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DESIGN-FOR-COMFORT AND FASHION HIGH-HEEL PUMP SHOES FOR WORKING WOMEN USING MELDED QFD, TRIZ, AND VALUE ENGINEERING

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ABSTRACT

While high-heel pump shoes are popular footwear among working women, they are also significant sources of discomfort, foot pains especially foot blisters. Using melded quality function deployment (QFD), TRIZ, and value engineering methods, the pump shoes were studied and re-designed for design-for fashion, fit, comfort, and durability Results of the study and prototype indicated significant improvement in comfort and reduction in blisters and cost-effectiveness on the bill of materials and standard of manufacture while maintaining design for fashion and styling.

Keywords: Design-for-fit and comfort high-heel pump shoes, Melded QFD, TRIZ, and VE methods, Function-cost analysis.

1. INTRODUCTION

According to ICON International Group, Inc, the world's largest publisher of global market research and business intelligence, the global per capita consumption of shoes in 2008 was 2.2 pair of shoes per year with USA at 4.4 pair's shoes per year while Asia was at 1.1 pairs of shoes per year. Cruz (2009) reported that the shoe per capita consumption in the Philippines in 2008 was at 1.4 pairs per person per year, or a total of around 120 million pairs of shoes and women's shoes accounting for more than 50%.

Footwear manufacturers in the Philippines are mostly found in Luzon with some are in Cebu. Around half of the locally produced footwear in the country comes from Marikina. Liliw is one of the emerging major producers of footwear. Marikina is regarded as the "Shoe Capital in the Philippines" while Liliw as "Slippers Capital in Laguna." Footwear made from these two places is known for their quality but low price. Furthermore, several local brands have become familiar among Filipino women. Among them are Rusty Lopez, Bandolino, Celine, CMG, Figlia, Marie Nicole, Viverde, Schubizz, Figliarina, Mario d' Boro, Mendrez, Via Venetto, Parisian, Chelsea, Wade, MKNY, Manels, World Balance, Cardams, Otto, Janeo, Effegi, Vivacci, Bocalo and Gibi, to name a few.

Local shoe manufacturers source their inputs both from local and foreign producers. The shoe industry, just like any other industries, depends heavily on the availability of these raw materials for continuous production. Most manufacturers attribute 55-70% of the total cost of footwear production to raw materials input (Cruz, 2009).

There are many women shoe types and designs in the market. The array of choices ranges from (ballet) flats up to 4-inch high-heeled shoes. Among the popular shoe styles and designs are boots, mary janes, mules, ballerina flats, pumps and sandals.

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Figure 1. Types of Shoes

High-heel pumps are considered as one of the favorite footwear among working women. The versatility and the elegance they lend to the wearer's appearance are two of the main reasons why women buy and wear high-heeled pumps despite the pain they inflict on women's backs as well as on ankles and calves in the form of blisters. As a classic style, pumps are designed to be worn with almost anything, although they look best when worn with skirts, dresses or dress pants. The style can be worn with jeans to liven up a casual outfit, but the pump is primarily a formal shoe, which is most commonly worn to offices, dinners and parties. High heels may make the leg look longer but as the heel height goes up, so does the pressure on the forefront, thus causing sores and blisters. Wearing high heels cause the foot slides forward, cramming the toes into the front of the shoe.

For women, style supersedes comfort when it comes to choosing shoes. Shoes are abode to feet. Unfortunately, those stylish shoes often inflict feet pain and injury in the form of wounds and blisters. Blisters and wounds occur when women wear their newly-bought shoes for the first time. Blisters commonly occur on the toes, ball of the foot, and calves as shown in Figure 2.

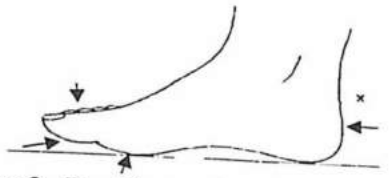


Figure 2. Foot Parts where Blisters Occur

Common causes of blisters are incorrect fit, the weight of the wearer, the height of the heels, and the type of materials used. A mismatch between the shoe size and the wearer's feet could either be wrong shoe size (length) or the shape of the shoes is not matched with the contour of the wearer's feet. Either one of them can cause blisters. When shoes are not perfectly fitted to the wearer's feet, it can cause more frequent rubbing of the skin (friction), thus causing blisters. Tightness and friction can cause the release of heat.

Prolonged exposure to heat can also cause skin blisters. Pressure also creates blisters to the wearer's feet of the high heel shoe. Pressure is defined as the force on an object that is spread over a surface area.

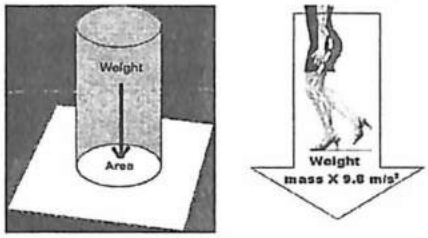


Figure 3. Pressure Created by Weight

The force created by the weight of the wearer contributes to having blisters. The pressure caused by the weight is borne by the foot especially when the wearer stands over a long period of time, which can cause blisters. Scientifically, there is a significant relationship between pressure and the force, which is in this case the weight of the person. The relationship between the weight of the person and the pressure can be stated as follows:

$$P = \frac{F}{A} = \frac{\text{weight of the wearer}}{\text{surface area where the force is applied}}$$

The raw material used to manufacture the shoes also contributes to causing blisters. Hard leather and other stiff materials cause more friction with the wearer's foot that results in foot blisters.

Table 1 System Operator Representation of High-heel Pump Shoes for Working Women

	Past	Present	Future
Super system	*People bought foot **apparels** to protect feet and to signify nobility and wealth. *Driven by the availability of materials.	*People buy **foot apparels** to keep up with trend and fashion. *Driven by designer brands.	*People buy comfortable, personalized/ customized and fashionable **foot apparels.** *Eco-friendly and user-friendly foot apparels.
System	Ladies' shoes were designed according to functionality, norms of the society and culture.	Ladies' shoes designs are fashion driven, cost-driven, and durable Foot blisters occur when worn the first time.	Ladies' shoes designs are personalized, customized, blister-free and pain-free and stylish and fashionable.
Sub-system	Shoe parts were made from limited and available materials. Shoes were manually made.	Shoe parts are made from numerous types of materials (e.g., plastic, cloth, canvass, rubber, leather, metal, etc.). Some materials are hard and stiff. Shoes are made through the use machine combined with manual labor.	Shoe parts are made from very light and soft materials. Shoes are made using electronics and computers.

This study focuses on improving the design of high-heeled pump shoes for working women to make them design for fit and comfort, durability, and cost-effectiveness using the integrated methods of quality function deployment, TRIZ, and value engineering. Table 1 demarcates the scope and boundaries of this study using the space-time system operator.

2. STATEMENT OF THE PROBLEM

Engineering system	High-heeled pump shoes for working women designed-for-fashion, fit, comfort, and durability.
Operating environment	Worn by working women at least three times a week to work
Resource requirements	Durability of materials and pressure from heels
Primary useful function	Protect the feet from forces of the ground and from extreme temperature. Provide comfort
Harmful effects	Foot blisters, Sores, Foot Pains and Cost of materials
Ideal results	Durable, stylish, comfortable and affordable pump shoes without causing foot blisters

3. ANATOMY OF THE FOOT AND PARTS OF A TYPICAL HIGH-HEEL PUMP SHOES

In this section we present the anatomy of the human foot and the parts of a typical high-heel pump shoes .The parts of a foot are the sole, heel, instep, ball, ankle, five toes, and the dorsum of the foot. This is shown in Table 2.

Human Foot Morphology

Human foot morphology is being studied to improve the fit of mass-produced shoes. The size and shape of a shoe is determined by the shoe last (or mold) on which it is manufactured. Foot size is used to determine the shoe size and foot shape provides information on how to design the last shape.

Figure 4. Determining the Mold of the Foot

How foot dimensions are measured

Shoe size is represented by length and the ball girth. The foot length and foot circumference of a human foot correspond to these two measurements, respectively. Foot measurements are taken with the subject standing on their foot and with weight distributed equally on both feet. The distance between the rearmost point of the heel and the tip of the longest toe is measured parallel to the foot axis.

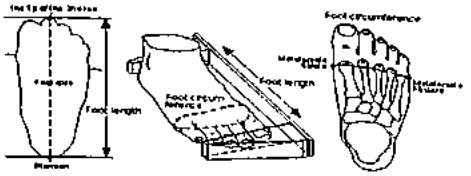
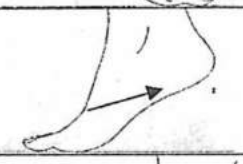
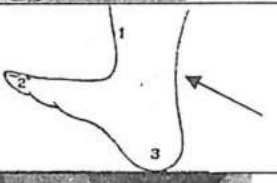
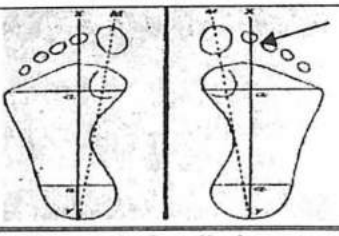


Figure 5. Measuring Foot Dimensions
Source: Digital Human Laboratory, AIST. http://www.dh.aist.go.jp/en/research/centered/foot/

Table 2. Anatomy of the Foot

PART	DESCRIPTION	IMAGE
Sole	The sole is the bottom part of the human foot.	
Heel	The heel is the rounded posterior portion of the human foot under and behind the ankle.	
Instep	The instep is the arched middle part of the human foot between the toes and the ankle.	
Ball	The ball of the foot is where the toes join with the rest of the foot. It is muscular and easily blistered.	
Ankle	The ankle is the slender section of the leg immediately above the foot which connects the foot with the leg.	
The dorsum of the foot	The dorsum of the foot, also called the dorsal surface of the foot, is the upper surface of the foot between the toes and ankles.	
Five toes	These are the digits of the foot which include the hallux or big toe, index toe, middle toe, fourth toe and little or pinky toe.	

Source: http://wiki.answers.com/ and http://www.thefreedictionary.com

Description of Pumps

Pumps, in their most classic form, are lightweight, strapless shoes with closed backs. Generally speaking, pumps have a seamless front upper that is cut closer to the toes than the top of the foot.

They need no fastening or lacing, as the foot can be slipped into them easily, although some styles have buckles or laces as a design feature, rather than a necessity. Pumps can have any heels of any height. Though the pump has been a staple in women's shoes for centuries, it was originally worn (without a heel) by men and servants in the 1500s - then they were called a "pompes."

A typical high-heeled pump shoes has the following parts as shown in Figure 6.

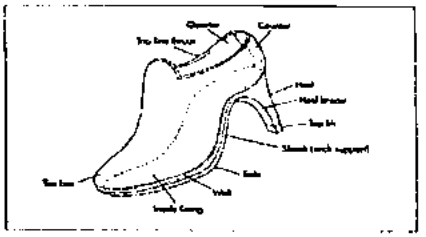


Figure 6: Parts of a Typical high-Heeled Pump Shoes
Source: http://www.madehow.com/Volume-5/High-Heel.html

Shoe sizing

Shoe sizing standards can vary dramatically between different shoe brands, and even for different styles within the same brand (Size Fit Guide.com, 2009). Figure 7 roughly summarizes shoe size conversions among countries.

Italy	36	36.5	37	37.5	38	38.5	39	39.5	40
UK	3	3.5	4	4.5	5	5.5	6	6.5	7
USA	5	5.5	7	7.5	8	8.5	9	9.5	10
France	37	37.5	38	38.5	39	39.5	40	40.5	41
Japan	23	23.5	24	24.5	25	25.5	26	26.5	27

Figure 7. Shoe Size Conversions
Source: Size Fit Guide.com, 2009).

4. REVIEW OF RELATED LITERATURE

Shoe height has historically reflected nobility, authority and wealth. (Holmes, undated) France's King Louis XIV (1638-1715) was only 5'3" tall until he donned specially-made high-heeled shoes with curved heels constructed of cork and covered with red-dyed leather, with the red color symbolizing nobility. Other heel-wearers used their footwear to boast of their wealth; the heels were so high that servants had to break them in, so to wear high heels also proved one could afford servants for this task.

Today, heels are blessed for the elegance they lend to the wearer's appearance and cursed for the damage they inflict on ankles, calves, and backs. Wikipedia (2009) identified reasons that somehow trigger women to continuously wear high-heeled shoes:

- they change the angle of the foot with respect to the lower leg, which accentuates the appearance of calves;
- they change the wearer's posture, requiring a more upright carriage and altering the gait in what is considered a seductive fashion;
- they make the wearer appear taller;
- they make the legs appear longer;
- they make the foot appear smaller;
- they make the toes appear shorter;
- they make the arches of the feet higher and better defined; and
- they make the lower leg muscles more defined.

Dr. Maria Cerruto (2008), an Italian urologist, conducted a study that suggested that wearing high-heeled shoes boosted the sex life of a woman. Her research indicated that wearing high heels may improve pelvic floor muscles of a woman and in doing so it boosts the satisfaction a female gets from having sex. In her study of 66 women with ages under 50 years, she found out that those who held their foot at a 15 degree angle to the ground - the equivalent of a two inch heel - had as good posture as those who wore flat shoes, and crucially showed less electrical activity in their pelvic muscles.

Marie Claire (2009) found that almost 50 percent of women stated that they had been injured by wearing a pair of too-small heel. Yao-dong and Jian –she (2005) cited the survey of Essenyel (2003) that showed that 37-69% of women wear high heels every day. Danaberg (1989) cited a survey that showed as many as 20% of the users of conventional high-heeled shoes experienced foot pain related to the shoes immediately, and the majority of users experienced such pain after as little as four hours of use.

Cutnell (1998) indicated that high-heeled shoes can cause tremendous pressure applied on the floor. For a 6- mm radius of a heel, the pressure exerted on the floor by a 50-kg woman is about 4,300kPa. At times, during a normal walking motion, nearly the entire body weight acts perpendicular to the surface of such a heel. Bennett(2003) showed that humans will only have one foot on the ground while walking. A 100-lb woman exerts more pressure when she wears heels. Depending on the area of the heel, she can exert as much as 1600 psi under a "stiletto heel', ¼-inch on a side. "This explains why people with wood floors do not want women walking on them in high heels. " BBC (2003) reported that a 65-kg woman on a surface of 2- cm^2 high heel shoes will result in a pressure of 3, 250 kPa beneath the high heels, if the person is standing on the surface of planet Earth.

Anna Russell (2008) sent her high-heeled shoes entry on the 2008 AAPT High School Physics Photo Contest as shown in Figure 8. From the picture, it is clear that high heeled shoe which has smaller heel surface area has the greater pressure compared to the one which has bigger surface area.

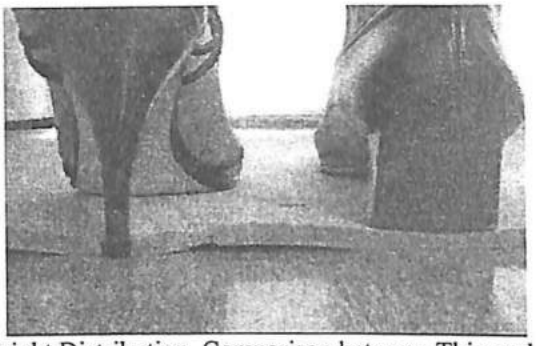


Figure 8. Weight Distribution, Comparison between Thin and Thick Heels
Source: http://www.aapt.org/upload/poster082.pdf

In addition, a survey conducted by the Society of Chiropodists and Podiatrists (Gorgan, 2009) showed that many women would endure pain and even risk deformities just to wear a fashionable shoes, even at those times when the shoe was not a good fit. Aside from this, 80 percent of all women suffered from some form of foot problem, like cracked heels, bunions, corns and in-growing nails (Jones L., http://news.softpedia.com). This is one of the evidences showing that foot problems such as blisters are caused by mis-fitting. Thus, one could conclude that one of the primary reasons why women wear high heel shoes even if it is associated with ill-fitting is because of their fashionable feature.

Moreover, foot pains and other foot problems caused by the personal choice of foot wears are not new. This was one of the concerns of the consumers few years ago. Grogan (2009) reported a cross-sectional study conducted by a group of students of Harvard University on 3378 respondents. These people took foot examinations from 2002 to 2008. The study showed that wearing of shoes specifically high heel shoes was associated with hind foot pain (Grogan, 2009). It is worth noting that one of the recommendations by the researchers was to conduct further studies that would address specific support and structural features of shoes. In this context, foot problems relating to foot wears have something to do with physical orientations or designs of the foot wear.

Another study was conducted by Alyssa Dafour (Smith, 2009) and her colleagues at the Institute for Aging Research, Hebrew Senior Life in Boston. It was found out that problems were actually occurring at the nails, fore foot, hind foot, heel, arch and ball of the foot. Also, the study showed that 25 percent of the respondents reported that they were experiencing generalized foot pain on most days (http://abcnews.com). This was also true with blisters. In most cases, blisters were actually located at the mentioned specific parts of the foot.

A study was also conducted on 3300 men and women to determine hind-foot a pain relating to foot wears. Based on the result of the study, high heel shoes were categorized as poor after the researcher divided all the shoes in categories according to their impact with the owner's health. Part of the findings as well was that hind-foot pain risk was high to women who wear heels or pumps with lack of support and sound structure (http://news.softpedia.com).

A study of Lee Yung-Hui and Hong Wei-Hsein (2005) entitled "Effects of Shoe Inserts and Heel Height on Foot Pressure, Impact Force, and Perceived Comfort During Walking" showed that distribution of foot pressure varies as heel height increases (see table 3). Aside from this, based on their findings increasing heel height increases medial forefoot pressure, impact force, and perceived discomfort during walking.

These studies confirmed that high heel problems are not new .Women users have been repeatedly advised that wearing high heeled shoes would lead to health problems. Having blisters has become a bane when women purchase foot wears.

Table 3. Effects of Shoe Inserts and Heel Height on Foot Pressure, Impact force and Perceived Comfort During Walking

Table 1
Comparisons of impact forces for each test condition (units: % BW)

Insert conditions	Flat shoe	Low heel	High heel
Shoes only	45.6 (15.3)	47.5 (16.0)	60.5 (17.2)
Heel cup	35.6 (13.6)[a]	35.2 (16.3)[a]	48.6 (11.7)[a]
Arch support	40.8 (7.8)	41.6 (8.2)	51.5 (10.0)
Metatarsal pad	42.5 (12.0)	42.6 (11.4)	54.8 (14.2)[b]
TCI	33.4 (15.2)[a]	35.8 (16.3)[a]	40.6 (13.0)[a]

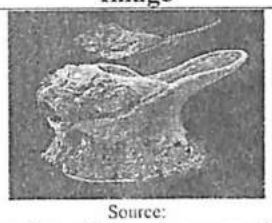
Data are presented as mean (SD); TCI, total contact insert.
[a]Significant difference in a insert condition compared to shoe only condition, $p<0.01$.
[b]Significant difference between TCI and metatarsal pad, $p<0.01$.

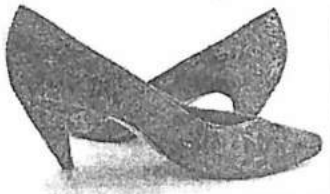
*Source: Lee Yung-Hui and Hong Wei-Hsein

5. EVOLUTION OF WOMEN SHOE DESIGN

During the High Renaissance period, women's footwear was usually a soft slipper. They were made of delicate fabrics such as brocade, silk, or embroidered leather, none of which were waterproofed. This necessitated the *patten*, an overshoe with a wooden sole, usually aspen, with an open leather vamp. The *patten* was tied with latchets onto the foot over the shoe. For the wealthy, it became common for the shoe and *patten* to be made of the same fabric. In this century, the *patten* was worn only as a necessity. Soon after, using footwear as a fashionable piece had begun. How the design of footwear evolved since the High Renaissance period is summarized in Table 4.

Table 4. Evolution of Shoe Design

Era	Image	Significant Event
High Renaissance	 Source: http://www.historyandwomen.com/2010_06_01_archive.html	The chorine, a piece of footwear with a raised sole was introduced to Europe in this period. These overshoes were on a raised platform, and like the *paten*, were worn over a slipper shoe, giving height to the wearer. They were made of wood with painted and gilded motifs. The chopines became so high, up to thirty inches, that when a woman went out, she needed a maidservant to help keep her upright.
Restoration 1660-1715	 Source: http://figliashoes.multiply.com/journal/item/75	Women wore clogs and *pattens* during this period. The clog was a small wooden wedge that fit under the arch of the shoe. The heel end had a socket into which the shoe heel would fit. The whole shoe was underlain by a flat sole, which prevented the shoe heel from digging into the ground.
1775-1815	 Source: http://www.ihs.issaquah.wednet.edu/teachers/fine/history_of_footwear.htm	The toes of women's shoes were quite pointed at the beginning of the period, with a matched pointed tongue. Sandals begin to be worn in the 1790's, At the very end of the period, in 1813, Grecian sandals appear, leaving the foot almost bare. These were low cut pumps with ribbons to cross and tie around the ankle. These were so simple to make that wealthy women took to making their own as a hobby.
The Forties	 http://figliashoes.multiply.com/journal/item/75	The cork-soled, covered platform and the wedge were high in fashion. However, during wartime the platform and the wedge were stripped of their covering, leaving the cork exposed.
The Fifties	 Source: http://figliashoes.multiply.com/journal/item/75	In Italy's post-war boom, the shoe factories made many technical and design changes. The light, elegant sandal was the most distinctive creation of the Italians, and the race to slim down the heel began. Women's shoes of the 1950's were arched, sophisticated and cut away to reveal the maximum of the foot. These were perched atop narrow delicate heels that only diminished in width as the decade wore on. At the beginning of the decade, color and fabric were of little importance to shoe fashion. Shape was everything.

The Sixties	 Source: http://shoes.about.com/od/imagegalleries/ig/Vintage-Shoes/1960s_boots.htm	The slip-on shoes with clunky heels followed. Go-go boots are one of the most remembered fashion trends of the 1960s. They came in a variety of heights from including ankle, thigh-high, and space age. They were a "must" in a young woman's wardrobe. The shoes of this period vary greatly depending on which social group one focuses on.
The Seventies	 http://blog.leffot.com/2009/12/04/that-70s-shoe/	Platform and wedge heels dominated this decade. Some of the platform soles sported stiletto heels, Athletic shoes became of extreme importance in the late 1970's. A craze for jogging brought on its own shoes, which were satin covered canvas or leather in bright colors that matched tracksuits.
The Eighties	 http://www.etsy.com/listing/12915745/vintage-1980s-unique-multi-color-damask	The business and dress shoes for women were styled with classic lines and construction. The classic sling back court shoe was suited to the professional woman of the eighties. Chanel offered seven different variations of this shoe each season. Toes again became pointed, and the heels were slender throughout the decade. Loafers and man-styled oxford pumps were approved with tailored power suits.
The Nineties	 http://www.rustyzipper.com/womens/shoes	Women can select from a broad range of styles to suit every mood, business, or social occasion. Comfortable low-heeled walking shoes, high stilettos, and mid-height heels are executed in a variety of leathers, suedes and fabrics.

Source: http://www.footwearhistory.com/restwomens.shtml

6. METHODOLOGY

The study was conducted using a melded Quality Function Deployment QFD) for eliciting the voice of the user-customer, Theory of Inventive Problem Solving (TRIZ) for specifying the voice of the product, Value Engineering (VE) for defining the most cost-effective way of manufacturing and process .

In this study, we invoked the operational systems perspective of improving product design that holistically comprehends the voice of the user/customer, the translation of the voice of the customer into the voice of the product, the conversion of the voice of the product into the voice of the process and its seamless deployment throughout the customer-customer chain .

The power of integrating stand-alone improvement methodologies has been recognized. The integration of meta- models, QFD, TRIZ and VE as an integrated customer-driven improvement methodology (ICIM) has been researched and studied, but practical applications are few and limited. Hua, *et al* (2006) did a comprehensive literature review of integrating TRIZ with other problem solving tools from 1995 to 2006 and highlighted the synergy of integrating TRIZ with QFD. Clarke (1999) studied the integration of TRIZ with Value Engineering as a means of bridging the conceptual ideation steps with the implementation process. Mendoza, *et. al* (2009) summarized how an integrated QFD, VE, and Design for Manufacturability and Assembly (DFMA) was used to maintain focus in coming up with a functional product that is compatible with assembly and manufacture. Yuqin, *et.al* (2009) showed an integrated mode research of QFD and TRIZ with an application of integrated QFD and TRIZ in designing and optimizing the vice - a clamping device. Yeh ,et. al (2010) described how the four-phase QFD was integrated with TRIZ in product R and D using the computer notebook case study. Yang (2003) proposed and showed the establishment and application of an integrated model of service quality measurement. Berger, *et. al* (1993) provided the classic and most comprehensive treatment of the Kano's methods for understanding customer-driven defined quality while Zultner and Mazur (2006) exploited the creation of "attractive " quality based on the Kano model in relation to QFD. Tan, *et. al* (1999) introduced the development of innovative product using Kano's model and QFD.

Raneses et al (2010) presented the redesign of an automotive battery using an integrated customer-driven QFD, TRIZ and VE methodology. The approach melded in a practical way the QFD structure embedding the Kano Satisfaction model in eliciting the needs and requirements of the user-customer, converting the Kano-ordered requirements into innovative product ideas using the TRIZ classical methods of inventive principles and contradiction matrices , and cascading the ensuing product improvement options into workable and value-adding product using VE's function cost analysis procedures. A simple heuristic algorithm that connected the QFD, TRIZ and VE selected methods into an integrated improvement process was developed and employed for the re-design of "design for" comfort and style pump shoes for working women presented in this paper.

Voice of the customer – QFD and Kano Satisfaction model

QFD is an integrated process of listening to the voice of the user-customers, translating and prioritizing these customer wants and needs into product attributes, characteristics, and specifications, and cascading them into the manufacturing and supply chain in a coherent fashion. (Zultner and Mazur, 2006) . Originated in Japan in 1966 by Prof. Yoji Akao, the power of QFD was well-developed by the Mitsubishi Heavy Industries Kobe Shipyard in 1972. (Hauser and Clausing , 1988) , The primordial aims of QFD are to translate the articulated user needs into workable and feasible technical attributes and specifications, and produce and deliver quality product by embedding customer satisfaction during the whole product development and production cycle.

To elicit formally the "voice of the customer" the Kano customer satisfaction model was employed. The Kano Satisfaction model relates different levels of customer satisfaction to product quality. Developed by Prof. Noriaki Kano of Tokyo Rika University, he defined four major quality attributes that engender different customer satisfaction behavior: dissatisfied, satisfier, delighter and indifferent. (Berger, et al, 1993) The dissatisfies are the attributes expected in a product/service and create dissatisfaction when absent. They do not offer an opportunity for product/service differentiation. Increased performance of these attributes does not have any consequence on customer satisfaction while absence or decreased performance results in extreme customer dissatisfaction. Satisfiers are the attributes for which an increased performance is correlated with customer satisfaction. Absence or decreased performance of these attributes causes customer dissatisfaction while their presence drives higher satisfaction. Delighters are the attributes unspoken and unexpected in a product/service but can provide a high level of customer satisfaction when present. Their absence does not lead to customer dissatisfaction. The delighters represent the latent needs of the customers which generally provide the product/service the competitive advantage. Attributes that belong to the indifferent category are those that are often of little or no effect on customer satisfaction. (Sauerwein et al, 1996)

Problems with the current design of mass-produced pumps were identified through a preliminary survey of 40 working women, interviews with footwear manufacturers and review of related studies. Using a survey questionnaire patterned from the Kano Customer Satisfaction model, one hundred one (101) young working women were selected randomly. Their ages ranged from 21 to 20, working in offices within the business districts of Metro Manila. They were asked about their feelings towards pre-identified features of pump shoes. These features were then classified as dissatisfies, satisfiers, and delighters based from the answers of the respondents. Correlation of the technical attributes on the roof of the house of quality (HOQ) served as the input to the next stage – the voice of the product

Voice of the product – QFD and TRIZ

To determine the voice of the product, the customer attributes generated from the Kano Satisfaction model were converted into technical attributes using the HOQ of the QFD structure. Customer attributes were matched with the technical attributes. The technical attributes with the highest matches with the customer attributes were prioritized as most critical and significant quality characteristics. Relationships between the technical attributes were then converted as technical contradictions using the TRIZ methods. TRIZ is a combination of methods, tools and techniques that aimed to come up with inventive solutions by re-framing problems as contradictions. (Yang, 2008) There are two kinds of contradiction in TRIZ- technical and physical contradictions. A technical contradiction occurs when one attribute of the system improves while another attribute of the system worsens or degrades. A physical contradiction occurs when an attribute exists to the mutual exclusion of the other characteristic. To resolve technical contradictions, TRIZ invokes the use of the Table of the Contradiction Matrix of 39 Engineering Parameters in tandem with the Forty Inventive Principles. (Raneses, 2010). To resolve physical contradictions, TRIZ employs the Four Separation Principles of space, time, whole and parts and conditions. (Domb, 1997)

From the prioritized technical attributes, the problems are re- defined as technical contradictions. Solutions are then obtained from the most applicable inventive principles that would improve the design of the pump shoes. The results of TRIZ analysis are then fed into the voice of the process using value engineering.

Voice of the Process – VE

Value Engineering is generally regarded as a systematic, team-oriented, creative approach that seeks to deliver customer-desired functions at the least life-cycle cost of the product, service, system, or process. Developed more than 60 years ago by Lawrence D Miles at Westinghouse USA, the Society of American Value Engineers (SAVE) defines Value Engineering as the systematic application of recognized techniques which identify the functions of a product or service, establish a monetary value for that function and provide the customer-desired functions at the lower cost. (Clarke, 1999) From the results of the TRIZ analysis, the next step was to evaluate the bill of materials of the pump shoes by using the function –cost analysis and multi-criteria evaluation.

7. DISCUSSION OF RESULTS

Preliminary Survey

The preliminary survey of 40 working women indicated 88% of them experienced "first-day foot blisters the first time they wore newly-bought shoes. Pump shoes were the second mostly-bought footwear type next to sandals. Working women considered fashion trend, the design and the brand as the top three reasons for buying a pair of shoes. These data were then used to formulate the survey design for the 101 working women respondents.

Main Survey

The age distribution of the respondents was 48%, 21-25 age bracket, 28%, 26-30 years age bracket, 20%- 31-35 years age bracket while 4% was in the 36-40 age bracket.

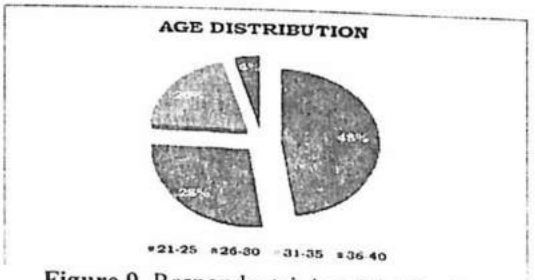


Figure 9. Respondents' Age Distribution

Respondents were working in Taguig (37%), Makati (24%), Quezon City (21%), Pasig Ortigas (11%) and Mandaluyong (7%).

Figure 10. Respondents' Office Location

About 58% of the respondents had shoe size of 5 ½ to 7, the observed shoe size of a typical Filipino woman. To look professional and respectable, fashionable and trendy were the top two reasons for wearing pump shoes at 62% and 79%, respectively. To be attractive to the opposite sex was the third reason at 15%. The top reasons for buying pump shoes were design of the shoes (79%), purpose and occasion (65%), price (54%) and designer/brand (28%). It is interesting to note that comfort was at the bottom at 5%.

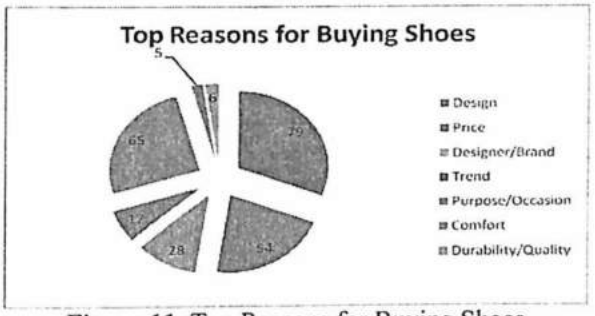


Figure 11. Top Reasons for Buying Shoes

House of Quality

From the survey , the most important customer attributes identified were design of the pump shoes, price , designer/brand, trendy or fashionable, durability and comfort in that order . Matching these with the technical attributes of the pump shoes pointed to the most highly influential technical attributes namely the heel height, weight , cushion-lining, shape of the upper , material used and the cost. From the roof of the house of quality, it could be seen that heel height is correlated with weight and the cost is strongly correlated with almost all parts of the pump shoes.

House of Quality

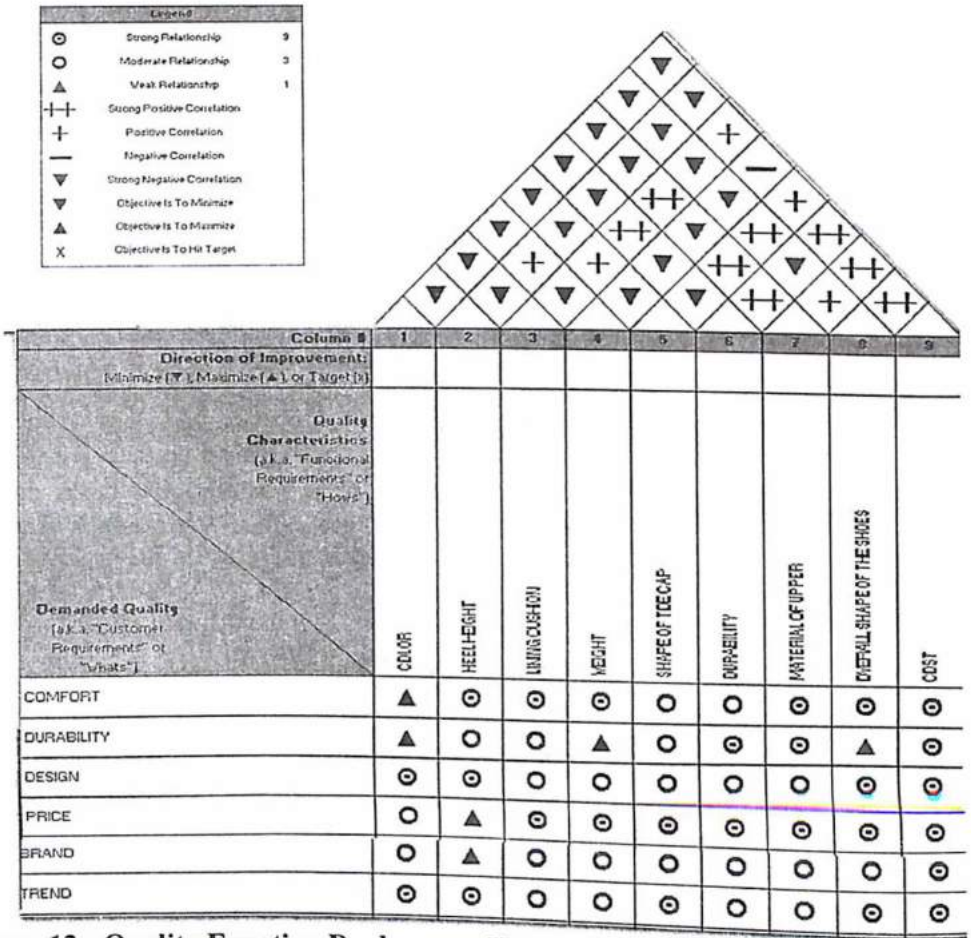


Figure 12: Quality Function Deployment House of Quality *using QFD Online™ HOQ Template Version 2.0, 3.0 and 6.0*

Kano Survey

Three out of the ten pre-identified features were classified as satisfiers (one-dimensional). That is, more of these features would increase customer satisfaction from the product. These features were cushioned lining, lightweight and sexy shape. Their coefficients of satisfaction were at 0.91, 0.84, and 0.94, respectively.

Four features were considered as attractive (delighters), or the "wow" factor – neutral color, high price (i.e., more than Php 1,000.00), and high heels and durability. The extent of their satisfaction levels were at 0.57, 0.55, 0.51 and 0.60, respectively. Evidently, working women wanted their pumps to be of either black or brown color, and they want it to be priced more than a thousand pesos. On the other hand, working women were indifferent to the shape of the shoe's toe cap (whether pointed or rounded), to the appearance of the outer (whether glossy or non-glossy) and the presence of cluck sound. Table 5 summarizes the results of the Kano survey.

Table 5. Summary of Kano Survey

Product Feature	A	M	O	R	Q	I	TOTAL	Modal Category	Extent of Satisfaction	Extent of Dissatisfaction	Recommend for Final Product
Neutral color (e.g., black, brown)	29	2	11	19	12	28	101	Attractive	0.57	-0.19	YES
Less-than-one-inch heels	18	4	8	38	12	21	101	Reversal	0.51	-0.24	NO
Cushioned lining	9	4	69	14	1	4	101	One-dimensional	0.91	-0.85	YES
Lightweight	13	8	63	11	0	6	101	One-dimensional	0.84	-0.79	YES
Pointed tips	18	1	8	19	13	42	101	Indifferent	0.38	-0.13	NO
Durability (will last for more than one year given usage of three times a week)	25	7	24	12	7	26	101	Attractive	0.60	-0.38	NO
Non-glossy outer	21	1	9	12	19	39	101	Indifferent	0.43	-0.14	NO
Sexy shape	12	4	71	11	2	1	101	One-dimensional	0.94	-0.85	YES
Price of more than Php1,000.00	31	6	9	20	8	27	101	Attractive	0.55	-0.21	YES
Cluck ('tok tok') sound	19	8	20	22	3	29	101	Indifferent	0.51	-0.37	NO

Legend: A =Attractive
M= Must have (expected)
O= One-dimensional
R= Reverse
Q= Questionable
I= Indifferent

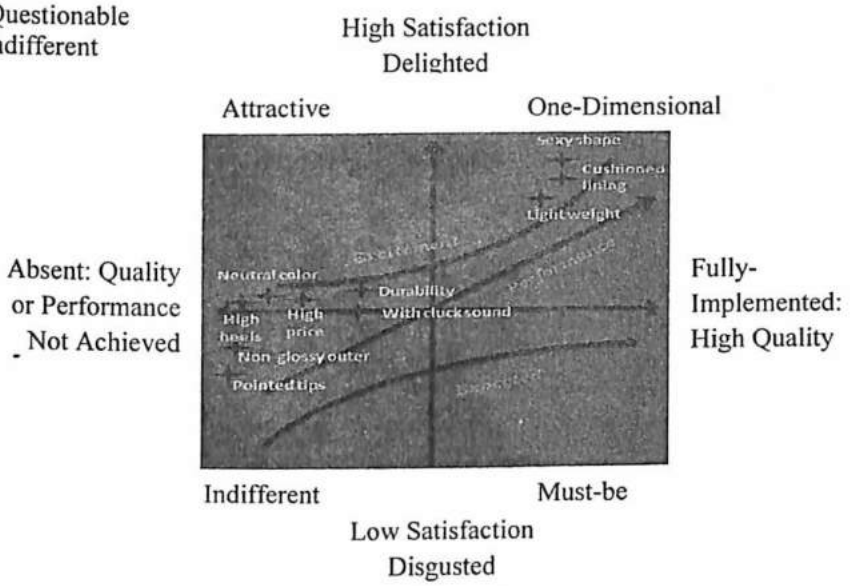


Figure 13. Influence of Product Features on Satisfaction and Dissatisfaction

Design for comfort, fashion and durability

To design comfortable and durable pump shoes, the shoes need to be lightweight to reduce stress from walking. As the weight of the shoe heels become lighter, it become less durable creating contradiction between weight and durability. The applicable inventive principle to overcome this contradiction is taking out. Single out the shoe heel and sole that contribute the most weight to the shoes and choose light material for both of them. The recommended solution is light rubber for the sole and light wood for the heel.

To be fashionable, the heel needs to be longer than one inch to look sexy. As the heel height increases, the pressure on the heel increases causing blister to form. This creates a contradiction between the length of anon-moving object (heel height) and the tension/pressure on the feet. The applicable inventive principle is curvature. Instead of using rectilinear parts, use curvilinear parts, surfaces or forms. The solution is change the heel from thin and straight form to a curved one and increase the diameter of the top lift.

Additionally, to be stylish and fashionable, the shape of the upper needs to be sexy/ thinner (coca-cola shape) to appear stylish. However, the pointed toe cap or upper causes blister formation on the ball of the feet and toes of the wearer. This creates a contradiction between the shape and harmful side effects. The most appropriate principle is parameter change. Change the degree of flexibility. Replace the hard, rigid material of the upper to soft, slightly elastic material such as soft leather and latex foam.

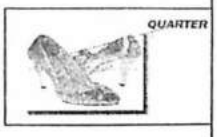
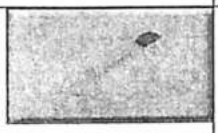
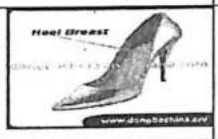
Finally, to design for comfort and fit, the materials used that are in direct contact with the feet should not be hard and rigid. The contradiction is the object generating harmful effect and the stability of the object. The applicable inventive principle is use composite materials. Change the material used for the upper and inner lining to soft leather. Place foam latex in between the sole and the upper lining.

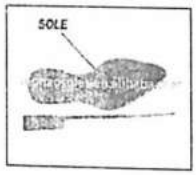
Table 6 Products Attribute, Customer Requirement, Contradiction, Inventive Principle and Solutions

PRODUCT ATTRIBUTE	PROBLEMS/ CUSTOMER REQUIREMENT	CONTRADICTIONS		APPLICABLE INVENTIVE PRINCIPLE	RECOMMENDED SOLUTION	Picture
		Feature to improve	Parameter that is in conflict			
Comfortable and durable	The shoes need to be lightweight to reduce stress from walking.	#2 Weight of nonmoving object	#16 Durability of nonmoving object	#2: Taking out Single out shoe parts that contribute the most weight and change their properties.	Sole and heel contribute the most weight to the shoes. Choose light material for the sole and heel. Imported "bonhav" for the sole and wood for the heel	Soft &light Material heel: wood upper: soft leather cushion:latex foam Sole: light rubber
		As the weight of the shoe heels become lighter, it becomes less durable.				
Fashionable	Heel needs to be longer than one inch to look sexy and fashionable.	#4 Length of nonmoving object	#11 Tension/ Pressure	#14: Curvature Instead of using rectilinear parts, surfaces or forms, use curvilinear ones; move from flat surfaces to spherical ones; from parts shaped as a cube to ball-shaped structures.	Change the heel from thin and straight to a curved one; increase the diameter of the top lift.	HEEL DESIGN
		As the heel height increases, pressure on feet increases, which contributes to blister formation.				
Fashionable	The shape of the upper needs to be sexy/ thinner (coca-cola shape) to appear stylish.	#12 Shape	#31 Harmful side effects	#35 Parameter changes Change the degree of flexibility	Change the hard, rigid material of the upper to soft, slightly elastic material such as soft leather and latex foam.	latex Foam Soft Leather
		Pointed toe cap/ upper causes blister formation on the ball of the feet and feet fingers of the wearer.				

Comfortable	Force applied on feet (caused by shoe parts that come in contact with the feet) directly affects the stress on the ankle, foot fingers and ball of the feet of the wearer.	#10 Force (Intensity)	#11 Pressure or stress	#11 Beforehand cushioning	In between the sole and the lining, place latex foam especially to areas that come in contact with feet points that are prone to blisters (e.g., ball of the feet, heel)	
Comfortable	Materials used in parts that come in contact with the feet should not be hard/ rigid to avoid blister formation due to friction.	#31 Object generated harmful factors	#13 Stability of object's composition	#40 Composite material Change from uniform to composite (multiple materials	Change the materials used for the upper and inner lining to soft leather, and place latex foam in between the sole and the inner lining.	

Table 7 Parts and Functions of the Pump Shoes

PART	DESCRIPTION	FUNCTION	MATERIALS	PICTURE	COST/UNIT (PHP)
Counter	Sits behind the heel of the foot, used to stiffen the back part of the shoe, and to give it structure	Maintain the shape of the shoe; Strengthen the rear of the shoe	Leather		35.00
Quarter	The part of the shoe's upper that covers the sides and the back of the foot. In some shoe styles, the quarter is a separate piece that is sewn to the vamp of a shoe.	Support the rear of the foot.	Leather		Combined costing with counter
Heel	The part of the sole that raises the rear of the shoe in relation to the front.	Support the heel of the foot	Metal, Rubber, Acrylic, Polypropylene, plastic		10.00
Heel breast	The side of the heel that faces forward when the shoe is on the foot.	Adjoins the shank			Combined costing with heel
Top lift/pc	The bottom-most part of a shoe's heel, the part of the heel that comes in contact with the ground.	Maintain friction with the ground. Maintain traction	Rubber, Metal, Plastic		1.00
Throat	The top opening of a shoe	"Receives" the foot			Combined costing with sole
Toe cap/box	The front upper of the shoe.	Cover and protects the toes	Metal, Wood, Plastic, Rubber		

Shank	The part between the heel and the outsole, which sets under the arch of the foot.	Supports the instep and helps give the shoe its structure	Metal or fiberglass		Not applicable
Sole	The entire part of the shoe that is positioned below the foot of the user. Also referred to as the "outsole" of the shoe.	Shapes the lower part of the shoes.	Leather, Natural rubber, Wood The outsole may comprise a single piece, or may comprise separate pieces of different materials.		150.00
Welt	A strip of material that joins the upper to the sole.	Joins the upper/toe box to the sole.	Leather, rubber, plastic		Combined costing with sole
Insole	A layer of material that sits inside the shoe that creates a layer between the sole of the shoe and the wearer's foot.	Adds comfort to the user and hides the welt.	Sheep skin		Combined costing with sole
Lining	The inside material that touches the sides of the foot, the top of the foot, and/or the back of the heel.	Covers the inside seams of the shoe.			10.00
Upper	Refers to the part or parts of a shoe that cover the toes, the top of the foot, the sides of the foot, and the back of the heel. It is attached to the outsole of a shoe.				Combined costing with counter
TOTAL COST					**206.00**

Value Engineering/Function Cost Analysis

The different parts of pump shoes were classified according to their function – basic, secondary useful and support functions. This was to evaluate the relative importance of each part vis-à-vis the product. Secondary useful functions, on the other hand, are those functions which are not as important as the basic functions but must also exist as customers need them while supporting functions are those functions which support the main basic function or another useful function. Thus, basic and secondary functions are important as they provide benefits to the customer while supporting functions are useful but do not provide direct benefits to the customer. The different functions of the parts of pump shoes are summarized in Table 7.

Table 8. List of Functions per Part

Part	Function List		Classification		
	Verb	Noun	Basic	Secondary	Support
Counter	Maintain	Shape of the shoes	X		
Quarter	Support	Rear of the shoes	X		
Heel	Support	Weight of the wearer	X		
Heel breast	Adjoin	Shank			X
Top lift/toe piece	Maintain	Friction with ground		X	
Throat	Receives	Foot	X		
Toe cap/box	Protect	Toes	X		
Shank	Support	Instep	X		
Sole	Shape	Lower part of the shoes	X		
Welt	Connect	Sole and toe box			X
Insole	Hide	Welt			X
Lining	Cover	Inside seams of the shoes		X	

Table 9: Function Cost Analysis

Parts	Function							Cost of Component	
	Basic				Secondary		Support		
	Shapes the structure of the shoes	Support the weight of the wearer	Receives foot of the wearer	Protects toes	Maintain friction with the ground	Cover inside seams of the shoes	Adjoin parts of the shoes	Total Cost	% of Total Cost
Upper	35							35	16.2
Heel & heel breast		10						10	4.6
Sole	150							150	69.5
Insole & welt							10	10	4.6
Lining						10		10	4.6
Top lift pc.					1			1	0.5
Cost of Function	185	10	0	0	1	10	10	216	100
% of Total Cost	85.7	4.6	0	0	0.5	4.6	4.6		

The value of conducting the functional analysis was to determine how each part contributed to the performance of the product and how the product creates benefits, harm, and costs.

From the function cost analysis, it could be gleaned that the bulk of the costs was in performing the basic function of pump shoes. This implied finding the equally or cost-effective materials for the parts contributing to the basic functions.

The functional analysis was equally important in determining which parts of the shoes give benefit and harm to the user. It was found out that though heels perform a basic function of the product (supports the weight of the wearer) it could also cause a harmful effect (blisters). The implication of having a basic function that causes a harmful effect is that we cannot eliminate that part; rather we can only find ways to eliminate its harmful effects. One way to eliminate the harmful effects of a basic function is to enhance the performance of the secondary functions – another benefit of conducting the functional analysis

Based from the foregoing analysis conducted by the team, our recommendations could be summarized as follows:

PRODUCT ATTRIBUTE	RECOMMENDATION
Comfort	-Place cushions (latex foam) on the pain point areas to address the problems on blisters.
Design	-The shape of the heels should be changed to a curved one. The diameter of the middle should be smaller than the heel tips (top piece). This will allow the heels to cover a greater so that pressure and stress from the floor and the wearer will be lessened.
Durability	-Though based from the survey, the typical customer is indifferent about this attribute the team still recommends the use of durable and quality raw materials.
Price	-As per results of survey, customers prefer higher-priced pumps.

Shoe Dimensions and Specifications

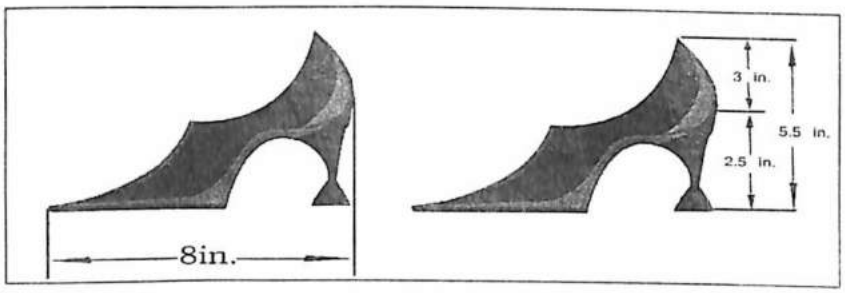


Figure 14. Specifications, Side View

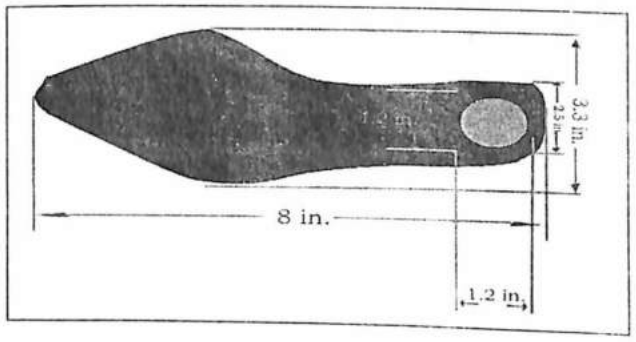


Figure 15. Specifications, Rear View

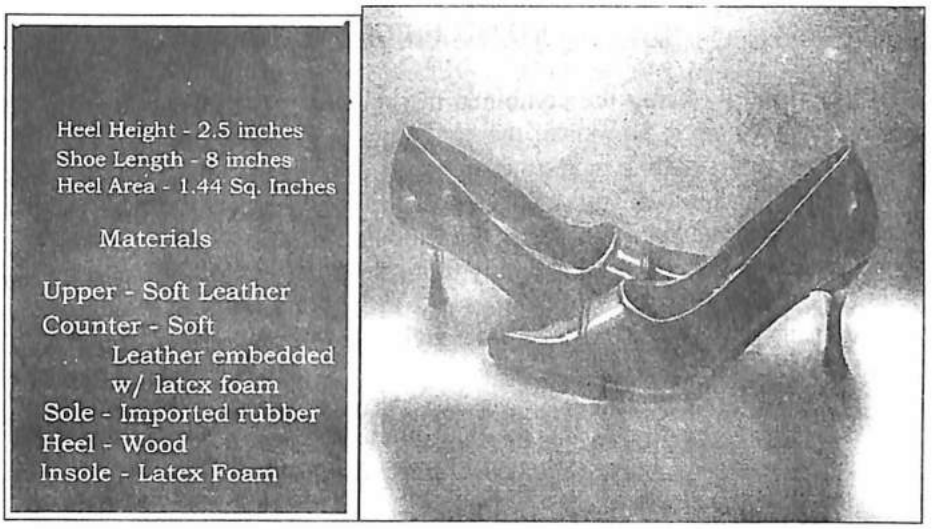


Figure 16 Designed Shoe Specifications

PROTOTYPING AND VALIDATION

A prototype, with specifications shown in Figure 16, was manufactured by a small-scale shoe manufacturer in Marikina. The manufacturer was able to produce the pump shoes in two weeks, which showed that in terms of manufacturability, it was indeed feasible to manufacture a pump shoes that are designed for comfort and style.

Ten working women, with ages ranging from 23-25, were asked to use the shoes for four hours. They were then asked to rate their perceived wearing experience using a five-point rating scale. Color, durability and style were rated very high with an average rating of 4.3, 4.2.and 4.1 respectively while comfort, quality and price were rated moderately high with average rating of 3.9, 3.5 and 3.2, respectively. They also indicated that the new design of shoes was comparable in quality and value to existing major brands. They were comfortable, more stable, the sole was soft and the height of the heels was just right. They also noted that the shoes made their feet looked sexy and they would buy them if available in the market. After four hours of use, they did not experience any discomfort and no sign of having blisters.

8. CONCLUSIONS

We have shown that by using the combined methods of qualify function deployment, TRIZ, and value engineering , we could eliminate the contradiction between design for fashion and style and design for comfort and fit while making it affordable and not pricey . We have also shown that by proper shoe design and choice of materials we can eliminate the formation of blisters that has been glossed over and assumed to be secondary to fashion and style.

Finally, we conclude that by systematically concatenating quality function deployment with TRIZ, and value engineering, the voice of the users are articulated well in the design features of the product, thus , assuring design for ease of use, style , comfort, and fit. We also recommend extending this study to detailed design for manufacturability, sustainability, and profitability.

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