injury is reduced. Basically, physical activity of an employee plays a significant role in the prevalence of CTD.

Aside from the physical factors, several studies have found that individual or personal variables also affect the development of UECTD. Studies Guo et al., 1995; English et al., 1995; Ohlsson et al., 1994; Biering-Sorensen, 1983) concluded that age factor significantly affect the occurrence of CTD. Another studies (Hales et al., 1994; Johanson, 1994; Chiang et al., 1993; Armstrong et al., 1987) showed that gender is a significant contributing factor. In addition, more researches (Werner et al., 1994; Nathan et al., 1993; Heliovaara, 1987) strongly claimed that anthropometry of a person such as the Body Mass Index (BMI), weight and height are significant factors. Other researchers (Finkelstein, 1995; Kelsey et al., 1990; Hildebrandt, 1987; Owen et al., 1984; Svensson and Andersson, 1983) found that smoking habit of a person is a significant factor. These are just some of the personal factors that could affect CTDs. Other factors may include job experience, wage and marital status.

Arm Support Device

Bart Visser et al. (2000) claim that reduction of muscle activation in the neck-shoulder region during standard visual display unit work can be achieved with arm supports. P.K Nag et.al (2009) believe that the forearm support significantly reduced the activity of forearm muscles over the floating posture. The essential role of arm support in some professions has been studied. Bergqvist et al. (1995) claim that various studies have confirmed that lack of arm support is a predictor of CTD development. Other researchers have proven that pressure can be reduced using an arm support. Rose (1991) believes that key activation forces are reduced from 1.1N to 0.7N when arm support is used. Some researchers (Aaras, 1990; Ro, 1997; Anderson, 1980; Jorgensen et al., 1989) and Pheasant (1997) stated that working with unsupported or elevated arms increases the load on the neck, shoulder and back. It has been noted also that static loads are pronounced when sitting rather than standing (Steelcase, 2002). Designing an arm support is difficult since a lot of factors must be considered. There are available arm support devices in the market but these are all intended for typists and other office professions and health related uses.

KANO Model Analysis

Determining the ergonomic needs for a certain product or design is difficult. This challenge is driven by the fact that user's behaviour and physical characteristics vary. Designers and engineers integrate tools that can quantify the customer requirements and perception toward product attributes. One of the techniques which is commonly used is the KANO model. A KANO model analysis was developed by Professor Noriaki Kano of Tokyo Rika University in the 1980s. The main idea of this analysis is to determine and categorize the product or service attributes and their potential influence on customer satisfaction. This divides the attributes into three category modals namely attractive, one-dimensional and must-be. The must-be requirements indicate that dissatisfaction level tend to increase when the product or service is less functional. However, no matter how the product or service becomes functional, the satisfaction level never rises. The attractive requirement states that when the product or attribute is fulfilled, user or customer becomes satisfied. However, dissatisfaction level does not increase if it is not fulfilled. Furthermore, one-dimensional requirement refers to the attribute that states that the more it is fulfilled, the higher the satisfaction level and vice versa. KANO model is integrated in a study to establish the relationship between performance attributes and measure the influence of the features to the satisfaction or dissatisfaction level. Chen, C. and Chuang, M. (2008) used KANO model to better understand the relationship between performance criteria and customer satisfaction, and to resolve trade-off dilemma in multiple-criteria optimization by identifying the key criteria in customer satisfaction. This tool is not just applicable for product or service improvements but also for other essential aspects of the organization. Llinares, C. and Page, A. (2011) used KANO model to analyse the impact of different subjective attributes on consumers' purchase decisions.

Quality Functional Deployment (QFD)

Identifying the technical requirements of a product or service is a crucial aspect in any product development process specially in giving consideration to the customer requirements. In terms of designing, QFD is a tool commonly employed to achieve the engineering attribute values without sacrificing the voice of the customers. Sireli et al. (2007) stated that QFD can help to evaluate the impact values of design requirement characteristics on meeting customer requirement expectations by prioritizing the design requirement based on their important values. Also, this method has been considered as a powerful tool in assessing the customer standards and at the same time providing ergonomic guides for product or service designs. Guedez, V. et. al (2001) used QFD to achieve the ideal container design in a flexible manufacturing system. It has been used as well to gather useful information in the ergonomic design for hand tools. Haapalaine, M. et. al (1999) concluded that QFD is a suitable method for the ergonomic design of hand tools.

Theory of Inventive Problem Solving (TRIZ)

Problems during the product development process are inevitable. In most cases, these problems are generated when one aspect of the product or process is changed. These problems are described as contradictions. There are numerous methodologies that are typically employed to address this issue. One of these methodologies is the Theory of Inventive Problem Solving (TRIZ). TRIZ was developed by Genrich Altshuller and his collegues in the year 1946. This was created by examining and codifying over 2 million patents in terms of principles and means of solving the problem. Domb (1997) suggested that the main concept of the theory can be summarized into ideality, contradictions and technical system evolution. Various studies had been conducted already using TRIZ for designing products and services. Butdee, S. and Vignat, F. (2008) successfully applied TRIZ methodology to assist light weight bus body design. The strength of the new designed light weight bus was tested and the result was accepted. Another study was on developing innovative designs for automated manufacturing systems (Li, T. & Huang, H., 2008). The authors applied TRIZ and Fuzzy Analytical Hierarchy Process (AHP) to come up with a design of automated connector assembly line.

Today, TRIZ is commonly employed in product or process development together with the other design and problem solving methodologies. Marsot, Jacques and Claudon, L. (2004) demonstrated how to integrate ergonomics into product design by using Functional Analysis, QFD and TRIZ in designing a boning knife. The study showed how the three methods effectively integrated ergonomic design into the design stage. TRIZ and other methods such as the KANO model and QFD are also applied in the furniture industry. Hashim, A. and Dawal, S. (2012) improve the school workshop's workstation design for adolescent in terms of ergonomic and users need by combining KANO model and QFD. Also, Raneses, N. et. al (2012) conducted a study on combining QFD, TRIZ and Value Engineering in designing ergonomic classroom desks and chairs. In these studies, researchers were able to determine the requirements of the users and translate them into design parameters. Another interesting application of TRIZ methodology, QFD and KANO model is when it is used to prevent health hazards. Panabang, M. et. al (2011) were able to design working women pump shoes to minimize blister problem by combining melded QFD, TRIZ and Value Engineering. In this paper, the authors determined the voice of the working women and manufacturers and translate them into parameters to design ergonomic pump shoes.

METHODOLOGY

Phase I: Preliminary Investigation

The target respondents of this study were the self-employed Filipino electronic technicians. Fourteen right handed Filipino male technicians participated in the experiment. Due to resources constraints, all the respondents were selected within Cagayan de Oro areas. The video and photograph analyses were conducted at the Electronics and Communications Laboratory of Mindanao University of Science and Technology at Lapasan Highway, Cagayan de Oro City. This paper used two surveys to gather data. The first survey was intended for the preliminary investigations which include profiling, video and photograph analyses, job analysis and anthropometric measurements. The videos gathered were also used in conducting the RULA. Also during the first survey technicians were asked as to the desired features of the arm support device. The second survey focused on the importance rating of the desired features gathered during the first survey and KANO model survey. To efficiently gather data, video recording and photograph analyses were used. Filming took place from the right and left laterals of the technician. Two cameras were positioned perpendicular to the plane of movement to be studied (Cook et al., 2003). Each respondent was monitored relative to their tasks. The recording was analyzed and monitored frame-by-frame. Job and task analyses were employed in this study to determine the tasks involved and the amount of time required to complete the task when troubleshooting. This also helped in determining the critical activities that are to be considered when designing the arm support device. In addition, technicians were asked to list down the tasks that they are performing when troubleshooting and asked them to give the estimated percentage time spent to do the tasks.

Phase 2: Designing Stage

In the designing stage, results from the preliminary investigation were utilized. During phase 1, features that were listed down were then summarized and used as inputs for the second survey. The summarized customer requirements gathered during Phase 1 were then used during the second survey to determine their importance rating (5-very important, 4-somewhat important, 3-moderately important, 2-somewhat unimportant, 1-very unimportant). The results were then used in the QFD analysis. QFD is a method used to develop a design and at the same time to satisfying the customer requirements without sacrificing the product or technical requirements. Among the pre-identified engineering requirements of the arm support device were following the lower arm in any direction; having adjustable height; base and body metallic materials; pads are made of foam; smooth texture of the pads; mounted on the table; can support both the upper and lower arms; detachable capability; Width of the pads; price; weight; colour; edges regularity; and the size. To get the over-all importance score or the prioritization of "hows" for each engineering characteristic and at the same time considering the weight of the demanded features, sums of the relationship score that were multiplied to the corresponding relative weight (percentage) were calculated. Then, technicians were asked how they are going to feel if a particular engineering feature is fulfilled or not fulfilled. The answers were outlined as "must be that way", "like it that way", "neutral", "can live with it" and "dislike it that way". There were twenty eight questions that were formulated. After the survey, responses were analyzed using the KANO evaluation table. Opposing questions were analyzed to get the category modal. After determining the modal of each engineering feature, frequencies were then tabulated. The tabulated frequency of all the category modals of each category was then summarized. To determine the highest modal, percentage of each category modal was calculated. The highest percentage was then considered as the modal that represents the feature. Then, satisfaction and dissatisfaction coefficients were calculated using the calculated modal values. The customer satisfaction coefficient states whether satisfaction can be increased by meeting a product requirement, or whether fulfilling this product requirement merely prevents the customer from being dissatisfied (Berger et al., 1993). To calculate the coefficients, the following formulas were followed:

$$\underset{\text{(Satisfaction Coefficient)}}{\text{Extent of Satisfaction}} = \frac{(A+O)}{(A+O+M+I)} \quad \Big| \quad \underset{\text{(Dissatisfaction Coefficient)}}{\text{Extent of Dissatisfaction}} = \frac{(O+M)}{(A+O+M+I)X-1}$$

After QFD and KANO model analyses (product analysis), the results were then tabulated. Using the tabulation of results, assessment about whether a certain engineering feature is to be recommended for the final design was conducted. The tabulation of results was also used as inputs for TRIZ. Various complex problems were identified after the product analysis. These problems were caused by the physical and technical contradictions noted during the QFD process. Problems or contradictions identified after the product analysis were used as the specific problem. The specific problem was then transformed as the 39 parameters. The 39 parameters of contradiction matrix were used to determine the TRIZ general problem. Then, the TRIZ general problem was transformed into the 40 inventive problem solving principles. Applicable principles were chosen based on the suggested 40 inventive problem solving principles. The selected principles pertained to the TRIZ general solution. Then, these principles were converted to a sound and rational specific solution. The recommended engineering features from QFD and KANO model analyses and the derived specific solutions from TRIZ analysis were then utilized to come up with the design of arm support device.

To get the best fit and other dimensions of the design, upper extremity anthropometry measurements among Filipino electronic technicians were utilized. In this paper, there were ten upper extremity anthropometric dimensions that were considered namely setting height, forearm hand length, forearm circumference (flexed), bicep circumference (relaxed), forearm circumference (relaxed), thumb-tip reach, bicep circumference (flexed), wrist circumference, table height and chair height. These measurements were matched with the final resulting design attributes.

RESULTS AND DISCUSSION

In terms of age bracket distribution, 50% of the respondents (n=14) belong to 25-29 age bracket, 22%, 20-24 age bracket and 14%, 30-35 and 36-40 age brackets. Majority of them are single, (57%) and 43% of them are married. 28.57% of the respondents are within the weight bracket of 129-139 kilogram, 21.43% belongs to 140-150 kilogram weight bracket, 14.29% for 120-128 kilogram, 162-172 kilogram and 173-183 kilogram weight brackets while 7.14% of the total respondents are within the weight bracket of 184-194 kilogram. The maximum weight among the respondents is 187 kilogram while 128 kilogram is the minimum weight. In terms of height, majority (42.86%) of the respondents are within the height of 63 and 65 inches, 28.57% are 64 and 66 inches tall, 21.43% of them are 67 inches tall while 7.14% is 62 inches tall, with the shortest at 62 inches and the tallest at 67 inches.

Moreover, among the fourteen electronic technicians who participated, 28.57% have been working as an electronic technician for four years. 21.43% of them have been in a technician profession for five years. Among the respondents, 35.72% of them said that they have been working as technicians for five to six years. Three respondents (21.43%) claim that they have been working as technicians for eight to twelve years. With regard to the working hours, more than half (57%) of the technicians are working eight hours per day, followed by technicians who work six hours a day (22%). 14% is working seven hours per day and only 7% of them said that they spend five hours a day doing troubleshooting activities.

In addition, desoldering, multitesting, soldering and other tasks such as board cleaning, wire cutting and parts adjustments are among the tasks identified. An average of 35.21% of the time during the troubleshooting session is spent to multitesting. 29.64% is the average time spent to soldering task per repairing session, followed by desoldering task (26.64%). An average of 8.50% of the time is accounted to other tasks which included cleaning, wire cutting and alignment and part adjustments. Among the top equipment that the respondents usually repair include TVs or monitors, radio cassettes, DVD players and Amplifiers. Other appliances that are mentioned during the survey are electric fan, speaker and microphone.

Rapid Upper-Limb Assessment (RULA) Results

The top tasks performed by the technicians are multitesting, soldering and desoldering which accounted for 91.50% of the total time when troubleshooting. During the multitesting task, the right view analysis has a total RULA score of 5.714 while the left task receives a score of 5.286. In terms of the soldering task, on the right hand side, the technicians are using soldering iron. With regard to the soldering task, 28.57% of the respondents derive a total score of 7 while using the soldering lead (left view) that resulted to an average of 6.071 RULA score. In contrast, the right hand uses a soldering iron which obtains an average score of 5.786. Lastly, it can be noted that both the desoldering and soldering (right views) have equivalent scores of 5.786. This is because the right hand uses soldering iron in which the analysis is already been performed during the soldering task RULA analysis.

The mean upper arms grand score is 3.631, which indicates an average degree of shoulder flexion more than 90, while the average lower arms score is 2. The average wrist twist score is 1.00, which means that the wrists were placed in an extension position with an angle less than 15. The final average wrist grand score of 3.595 shows that wrist flexion angle is greater than 0 degree but less than or equal to 15 degrees. Most of the wrists of the technicians are bent from the midline. The mean neck score is 2.738 and the mean trunk score is 2.095, which indicates that the neck and trunk of the participants are either in flexion, rotation, side bending or in combination. The final RULA grand score of electronic technicians during the multitesting, desoldering and soldering tasks ranges from a minimum of 5 to a maximum of 7 with an average score of 5.774 approximately equal to 6.0 indicating that the average worker needed an action level 3 which is "further investigation and change soon". Furthermore, no participants have an acceptable RULA score of 1 or 2.

Table 1. RULA Analysis Results

Body Parts	Multitesting				Soldering				Desoldering				Grand Scoring	
	Right		Left		Right		Left		Right		Left			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Final Upper Arm	3.714	0.469	3.500	0.519	3.714	0.469	3.714	0.469	3.714	0.469	3.429	0.514	3.631	0.485
Final Lower Arm	2.357	0.497	2.429	0.514	2.786	0.426	2.786	0.426	2.786	0.426	2.714	0.469	2.643	0.482
Final Wrist	4.000	0.000	3.214	0.426	3.357	0.497	3.643	0.497	3.357	0.497	4.000	0.000	3.595	0.494
Wrist Twist	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
Posture Score A	5.357	0.497	4.571	0.514	5.071	0.829	5.071	0.829	5.071	0.829	5.214	0.426	5.060	0.700
Muscle Use Score	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
Final Wrist & Arm Score	6.357	0.497	5.571	0.514	6.071	0.829	6.143	0.864	6.071	0.829	6.214	0.426	6.071	0.708
Neck	2.500	0.519	2.643	0.497	2.643	0.497	3.000	0.000	2.643	0.497	3.000	0.000	2.738	0.442
Trunk	2.000	0.000	2.000	0.000	2.000	0.000	2.571	0.514	2.000	0.000	2.000	0.000	2.095	0.295
Legs	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
Posture B Score	2.571	0.514	2.643	0.497	2.643	0.497	3.429	0.514	2.643	0.497	3.000	0.000	2.821	0.541
Muscle Use Score	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
Final Neck Trunk & Leg	3.571	0.514	3.643	0.497	3.643	0.497	4.429	0.514	3.643	0.497	4.000	0.000	3.821	0.541
Final Score	**5.714**	**0.469**	**5.286**	**0.726**	**5.786**	**0.426**	**6.071**	**0.730**	**5.786**	**0.426**	**6.000**	**0.000**	**5.774**	**0.567**

Based on the Rapid Upper-Limb Assessment (RULA), the tasks multitesting, soldering and desoldering are associated with musculoskeletal loads due to risk factors namely posture, repetition, force and static loading. In addition, the risk of developing Upper-Extremity Cumulative Trauma Disorder is high based on the RULA results. RULA analysis also suggests that steps should be taken to reduce the risk factors that would lead to the minimization of the risk of UECTD development. The recommended ergonomic solution for this particular problem is undertaking changes on the workstation which is the application of the arm support. Designing an arm support device has no generic method particularly in giving considerations to the ergonomic aspect of the design. In this paper, Quality Function Deployment (QFD) method was used to assess the needs and wants of the technicians. This is to ensure that the voice of the technicians regarding the design of the arm support device is captured and translated into product and process parameters. During the first survey, it was noted that there were eleven features that the technicians mentioned namely usability, rigidity, affordability, controllability, portability, versatility, stability of motion, adjustability, and stability of mechanisms, aesthetic, shape and safety factor.

Table 2. Summary of the Customer Requirements and Importance Mean Ratings

Design Utilities (Voice of the Technicians)	Description	Rate (Mean)
Usability	How easy it is to use the arm support device to perform prescribed tasks.	4.4
Rigidity	Relative stiffness of the materials of the arm support device that allows it to resist bending, stretching and other deformation when used.	3.9
Affordability	The extent to which the arm support device price is reasonable, as measured by its cost relative to the amount that the purchaser is able to pay.	4.6
Controllability	The extent to which the arm support device is controlled during troubleshooting activities.	3.9
Portability	The quality of the arm support device of being light enough to be carried and moved from one workstation to another.	3.9
Versatility	The ability of the arm support device whether or not it can be used for both arms and whether it can be used for multitesting, soldering and desoldering.	4.2
Stability of Motion	The ability of the arm support device to safely support and contain the arm for desired the functions (arm extension, shoulder flexion, elbow flexion).	4.1
Adjustability	Ability of the device to adapt to different Filipino upper extremities anthropometric dimensions.	4.3
Stability of Mechanism	This refers to the device capability and strength of the materials and parts to assist the upper extremities.	3.6
Aesthetic	This pertains to the over-all appearance of the arm support device.	3.5
Shape	The over-all form of the arm support device relative to Ergonomic functionality.	3.2
Factor of Safety	This refers to the over-all safety of the device including the pads, base, body, edges and materials.	4.1

Among the technician requirements, affordability has the highest importance score which is 4.6, followed by usability and adjustability. Other requirements which are given higher importance rate of 4.1 to 4.3 are the safety factor, stability of motion and versatility. Other features such as portability, controllability and rigidity are given 3.9 score. Stability of mechanism, aesthetic and shape are among the requirements which received fair importance. In addition, it is noted that none of the mentioned features received a 1 or 2 score.

QFD, KANO Model and TRIZ Analyses Results

The above-mentioned feature requirements are then translated into measurable engineering requirements. In this type of design, there are fifteen identified critical specifications. These specifications include following the lower arm in any direction, having adjustable height, base and body are made from metallic materials, pads are made of foam, smooth texture of the pads, mounted on the table, can support the upper and lower arms, detachable capability, width of the pads, price, weight, colour, edges regularity and the size.

The direction of improvement for each engineering feature was determined. Features such as the cost, weight and size must be minimized. The rest of the requirements are described as target values or characteristics. Forty eight correlations are noted among the requirements. Nineteen are strong positively correlated to each other. Twenty two are positively correlated while seven of them are negatively correlated. From the House of Quality (HOO), there are 168 relationships that are noted. 36.90% or 62 of the relationships belong to the strong relationship category. There are 55 (32.74%) relationships that fall under medium category. 51 or (30.36%) of the total identified relationships belong to the weak relationship.

Product Requirement	Based on QFD Results		Based on KANO Survey and Modelling Results				Recommendation to the Final Design (Yes or No)
	Weight/Importance	Relative Weight	Modal Weight	Modal Category	Extent of Satisfaction (A+O)/A+O+M+I	Extent of Dissatisfaction (O+M)/(A+O+M+I)*-1	
Follows the lower arm in any direction	447.5	6.9	0.5714	A	0.7143	-0.2143	Yes
Adjustable Height	534.3	8.3	0.5714	O	0.6923	-0.7692	Yes
Base is Metal	627.1	9.7	0.7143	I	0.2308	-0.2308	Yes but Modify
Body is metal	800.4	12.4	0.7857	I	0.0769	-0.1538	Yes but Modify
Pads are made of Foam	475	7.3	0.3571	A	0.5714	-0.2857	Yes
Smooth Texture of the Pads	417.1	6.4	0.5000	O	0.7857	-0.6429	Yes
Mounted on the table or Workstation	677.1	10.5	0.5000	A	0.5714	-0.0714	Yes
Can support both the upper and lower arms	506	7.8	0.5714	A	0.6923	-0.0769	Yes
Detachable from the workstation or table	347.5	5.4	0.5714	A	0.6429	-0.2143	Yes
Width of the pads is adjustable	267.7	4.1	0.5000	A	0.6429	-0.2857	Yes
Price is < 1000 pesos	491.2	7.6	0.4286	O	0.7857	-0.5714	Yes
Lightweight	372.6	5.8	0.5000	O	0.6923	-0.6923	Yes
Light Colour	207.8	3.2	0.5714	I	0.1000	-0.1000	No
Curved edges	299.8	4.6	0.5714	O	0.7143	-0.7143	Yes

Table 3. Summary of QFD and KANO results and Feature Recommendations on the Final Design

As a result, the feature that states that the body of the arm support device should be metal has the highest weighted importance score (12.6%). This is followed by 9.9% (base is metal feature), 8.9% (size), 8.4% (adjustable height), 8.0% (support both the lower and upper arms), 7.7% (cost), 7.5% (pads made of foam) and 7.0% (follows the lower arm in any direction), 6.6% (texture of the pads) and 5.9% (weight). Among the features that got the lowest weighted importance are colour (3.3%), width of the pads (4.2%), curved edges (4.7%) and detachable from the table (5.5%).

Generally, QFD has shown that many engineering features are associated with each other. These relationships serve as guides in coming up with the final design by taking into account the possible effects of one engineering requirement to another feature. Aside from this, the notion of the technicians toward the design of the arm support device was also considered. It exemplified the features that need to be focused.

Based on Table 3, the features such as following the lower arm in any direction (57.14%), mountable on the table (50.00%), can support both the upper and lower arms (57.14%), and adjustable width of the pads (50.00%) are among the attractive requirements. One-dimensional requirements include adjustable height (57.14%), smooth texture of the pads (50.00%), lightweight (50.00%) and curved edges (50.00%). Metallic base (71.43%), metallic body (78.57%) and light colour (57.14%) are among the indifferent features. It can be noted as well that the feature foam as the main material of the pads (35.71%) was included either in the attractive or indifferent requirements. 28.57% of the respondents claimed that dark colour is better. 7.14% gave a questionable response on the feature that states that the arm support should follow the lower arm in any direction feature. Also, based on the table above, the price, adjustable height, support both lower and upper arms, detachable from the table, adjustable width of the pads, pad texture, curved edges and follows the lower arms in any direction are among the features that greatly affect satisfaction. The requirement pertaining to the following the lower arm in any direction has the lowest dissatisfaction influence. Curved edges, weight, base material, and colour feature have equal weight in terms of satisfaction and dissatisfaction influences. However, colour feature has the least influence. In addition, among the engineering features that have lowest influence on customer satisfaction are body material, colour and base material. The features that slightly affect dissatisfaction include colour, support on both lower and upper arms, mounted on the table and body is metal requirement

All the features are recommended in the final design but the light colour feature. This is because it has the least importance rating and at the same time it will slightly affect the satisfaction and dissatisfaction level of the technicians. Two features namely metallic base and body are still recommended for the final design but subject to modifications. These features did not influence the satisfaction or dissatisfaction level of the users but have the highest importance ratings. Also, these features are included in the design process since they are strongly correlated with the other engineering and customer requirements. Another observation from the results is the adjustable width of the pads being recommended to the final design even if it does not greatly affect the dissatisfaction level if it is not included and has the least importance weight. This feature will delight the users if it is included.

The product analysis included the measurement of the relationships between engineering features and other engineering feature items and between the customer requirements and the engineering features. From the product analysis, various problems are identified specifically the contradictions among features. To resolve this, Theory of Inventive Problem Solving (TRIZ) was employed. The complete TRIZ analysis is summarized in Table 4.

Table 4. TRIZ Analysis Results

Product Feature	Customer Requirement	Problems	Contradictions		TRIZ Suggested Inventive Problem Solving	Applicable Inventive Problem Solving	Recommended Solutions
			Feature to Improve	Parameter in conflict			
Body and Base are made of metals	Safety Factor	Metal elements are necessary to achieved rigidity and stability of the device but metal exposes technicians to electrocutions since it is a good conductor of electricity.	**#13** Stability of the object's composition	**#31** Object Generated-Harmful factors	**#35** , **#40** , **#27** , **#39**	**#35** Transformation of the physical and chemical states of an object, parameter change, changing properties. **#40** Composite	The base is still made of metal but should be enfolded with insulators such as plastics.
Mounted on the Table	Portability	The arm support should have firm grip when mounted on the table but tend to loosen the grip when the lower and upper arm weights are applied	**#2** Weight of Stationary Object	**#14** Strength	**#2** , **#10** , **#27** , **#28**	**#2** Extraction, Separation, Removal, Segregation **#28** Replacement of a mechanical system with 'fields'	Mechanical element specifically screw should be integrated to achieve the maximum tightness of the base. The area of locking screw should be increased to increase the gripping force.
Detachable from the Table	Safety Factor	Arm support device should be detached in case it is not used or disliked but technician may be prone to do various tasks to achieve this.	**#33** Ease of Operation	**#38** Extent of Operation	**#1** , **#3** , **#12** , **#34**	**#12** Equipotentiality, remove stress **#34** Rejection and regeneration, Discarding and recovering	The operation of detaching should be focused on the screw adjustment. The screw must be positioned in such a way that it can be easily adjusted.
Weight	Portability	Arm support should be light weight but the base and body have elements of metal	**#2** Weight of Stationary Object	**#13** Stability of the object's composition	**#1**, **#26**, **#39** ,**#40**	**#1** Segmentation **#40** Composite materials	Base should be created with elements of non-metallic materials. The body should be made of lighter metal.
Height	Safety factor	The height of the arm support determines the amount of pressure in the trunk and neck of the technician.	**#4** Length of stationary object	**#11** Stress or Pressure	**#1, #14 , #35**	**#35** Transformations of the physical and chemical states of an object, parameter change, changing properties.	The body of the arm support should have an adjustable mechanism.
Follows the lower arm in any direction	Controllability	Device needs to follow the lower arm in any direction but might go beyond the motion range of the technician which is hard to determine.	**#15** Duration of action of moving object	**#37** - Difficulty of detecting and measuring	**#19, #29 ,#35** , **#39**	**#19** Periodic action	Stopping lock should be integrated in the design to prevent the swing of the arm device beyond the desired range.
Weight	Rigidity/ Stability of Motion	When the weight is minimized the strength of the arm support device decreases.	**#2** Weight of Stationary Object	**#14** Strength	**#2** , **#10** ,**#27** **#28**	**#27** Cheap, disposable objects	Metals that are to be used on the arm support device should be complemented with non-metallic material but with comparable quality with metals.
Cost	Stability of Motion	When stability is achieved up to its maximum, the cost also increases.	**#39** Productivity	**#13** Stability of the object's composition	**#3**,**#22** ,**#35** **#39**	**#3** Local Quality **#35** Transformation of the physical and chemical states of an object, parameter change, changing properties	Changing/adding materials that have the same quality with metals/plastics to achieve the target stability (perhaps, local materials).

Anthropometry

Table 5 summarized the upper-extremity anthropometric measurements of Filipino technicians. The maximum range which is the 5th to 95th percentile is used (ergonomics4schools.com) since this paper aimed for the safe and comfortable posture and good match between the technicians and the arm support device,). For instance, the bicep circumference (relaxed), the measurements considered are from 21 cm (5th percentile) up to 31.88 cm (95th percentile). Maximum and minimum data are not utilized to provide space for errors or outliers. These data are matched with the dimensions of the arm support resulting attributes to get the best.

Table 5. Upper Extremity Anthropometric Measurements Data

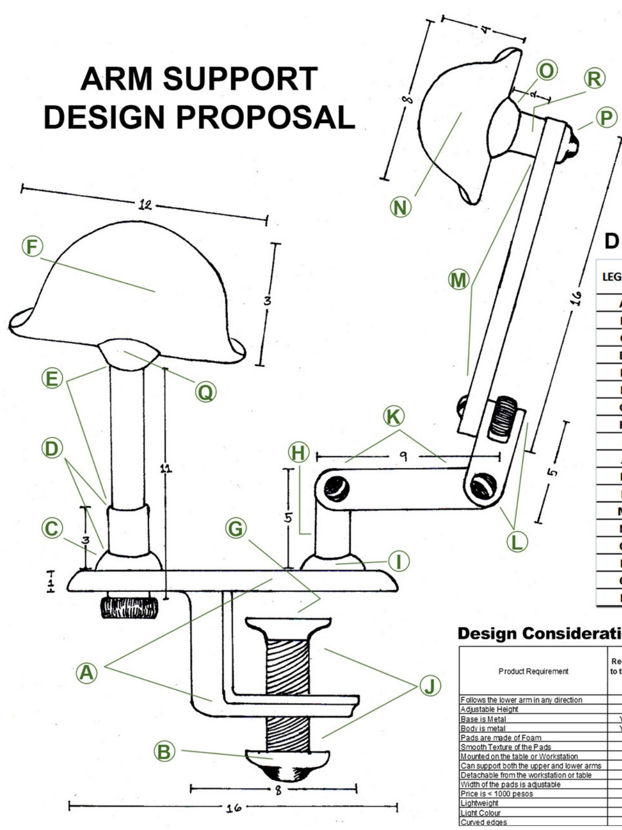
Upper extremity Parts	Measurement (cm)					
	95th Percentile	50th Percentile	25th Percentile	5th percentile	Maximum	Minimum
Sitting Height	90.92	85.00	84.00	78.18	91.70	72.00
Forearm Hand Length	44.81	42.00	39.25	38.65	45.00	38.00
Forearm Circumference (Flexed)	29.14	25.55	25.00	23.59	29.40	23.00
Bicep Circmference (Relaxed)	31.88	26.65	25.00	21.00	33.50	21.00
Thumb-Tip Reach	82.28	76.50	71.50	65.00	86.50	65.00
Bicep Circumference (Flexed)	34.00	30.50	26.30	22.00	34.00	22.00
Wrist Circumference	17.50	16.00	15.28	14.00	17.50	14.00
Table Height	72.00	71.00	71.00	71.00	72.00	71.00
Forearm Circumference (Relaxed)	28.00	24.75	23.00	22.76	28.00	22.30
Chair Height	44.70	40.00	39.00	37.95	46.00	36.00

In general, the relationships and relative importance ratings of the arm support features both the customer and technical requirements resulted from the QFD analysis, the KANO model results which are the perception of the technicians on the technical features of the product and how these features affect the level of satisfaction or dissatisfaction, the TRIZ recommended solutions to the identified contradictions or problems, and the 5th to 95th percentile of the anthropometric measurements are utilized to arrive to a reasonable and ergonomic arm support design.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The tasks performed by the Filipino technicians such as multitesting, desoldering and soldering are indeed highly associated with risks particularly due to awkward postures and static muscle loading that increase the UECTD risk development. Based on the studies, arm support is suggested to reduce the pressure and activity of the muscles in the upper extremities particularly on the shoulders, wrists, upper and lower arms and neck. It is concluded as well that designing an arm support intended for electronic technicians is deemed necessary given the tasks involved in this kind of profession to minimize the risk of UECTD development.

Moreover, this paper have shown that QFD is an effectual tool in assessing the standards of the users and developing a design and at the same time satisfying customer requirements without sacrificing the product or technical requirements. This paper confirms the usefulness of Kano model as a method in gauging the perception of the technicians on the technical features of the product and how these features affect their level of satisfaction or dissatisfaction. This study also shows a clear application of TRIZ as a systematic approach in identifying design contradictions and providing ideal solutions. The application of anthropometry in this study has evidently shown a logical approach in achieving the best fit and broadening the range of befitting users. In general, this research paper demonstrated that the combined applications of QFD, KANO Model, TRIZ and Anthropometry is an effective approach in addressing design problems and achieving the target arm support ergonomic and functional design parameters without sacrificing the user requirements. By combining the four different methods, the authors were able to come up with the following design specifications:



D E S I G N   S P E C I F I C A T I O N S

LEGEND	Part Name	Dimension (cm) Length	Height	Width	Materials
A	Base	16	18	1	Metallic, Plastics and Rubber
B	Screw Grip Adjust	4	1	1	Plastic
C	Upper Arm Support Sub-Base	1.5	1	1	Lighter metal with insulator
D	Upper Arm Support Sub-body Base	1.2	2	1	Lighter metal with insulator
E	Upper Arm Main Body	1	8	0.8	Lighter metal
F	Upper Arm Pad	12	3	5	Plastic and foam (coat)
G	Screw Grip Lock	4.5	1.5	1.2	Metal with some insulators
H	Lower Arm Sub Body A	1	4	0.8	Lighter metal with insulator
I	Lower Arm Sub Base	1.5	1	1	Lighter metal with insulator
J	Screw	2.5	6	1	Metal (Solid)
K	Lower Arm Sub Body B	9	2	1	Lighter metal with insulator
L	Lower Arm Link (Pivot Link)	2	5	1	Spring/ Metal
M	Lower Arm Main Body	1.5	16	1	Lighter metal with insulator
N	Lower Arm Pad	8	4	3	Plastic
O	Lower Arm Pad Ball and Joint Lock	2	1.5	1.5	Metal (Solid)
P	Adjust Lock	2	2	1	Plastic (hard)
Q	Upper Arm Pad Ball and Joint Lock	2.5	2	2	Plastic (hard)
R	Lower Arm Pad Base	1.8	1.8	1.8	Lighter metal with insulator

Design Considerations as per TRIZ, QFD, KANO Analysis and Anthropometry Results

Product Requirement	Recommendation to the Final Design (Yes or No)
Follows the lower arm in any direction	Yes
Adjustable Height	Yes
Base is Metal	Yes but Modify
Body is metal	Yes but Modify
Pads are made of Foam	Yes
Smooth Texture of the Pads	Yes
Mounted on the table or Workstation	Yes
Can support both the upper and lower arms	Yes
Detachable from the workstation or table	Yes
Width of the pads is adjustable	Yes
Price is < 1000 pesos	Yes
Lightweight	Yes
Light Colour	No
Curved edges	Yes

Product Feature	Recommended Solutions
Body and Base are made of metals	The base is still made of metal but enfolded with insulators such as plastics.
Mounted on the Table	Mechanical element specifically screw was integrated to achieve the maximum tightness of the base. The area of locking screw was increased to increase the gripping force.
Detachable from the Table	The operation of detaching was focused on the screw adjustment. The screw was positioned in such a way that it can be easily adjusted.
Weight	Base was created with elements of non-metallic materials. The body was made of lighter metal.
Height	The body of the arm support had adjustable mechanism
Follows the lower arm in any direction	Stopping lock was integrated in the design to prevent the swing of the arm device beyond the desired range.
Weight Cost	Metals that were used on the arm support device were complemented with non-metallic material but with comparable quality with metals. Changing/adding materials that had the same quality with metals/plastics to achieve the target stability. Perhaps, local materials

UPPER EXTREMIITIES ANTHROPOMETRIC	95th Percentile	5th percentile
Sitting Height	90.92	78.18
Forearm Hand Length	44.81	38.65
Forearm Circumference (Flexed)	29.14	23.59
Bicep Circmference (Relaxed)	31.88	21.00
Thumb-Tip Reach	82.28	65.00
Bicep Circumference (Flexed)	34.00	22.00
Wrist Circumference	17.50	14.00
Table Height	72.00	71.00
Forearm Circumference (Relaxed)	28.00	22.76
Chair Height	44.70	37.95

Prototyping and validation of the effects of using the proposed design of the arm support model on work performance and comfort are recommended. Also, further studies as to the other possible factors such as the type of tools and equipment used that potentially influence UECTD risk development among Filipino technicians should be conducted. Replicability of this study to other product and process development particularly on prosthesis and other health related equipment, tools and systems is also recommended.

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