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The Creation Of Tools And Models To Characterize And Quantify User-centered Design Considerations In Product And System Developm

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THE CREATION OF TOOLS AND MODELS TO CHARACTERIZE AND QUANTIFY USER-CENTERED DESIGN CONSIDERATIONS IN PRODUCT AND SYSTEM DEVELOPMENT

by

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ABSTRACT

Ease of use differentiates products in a highly competitive market place. It also brings an added value that culminates in a higher degree of customer satisfaction, repeated business, increased sales, and higher revenue. User-centered design is a strategic asset that companies can use to improve their customer relationships by learning more about their customers, and increase their sales. In today's economy, the measurement of intangible assets such as user experience has become a major need for industries because of the relationship between user-centered design and organizational benefits such as customer loyalty.

As companies realize that the inclusion of user-centered design concepts in product or system design are a key component of attracting and maintaining customers, as well as increasing revenue, the need for quantitative methods to describe these benefits has become more urgent. The goal of this research is to develop a methodology to characterize user-centered design features, customer benefits and organizational benefits resulting from developing products using user-centered design principles through the use of an integrated framework of critical factors. Therefore, this research focuses on the identification of the most significant variables required to assess and measure the degree of user-centered design (UCD) characteristics included in the various aspects of product development such as physical design features, cognitive design attributes, industrial design aspects and user experience design considerations. Also this research focuses on the development of assessment tools for developers to use when evaluating the incorporation of user-centered design features in the creation of products and systems. In addition, a mathematical model to quantify the inclusion of UCD factors considered in the design of a product and systems is presented in this

research. The results obtained using the assessment tools and the mathematical model can be employed to assess the customer benefits and organizational benefits resulting from including user-centered design features in the creation of products and systems. Overall, organizational benefits such as customer loyalty, company image, and profitability are expected to be impacted by the company's capability to meet or exceed stated design claims and performance consistency while maintaining aesthetic appeal, long product life, and product usefulness.

The successful completion of this research has produced many beneficial research findings. For example, it has helped characterize and develop descriptors for estimating critical quantitative and qualitative components, sub-components, and factors influencing user-centered design that are related to customer and organizational benefits through the use of fuzzy set modeling. In addition, the development of specific tools, methods, and techniques for evaluating and quantifying UCD components resulted from this study.

This work is dedicated to my family and friends. Thank you for all the patience and support. To my family, you have been my motivation to keep going. To Dr. C-Y, you have seen me evolve in every aspect; as a student, as a researcher, as a professional, as a person. You have been more than just an academic advisor; you have been my guiding light. I will always miss our all-nighters. To my friends, you have been my support system; together we have shared long days and nights of tears, exhaustion, and laughter. I am glad I got the opportunity to share this experience with you. To all my family and friends, I am grateful for all the times you all were there when I needed you, for never letting me give up, and for never giving up on me. You have all had such an impact in my life and have made this journey so unforgettable; I would have never made it without all of you.

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LIST OF ACRONYMS/ABBREVIATIONS

ABC - Activity-Based Costing

AHP - Analytic Hierarchy Process

ATROS - After-Tax Return On Sales

CB - Customer Benefits

CD – Cognitive Design

FCS - Faceted Classification System

FMADM - Fuzzy Multiple Attribute Decision Making

FMODM - Fuzzy Multiple Objective Decision Making

FST - Fuzzy Set Theory

ID – Industrial Design

IRR Internal Rate of Return

MCDM - Fuzzy Multiple Criteria Decision Making

MTFA - Modular Transfer Function Area

OB - Organizational Benefits

PD – Physical Design

R&D - Research and Development

SME - Subject Matter Experts

TSM - Total System Maturity

UCD – User-Centered Design

UCSD - User Centered System Design

UED – User Experience Design

UMM - Usability Maturity Model

VOC - Voice of the Customer

CHAPTER I: INTRODUCTION

This research provides an evaluation tool for user-centered design that could be used to support product developers and is capable of improving the effectiveness and efficiency of the product development process. Specifically, the tool supports a design methodology based upon the combination of developing taxonomies and applying fuzzy set theory. The taxonomy was used to characterize the major components of user-centered design, customer benefits, and organizational benefits. Fuzzy set theory was then used for the development of indices that lead to the quantification of user-centered design, customer benefits and organizational benefits.

Motivation

As companies learn that including user-centered design concepts in product or system design is a key component to attracting and maintaining customers, as well as increasing revenue, the need for quantitative methods to describe these benefits has become more important (Bard, 1990). According to IBM, "Throughout the entire development process and beyond, users play a critical role in the design of easy-to-use products. After all, who knows more about which products are easy to use than the people who use them?"(User-Centered Design Group, 2002). For developers and manufacturers, the advantages of creating usable products far outweigh the costs. "The rule of thumb in many usability-aware organizations is that the cost-benefit ratio for usability is $1:$10-$100. Once a system is in development, correcting a problem costs 10 times as much as fixing the same problem in design. If the system has been released, it costs 100 times as much relative to fixing in design." (Gilb, 1988). IBM also restated that the rule of thumb that every dollar invested in "ease-of-use" design consideration returns $10-$100 (IBM, 2001). Ease of use differentiates products in a highly competitive market place. It also brings an added value that culminates in a higher degree of customer satisfaction, repeated business, increased sales, and higher revenue. User-centered design is a strategic asset that companies can use not only to improve their customer relationships, but also to learn more about their customers and serve them better. Therefore, it is highly valuable to transform theoretical user-centered design into quantifiable organizational benefits.

Reasons such as lack of commonly agreed upon terminology and application consistency have not allowed a clear quantification of the UCD benefits. According to Goransson, there is no commonly agreed-upon understanding of usability and user centered system design (UCSD). Many companies do not give value to usability, because they believe it is included in the design by simply adding graphics to the user interface, while other companies incorporate user-centered activities without making major changes to their current development process (Goransson, 2004).

Significance of the Problem

Approximately 70-80% of the product's ultimate acquisition or life cycle costs are determined by decisions made from conception through the product development cycle (Crow, 2000). Although the UCD field has significantly grown since it was first established, there is still much room for development. According to Fineberg, "What is still lacking is a deeper appreciation of the interaction between the internal capacity of the human operator and the external demands placed on him by the task at hand and the stakes of the game"

(Fineberg, 1991). Many of the development organizations do not have design activities within the development process that focus on designing the “user experience”. It is vital that developers consider users during the application design and that they make usability as important in product design as reliability, scalability, and manageability (Clark, 1999). The user experience consists of all aspects of a product or service as perceived by users from a user's initial awareness, through additional discovery, ordering, installation, fulfillment, initial use, day-to-day use, support, service, upgrades, and end-of-life. Incomplete requirements can have a profound impact on system effectiveness and cost. Boar stated that 60-80% of the systems’ problems originate from inaccurate requirements specifications, which justifies the need for UCD evaluation tools (Boar, 1984). Therefore, it is imperative that the design requirement specifications of newly developed products and systems be based on the user and the intended use of the product as well as the environment in which the product will be used. To accomplish this goal, user-centered design must be included in the product development process.

Problem Statement

Developing design aid tools helps to enhance designers’ human factors knowledge, overcome the resistance of designers’ reading and written standards, guidelines, etc., as well as reduce development costs by using predefined methods and tools while guaranteeing conformity of the user interface with standards for quality assurance (Reiterer, 1993). Additional justifications for incorporating UCD within products and systems have been identified by Goransson and consist of the following (Goransson, 2004):

1. Economic – decrease costs and increase earnings

2. Business and organizational – broaden the view of systems development and facilitate IT system integration
3. Quality – increase quality level in the development process and systems
4. Legal – assurance of laws and regulations
5. Ethics and moral – develop systems that consider basic human values

Different reasons to consider users in the development process will appeal to different stakeholders. For instance, economic reasons are strong arguments when dealing with business people and managers; quality in use and system validity are concerns for the business and the user. Regardless of the reasons, the point is that each stakeholder is impacted by the implementation or lack of implementing UCD tools in the product or system development process. The real challenge is to incorporate all of the stakeholders in the design process and identify beneficial measures relative for each stakeholder.

Research Goals and Objectives

The goal of this research is to develop a methodology that characterizes UCD requirements, customer and organizational benefits resulting from developing products using user-centered design principles through the use of an integrated framework of critical factors (i.e. safety, quality, and customer satisfaction, etc.). Specifically, this research generated a methodology that is useful for top managers, marketing, sales, and designers within the organization. Thus it provides tools and information to rapidly augment decision making related to product development by identifying quantitative measures to assess the significant factors of user-centered design, customer benefits and organizational benefits. Therefore, measurement tools to quantitatively describe these significant factors were developed. This research answered the following questions:

1. What are the critical user-centered design requirements?
2. What are the measures to assess/evaluate these user-centered design factors?
3. What are the measures to evaluate customer benefits and organizational benefits?
4. How do user-centered design components relate to customer benefits and organizational benefits?

This research developed a valid, and reliable methodology for describing and quantifying user-centered design while considering the inter-relationships of customer benefits and organizational benefits. The specific steps and objectives pursued to meet the stated research goal include:

1. Characterize the significant component, sub-component, and factor variables of user-centered design, customer benefits and organizational benefits.
2. Identify and select tools, techniques, and methods of quantitatively analyzing component, sub-component, and factor variables that best define the relationship between user-centered design with customer benefits and organizational benefits.
3. Test and evaluate tools, techniques, and methods identified to quantify the relationship between user-centered design with customer benefits and organizational benefits.
4. Develop indices that aggregate multiple inputs from various tools, techniques, and methods designed to develop an index for each component using information derived from sub-component and factor variables.

5. Validate the various user-centered design indices developed to ensure accurate and consistent results in an industrial setting.

In today's economy, the measurement of intangible assets such as customer satisfaction has become a major need for the industry. Overall, customer benefits and organizational benefits are expected to be related to the company's capability to meet or exceed stated design claims and performance consistency while maintaining aesthetic appeal, long product life, as well as product usefulness.

Research Scope

Given the understanding that it was imperative for valid and reliable methods to be developed for the measurement of user-centered design, the goal of this research is to characterize and measure user-centered design variables that lead to the mathematical quantification which can help determine the combined effect of user-centered design on customer benefits and organizational benefits through the use of fuzzy set modeling. Specifically, this research generates a methodology to characterize, measure and quantify user-centered design, as well as the relationship with customer benefits and organizational benefits.

Figure 1 is a representation of the relationship between user-centered design components, customer benefits and organizational benefits as being explored in this research. Figure 1 illustrates the components of UCD as well as the customer benefits components, which consist of the quality product, safety, and customer satisfaction. In addition, within the organizational benefits, the following components are also identified: profitability, customer loyalty and company image.

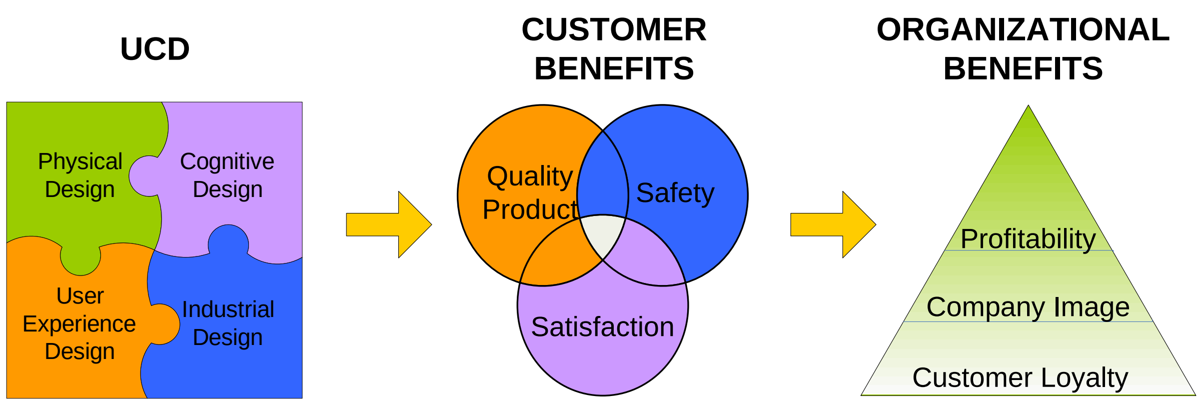

Figure 1 Relationship between User-centered design, Customer benefits, and Organizational benefits

In this research, user-centered design considerations are characterized using four major components:

1. Physical design (PD) - User's physical interaction with the product such as muscular activity and strength. It unifies the design process to generate a product that not only meets functional requirements but also creates the visual/tactile form that relates the product to the user.
2. Industrial design (ID) - Product characteristics such as texture, dimensions, and form. It focuses on defining the form/function interface.
3. Cognitive design (CD) – Product features dealing with human-product interaction in which the human must use a mental process including aspects such as awareness, perception, and reasoning. It focuses on developing designs that are within human information processing capabilities and limitations.
4. User experience (UE) - Emotions experienced by the user as a result of the interaction with the product/system. User experience is a term used to describe the overall experience and satisfaction a user has when using a product or system.

Likewise in this research, customer benefits are characterized using:

1. Quality product: The degree to which the product or service meets desired design specifications and customer demands.
2. Safety: The condition or state of being safe; freedom from danger or hazard; exemption from injury or loss.
3. Customer satisfaction: The fulfillment or gratification of a desire or need, as well as the pleasure or contentment that is derived from such gratification.

Additionally in this research, organizational benefits are characterized using:

1. Customer loyalty: The degree to which the company is capable of maintaining customer commitment to the company or product/repeated business.
2. Profitability: Quality of affording gain or benefit or profit. The profitability index is used to identify the relationship between costs and benefits of a proposed project.
3. Company image: Composite mental picture or impression held by customers about a specific company or a brand's product or service.

CHAPTER II: LITERATURE REVIEW

This chapter provides a background and review of approaches previously investigated in the field of user-centered design, as well as a closer examination of the theory and methodology. Topics included in these sections are primarily used to provide an appreciation of the approaches previously investigated in this field that have lead to the creation and improvement of the product development process.

Defining User-Centered Design

Research performed by Carr-Chellman and Savoy (2004) identified that all of the studies they investigated illustrate difficulties with a common language and agreed-on standards for calling an approach true user design or user-centered design. The studies draw conflicting conclusions in terms of whether user-centered design and usability testing are instrumentally valuable. This section includes an overview and clarification of the common misconceptions and misunderstandings in some of the terms used in this field.

Three main concepts are often confused or misunderstood: user-centered design (UCD), usability, and ease of use. User-centered design is a method used to obtain the product attributes based on what the market research has stipulated should be designed to meet functionality and usability specifications. Simply stated, UCD is a method in which a product should be designed. This method should include multidisciplinary design, task analysis, competitive evaluation, design walkthrough, interactive design evaluation and validation, and a benchmarking assessment. Usability is a tool used in user-centered design that considers the time to learn, performance speed, rate of errors, retention over time, and a subjective satisfaction evaluation, whereas, ease of use deals with the product attributes the customer or user wants in a product. For instance, it looks at the learnability (ease of learning), ease of installing the product, ease of using the product (does not cause errors), the engagement, integration, and whether it is fun, enjoyable, and makes the user feel good (Vredenburg, Isensee, and Righi, 2002).

Usability

Usability is defined by ISO as, "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO/IS 9241-11 Guidance on Usability). It is concerned with the system acceptability, which focuses on the aspects of the system that satisfy the needs and requirements of the user and potential stakeholders that are influenced by the system either directly or indirectly. Some of the acceptability attributes identified by Nielsen are social acceptability and practical acceptability, which consists of usefulness, cost, compatibility, and reliability. Usefulness is divided into utility and usability, where the later is further divided into easy to learn, efficient to use, easy to remember, few errors, and subjectively pleasing (Jeffrey, 1984, Nielsen, 1993).

Rubin (1984) describes usability objectives as:

1. Usefulness - product enables user to achieve their goals.
2. Effectiveness (ease of use) - quantitatively measured by how fast a percentage of users that are able to perform a task or the error rate

3. Learnability - user's ability to operate the system to a determined level of competence after some defined period of training. Also, refers to how infrequent users are able to relearn the system.
4. Attitude (likeability) - user's perceptions, feelings and opinions about the product, usually captured through written and oral communication.

In order to consider a user-centered design product, the user's needs and requirements must be taken into consideration. For instance, the usability of the product and the user experience must be included in the design requirements. The following characteristics are considered when referring to the usability of a product: efficiency, effectiveness, safety, must have good utility, and must be easy to remember and learn. The user experience goals consist of the product being satisfying, fun, emotionally fulfilling, rewarding, supportive of creativity, aesthetically pleasing, motivating, helpful, entertaining, and enjoyable (Preece, Rogers, and Sharp, 2002).

User-Centered Design

In general, ISO 13407 describes user-centered design as a multi-disciplinary design approach based on the active involvement of users to improve the understanding of user and task requirements, and the iteration of design and evaluation, which incorporates human factors and ergonomics knowledge and techniques with the objective of enhancing effectiveness and productivity, improving human working conditions, and counteracting the possible adverse effects of use on the user, safety and performance. The user-centered approach usually consists of including the users in the design and evaluation of the designed product in order to obtain their feedback. Therefore, creating products that are easier to use and understand, improves the user's quality of life by reducing stress, increasing satisfaction, and improving the productivity and operational efficiency of the user and the organization.

According to Lawton and Martison (2004), UCD is a user interface design process that focuses on usability goals, user characteristics, environment, tasks, and workflow in the design of an interface. It follows a series of well-defined methods and techniques for analysis, design, and evaluation. According to Carr-Chellman and Savoy (2003), UCD differs from other design methods in that the user is considered, not empowered. It is focused on understanding the user and the context in which they work (Ambler, 2005).

Gould, Boies, and Lewis (1991) identified four important user-centered design tenets:

1. Early focus on users – The needs of the users should be determined and understood early in the design process.
2. Integrated design – All of the design aspects should evolve in parallel instead of in sequence.
3. Early and continual testing – Designers should always keep in mind that the design works if real users decide that it works.
4. Iterative design – Designers and developers should revise the design through several rounds of testing.

According to Jess McMullin (2002), UCD has three main drawbacks:

1. Often ignores other aspects in placing the user at the center of the process, causing the process and projects to become unbalanced.
2. In assuming that UCD is THE right approach, people are often mislead to the belief that there is a moral imperative to pursue a user-centered methodology, causing a feeling of inferiority when others do not buy into doing things the "right" way.
3. The information and terminology used is often in terms that others outside the field are not familiar with. Managers should be addressed with terminology that they understand such as return on investment (ROI).

However, some of the identified benefits of UCD are (Bevan, 2005):

1. Reduced development costs by developing relevant functionality, reducing the number of redesign iterations, minimizing or eliminating documentation need, and product failure risk reduction
2. Improved e-commerce sales
3. Increased product sales by obtaining competitive edge and increasing customer satisfaction and loyalty
4. Easier to use systems for employers through faster learning and better information retention, task time reduction and productivity increase, employee error reduction, and turnover reduction by increased satisfaction and motivation
5. Reduced support and maintenance costs through support and help lines cost reduction, training cost reduction, and maintenance cost reduction

According to Magrab (1997), customers purchase products based on attributes that can be grouped into 8 categories classified as $APPEALS. These desired characteristics consist of cost, availability, packaging, performance, ease-of-use, assurances, life cycle costs, and social standards. The identified appeals are key words used for tailoring products and the factors that influence them. Although all of the appeals are considered to be important, only performance, ease of use, and assurance are considered in this research since the user-centered design by definition considers the involvement of users to understand the requirements and incorporation of ergonomics. Performance relates to the consideration and understanding of the user requirements. Ease of use relates to the fact that user feedback is obtained during the design process thus facilitating the ease of use in an important consideration in user-centered design. Assurance is related to human ergonomics, which is used to ensure product safety, among others. There are many related components to the key words; however, this is only a broad explanation of their relationship to user-centered design.

In user-centered design, users are considered central to the design specifications; however, design control remains in the hands of the professional designers and approval power remains with leadership. In order to have an effective implementation, it is important that leaders understand the significance of user perspectives and needs and are willing to lend their support (Carr, 1997).

User centered design has received a wide range of definitions as it has evolved. However, for the purpose of this research, it is considered as a comprehensive product development methodology driven by system performance mission and objectives, user needs, preferences and limitations. Information collected using UCD analysis is applied during the design, testing, and implementation phases of developing products and systems. When thoroughly applied, a UCD approach meets both user needs and business objectives of the organization. It may include but is not limited to ethnographic research, usability engineering, cognitive design, industrial design, user experience, and physical design considerations.

User-centered design focuses on understanding users and their tasks and on gathering their input on iterative designs of the product. Its principles consist of the following (IBM, 2005):

1. Set business goals: Determining the target market, intended users, and primary competition is central to all design and user participation.
2. Understand users: A commitment to understand and involve the intended user is essential to the design process. If a product developer wants a user to understand the product, they must first understand the user.
3. Assess competitiveness: Superior design requires ongoing awareness of the competition and its customers. Once the user's tasks are understood, the tasks must be tested against competitive alternatives to compare the results.
4. Design the total user experience: Everything a user sees and touches are designed by a multidisciplinary team. This includes the way a product is advertised, ordered, bought, packaged, maintained, installed, administered, documented, upgraded, and supported.
5. Evaluate designs: User feedback is gathered early and often, using prototypes of widely ranging fidelity; this feedback drives product design and development.

6. Manage by continual user observation: Throughout the life of the product, it is important for developers to manage and continue to monitor and listen to users, and let their feedback inform their responses to market changes and competitive activities.

User-centered design has a great influence on the customer benefits and organizational benefits. Just as a company will suffer if a piece of equipment fails, the organization will also suffer if the user cannot use the product provided, or uses it incorrectly because they will stop purchasing the product. Therefore, the customer benefits and organizational benefits may be improved by incorporating user-centered design in product development, and the product performance can be managed by understanding and controlling the factors that significantly affect user performance. For this reason, a means to quantitatively characterize customer benefits and organizational benefits would be valuable.

User-Centered Design Previous Approaches and Methodologies

The importance of UCD is that it helps to address questions that guide developers in the design of a product that will create a demand in the market where the product is intended to be sold. Usually this approach includes four steps: problem definition, specifications development, the building phase and finally the testing and evaluation phase. As discussed in the previous section, user-centered design is a concept that has been around for quite some time and has progressed with the passing of the years thanks to the great efforts of many researchers. This section provides a review of some of the approaches and methodologies previously performed by some of those researchers.

Jokela's (2001) research consists of conducting an assessment approach of UCD that provides a basis for improvement of performance in product development projects. The approach consists of a new UCD process model, a three-dimensional process performance model and the implementation of the assessment as part of a workshop. The UCD process model is method-independent and has six processes assessed in terms of quantity, quality, and integration. He wanted to know what were the useful approaches-constructs, models, methods, and instantiations to assess UCD processes as a basis for the improvement of process performance in product development as well as what would be a useful assessment. In this research he summarized some of the most significant outputs from other researchers. For instance, March and Smith (1995) defined artifacts, model, methods, and instantiations, and showed how each of these relate, including their evaluation metrics.

Jarvien (2000) adds to the research by March and Smith by identifying additional research outputs, prescriptive and descriptive models, normative method, and description.

Some of the additional approaches identified in this study include:

1. E&R: Stages of Acceptance of user-centered design, by Ehrlich and Rohn, (Ehrlich and Rohn, 1994)
2. Trilliun: Bell Canada, (Coallier et al., 1994)
3. IBM: Usability Leadership Assessment (Flanagan, 1995)
4. TSM, Total Systems Maturity (Sherwood-Jones, 1995)
5. HUSAT: user-centered design Maturity by Loughborough University (Eason and Harker, 1997)
6. Philips: Humanware Process Assessment, (Gupta 1997), Taylor et al. 1998)

7. INUSE HCS: Usability Maturity Model: Human Centredness Scale by the European INUSE project (further refined in the TRUMP project), Earthy 1998b)
8. INUSE Processes: Usability Maturity Model: Processes by the INUSE project and further refined by the TRUMP project, (Earthy 1998a)
9. ISO 18529: A technical report based on the INUSE Processes model (ISO 18529 is a subset of the INUSE Processes model) (ISO/IEC 2000a)
10. HIS, Air Force Human Systems Integration Office, UK (Young 2000)
11. HSL: Human-System Lifecycle Processes (ISO/IEC 2001). A revised version of the QIU. Published during the writing of this thesis.

Although many of the approaches were developed in isolation of each other, most have been developed using each other as foundations. For instance, INUSE Processes and QIU/HSL use the format and structure of ISO15504 and extend it to cover user-centered design. In these approaches, the usability capability of a product development organization is analyzed through the capability of the processes carried out during development; how extensively the different processes related to user-centered design are performed, and how well they are planned and managed. INUSE HCS considered several approaches, and mentions the Total Systems Maturity Model (Sherwood-Jones 1995) as the base source of their approach - the IBM approach and the well-known general quality model of Crosby (Crosby 1978). The work performed by Crosby was used as the foundation for Total System Maturity (TSM) and HUSAT model. Crosby, TSM, IBM and ISO 134707 were used as the basis for the development of the Usability Maturity Model (UMM HCS), which are generic assessments rather than process assessments. The work by Ehrlich and Rohn (1994) is not a model, it is a description of the four stages of the user-acceptance model; therefore, it is not used as basis or source of any other assessment. The CMM model was used as the basis for the Philips, Trillium, HSI and ISO 15504. The ISO 13407 and ISO 15504 were used for the Usability Maturity Model (UMM) Processes, which combined with ISO/TR 18529 were used to develop QIU, the basis for HSL (Jokela, 2001). This research uses ISO 13407 as the base for its development.

The research by Jokela (2001) stated that improving the status of user-centered design in product development proved to be a challenge. The main result of his research is an assessment approach, where the objective is to provide a basis for performance improvement of user-centered design in product development. The approach consists of a user-centered design process model, a three-dimensional process performance model and the implementation of the assessment in the form of a workshop. The user-centered design process model is method-independent, and consists of six processes that are defined through outcomes and are assessed from the viewpoints of quantity, quality, and integration. The KESSU Process Performance Dimensions Model uses the scales of rating (Not achieved, Partially achieved, Largely achieved, and Fully achieved) from ISO 15504. Some of the benefits of this model are that it focuses on UCD and should be effective for training purposes; the assessment can be carried out efficiently, without a massive need of resources, and can be performed frequently within an organization; and the dimensions make it possible to identify areas of improvement also in organizations where projects represent high performance in UCD. Some limitations to this model are, for instance, that the focus of the assessment is limited to an examination of individual projects only; all the aspects of the approach are not fully developed, and there is limited experience using the approach. The present research however, will develop relative weights based on the product classification and environment prioritization.

The closest research that has attempted to do something similar to the goal of this study, which is to measure the impact of user-centered design, is the study conducted by Hietamaki, Hytonen, and Lammi (2005). It consists of the development of an 'Evaluation Model for the Strategic Impacts of Design', which focuses on the impacts of design in different types of companies and the economic benefits of design to businesses. The purpose is to depict design decision-making at the strategic level and to ascertain the extent of design usage, such as the processes in which design is utilized. It was found important for the companies to have indicators for evaluating the design activity as a whole: design drivers, strategic decision making, operative design usage, design management, learning and process results, as well as external results, such as customer results and financial results. However, even this investigation is limited because it does not focus in user-centered design. In fact, it only attempts to model the impact of design, which in actuality is quite an accomplishment. According to this study, researchers have not been able to determine unquestionably the causal connections between design usage and its impacts. Research has provided either correlations between good design and business performance, or management views on the impacts of design.

The research by Hietamaki et. al (2005) is divided into process results, customer results, and financial results. The process results are measured in terms of time, quality, and costs that are dependent on the product image, which are defined by product attributes such as aesthetics, ergonomic, attraction, functional, innovativeness, communication, productivity, competence, and personnel satisfaction, among others. The results are reflected in the customer satisfaction with the value and image, which affect the customer acquisition and retention that in turn affects the market share and customer profitability. The customer results affect the financial outcome, driving the net sales profit ROI and share price (Hietamaki et. al (2005). Based on the interviews conducted in the first part of the study, it was established that even though some of the participating companies occasionally measured internal design impacts, they do not have a systematic and continuous method for evaluating design results. The companies collect the design success information by conducting user tests and collecting feedback from sales personnel or directly from customers; however, according to the case companies, customers' positive feedback on design is rare. The four most important impacts of design were identified to be the product image, corporate image, customer satisfaction, and product attributes. This study had limitations such as: the companies that participated in this research did not have systematic methods for evaluating design impacts. The design results of this research were tacit knowledge and understanding or fragmented information on the impacts of design, instead of systematically proven results of design usage; therefore, they were not able to verify objectively the causal relations of design and its strategic impacts (Hietamaki et. al (2005).

The following figure illustrates the research gaps identified in the literature review and contributions obtained from conducting this research investigation.

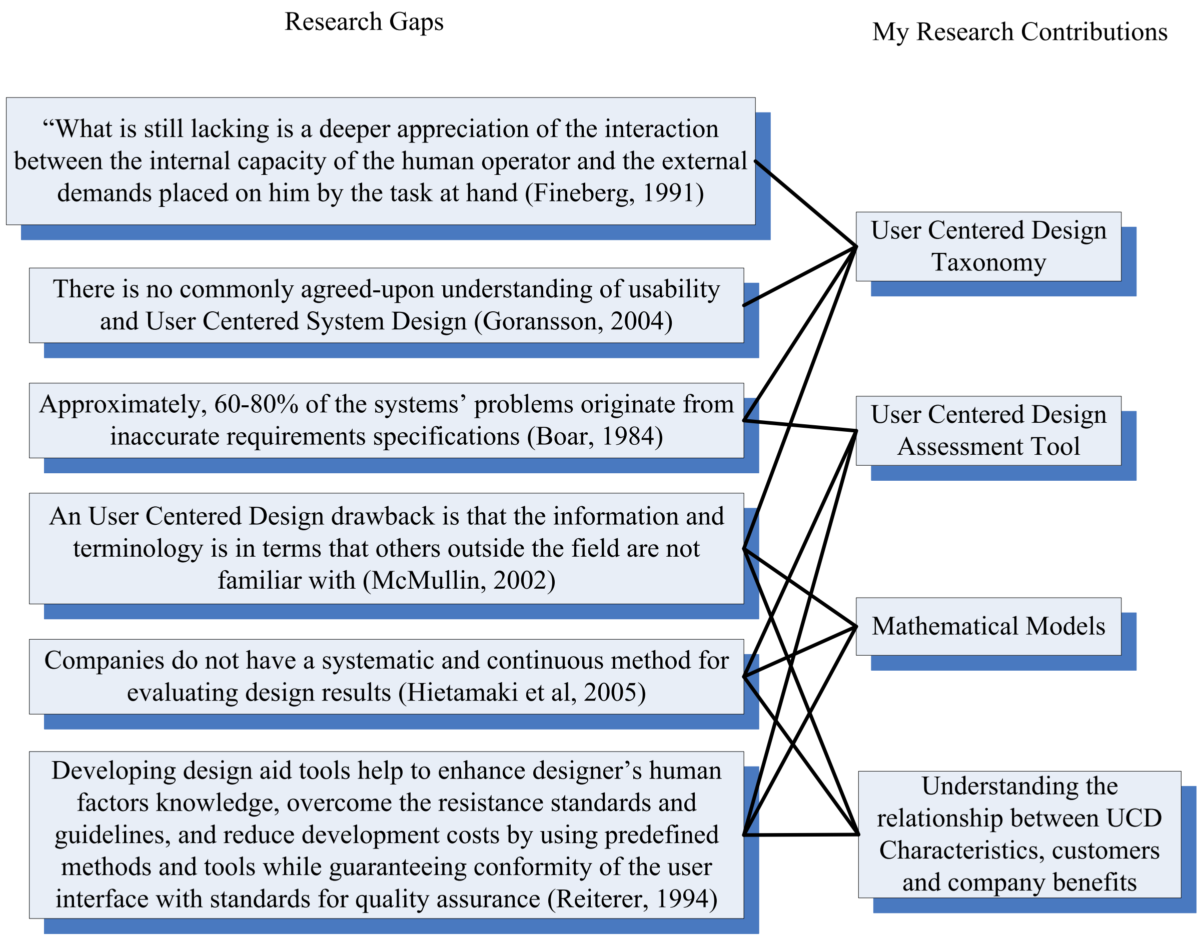

Figure 2 Research gaps and contributions

In addition to the findings from the user-centered design model, customer benefits and organizational benefits were also analyzed.

Customer Benefits

It is important to consider customer benefits in the product development process because the impact of the product on the intended use will affect the prosperity of the organization. It has been known that the customer is of vital importance to the success of any business. Hauser and Zettelmeyer have stated that in order for the firm to have a good bottom-line (profits) it must have a good top-line (revenue). Therefore, good top-line performance requires products and services designed to fulfill customer needs and satisfy customers (Hauser and Zettelmeyer, 1996).

Industry traditionally uses the “Voice of the Customer” (VOC) to represent customers’ requirements, expectations, and desires in any product. In the automotive industry, the VOC is obtained through market research and consumer feedback from surveys and third-party sources such as J.D. Power & Associates, a marketing information firm that conducts independent and unbiased surveys of product quality, customer satisfaction, and buyer behavior for companies worldwide. The VOC is important for defining and refining feature characteristics such as styling, comfort and convenience items. Electronics is an example of an item that can be evaluated in customer clinics. Since the VOC is very elusive in nature, the companies need methods to translate what might be called "the soft points of customer preferences" into specific financial criteria (Economics and Business Group, 2007).

Organizational Benefits

According to the Economics and Business Group, “Brand values are paramount in shaping vehicle programs, and a brand's identity is strongly tied to its customer base. Corporate image is secondary by comparison but corporate vision can play a strong role in setting direction”. The brand image is different from the company image, and better defined. Having a distinctive product is crucial for the success of a company because customers will relate either a positive or negative impression to the brand, which will as a result affect the customer loyalty and profitability. Companies measure profitability with the return on investments in a variety of ways such as return on sales internal rate of return (IRR), after-tax return on sales (ATROS) and contribution margin. In some companies, different programs may have different profit margin targets (Allen, 2002, Economics and Business Group, 2007).

Mao, Vredenburg, Smith, and Carey (2002) conducted a study on UCD practice; their survey was on the organizational impact and practice of UCD, including measures of its effectiveness, a representative UCD process, and the most commonly used UCD methods. Experienced practitioners of UCD were surveyed, where the majority stated that UCD methods had improved the usefulness and usability of products. The participants were asked to describe a few quantitative and qualitative measures of UCD effectives in their organizations; the top cited measures consisted of the following:

1. External (customer) satisfaction
2. Enhanced ease of use
3. Impact on sales
4. Reduced help desk calls
5. Prerelease user testing/feedback
6. Error/success rate in user testing
7. Users' ability to complete required tasks
8. Internal (company) critical feedback
9. Savings in development time/costs

Overall, the response was sparse and idiosyncratic; in fact, a total of 191 indicators were mentioned and 15 of the 103 participants reported that no effectiveness measure was in place. Furthermore, the study reflected that namely focusing on the total user experience, end-to-end user involvement in the development process, and tracking customer satisfaction; common characteristics of an ideal UCD process were not found in practice. Also, a rigorous end-to-end methodology is not currently in practice.

Defining Taxonomy

Taxonomy is the practice and science of classification. One of the advantages to using taxonomy is that it provides a system for defining a relationship between the information given. It also provides different categories for the information, which in many cases can be considered a disadvantage because it takes a significant effort to obtain the information added to the different categories, and in many cases, the information will be incomplete.

Taxonomy is a classification system tool available for managing information overload (Levy, 2004). Although taxonomies only represent a link between the two items, it does not explain how one item relates to another. They can provide benefits such as more efficient content management systems because they classify organisms in an ordered system to indicate natural relationships. Louie, Washington, and Maddox (2003) developed a faceted classification to provide a structure for information architecture, and defined the faceted classification system (FCS) as essentially being a multi-dimensional taxonomy. Four classification systems were identified:

1. Rational – uses logic and everything known
2. Empirical – uses observations from the “real” world
3. Cultural – uses what else agrees on
4. Contextual – uses what works best for each situation

According to Barnwell (2005), regardless of the classification type, the goal is still the same: "to name things in order to place them in intuitive classifications that can suggest familial relationships and meaningful associations. When you name and classify, that's taxonomy in practice." A well-structured taxonomy will both reveal and serve a logical, narrative flow of information. Most taxonomies respect a hierarchical structure either bottom-up or top-down approach. Researchers and practitioners agree that taxonomies have had a great deal of intuitive appeal and that they make sense (Barnwell, 2005). For the purpose of this dissertation research, the top-down approach is employed for the classification of user-centered design, customer benefits, and organizational benefits.

Fuzzy Set Theory (FST) and the Analytical Hierarchy Process (AHP)

Many methods have been proposed to deal with the approximation concept such as fuzzy set theory and the bayesian decision theoretic framework, which provide a plausible unification of the fuzzy set and rough set approaches for approximating a concept (Yao and Wang, 1992). Fuzzy set theory becomes a more logical selection because it is used in situations where it is more natural to handle uncertainty such as in the case of dealing with inherent imprecision of concepts involved in human reasoning and natural language (Bonisson, 1980).

The concept of fuzzy set theory was originally introduced by Zadeh in 1965 as a way of representing and analyzing "imprecise" concepts such as key attributes in the human thinking process because it could not be numerically represented. By using linguistic variables, it provides a method for transforming verbal values into numerical values. It is used to describe event ambiguity or generality by measuring the degree to which an event occurs, not whether it occurs, which is obtained through probability. Fuzzy set theory allows for the description of concepts in which the boundary between having a property and not having a property is not sharp. According to Badiru, the probability of whether an event occurs is “random”, but the degree to which it occurs is considered “fuzzy”. Fuzzy is used when something is ambiguous (a parameter may represent two or more conditions), vague (a parameter that cannot be numerically quantified, usually due to a lack of information), or general (a parameter that is used to describe a range of conditions such as a nice car) (Badiru et.al., 2005).

Fuzzy set theory is a method of approximate reasoning that uses multi-valued logic to represent the condition of an element in order to express imprecise or approximate concepts and relationships (Badiru et. al., 2005). It provides “a convenient point of departure for the construction of a conceptual framework which parallels in many respects the framework used in the case of ordinary sets, but is more general than the later” and proves to be more useful in the fields of pattern classification and information processing (Zadeh, 1965).

In the field of fuzzy set theory, methodologies for valid quantification of somewhat abstract or difficult to measure conditions have been demonstrated (Adedeji, 2005). Although this method has been used in other applications such as human factors assessments, it has not to date been applied to the domain of user-centered design. This research fuses the domain and challenges of organizational benefits quantification with the domain area of fuzzy set theory in order to develop indices for the major components of user-centered design as well as customer benefits and organizational benefits.

Other various techniques exist to obtain the weighing of factors. These techniques include rating scales, pair wise comparison, and analytic hierarchy processing (AHP). Saaty developed AHP in the 1980s, and it is considered a very useful systematic decision analysis tool that includes both quantitative and qualitative methods. It has been successfully applied to many fields for a very long time. For instance, the study conducted by Kong and Liu (2005) aimed at determining the key factors that affect success in e-commerce using AHP, and the development of an evaluation method for e-commerce.

Several data collection techniques may be employed to collect information. Using the analytical hierarchy process, relative weights can be assigned to each risk factor based on the opinion of subject matter experts (SME). One of the critical steps of the AHP method is setting up the comparison matrices (Cambron, 1991). As the number of attributes (or alternatives) in the hierarchy increases, the comparisons between attributes (or alternatives) also need to increase. The following table provides the pairwise comparison scale developed by Saaty (1980).

Table 1 Saaty's scale for pairwise comparison

Saaty's Scale	The relative importance of the two sub-elements
1	Equally important
3	Moderately more important with one over another
5	Strongly more important
7	Very strongly more important
9	Extremely more important
2,4,6,8	Intermediate values

The "1" represents equal importance of the two variables where "9" suggests that "x" is more important than "y". When several experts are involved, their opinions must be properly aggregated to determine relevant membership. The membership grade of belonging to a fuzzy set is a calculation of the ratio between the total number of favorable answers and the total number of possible answers (Klir, 1997). The inverse of the values can be used if an inverse relationship exists among the variables. Once the pair-wise matrix is developed, the relative weights are obtained from the estimate of the maximum eigenvector of the matrix. The normalized average weighing indicates the relative significance of each factor (McCauley-Bell, 1999).

Since the approach takes into account both objective and subjective factors, it retains the merits of both approaches to determine relative weights by solving mathematical models automatically, while considering the decision maker's preferences. According to Forman and Gass (2001), "it converts individual preferences into ratio scale relative weights that can be combined into a linear additive weight *w(a)* for each alternative *a*. The resultant *w(a)* can be used to compare and rank the alternatives and, hence, assist the decision maker in making a choice. Given that the three basic steps are reasonable descriptors of how an individual comes naturally to resolving a multi-criteria decision problem, then the AHP can be considered to be both a descriptive and prescriptive model of decision making (Anderson, 2004, Forman and Gass, 2001)." It also overcomes the shortcoming, which may happen when either a subjective approach or an objective approach is used (Kong and Liu, 2005).

The study performed by Kao et. al. (1993) consists of using multivariate regression analysis with fuzzy sets for modeling a correlation between consumer-perceived product quality attributes and designer-controlled design factors. The procedure for processing fuzzy information is based on the Monte Carlo technique called the JHE method. This method was identified as being most appropriate for use when a product has multiple quality attributes that could best be assessed with linguistic terms. A mathematical model is formulated in this study based on quality attributes and design factors of product alternatives. The authors in this study stated that fuzzy sets theory provides a mathematical framework that can study with precision both vague and conceptual phenomena. Although this study showed very promising results, further studies are required to validate the presented technique, especially using actual data (Kao et. al., 1993).

Terpenny and Wang (2003) worked on an interactive approach to synthesize component-based preliminary engineering design problems. The methodology uses hierarchical design, set-based design generation, fuzzy design trade-off analysis, and interactive design adaptation for evolutionary synthesis to accommodate future changes. This method incorporates multi-criteria evaluation and constraint satisfaction. It is applicable to general multi-domain applications, specifically the physical modeling of dynamic systems. The hierarchical multi-agent technology is used to define top-level functions that may be too vague or abstract. These functions are translated into a series of operational sub-functions. The developed design representation is used to represent and understand functions, behaviors, components, and their relationships. According to Terpenny and Wang, the application of fuzzy set theory has received more attention recently because it allows for imprecise information such as design variables and attributes to be represented by a continuous or discrete range as needed. Fuzzy set theory was selected to develop multi-attribute preference aggregation functions for engineering design. The Zionts-Wallenius method was also implemented in this study, where decision makers answered "yes" or "no" questions to identify importance relative weights and explore objective trade-offs. Fuzzy set theory plays an important role in preference modeling since human judgments that include preferences are often vague (Terpenny and Wang, 2003).

The work by Hancock, Masalonis, and Parasuraman (2000) combines fuzzy set theory with signal detection theory into a theory called Fuzzy SDT, which is used to illustrate the relevance of fuzzification in the larger cycle of design, configuration, and use of technology. This study shows that fuzzy set theory can be helpful in various realms because parameters can be measured in terms of the degree to which a response has been made. The study results are analyzed using response surface, which show how the sequential response between categories may be related. In the case where [0, 1] mapping may be excessively arbitrary, the mean and/or variance of the error score between actual and predicted values may be used. A mean with a negative error score would show a liberally-biased system, as opposed to a positive error score which would show conservatism. The absolute value of the mean error score would represent sensitivity, and the variance would represent system predictability. Since signal detection can change, the membership value of a sample can also vary over time. Therefore, the study then goes into the analysis using a combination of fuzzy and ANOVA, which results in a method called FANOVA. This method can be used in dynamic environments that can show phenomena evolve over time like a sequence of repeated analysis; however, it proves to be time-consuming and tedious (Hankock et.al, 2000).

Murphy et.al. have performed other investigations such as the Comparison of Fuzzy Signal Detection and Traditional Signal Detection Theory: Analysis of Duration Discrimination of

Brief Light Flashes. The importance of this study is that it compared both theories and also conducted experiments which led to the distinction that the FSDT is more applicable to the real world conditions because it can distinguish from a range of stimuli and can indicate if it has characteristics of more than one category, as opposed to SDT where the stimuli can only be assigned to one category. In this study two factors were manipulated: difficulty and bias. There is still additional research that needs to be conducted, however the results based on the study performed by Murphy, Szalma and Hancock (2004) indicate that the fuzzy SDT proved that the assumption of a normally distributed noise and signal plus noise distribution holds. The researchers plan to develop a statistical program that can test the significance of the fuzzy SDT ROC curve in a quantitative manner. Also, future studies need to be done to study the effects of the stimulus size and response sets on signal detection using fuzzy SDT.

The study by Jiang and Hsu (2003) on the development of a fuzzy decision model for manufacturability evaluation emphasizes on the treatment of the linguistic and vagueness at the early product development stage. It also considers the function integration of the total product life cycle. Therefore, it looks at the integrated decision model which considers multiple criteria such as the decision space, the function space, the activity space, the development space, and the goal space. The activity decision space is measured with the fuzzy multiple attribute decision making (FMADM) and activity-based costing (ABC) method. The FMADM deals with discrete variables in a decision space, and involves aggregation, and rating and ranking, as opposed to the fuzzy multiple objective decision making (FMODM), which focuses on continuous decision space and mathematical programming with several objective functions. Typical problems solved with FMADM include methods such as the fuzzy simple additive weighing method, the fuzzy conjunctive/disjunctive method, the fuzzy analytic hierarchical method, and the heuristic approach, among others. However, broader applications are achieved when it is combined with other decision making methods, such as neural networks modeling and group decision methodology. This study used the FMADM to develop a manufacturability evaluation model. The FMADM method consisted of aggregating the performance scores with respect to the attributes for each alternative, and then ranking the alternatives based on the aggregated scores. Although this method is applicable in many fields, it proved to be problematic and inefficient when handling more than ten attributes. Therefore, future research is expected for solving large scale problems. A recommended approach for product development is the use of a method that combines neural network learning with fuzzy representation, called fuzzy adaptive network (Jiang and Hsu, 2003).

Tsai and Chang (2003) performed a study on fuzzy neural networks for intelligent design retrieval using associative manufacturing features. The intelligent retrieval system involved soft computing techniques for feature and object association functions. Although association models show an improvement in the computational process for design retrieval systems, they also have some significant drawbacks that make it difficult to use in practice, such as lack of robustness in searching mechanisms; similarity relation between individual features is not considered, therefore, designers are forced to constantly modify requests and develop many sets of queries. This study showed that one of the benefits of using feature relation is shortening and increasing the search spectrum. Fuzzy ART neural network is used to search for relevant designs based on object form association whose results proved to be promising in a lab setting (Tsai and Chang, 2003).

The study by Wang et. al consists of the development of a fuzzy multiple criteria decision making (MCDM) approach for jag selection, where fuzzy sets are used to describe the cut-list, and pairwise comparisons and analytic hierarchy process (AHP) are used to determine the relative weights for the multiple criteria. The AHP method uses pairwise comparison to determine the attribute relative weights. Saaty's fuzzy AHP uses the estimation of a ratio scale and a consistency measure, which results in a cardinal order that can be used to rank the alternatives. In this study, only the operator's preference of multiple criteria is considered. Therefore, the authors recommended that future work should consider applying group decision making algorithms to account for conflicts between different interest groups. They also suggest the use of genetic algorithms for determining the cut-list components (Wang, et. al., 2004).

The aforementioned studies demonstrate various research efforts associated with design and user-centered design; as evident from these studies, additional research is needed to develop methods for quantifying the relationship between user-centered design, customer benefits, and organizational benefits, in terms of product advantages. Such methods could significantly advance the body of knowledge in the area of user-centered design. The research efforts of this dissertation were constructed to address this research void with the use of taxonomies and fuzzy set theory.

CHAPTER III: RESEARCH METHODOLOGY

To derive the user-centered design characteristics, designers must understand and specify the context of use, specify the user and organizational requirements, develop design solutions, and evaluate designs against customer requirements. The user-centered design process generally consists of the following procedure:

1. Identify the targeted audience
2. Form a multi-disciplinary UCD project team
3. Determine the purpose of the product, the environment to be used, priorities in using the product (to develop appropriate corresponding user requirements for designing a product or system)
4. Determine competitive products and assess key design characteristics and features
5. Develop a preliminary prototype. Test it with recruits from the targeted audience. Record their feedback
6. Based on the obtained feedback, develop a pre-release version of the product

Figure 3 illustrates the relationship and sequence of the user-centered design or human-centered design process as has been defined by ISO 13407 (UsabilityNet, 2006). This research focused on the section "understand and specify the context of use", which consists of determining the product design requirements.

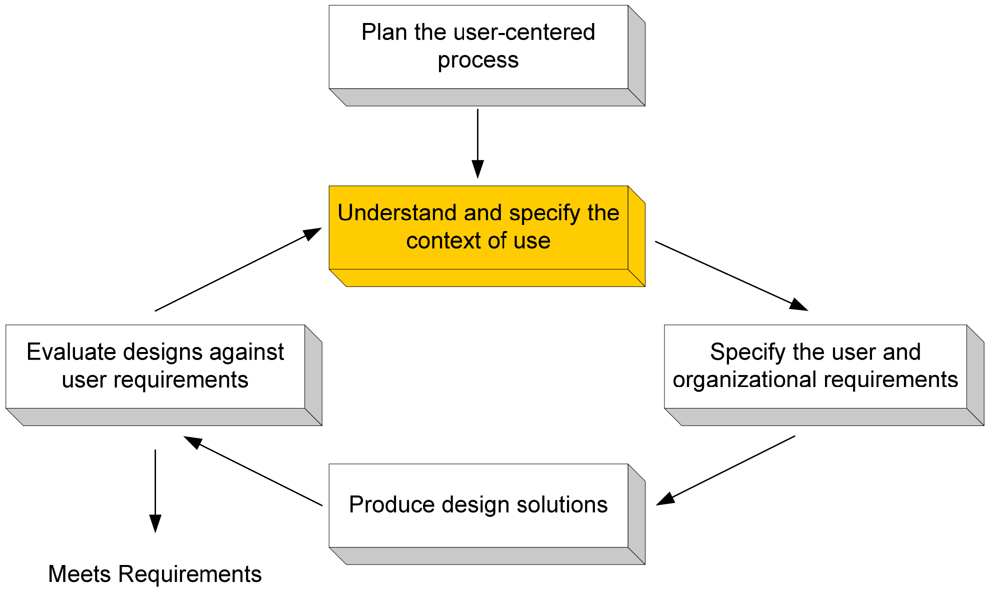

Figure 3 The human-centered design cycle (from ISO 13407)

According to Ryu et. al. (2002), the information content requirements can be presented in the context of the user, the object, the task, and the environment (Figure 4).

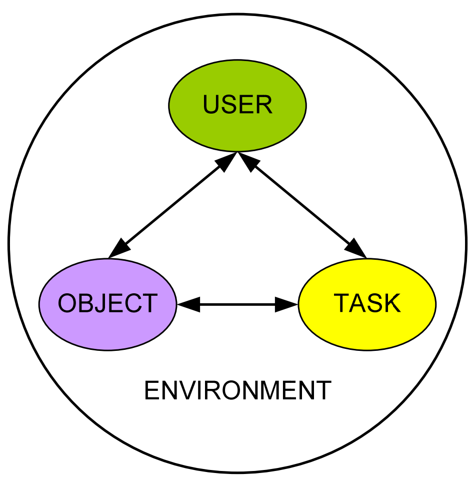

Figure 4 An Overview of user-centered design context used for the classification of information requirements developed by Ryu et. al. (2002)

Therefore, this research began with mapping the context of use (user requirements, task requirements, and environment requirements) with the user-centered design components identified (physical design, industrial design, cognitive design, and user experience design) as illustrated in Figure 5.

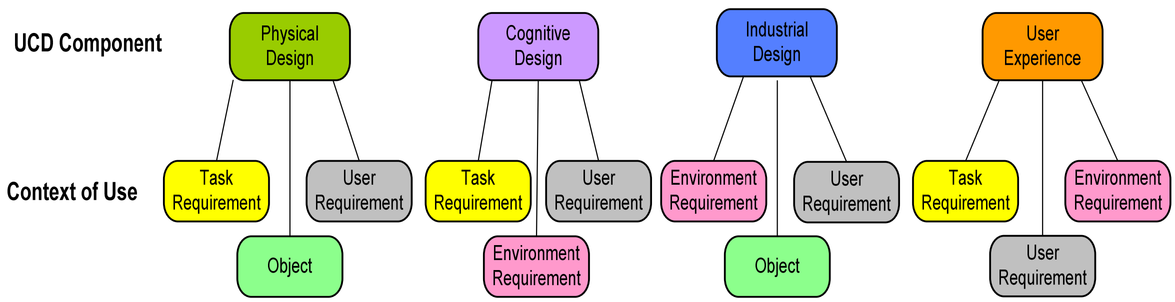

Figure 5 Mapping of context of use with user-centered design components

According to the Customers Experience Labs, additional factors may be considered in addition to usability as part of characterizing UCD; task analysis, analysis of the current system, and requirement specifications. Task analysis consists of the user characteristics, the user tasks, the characteristics of the task environment, and the task analysis model. In order to conduct the analysis of the current system, one must evaluate and analyze the existing system, the larger system, and the design space. The requirement specifications include the functional requirements as well as the non-functional requirements (Customer Experience Labs, 2008, Maguire, 2001, Myolopoulos, 2001).

Since UCD is considered to be the active involvement of users for a clear understanding of user and task requirements, iterative design and evaluation, and a multi-disciplinary approach, then UCD should NOT be seen as merely usability testing, it must also include other characteristics such as those considered for industrial design, which include the form and function as well as the aesthetics of a product. For instance, the anthropometry requirements, size, color, shape, and texture are all characteristics that must be included during the product development process as part of the user-centered design requirements because they all affect the way the user will feel, perform and interact with the developed system or product.

Research Approach

The following table illustrates the data resource or input as well as the output obtained throughout the study.

Table 2 Research approach input and output

Input	***Output***
Literature review, knowledge acquisition, and subject matter experts	UCD/CB/OB variable identification
Subject matter experts	UCD/CB/OB taxonomy development and validation
Literature review, subject matter experts	Selection of tools, methods, techniques
Literature review, subject matter experts	Development and validation of UCD tools
Experimentation with 5 types of products	Evaluation of UCD tools
Experimentation with 8 products	UCD index model development and validation
Experimentation (Historical Data)	Customer benefits index model development
Existing data sets	Customer benefits index model validation
Existing data sets	Organizational benefits index model development and validation

The research approach outlined in the following paragraphs and depicted in Figure 6 was followed to accomplish the stated goals and objectives of this research effort.

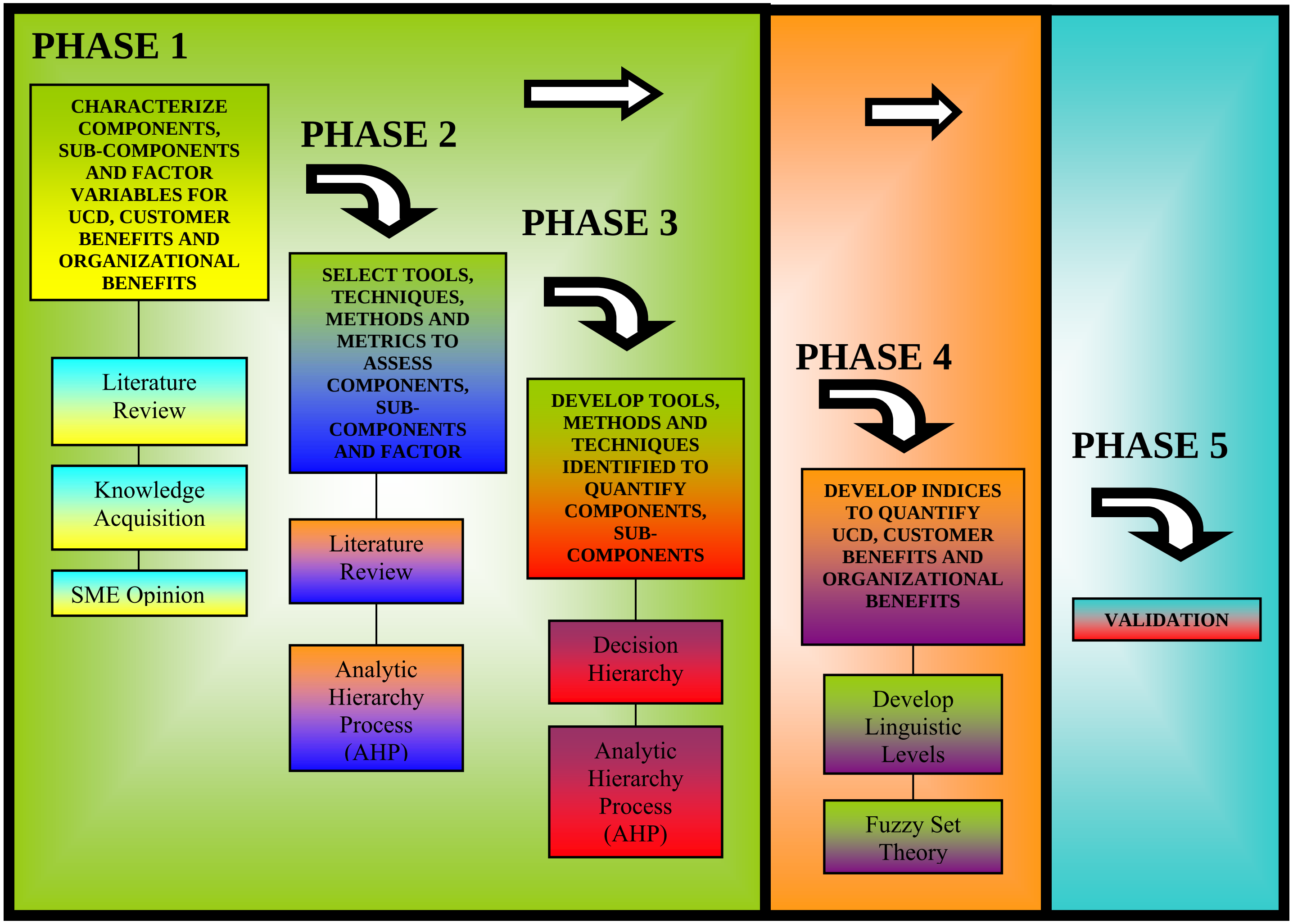

Figure 6 Evolution of research modeling activities needed to successfully measure and quantify User-Centered Design, Customer benefits and Organizational benefits

PHASE I - Characterize the components, sub-components and factor variables for User-centered design, Customer benefits, and Organizational benefits

This research was divided into five phases; the first phase was directed towards the use of various techniques to characterize/determine the significant components, sub-components, and factor variables. The taxonomy approach was used for explaining the interrelationships among components, sub-components, and factor variables in this study. The taxonomy was completed for all components identified to influence user-centered design, organizational benefits and customer benefits shown earlier in Figure 1.

The taxonomy application allows the problem to be structured through hierarchical levels, where the first level is identified as the component, the second level is the sub-component, and the third level is the factor variable. For example, the component "physical design" has sub-components such as anthropometry, muscular activity, and body position; these were analyzed to fully describe the impact of physical design on user-centered design. Lastly, factors associated with each sub-component were considered as well in this study. For instance, the sub-component "anthropometry", which has been defined by Sanders and McCormick (1993) as "anthropometry deals with the measurement of the dimensions and certain other physical characteristics of the body such as volumes, centers of gravity, inertial properties and masses of the body segments", has factors such as "range of motion" and "body segments". These components were included in the study to analyze their effect on anthropometry and their relationship to the rest of the components.

Figures 7-10 depict the characterization of each component, its associated sub-components and factor variables considered in this research. Traditionally a component is subdivided into two or more subcomponents; however, some of the developed taxonomies included one subcomponent for three main reasons: the hierarchy was defined with one subcomponent in the literature; the taxonomy is primarily intended for definition purposes; and to maintain consistency between developed taxonomies. The user-centered design components, physical design, industrial design, cognitive design, and user experience design were measured using an assessment tool that evaluates the consideration of the variables in the product design. Details on the developed design evaluation tool are provided in Phase III of the research approach section on page 61.

The "physical design" component refers to the user's physical interaction with the product such as body position and posture. One aspect of the physical components is the muscular activity requirement aspects of the product design. For instance, if the user has to perform a task, the frequency and endurance required to perform the task is considered. The number of times the task must be performed (repetition) is also important because the user can become frustrated by performing the same task too many times.

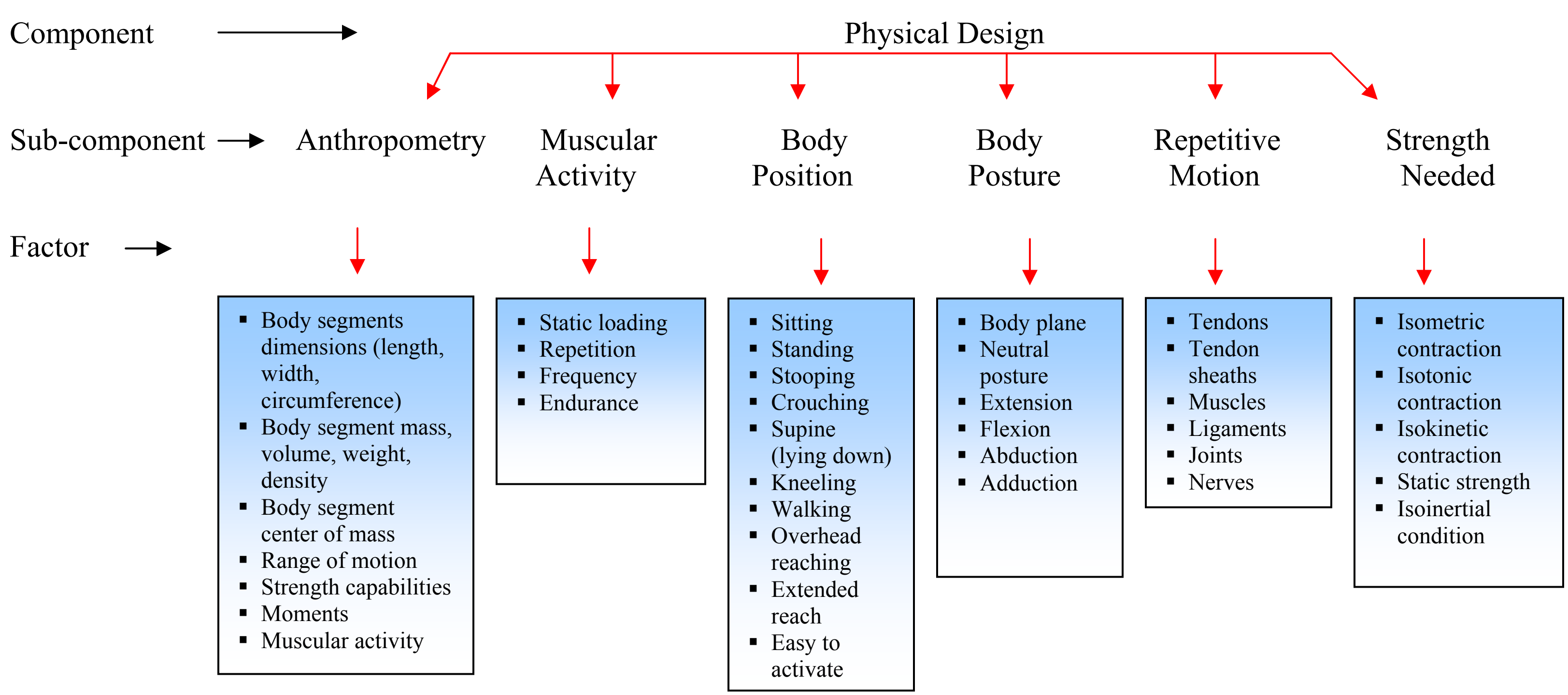

Figure 7 "Physical Design" categorization structure

The "industrial design" component is what most designers are familiar with, such as the form and function of a product. However, to ensure a product's success, others may be considered; such as the sound or noise level of the product, illumination or lighting of the product. Also considered were temperature and vibration, which may not be required for the development of every product but must be included and available for the instances when they are applicable.

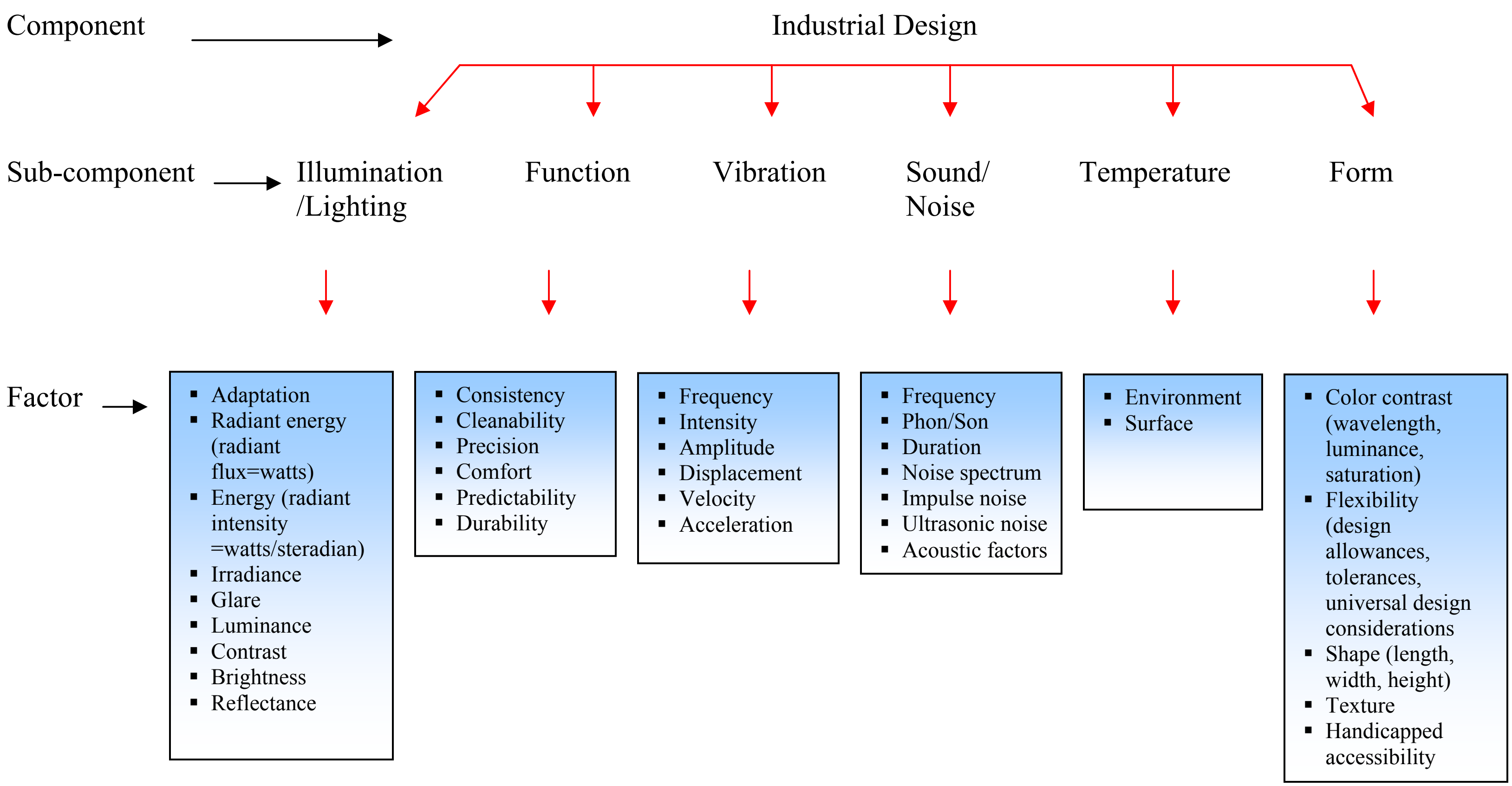

Figure 8 "Industrial Design" categorization structure

The "cognitive design" component refers to the mental processing of information and understanding in relation to how the product or product features are intended to work. One aspect of the cognitive components is the usability of the product. For instance, if the product can be easily understood and used by nearly any user, then the user will be able to complete tasks in a shorter amount of time and with fewer errors, making it a usable product. Familiarity and consistency are also important because a user must be able to become familiar with the product features of a product in order to continue its use. If features are not familiar, then the user will most likely not use it and make that feature or the whole product obsolete.

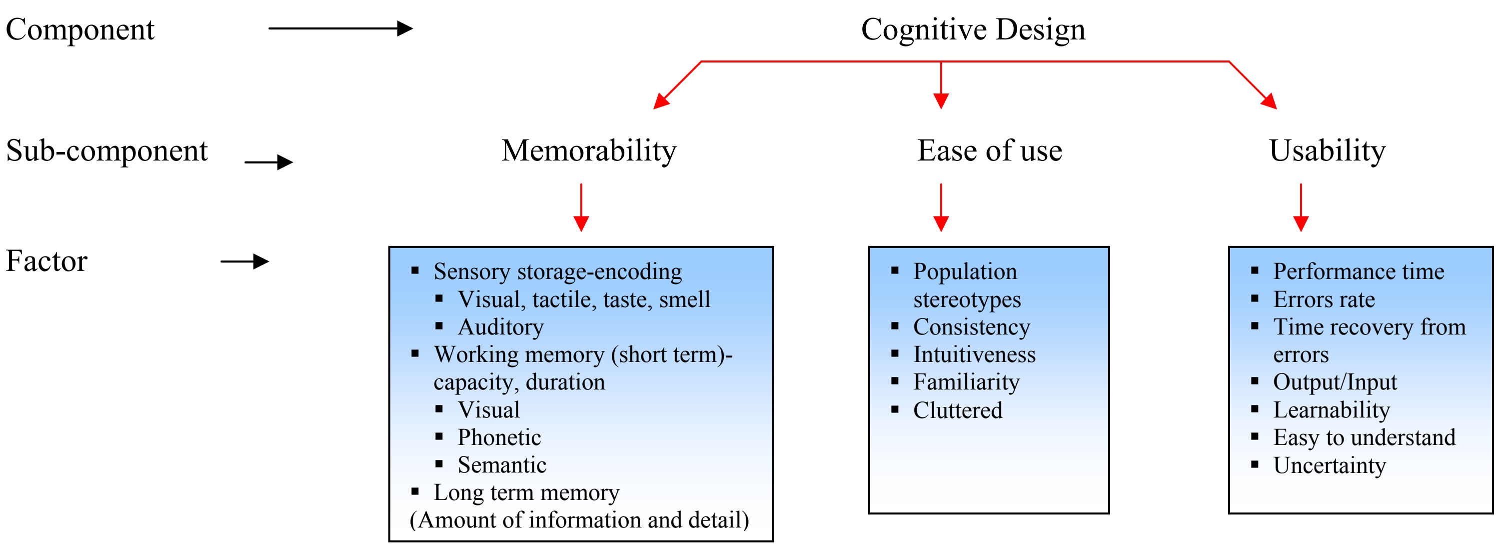

Figure 9 "Cognitive Design" categorization structure

The final user-centered design component considered in the design of a product is the "user experience". This component includes aspects such as the product value, credibility, accessibility, and usefulness. This component is very important in product development because if the user does not trust the product and feels uncomfortable with the product, then they will stop using that product and eventually stop purchasing other products from that company.

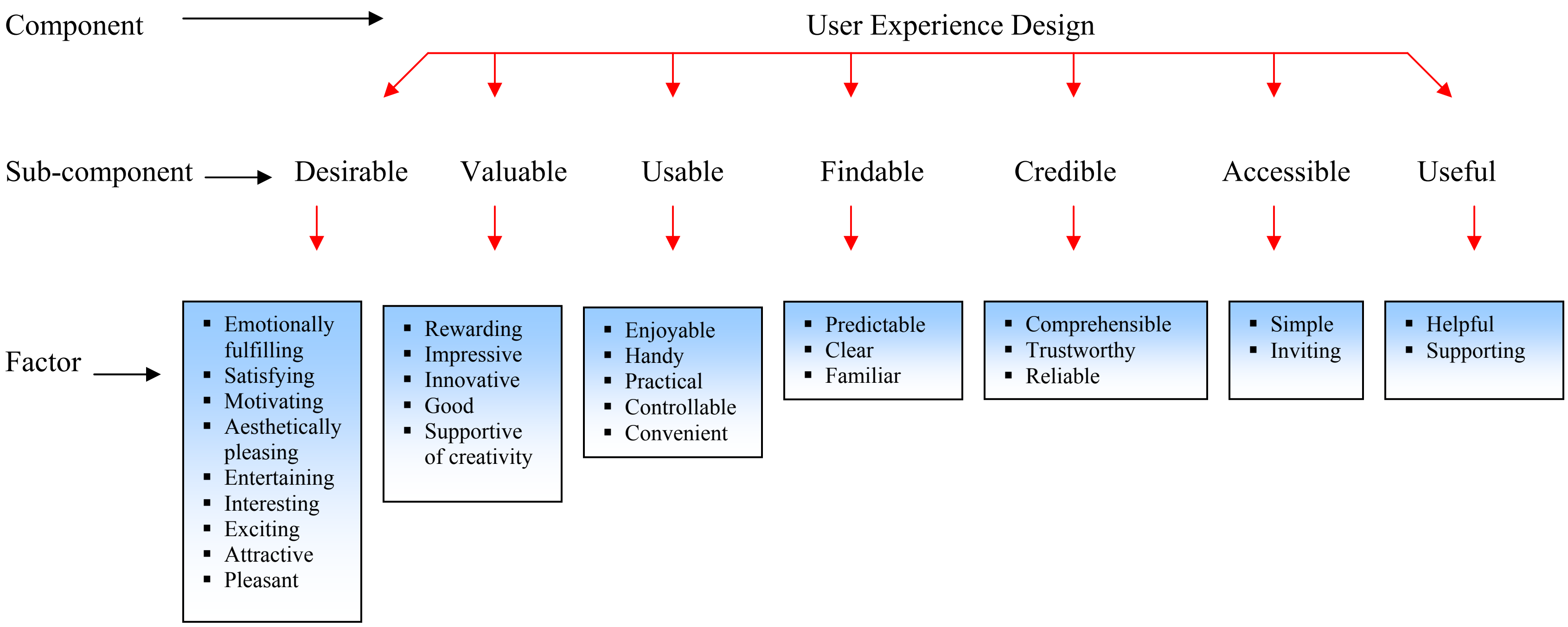

Figure 10 "User Experience Design" categorization structure

The following section discuses the taxonomy developed for customer benefits, which are significant for this research since the prosperity of a company is based on the customers. Figures 11-13 illustrate the taxonomy for the characterization of customer benefits, which include safety, quality product, and customer satisfaction.

The component "safety" has sub-components such as injuries, illnesses, and warnings, which were analyzed to fully describe the impact of safety on customer benefits. As previously mentioned, factors associated with each sub-component were considered as well in this study. The sub-component "injuries" includes factors such as "exposure to extreme temperatures" and "rubbing abrasions", which were included in the study to analyze their affect on safety and their relationship to the other components.

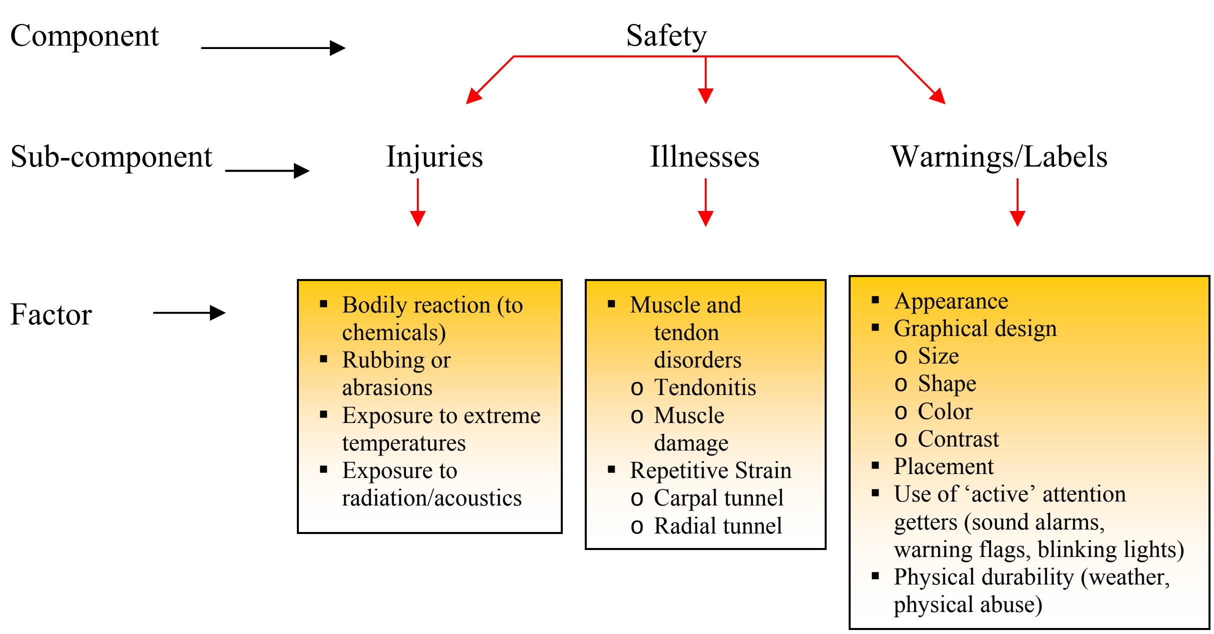

Figure 11 "Safety" categorization structure of Customer benefits

The component “customer satisfaction” has sub-components such as customer perception and appeal, which were analyzed to fully describe the impact of customer satisfaction on customer benefits. The sub-component “appeal” includes factors such as “visual appeal” and “motivation” that were included in the study to analyze their effect on customer satisfaction and their relationship to the remaining components.

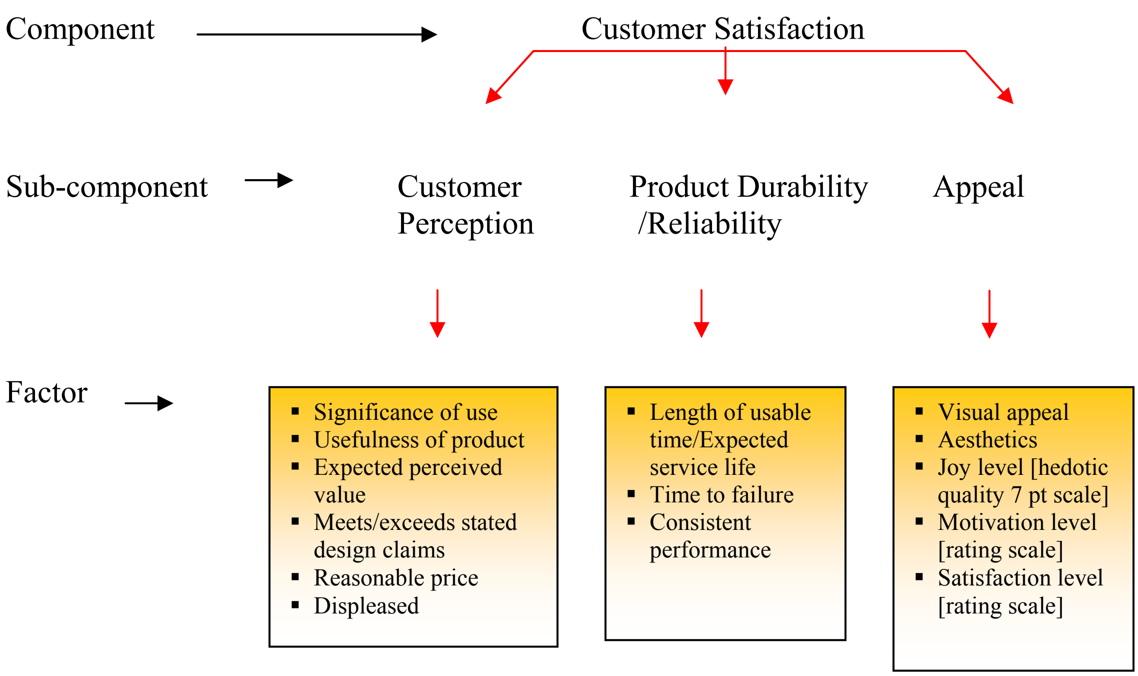

Figure 12 “Customer Satisfaction” categorization structure for Customer benefits

The “quality product” component considers sub-components such as “performance”, which refers to the quality aspects considered in a product to determine its overall performance. For instance it considers accuracy, reliability, stability, and repeatability, which, consist of the product repeating the same outcomes every time the same process or steps are performed.

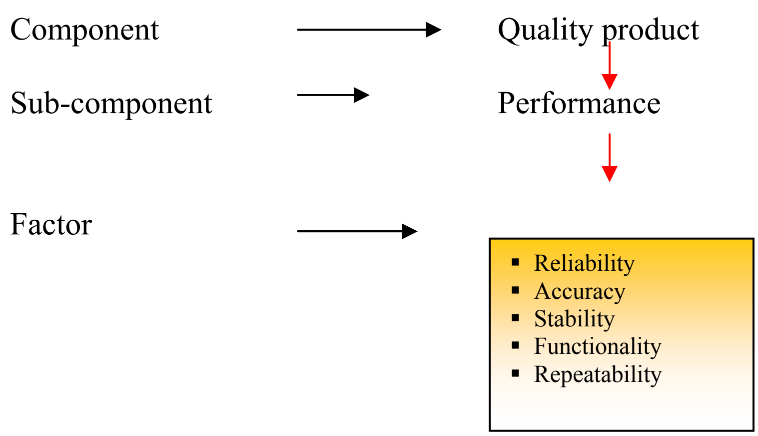

Figure 13 "Quality Product" categorization structure of Customer benefits

The taxonomy for organizational benefits is presented in Figures 14-16, and includes: profitability, customer loyalty, and company image. These components look at the public opinion as well as the production cost. In addition, it considers the company credibility and customer satisfaction by considering the service provided to the customer.

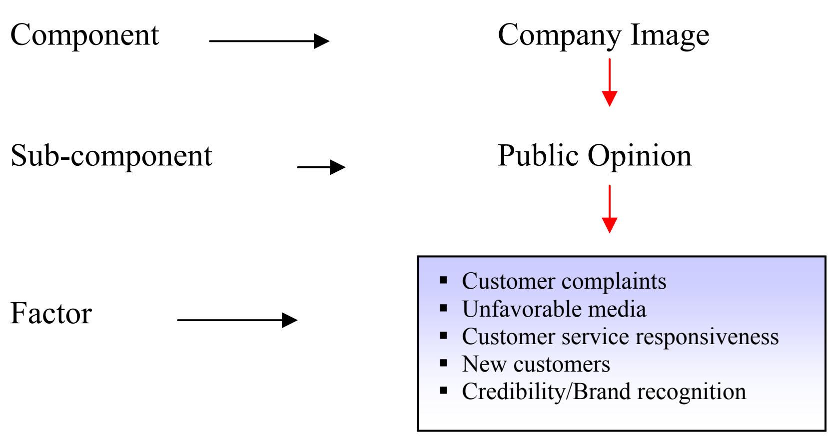

Figure 14 "Company Image" categorization structure of Organizational benefits

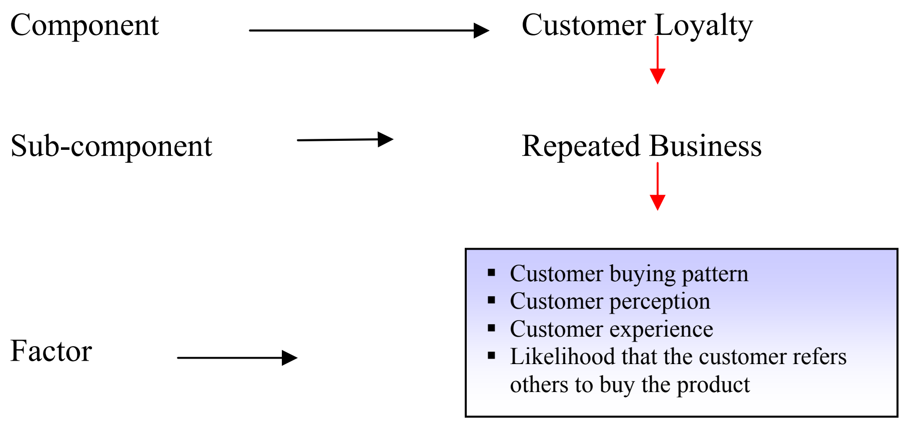

Figure 15 "Customer Loyalty" categorization structure of Organizational benefits

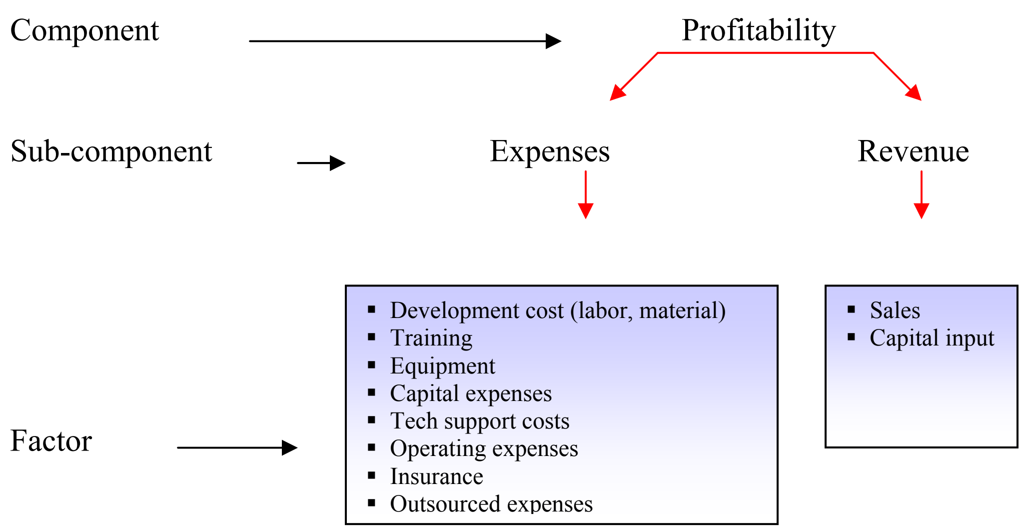

Figure 16 "Profitability" categorization structure of Organizational benefits

Once the taxonomies were developed, they were validated by subject matter experts (SME). The number of experts required was determined based on the optimization of time and resources. Three groups of subject matter experts were used to validate each of the main areas of the research. Therefore, three SMEs with specialty in product development validated the user-centered design taxonomy; three different SMEs with specialty in the area of human factors validated the customer benefits taxonomy; and three additional SMEs with specialty in business management validated the organizational benefits taxonomy. Each of the groups of SMEs consisted of a variety of backgrounds between academicians as well as industry practitioners. The user-centered design taxonomies were validated by four subject matter experts, two from the industry, and the remaining two from the academia. The subject matter experts from the industry have a background in human factors and ergonomics, and work for major industry leaders such as an automotive company and a manufacturing company. The academicians are professors and researchers from the University of Central Florida. The customer benefits taxonomies were validated by five subject matter experts, three from the industry, and the remaining two from the academia. The subject matter experts from the industry have a background in human factors and ergonomics, and work for major industry leaders such as automotive company and a manufacturing company. The academicians are professors and researchers from the University of Central Florida. The organizational benefits taxonomies were validated by four subject matter experts, three from the industry, and the remaining one from the academia. The subject matter experts from the industry have a background in human factors and ergonomics, and work for major industry leaders such as automotive company and a manufacturing company. The academicians are professors and researchers from the University of Central Florida. The variables that received a rating between 1 and 4 were kept in the taxonomy. Any variable that received a rating of "0" from all the subject matter experts was eliminated from the final taxonomy. The following table is an example of the validation form completed by the subject matter experts to validate the developed taxonomy. The validation forms are included in APPENDIX A.

Table 3 Example of Taxonomy Validation Form

Please rate how important each variable is when designing a product for the human user. In the table below you only need to enter your values in the column labeled "level of importance". Please use the following scale in your rating for each variable in the tables below:

0: Not Important
1: Mildly Important
2: Moderately Important
3: Strongly Important
4: Vitally Important

For example, if you believe that considering "physical design" is not important then you would enter a "0". If you believe that considering "industrial design" is extremely important, then you would enter a "4". You may use the Comments/Additions column to enter any comments regarding your rating for a variable. Also, you may use the Comments/Additions column to add any additional variable that you feel should be considered when designing products for human users.

EXAMPLE TABLE ONLY

Variable	Definition	Level of Importance	Comments/ Additions
Physical Design	User's physical interaction with the product such as muscular activity and strength. It unifies the design process to generate a product that not only meets functional requirements but also creates the visual/tactile form that relates the product to the user.	**0**	
Industrial Design	Products' design characteristics such as texture, dimensions, and form. It focuses on defining the form/function interface.	**4**	
Cognitive Design	Components dealing with human-product interaction in which the human must use a mental process including aspects such as awareness, perception, and reasoning. It focuses on developing designs that are within human information processing capabilities and limitations.	**3**	
User Experience Design	Emotions experienced by the user as a result of the interaction with the product/system user experience is a term used to describe the overall experience and satisfaction a user has when using a product or system.	**2**	

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Variable	Definition	Level of Importance	Comments/ Additions
Physical Design	User's physical interaction with the product such as muscular activity and strength. It unifies the design process to generate a product that not only meets functional requirements but also creates the visual/tactile form that relates the product to the user.		
Industrial Design	Products' design characteristics such as texture, dimensions, and form. It focuses on defining the form/function interface.		
Cognitive Design	Components dealing with human-product interaction in which the human must use a mental process including aspects such as awareness, perception, and reasoning. It focuses on developing designs that are within human information processing capabilities and limitations.		
User Experience Design	Emotions experienced by the user as a result of the interaction with the product/system user experience is a term used to describe the overall experience and satisfaction a user has when using a product or system.		

PHASE II – Selection of Tools, Techniques, Methods, and Metrics to Analyze the Components, Sub-components and Factor Variables

During the second phase, tools, techniques, and methods to quantitatively analyze the previously selected component, sub-component, and factor variables that most strongly define the relationship between user-centered design, customer benefits, and organizational benefits were identified. Although some of the variables had existing methods for measurement, several other factors did not have a method or tool available; therefore, a tool was developed. The user-centered design components were measured with a developed product evaluation tool intended to be used by the designer/developer in order to assess the amount of user-centered design variables considered in the design of a product. Since the variables for customer benefits are subjective, the identified tools for measurement are surveys and questionnaires that assess the customer's perception of product safety and quality, as well as customer satisfaction. For the measurement of the organizational benefits, a list of questions were developed for the identified variables, most of the data can be obtained from financial reports, safety audit reports, productivity analysis reports, and consumer reports, among others. The tools, methods and techniques identified are provided in the following table.

Table 4 Tools, Methods and Measurement Techniques

	Component	Sub-component	Factor	Measurement method/Metrics
UCD	Physical design	Anthropometry	Body segment dimensions (length, width, circumference) Body segment mass (volume, weight, density) Body segment center of mass Range of motion Strength capabilities Moments Muscular activity	Checklist with the range of standard measures
		Strength needed	Isometric contraction Isotonic contraction Isokinetic contraction Static strength Isoinertial condition	Checklist with the range of standard measures
		Repetitive motion	Tendons Tendon sheaths Muscles Ligaments Joints Nerves	• Checklist with the range of standard measures • Type of repetition • Number of repetition
		Muscular activity	Static loading Endurance Repetition Frequency	Checklist with the range of standard measures • Time • Count
		Body posture	Body plane Extension Flexion Abduction Adduction Neutral posture	Checklist with the range of standard measures

	Component	Sub-component	Factor	Measurement method/Metrics
		Body position	Sitting Standing Stooping Crouching Supine (Lying down) Kneeling Walking Overhead reaching Extended reach Easy to activate	Checklist with the range of standard measures
	Cognitive design	Ease of use	Population stereotypes Consistency Intuitiveness Learnability Familiarity Cluttered	Checklist with the range of standard measures
		Memorability	Sensory storage-encoding (visual, auditory) Working memory (short term - capacity, duration: visual, phonetic, semantic) Long term memory	Checklist/study will assess if user can perform similar tasks in shorter time after doing it more than once
		Usability	Performance time Output/Input Learnability Easy to understand Uncertainty Errors rate Time recovery from errors	• Checklist with the range of standard measures • Error rate • Time
	Industrial design	Form	Color Contrast (Wavelength, Luminance, Saturation) Flexibility (design allowances, tolerances, universal design considerations Shape (Length, width, height) Texture (Coarse, Fine, Even)	Checklist with the range of standard measures
		Sound/Noise	Frequency Phon/Son Impulse noise Ultrasonic noise Acoustic factors Duration Noise spectrum	• Checklist with the range of standard measures. • Sound level meter/ noise dosimeter.

	Component	Sub-component	Factor	Measurement method/Metrics
		Illumination/ Lighting	Adaptation Radiant energy Irradiance Glare Luminance Contrast Brightness Reflectance Energy	• Checklist with the range of standard measures. • Heavy duty light meter.
		Vibration	Frequency Intensity Amplitude Displacement Velocity Acceleration	• Checklist with the range of standard measures. • Vibration meter.
		Temperature	Environment Surface	Collected in study (thermometer)
		Function	Consistency Durability Cleanability Precision Comfort Predictability	• Checklist with the range of standard measures. • Survey/checklist.
	User experience design	Useful	Helpful Supporting	Hedonic scale
		Usable	Enjoyable Handy Practical Convenient Controllable	Hedonic scale
		Findable	Predictable Clear Familiar	Survey, Study evaluating number of errors

	Component	Sub-component	Factor	Measurement method/Metrics
		Desirable	Emotionally fulfilling Satisfying Motivating Aesthetically pleasing Entertaining Interesting Exciting Attractive Pleasant	Hedonic scale
		Credible	Comprehensible Trustworthy Reliable	Rating scale
		Accessible	Simple Inviting	Rating scale
		Valuable	Rewarding Impressive Innovative Good Supportive of creativity	Rating scale
Customer benefits	Safety	Injuries	Bodily reaction (to chemicals) Rubbing or abrasions Exposure to extreme temperatures Exposure to radiation / acoustics	Measure probability of an injury
		Illnesses	Muscle and tendon disorders (tendonitis, muscle damage) Repetitive strain (carpal tunnel syndrome, radial tunnel syndrome)	Measure probability of an illness
		Warnings/Labels	Appearance Graphical design (size, shape, color, contrast) Placement Use of 'active' attention getters (sound alarms, warning flag, blinking lights) Physical durability (weather, physical abuse)	Measure probability of an injury

	Component	Sub-component	Factor	Measurement method/Metrics
	Quality product	Performance	Reliability Accuracy Stability Functionality Repeatability	Survey Mean time between failures Whether (or what proportion) of typical users correctly complete the task Effectiveness/time or ((task time-unproductive time)/task time)*100%. Where unproductive time = help time + search time + snag time (overcoming problems) Number of possible failure modes
	Customer satisfaction	Customer perception	Significance of use Usefulness of product Expected perceived value Meets/exceeds stated design claims Reasonable price Displeased	Survey (Quality perception = Actual quality -expected quality)
		Durability/Reliability	Length of usable life/expected service life Time to failure Consistent performance	
		Appeal	Aesthetics Visual appeal Joy level Motivation level Satisfaction level	Survey Hedonic quality scale Rating scale Rating scale

	Component	Sub-component	Factor	Measurement method/Metrics
Organizational benefits	ROI/Profitability	Expenses	Outsourced expenses Development costs (labor, material) Capital expenses Tech support costs Operating expenses Insurance Training Equipment	Expense reports (production labor + direct material + process costs + overhead + outside processing) Expense reports (development cost + tooling)
		Revenue	Sales Capital input	Financial report
	Customer loyalty	Repeated business	Customer buying pattern Customer perception Customer experience Likelihood that the customer refers others to buy the product	Survey/Consumer reports/JD Powers reports
	Company image	Public opinion	Customer complaints Credibility/Brand recognition Unfavorable media New customers	Survey/Consumer reports/JD Powers reports

Once all of the tools, methods, and techniques to quantify user-centered design, customer benefits and organizational benefits were defined, efforts towards the development of the evaluation tools were initiated.

PHASE III – Development of tools, techniques, and methods to analyze the components, sub-components and factor variables

This third phase consisted of developing the tools, methods and techniques to analyze the components, sub-components, and factor variables. Once it was determined that previous research had not developed a tool or method of collecting the required data, new tools and methods were developed.

User-Centered Design

Product assessment tools were developed for collecting the user-centered design data. The tools evaluated the consideration of the variable inclusion in the design of the assessed product. For instance, the tools assessed whether user anthropometric measures, user interaction, and product usability were considered in the design of the product.

The evaluation tools have been designed to be very general such that they may be applicable for any industry product. However, modifications should be considered once a specific industry is identified for application in order to obtain more accurate results; accounting for the fact that design requirements depend on the user population. For instance, an automobile evaluation checklist may require the inclusion of the maximum population value since the automobiles must be designed to accommodate almost everyone. The user population is anticipated to be either men or women with ages ranging between 16-80 years of age and of any ethnic background.

According to Kantowitz and Sorkin (1983) there are three strategies to follow when designing: Design for the average individual, design for extreme individuals, and design for a specified range of individuals by allowing adjustments. Therefore, the measures were targeted to include the 95th percentile male and the 5th percentile female of the population to accommodate the large user population for the evaluated type of product. In addition, modifications should be considered for specific conditions such as extreme weather conditions, which would require the use of heavy clothing, thus needing the addition of adjustment allowances.

Overall, the primary focus is to design with the intent to accommodate as many users as possible taking to consideration the intended context of use and environment. For instance, manual controls and visual displays should be located where it is easy to reach and visible to all drivers. The following tables 5-8 are the user-centered design product assessment tools developed to help identify if the design components are implemented, and if the design meets the design goals and expectations. A product assessment tool has been developed for each component of user-centered design, physical design, industrial design, cognitive design, and user experience design. The assessment varies depending on the product and is intended to be used by the designer.

Table 5 Physical Design Assessment Tool

Instructions
The following is a Physical Design evaluation tool. Please evaluate the user's physical interaction with the product/system. Please circle one answer per evaluation factor. The scale to be used is from "1" if a design factor is not met in the product design to "7" if the design factor consideration is exceeded. An additional column is provided for design comments and recommendations.

PHYSICAL DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	**Design Comments/ Recommendations**
ANTHROPOMETRY									
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Length (Width, Circumference)	NA	1	2	3	4	5	6	7	
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Mass (Volume, Weight, Density)	NA	1	2	3	4	5	6	7	
The design accommodates the 95th percentile male and the 5th percentile female of the population Body Segment Center of Mass	NA	1	2	3	4	5	6	7	
The design accommodates the 95th percentile male and the 5th percentile female of the population Range of Motion	NA	1	2	3	4	5	6	7	
The design accommodates the 95th percentile male and the 5th percentile female of the population Strength Capabilities	NA	1	2	3	4	5	6	7	

The design accommodates the 95th percentile male and the 5th percentile female of the population Moments	NA	1	2	3	4	5	6	7	
Muscular Activity can be performed by 95th percentile male and the 5th percentile female of the target population	NA	1	2	3	4	5	6	7	
STRENGTH NEEDED									
Neutral body position	NA	1	2	3	4	5	6	7	
Isometric contraction can be performed by 95th percentile male and the 5th percentile female of the target population	NA	1	2	3	4	5	6	7	
Isotonic contraction can be performed by 95th percentile male and the 5th percentile female of the target population	NA	1	2	3	4	5	6	7	
Isokinetic contraction can be performed by 95th percentile male and the 5th percentile female of the target population	NA	1	2	3	4	5	6	7	
Static strength required can be performed by 95th percentile male and the 5th percentile female of the target population	NA	1	2	3	4	5	6	7	
Isoinertial condition	NA	1	2	3	4	5	6	7	
REPETITIVE MOTION									
Moderate tendon motion	NA	1	2	3	4	5	6	7	
Moderate tendon sheaths motion	NA	1	2	3	4	5	6	7	
Moderate muscles motion	NA	1	2	3	4	5	6	7	
Moderate ligaments motion	NA	1	2	3	4	5	6	7	
Moderate joints motion	NA	1	2	3	4	5	6	7	
Moderate nerves motion	NA	1	2	3	4	5	6	7	
MUSCULAR ACTIVITY									
Minimum static loading	NA	1	2	3	4	5	6	7	
Moderate endurance requirement	NA	1	2	3	4	5	6	7	
Moderate repetition requirement	NA	1	2	3	4	5	6	7	

Moderate frequency requirement	NA	1	2	3	4	5	6	7	
BODY POSTURE									
Neutral body plane	NA	1	2	3	4	5	6	7	
Neutral extension (No twisting required while extending)	NA	1	2	3	4	5	6	7	
Neutral flexion (No twisting required while flexing the muscles)	NA	1	2	3	4	5	6	7	
Neutral abduction	NA	1	2	3	4	5	6	7	
Neutral adduction	NA	1	2	3	4	5	6	7	
Neutral posture	NA	1	2	3	4	5	6	7	
BODY POSITION									
Neutral sitting position required	NA	1	2	3	4	5	6	7	
Neutral standing position required	NA	1	2	3	4	5	6	7	
Limited stooping required	NA	1	2	3	4	5	6	7	
Limited crouching required	NA	1	2	3	4	5	6	7	
Supine (lying down)	NA	1	2	3	4	5	6	7	
Limited kneeling required	NA	1	2	3	4	5	6	7	
Walking	NA	1	2	3	4	5	6	7	
Limited overhead reaching required	NA	1	2	3	4	5	6	7	
Activation is easy	NA	1	2	3	4	5	6	7	
Limited extended reach required	NA	1	2	3	4	5	6	7	
Signal levels – Signal levels are 15-16 dB above masking threshold for rapid response to a signal.	NA	1	2	3	4	5	6	7	
Location of alert – 15 degrees of maximum deviation for high priority alerts and 30 degrees for low priority alerts.	NA	1	2	3	4	5	6	7	

Additional Comments/Notes

Table 6 Industrial Design Assessment Tool

Instructions
The following is an Industrial Design evaluation tool. Please evaluate the product/system design characteristics. Please circle one answer per evaluation factor. The scale to be used is from "1" if a design factor is not met in the product design to "7" if the design factor consideration is exceeded. An additional column is provided for design comments and recommendations.

INDUSTRIAL DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	**Design Comments/ Recommendations**
FORM									
Color contrast ratio – Ratio of object luminance over the background luminance. Measured with Modular Transfer Function Area (MTFA). High contrast must be 10 MTFA.	NA	1	2	3	4	5	6	7	
Appearance - Durable yet attractive finish	NA	1	2	3	4	5	6	7	
Font size – Observer's visual angle should be between 14-22 minutes of arc.	NA	1	2	3	4	5	6	7	
Size of alert – Visual signals should subtend at least 1 degree of visual angle.	NA	1	2	3	4	5	6	7	
Contrast ratio – Visual signals are at least twice as bright as other displays.	NA	1	2	3	4	5	6	7	
Touchscreen sensor Size 19 mm square	NA	1	2	3	4	5	6	7	
Touchscreen size has a matrix of 5x6 or 6x7.	NA	1	2	3	4	5	6	7	
Meets design requirements for the shape (length, width, height)	NA	1	2	3	4	5	6	7	
Meets design requirements for the texture (coarse, fine, even)	NA	1	2	3	4	5	6	7	

Design provides flexibility (design allowances, tolerances, universal design considerations)	NA	1	2	3	4	5	6	7	
SOUND/NOISE LEVEL									
Duration of signal sounds are appropriate for receival and recognition	NA	1	2	3	4	5	6	7	
Maximum signal levels – Level of auditory signal is 30 dB above masking threshold.	NA	1	2	3	4	5	6	7	
Alarm signal minimum duration is 100ms	NA	1	2	3	4	5	6	7	
Pitch – The pitch of warning sounds is between 150-1000 Hz.	NA	1	2	3	4	5	6	7	
ILLUMINATION/LIGHTING									
Adaptation	NA	1	2	3	4	5	6	7	
Limited exposure to extreme radiant energy	NA	1	2	3	4	5	6	7	
Limited exposure to extreme irradiance	NA	1	2	3	4	5	6	7	
Limited exposure to extreme glare	NA	1	2	3	4	5	6	7	
Limited exposure to extreme brightness	NA	1	2	3	4	5	6	7	
Limited exposure to extreme reflectance	NA	1	2	3	4	5	6	7	
Limited exposure to extreme energy	NA	1	2	3	4	5	6	7	
VIBRATION									
Limited exposure to extreme vibration frequency	NA	1	2	3	4	5	6	7	
Limited exposure to extreme vibration intensity	NA	1	2	3	4	5	6	7	
Amplitude	NA	1	2	3	4	5	6	7	
Displacement	NA	1	2	3	4	5	6	7	
Limited exposure to impact forces	NA	1	2	3	4	5	6	7	
Velocity	NA	1	2	3	4	5	6	7	
Acceleration	NA	1	2	3	4	5	6	7	

TEMPERATURE									
Limited exposure to extreme environmental temperature	NA	1	2	3	4	5	6	7	
Limited exposure to extreme surface temperature	NA	1	2	3	4	5	6	7	
FUNCTION									
Features are consistent	NA	1	2	3	4	5	6	7	
Features are durable	NA	1	2	3	4	5	6	7	
Easy maintenance - Easy to clean	NA	1	2	3	4	5	6	7	
Features are precise	NA	1	2	3	4	5	6	7	
Features are comfortable	NA	1	2	3	4	5	6	7	
Features are predictable	NA	1	2	3	4	5	6	7	
Additional Comments/Notes									

Table 7 Cognitive Design Assessment Tool

Instructions
The following is a Cognitive Design evaluation tool. Please evaluate the product/system design in terms of the human information processing capabilities and limitations. Please circle one answer per evaluation factor. The scale to be used is from "1" if a design factor is not met in the product design to "7" if the design factor consideration is exceeded. An additional column is provided for design comments and recommendations.

COGNITIVE DESIGN EVALUATION TOOL									
Design Goals	**Requirement/Expectation**								
	Not Applicable	Does Not Meet	Barely Meets	Somewhat Meets	Meets	Strongly Meets	Very Strongly Meets	Exceeds	**Design Comments/ Recommendations**
EASE OF USE									
The design uses population stereotypes that users can relate	NA	1	2	3	4	5	6	7	
Tasks/Procedures required are consistent	NA	1	2	3	4	5	6	7	
Tasks/Procedures required are intuitive	NA	1	2	3	4	5	6	7	
New tasks/Procedures required are easy to learn	NA	1	2	3	4	5	6	7	
Small amount of time required to learn how perform a task	NA	1	2	3	4	5	6	7	
Features are familiar	NA	1	2	3	4	5	6	7	
MEMORABILITY									
Memorability – Maximum number of items a person needs to remember is between 5-9.	NA	1	2	3	4	5	6	7	
Sensory storage-encoding (visual, auditory)	NA	1	2	3	4	5	6	7	

Coding – For high accuracy identification the number of colors used on a display are 5. Red, yellow, and green are reserved for “danger”, “caution”, and “safe”, respectively.	NA	1	2	3	4	5	6	7	
Working memory (short term - capacity, duration: visual, phonetic, semantic)	NA	1	2	3	4	5	6	7	
Long term memory – Steps and items can be remembered easily after a long period of time.	NA	1	2	3	4	5	6	7	
USABILITY									
Short performance time is required to complete a task	NA	1	2	3	4	5	6	7	
Short amount of time is required to locate specific information	NA	1	2	3	4	5	6	7	
Output/Input – Large percentage of tasks successfully completed	NA	1	2	3	4	5	6	7	
Small number of times help is required	NA	1	2	3	4	5	6	7	
Small number of errors made performing a task	NA	1	2	3	4	5	6	7	
Short time spent recovering from errors	NA	1	2	3	4	5	6	7	
Additional Comments/Notes									

Table 8 User Experience Design Assessment Tool

Instructions

The following is an User Experience design evaluation tool. Please evaluate the emotions experienced as a result of the interaction with the product/system. Please circle one answer per evaluation factor. The scale to be used is from "1" if you strongly disagree to a "7" if you strongly agree with the statement. An additional column is provided for design comments and recommendations.

USER EXPERIENCE DESIGN EVALUATION TOOL									
	Strongly disagree	**Disagree**	**Somewhat Disagree**	**Neutral**	**Somewhat Agree**	**Agree**	**Strongly Agree**	**Not Applicable**	**Design Comments/ Recommendations**
USEFUL									
The design is helpful	1	2	3	4	5	6	7	NA	
The design is supporting	1	2	3	4	5	6	7	NA	
USABLE									
The design is enjoyable to use	1	2	3	4	5	6	7	NA	
The design is handy to use	1	2	3	4	5	6	7	NA	
The design is practical	1	2	3	4	5	6	7	NA	
The design is convenient	1	2	3	4	5	6	7	NA	
The design provides control	1	2	3	4	5	6	7	NA	
FINDABLE									
The design is predictable	1	2	3	4	5	6	7	NA	
The design is clear to use	1	2	3	4	5	6	7	NA	
The design is familiar	1	2	3	4	5	6	7	NA	
DESIRABLE									
The design is emotionally fulfilling	1	2	3	4	5	6	7	NA	
The design is satisfying	1	2	3	4	5	6	7	NA	
The design is motivating	1	2	3	4	5	6	7	NA	
The design is aesthetically	1	2	3	4	5	6	7	NA	

pleasing									
The design is entertaining to use	1	2	3	4	5	6	7	NA	
The design is interesting to use	1	2	3	4	5	6	7	NA	
The design is exciting to use	1	2	3	4	5	6	7	NA	
The design is attractive	1	2	3	4	5	6	7	NA	
The design is pleasant to use	1	2	3	4	5	6	7	NA	
CREDIBLE									
The design is comprehensible	1	2	3	4	5	6	7	NA	
The design is trustworthy	1	2	3	4	5	6	7	NA	
The design is reliable	1	2	3	4	5	6	7	NA	
ACCESSIBLE									
The design is simple to use	1	2	3	4	5	6	7	NA	
The design is inviting	1	2	3	4	5	6	7	NA	
VALUABLE									
The design is rewarding	1	2	3	4	5	6	7	NA	
The design is impressive	1	2	3	4	5	6	7	NA	
The design is innovative	1	2	3	4	5	6	7	NA	
The design is good	1	2	3	4	5	6	7	NA	
The design is supportive of creativity	1	2	3	4	5	6	7	NA	
Additional Comments/Notes									

User Centered Design Product Assessment Tools Evaluation

Voluntary participants were used to evaluate the user-centered design product assessment tools. For this section of the research, 8 participants, consisting of 4 novices and 4 experts were selected. All of the participants evaluated 5 different types of products thus resulting in a sample size of 40 evaluations. The expert participants were identified as having either some experience in working on product development and design, having some background in human factors and ergonomics, or having some experience in conducting usability evaluations; as opposed to the novice participants which had none of the above mentioned qualifications. The participants were timed while conducting the product assessments to determine the time taken to complete the assessments. An ANOVA analysis was performed to evaluate the differences between assessments conducted by novices and experts. The ANOVA analysis tests for the null hypothesis H_o of the product weighted averages comparing the differences between novices and experts:

$$H_o: \mu_{Novice} = \mu_{Expert}$$

$$H_a: \mu_{Novice} \neq \mu_{Expert}$$

All the participants individually evaluated 5 different types of products. The order of the product evaluation was randomly selected. The following different types of products were selected to evaluate the assessment tools:

Product 1 – Blood pressure monitor

Product 2 – Blender

Product 3 – Education learning toy for children

Product 4 – Personal GPS system

Product 5 – Chair

Table 9 is the usability questionnaire the participants filled out on the assessment tools once the assessments of the five products were completed.

Table 9 Usability questionnaire filled out on the product assessment tools.

Usability assessment of the developed User Centered Design (UCD) evaluation tool

Demographics (Circle)

Age Group:

1
a. 18-24 b. 25-31 c. 32-38
d. 39-45 e. 46-52 f. 53-60
g. Above 60

2 Gender: Female Male

Highest level of education completed:

3
a. High School/GED b. Vocational/Technical School
c. Associate Degree d. Bachelor Degree
e. Master's Degree f. Doctoral Degree

Years of professional product design experience:

4 a. 1-2 b. 3-5 c. 6-9 10 and Above
e. None

Evaluate the usability of the UCD Evaluation Tool by circling a number from 1 - 7 with 7 being Strongly Agree.

Perceived Usefulness	**Strongly Disagree**					**Strongly Agree**	
Using this tool allows me to evaluate products quickly	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Using this tool would increase my productivity	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Using this tool would enhance my effectiveness	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Using this tool would make product design easier	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Overall, I found the evaluation tool useful	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Perceived Ease of Use							
I found the instructions to be clear and understandable	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I found the terminology to be consistent	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I found the terminology to be clear and easy to understand	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I found the layout to be clear	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I believe that there is sufficient "white space" to make notes and comments	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I found the evaluation tool to be clear and understandable.	**1**	**2**	**3**	**4**	**5**	**6**	**7**

I found the evaluation tool to be flexible to use with different types of products	**1**	**2**	**3**	**4**	**5**	**6**	**7**
The evaluation tool is easy to use for different types of products	**1**	**2**	**3**	**4**	**5**	**6**	**7**
The evaluation tool is user friendly	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I can use the evaluation tool without written instructions	**1**	**2**	**3**	**4**	**5**	**6**	**7**
The evaluation tool is simple to use	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Overall, I found the evaluation tool easy to use	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Ease of Learning							
I learned to use this evaluation tool quickly	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I easily remember how to use this evaluation tool	**1**	**2**	**3**	**4**	**5**	**6**	**7**
It is easy to learn to use this evaluation tool	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I quickly became skillful with this evaluation tool	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Satisfaction							
I would recommend it to other product designers	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I feel product designers need to have it	**1**	**2**	**3**	**4**	**5**	**6**	**7**
The evaluation tool is pleasant to use	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Both occasional and regular users would like it	**1**	**2**	**3**	**4**	**5**	**6**	**7**

Additional Comments

Customer Benefits

The customer benefits were measured using the developed survey provided in Table 10. This survey is intended to be filled out by the intended user once they own the evaluated product.

Table 10 Customer Benefits survey

Instructions

The following is a Customer Benefits survey. Please evaluate the performance of the product/system. Please circle one answer per evaluating factor. The scale to be used is from "1" if you strongly disagree to a "7" if you strongly agree with the statement. Please circle NA if the evaluated factor does not apply to the evaluated product.

Customer Benefits Survey	Product Performance							
	Strongly disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree	Not Applicable
Safety								
INJURIES								
The product is safe	1	2	3	4	5	6	7	NA
The risk of rubbing or abrasions from using the product is small	1	2	3	4	5	6	7	NA
The risk of exposure to extreme temperatures is small	1	2	3	4	5	6	7	NA
The risk of exposure to radiation/acoustics is small	1	2	3	4	5	6	7	NA
ILLNESSES								
The risk of muscle and tendon disorders from using the product is small	1	2	3	4	5	6	7	NA
The risk of a repetitive strain injury from using the product is small	1	2	3	4	5	6	7	NA
WARNINGS/LABELS								
The appearance of the warnings/labels is appropriate	1	2	3	4	5	6	7	NA
The graphical design of the warnings/labels is readable and understandable	1	2	3	4	5	6	7	NA
The placement of the warnings/labels is visible	1	2	3	4	5	6	7	NA
The product uses 'active' attention getters (sound alarms, warning flags, blinking lights	1	2	3	4	5	6	7	NA
The product is resistant to weather and physical abuse	1	2	3	4	5	6	7	NA

Customer Benefits Survey	Product Performance							
	Strongly disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree	Not Applicable
Customer Satisfaction								
CUSTOMER PERCEPTION								
The product is useful	1	2	3	4	5	6	7	NA
The product meets my expected perceived value	1	2	3	4	5	6	7	NA
The product is significant for its intended use	1	2	3	4	5	6	7	NA
The product meets/exceeds the design claims/requirements/specifications	1	2	3	4	5	6	7	NA
The price of the product is reasonable	1	2	3	4	5	6	7	NA
I am pleased with the product	1	2	3	4	5	6	7	NA
PRODUCT DURABILITY/RELIABILITY								
The product meets the expected service life	1	2	3	4	5	6	7	NA
The product time to failure is reasonable	1	2	3	4	5	6	7	NA
The product performance is consistent	1	2	3	4	5	6	7	NA
SERVICEBILITY								
I am satisfied with the way of servicing the product	1	2	3	4	5	6	7	NA
I am satisfied with the customer service support	1	2	3	4	5	6	7	NA
APPEAL								
I am satisfied with the visual appeal of the product	1	2	3	4	5	6	7	NA
The product looks attractive	1	2	3	4	5	6	7	NA
The product is enjoyable to use	1	2	3	4	5	6	7	NA
The product is motivating	1	2	3	4	5	6	7	NA
I am satisfied with the product	1	2	3	4	5	6	7	NA

Please rate the product Quality Performance on each of the following:

	Unacceptable		Average			Outstanding		Not Applicable
Quality	1	2	3	4	5	6	7	NA
Reliability	1	2	3	4	5	6	7	NA
Accuracy	1	2	3	4	5	6	7	NA

Stability	1	2	3	4	5	6	7	NA
Functionality	1	2	3	4	5	6	7	NA
Repeatability	1	2	3	4	5	6	7	NA
Overall product performance	1	2	3	4	5	6	7	NA

Organizational Benefits

The questionnaire provided in Table 11 is intended for the collection of organizational benefits data. This questionnaire should be filled out by the evaluating company. This type of data may be obtained from financial reports, consumer reports, etc.

Table 11 Organizational Benefits Questionnaire

Company Image	**Product X**
What percentage of customer complaints does the company receive related to their products per year?	
What percentage of unfavorable media does the company receive per year?	
How is customer service responsiveness measured in your company? (i.e average amount of time customer waits have an issue solved) and how is your company doing in terms of customer service responsiveness?	
What is the percentage of new customers obtained per year?	
What percentage of customers purchase products based on Credibility/brand recognition?	

Customer Loyalty	
What is the percentage of customer referrals received per year?	
What percentage of Customer perception feedback is positive?	
What percentage of Customer experience feedback is positive?	
What is the percentage of returning customers per year?	

Profitability	
How much money is spent on product development? (i.e Research and Development)	
What percentage of the product development costs are spent on Training?	
What percentage of the product development costs are spent on equipment?	
How much money is spent on capital expenses?	
How much money is spent on tech support?	
How much money is spent on operating expenses?	
How much money is spent on outsourced expenses?	
How much money is being made from sales?	
How much money is spent on capital investment?	

Once all of the data was collected, the indices were developed using fuzzy set theory to quantify user-centered design, customer benefits and organizational benefits.

PHASE IV – Development of indices to quantify the components, sub-components and factor variables

The fourth phase consisted of developing indices for each component using linguistic modeling and fuzzy set theory (FST), which can be used to predict not only the presence or absence of satisfaction, but also the level of satisfaction that is experienced. Traditional modeling techniques attempt to eliminate or explain uncertainty associated with a system. Therefore, variables are often excluded from the representation of the system associated with uncertainty that cannot be explained, resulting in lost or omitted information about the system. However, situations exist in which the data is naturally vague. In addition, data may also be grouped into categories for data analysis and it can belong to multiple categories. Due to the vagueness of some of the identified components, it was expected that the fuzzy set theory method would be applied to measure the components of user-centered design. For instance, it was expected to be used within the "user experience design" component because it includes qualitative information such as a person's emotions towards a product.

Fuzzy set theory was considered to be more appropriate for this research because it was developed for problems that have components which do not have smooth boundaries or have imprecise or vague information (Wang, 1992). This allows variables that are deemed insignificant with traditional techniques to be included. Fuzzy set theory does not define sets as traditionally done in set theory. Set theory is governed by binary principles, such that a variable either belongs to a set (membership equals 1) or it does not belong to a set (membership equals 0). Fuzzy set theory however, does not restrict set membership to complete 0 or 1 (Crumpton-Young, et al, 1996). Rather, it allows membership to be defined over the interval [0, 1]. Membership expresses the degree to which an element belongs to a fuzzy set, and the imprecision of many situations. In addition, a weighting process is required to obtain a number that reflects the significance of each component. Therefore, the AHP was applied with pair-wise comparisons to the components in order to determine the relative significance of each.

Variable Quantification

The purpose of this phase is to develop indices that aggregate multiple inputs from various tools, techniques, and methods designed to develop the index for user-centered design, customer benefits and organizational benefits. Thus, this phase results in the development of quantifiable levels and measures within each component through the fuzzification process. This methodology has been used in previous research to quantify risk factors in human factors model development (McCauley-Bell and Crumpton, 1997). It enhances the ability to model systems by using a variety of methods designed to represent resultant fuzzy sets through interaction between two or more fuzzy sets. Fuzzy sets can be aggregated through the use of operations such as union, intersection, linear functions, and non-linear functions. The following are the stages of the methodology used to fuzzify:

1. Problem definition
2. Knowledge elicitation
3. Determination of dependent variables
4. Determination of independent variable(s)
5. Fuzzification of variables
6. Weighting of variables

7. Definition of aggregation approach
8. Output interpretation
9. Validation/verification

Weighting Method

A weighting process is required to obtain a number that reflects the significance of each component. Several techniques exist to obtain factor relative weights, such as rating scales, pair wise comparison, neural networks, analytic hierarchy processing (AHP), SME, congruency analysis, response surface method (RSM) and bayesian approach. The AHP approach is selected for this research because, although the length of the process increases as the number of levels increases, which can result in needing more pair-wise decisions; it simplifies a complex problem into simple pair-wise comparisons and integrates subjective judgments with numerical data. Some of the benefits of this method include its intuitiveness, mathematical rigor, and ability to accommodate multiple criteria (Ahl, 2005; and Linstrom, 2005).

The use of subject matter experts (SME) is also a beneficial approach to determine the variable relative weights; although it is believed to be less sensitive and more exposed to various biases from subjective judgment (Klir and Yuan, 1995; Terano, et. al. 1992). However, since many of the concepts are linguistic in nature, then the use of SME provides a method that helps quantify qualitative measures. Pairwise comparisons allow researchers to determine the relative order (ranking) of a group of items. Figure 16 illustrates a sample of the form subject matter experts used to conduct the pairwise comparisons.

Please use the following scale to rate each factor comparison:
-9 = variable **A** is ***Extremely More Important*** than variable **B**
-7 = variable **A** is ***Very Strongly More Important*** than variable **B**
-5 = variable **A** is ***Strongly More Important*** than variable **B**
-3 = variable **A** is ***Moderately More Important*** than variable **B**
1 = variable **A** is ***Equally Important*** as variable **B**
3 = variable **B** is ***Moderately More Important*** than variable **A**
5 = variable **B** is ***Strongly More Important*** than variable **A**
7 = variable **B** is ***Very Strongly More Important*** than variable **A**
9 = variable **B** is ***Extremely More Important*** than variable **A**

Example: If comparing Physical Design (variable B) and Cognitive Design (variable A), you consider that Physical Design is strongly more important than Cognitive Design; then, you would enter a value of 5.

Compare the relative importance with respect to user-centered design

A	-9	-7	-5	-3	1	3	5	7	9	B
	Extremely More Important	Very strongly More Important	Strongly More Important	Moderately More Important	Equally Important	Moderately More Important	Strongly More Important	Very strongly More Important	Extremely More Important	

A

		User Centered Design			
		Physical Design	Cognitive Design	Industrial Design	User Experience
B	Physical Design	1	5		
	Cognitive Design		1		
	Industrial Design			1	
	User Experience				1

Figure 17 Sample form for subject matter experts to conduct the Pairwise comparisons

Therefore, the analytic hierarchy process is applied with pairwise comparisons to determine the relative significance of each component. Relative weights were determined using knowledge acquisition, performance measurements, literature review results and subject matter expert opinion. Linguistic modifiers and boundaries for the variables are also identified based on subject matter experts.

Once the components were fuzzified, the weighting values for all the components were developed. The analytical hierarchy process was implemented where pairwise comparisons determine the relative significance of each component. AHP is a means to subjectively assess the relative importance of a set of variables and assign a weight relating to the importance of the variables to aid in decision-making or problem solving (Olson and Courtney, 1992).

Inconsistency Ratio

The AHP analysis was completed in a set of stages where variables were placed within a hierarchy, or ranking. The analysis was conducted by three subject matter experts (SMEs) within each area of this research; user-centered design, customer benefits, and organizational benefits. The consistencies of the combined and individual inputs were determined by analyzing the inconsistency ratio, which should be below 0.10. The inconsistency ratio is a measure that consistency, not randomness was used when making paired comparisons. The inconsistency ratio was calculated for each set of judgments. It follows the transitive property, for example, if an evaluator states that A > B, and B > C, then states that C > A, then there would be inconsistency in the evaluation. A set of perfectly consistent judgments will produce a consistency index of 0, whereas a consistency ratio of 1 indicates consistency similar to that which would be achieved if judgments were made at random rather than intelligently. Thus it can be concluded that the larger the value, the more inconsistent the judgments. Expert Choice, a frequently used software tool for developing the relative weights also reports an overall inconsistency ratio, which is a ratio between the inconsistency from the individual assessment compared to the expected inconsistency from a matrix with the number of variables evaluated.

Membership Functions

Membership functions were developed by using subject matter experts and by analyzing the literature and they are done through the mapping of functions (Whitnell, et al 1991). The goal of mapping functions is to map elements of a given universal set X with a grade of membership defined over the interval [0, 1] (Klir and Yuan, 1995). The mapping function provides a method to view the progression of changes in state of a variable over a membership function. In other words, it expresses the degree of strength that a particular element belongs in a fuzzy set. The grade of membership was developed with graphical representation. Clustering is used to detect natural subgroups based on similarities, difference, distance, etc. (McCauley-Bell, et at 1996). The development of the membership functions as well as most of the area of fuzzy set theory is challenged by researchers because of the inherent subjectivity; however, it has been proven to be useful in the translation of linguistic terms into quantitative values that can be used to aggregate measures given input factors (McCauley-Bell, Crumpton-Young, Badiru, 1999).

Mathematical Operands

Since the factors have an accumulating effect, the mathematical operands for the user-centered design, customer benefits, and organizational benefits Index models were determined to be additive.

Indices

Figure 18 is a representation of the indices developed. The impact of each system variable and the interaction between them was determined using this modeling technique.

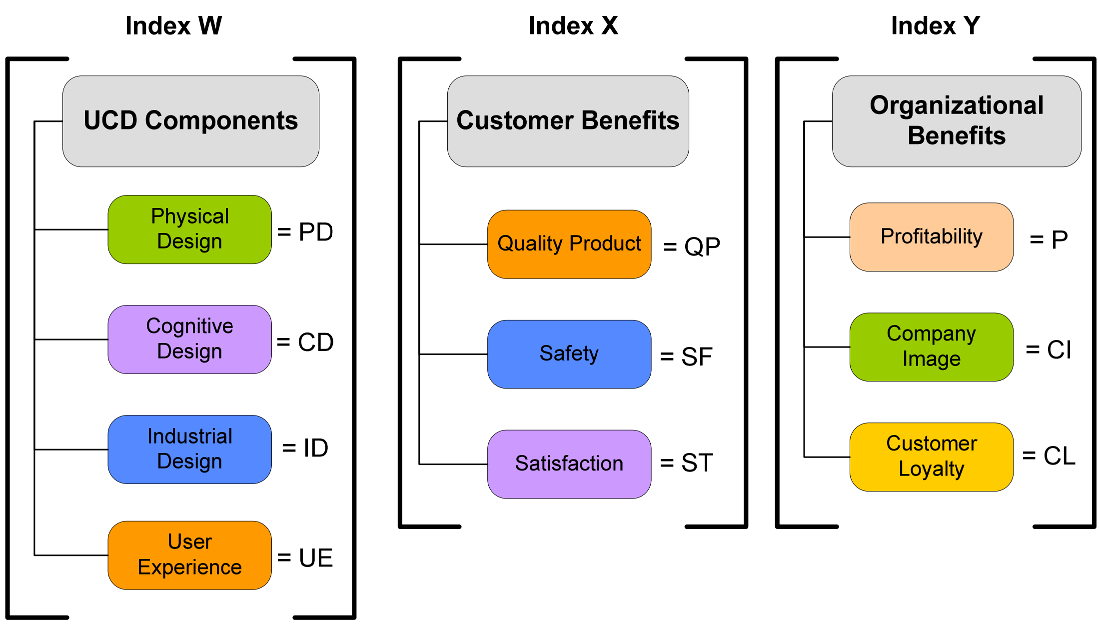

Figure 18 Representation of Index development for each Component

The aggregation of the model was then implemented, where the models are expressed in the following equation. An index for user-centered design, customer benefits, and organizational benefits was developed using fuzzy set theory as described below:

$$IndexW = PDS_1 + CDS_2 + IDS_3 + UES_4 \tag{3.1}$$

Where:

W = the level or measure of total user-centered design characteristics present in the product or system

PD = the degree of membership for physical design

S_1 *= relative weight for physical design*

CD = the degree of membership for cognitive design

S_2 *= relative weight for cognitive design*

ID = the degree of membership for industrial design

S_3 *= relative weight for industrial design*

UE = the degree of membership for user experience

S_4 *= relative weight for user experience*

$$IndexX = QPT_1 + SFT_2 + CST_3 \tag{3.2}$$

Where:

X = the benefits associated with the customer benefits characteristics

QP = the degree of membership for the quality product

T_1 *= relative weight for quality product*

SF = the degree of membership for safety

T_2 *= relative weight for safety*

CS = the degree of membership for customer satisfaction

T_3 *= relative weight for customer satisfaction*

$$IndexY = PTU_1 + CIU_2 + CLU_3 \tag{3.3}$$

Where:

Y = the benefits associated with the organizational benefits

PT = the degree of membership for profitability

U_1 *= relative weight for profitability*

CI = the degree of membership for company image

U_2 = *relative weight for company image*

CL = *the degree of membership for customer loyalty*

U_3 = *relative weight for customer loyalty*

Relationship between components

Once all the components were measured, the relationship that exists between user-centered design, customer benefits, and organizational benefits was evaluated. In order to assess this relationship, statistical methods such as correlation and nonparametric analysis were considered. An illustration of the relationship between the components is provided in the following figure.

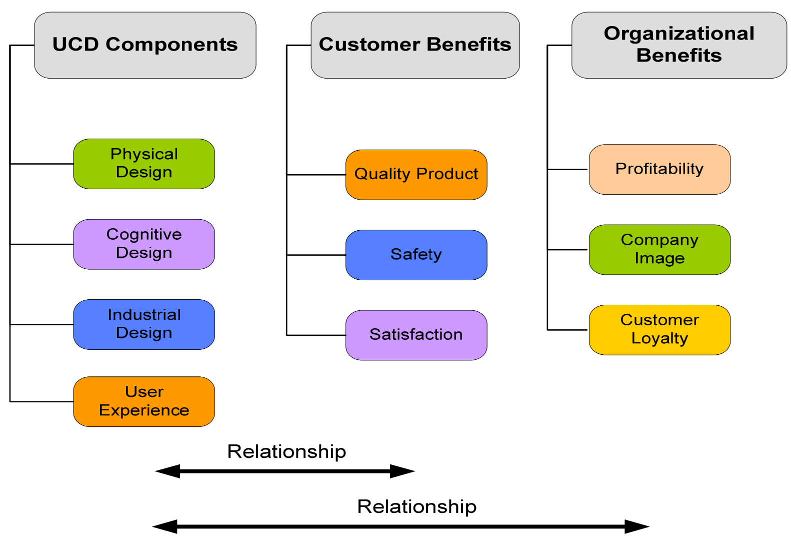

Figure 19 Relationship between user-centered design, customer benefits, and organizational benefits

The nonparametric analysis was considered for the comparison and evaluation of alternative system designs (“scenarios”). Nonparametric tests are distribution-free techniques that do not depend on the distribution of the sampled population; they focus on the location of the probability distribution instead of specific parameters, such as the mean. Nonparametric tests are applied when confidence intervals and test of hypotheses are unsuitable as a result of data sample size and when the responses are not susceptible to measurement but can be ranked in order of magnitude, such as ranking the "ease of use" of a product. Milton Friedman's test for a randomized block design was applied to determine the relationship between user-centered design, customer benefits, and organizational benefits because it is used when dealing with three or more populations (Mendenhall and Sincich, 1994).

PHASE V - Validation

The final phase of this research consisted of validating the model results. The company used for this research is a major automotive industry leader. It is one of the world's largest automakers that has been in the industry for over 75 years and sold over 9.17 million vehicles globally in 2005 alone.

Two validation methods were selected for implementation in this phase of the research. One of the most commonly applied validation methods used when developing a fuzzy model consists of comparing the model results with the results obtained from evaluating the data with a "gold" standard. This approach was applied for the validation of the customer benefits Index and the organizational benefits Index due to the fact that comparable "gold" standards are available. The user-centered design index however, was validated by using a technique called data partitioning, where the results from half of the novice and subject matter experts that evaluated products were compared to the second half of the product assessment results. Each of the developed indexes was then evaluated for accuracy, sensitivity, and specificity. Table 12 shows a breakdown of how each evaluation was calculated.

Table 12 Characterization of Accuracy, Sensitivity, and Specificity calculations

		Condition (As determined from "Gold" standard)		
		TRUE	***FALSE***	
Test Outcome	***Positive***	**True Positive (Accurate)**	**False Positive** (Type I error, P-value)	
	Negative	**False Negative** (Type II error)	**True Negative (Accurate)**	
		↓ Sensitivity	↓ Specificity	Accuracy

The positive predictive value is the ratio of true positives to the combined true and false positives, whereas the negative predictive value is the ratio of true negatives to the combined true and false negatives.

Accuracy has been defined as the degree that a measured or calculated quantity is to its actual (true) value. It is closely related to precision/repeatability, defined as the degree to which additional measurements or calculations show the same or similar results (Arbiter Systems, 2008). The results can be accurate and precise, precise but not accurate, accurate but not precise, or neither; however, a result is considered valid if it is both accurate and precise. Accuracy is calculated as follows:

$$\text{Accuracy} = \frac{\text{number of True Positives} + \text{number of True Negatives}}{\text{True Positives} + \text{False Positives} + \text{False Negatives} + \text{True Negatives}} \qquad (3.4)$$

Sensitivity, measures the rate of how well a test correctly identifies a condition. A sensitivity of 100% means that the test recognizes all the positive results as such. Sensitivity is calculated as follows:

$$\text{Sensitivity} = \frac{\text{number of True Positives}}{\text{Number of True Positives + number of False Negatives}} \quad (3.5)$$

Specificity measures how well a test correctly identifies the negative cases. It is the proportion of true negatives of all negative cases in the population. Specificity is calculated as follows:

$$\text{Specificity} = \frac{\text{number of True Negatives}}{\text{Number of True Negatives + number of False Positives}} \quad (3.6)$$

A specificity of 100% means that the test recognizes all good products as good (Swets, 1988).

Due to the sample size, nonparametric analysis was applied as an additional validation method. Nonparametric tests are distribution-free techniques that do not depend on the distribution of the sampled population; they focus on the location of the probability distribution instead of specific parameters, such as the mean. Nonparametric tests are applied when confidence intervals and test of hypotheses are unsuitable as a result of data sample size and when the responses are not susceptible to measurement but can be ranked in order of magnitude, such as ranking the "ease of use" of a product. The Wilcoxon rank sum test was used to validate the models because it compares two populations by performing matched-pairs tests. The Wilcoxon rank sum test compares all the distributions not just the median, and it is set up as follows (Harrell, 1997, Johnson, 2005, Mendenhall and Sincich, 1994):

H_o: Populations have the same distribution

H_a: one distribution is shifted (either to the right or left) of the other

CHAPTER IV: RESULTS

This section discusses the research results. The first set of results focus on the development of the user-centered design index, followed by the development of the customer benefits index and organizational benefits index, and finally the generation of the relationship between the three index models.

User-Centered Design

The results of the user-centered design section are divided between the development of the product assessment tools and the development of the index model.

User-Centered Design Product Assessment Tools

The results from the usability evaluation of the assessment tools reveal that of the eight participants, 56% were in the 18-24 age group, and 44% were in the 25-31 age group. Figure 20 is an illustration of the participants' years of experience in product development and design. The figure shows that 57% of the participants had 1-2 years of experience, 29% of the participants had 3-5 years of experience, and 14% had 6-9 years of experience in product development and design. Participants were classified into two groups (Novice and Experts) based on the experience in product development and design, usability assessment or background in human factors and ergonomics.

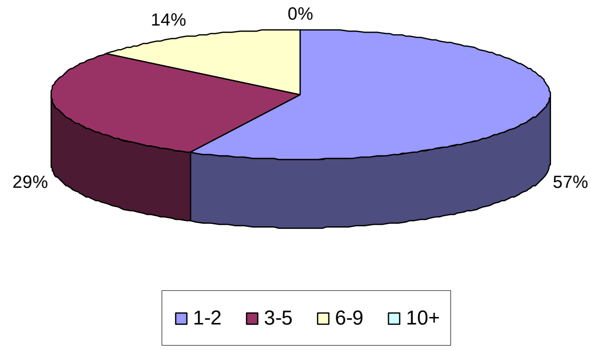

Figure 20 Years of Experience in Product Development and Design

Tables 13-17 are the results of the average time the participants took to evaluate the products with the user-centered design assessment tools (physical design, industrial design, cognitive design, and user experience design). The results reflect that the blood pressure monitor took the longest to complete; however, the values decrease significantly for both the novice and expert users as the participant became familiar with using the assessment tools.

Table 13 Product 1 - Blood pressure monitor

Assessment Tool	Novice Average (Mins.)	Expert Average (Mins.)	Overall Average (Mins.)
Industrial Design	8.692	6.329	7.510
Physical Design	9.358	6.510	8.410
User Experience Design	5.271	3.373	4.496
Cognitive Design	3.013	2.097	2.467

The most significant conclusion derived from Table 13 is the variance between the Novices and Experts. The physical design (PD) assessment tool had the longest average completion time of 9.358 minutes, which may have resulted from lack of background knowledge since the assessment was conducted by novices. The assessments conducted by the experts reflect an average completion time to range between 2.097-6.510 minutes.

Table 14 Product 2 - Blender

Assessment Tool	Novice Average (Mins.)	Expert Average (Mins.)	Overall Average (Mins.)
Industrial Design	4.267	4.277	4.402
Physical Design	4.842	4.777	5.046
User Experience Design	2.425	1.993	2.229
Cognitive Design	1.913	1.487	1.696

Table 14 reflects the average assessment duration times to range between 1.487 and 5.046 minutes. The high industrial design and physical design values may have been a result of the antiquity of the blender used for evaluation. The blender evaluated had an aging appearance and design that may not have been considered attractive to the participants.

Table 15 Product 3 - Learning toy

Assessment Tool	Novice Average (Mins.)	Expert Average (Mins.)	Overall Average (Mins.)
Industrial Design	3.021	2.203	2.665
Physical Design	3.483	2.973	3.429
User Experience Design	1.850	1.863	1.904
Cognitive Design	1.688	1.317	1.550

Tables 15 and 16 reflect the average assessment duration times to be close between novices and experts. The values range between 1.317 and 4.842 minutes, which may have been the result of participants becoming comfortable with using the evaluation tools.

Table 16 Product 4 - GPS System

Assessment Tool	Novice Average (Mins.)	Expert Average (Mins.)	Overall Average (Mins.)
Industrial Design	2.900	1.913	2.475
Physical Design	3.896	2.130	3.096
User Experience Design	1.829	1.263	1.544
Cognitive Design	1.513	2.043	1.838

The most significant conclusion derived from Table 18 is the shortest average time taken to conduct an assessment. The cognitive design (CD) assessment tool had the shortest average completion time of 0.929 minutes, which may have resulted from the type of product assessed. Since the chair is the least technical of all the evaluated products, and did not require a significant cognitive design application, then it is reasonable for the results to reflect the cognitive design average assessment duration to be smallest.

Table 17 Product 5 - Chair

Assessment Tool	Novice Average (Mins.)	Expert Average (Mins.)	Overall Average (Mins.)
Industrial Design	1.742	1.730	1.792
Physical Design	3.650	1.667	2.710
User Experience Design	1.796	1.497	1.635
Cognitive Design	0.929	0.960	0.969

Table 18 illustrates the average amount of time the novices and experts spent to complete the evaluations of the five products using each of the assessment tools. The results reflect that the physical design assessment tool took the longest amount of time to complete for both the novices and experts. The cognitive design assessment tool took the shortest completion time.

Table 18 Average completion time in each assessment tool for all products

Assessment Tool	Average Completion Time (Mins.)	
	Novice	Expert
Industrial Design	4.125	3.413
Physical Design	5.046	4.031
User Experience Design	2.634	2.089
Cognitive Design	1.811	1.597

Figure 19 illustrates the results of the usability evaluations performed by the participants on the UCD assessment tools, where S1-S9 represent an assigned letter and number used to maintain confidentiality on the identity of the volunteers. The chart shows that on a likert scale ranging from one to seven, where one is the lowest score and seven is the highest score. The lowest usability rating had a score of 4.48, resulting in an above average overall usability evaluation of the UCD assessment tools. Therefore, the participants considered the assessment tools to be easy to understand and use.

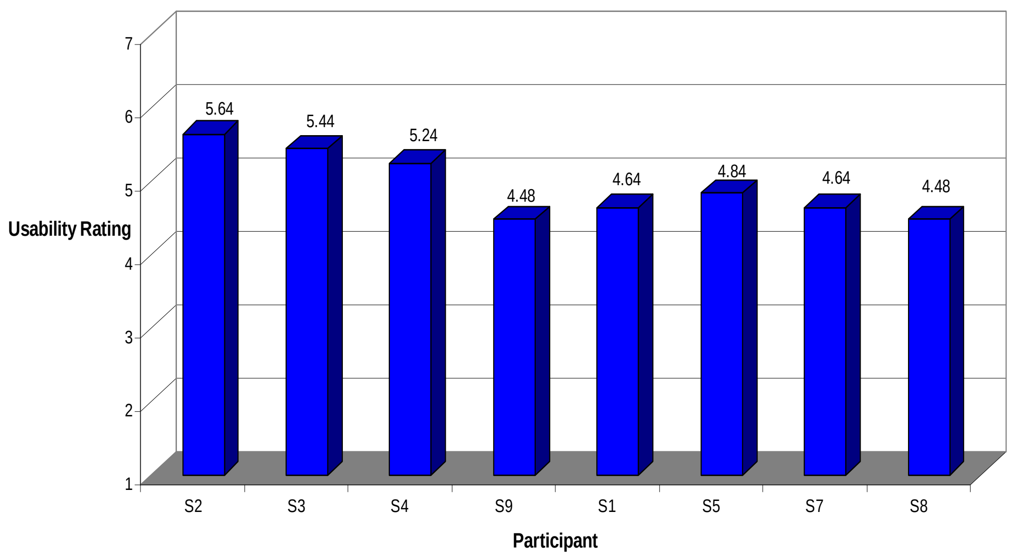

Figure 21 Usability evaluation of the user-centered design assessment tools

Some of the questions most frequently asked by the participants about the assessment tools consisted of the following:

- What is the design supporting? Is the design supporting the task?
- What is meant by sympathetic?
- What is meant by stooping?
- What is meant by isoinertial?
- Is neutral body posture required to operate the product?

Some of the comments made by the participants about the assessment tools consisted of the following:

- Probably, questions within same category should refer to same subject: either the effects on the product OR the effects on the user. Overall, very good!
- Percent of measurement should be changed for kids
- Need more writing room; use larger font
- Where I put comments, perhaps things could be made more understandable. A lot of information in one sheet.
- Letters are too small
- Specify that it is a general tool and not all the factors have to apply.
- The evaluation tool should be used only for the primary function of the product
- In industrial design, alarm signals can be that you did something right.
- I think the most useful assessment tools were the user experience design and cognitive design evaluation tools
- I am not sure about some of the vocabulary in the physical design evaluation tool
- I think designers should take many of these factors into consideration. However, the application of specific factors is product dependent. A designer might gloss over some areas thinking they're irrelevant while wanting to delve into further detail in others.

Table 19 displays the results obtained from the ANOVA analysis conducted to determine if there is significant difference between the product assessments conducted by the novices and experts. The ANOVA analysis tests for the null hypothesis, H_o of the product weighted averages comparing the differences between the assessments conducted by the novices and experts:

$$H_o: \mu_{Novices} = \mu_{Experts}$$

$$H_a: \mu_{Novices} \neq \mu_{Experts}$$

Where:

H_o: Null hypothesis

H_a: Alternative hypothesis

$\mu_{Novices}$: the average results obtained by the novices

$\mu_{Experts}$: the average results obtained by the experts

Table 19 ANOVA analysis of product weighted averages comparing Novices vs Experts using the User-centered design assessment tools.

		Sum of Squares	df	Mean Square	F	Sig.
PD	Between Groups	.456	1	.456	.336	.566
	Within Groups	51.552	38	1.357		
	Total	52.008	39			
ID	Between Groups	2.987	1	2.987	3.849	.057
	Within Groups	29.487	38	.776		
	Total	32.473	39			
CD	Between Groups	.002	1	.002	.001	.970
	Within Groups	64.662	38	1.702		
	Total	64.665	39			
UE	Between Groups	.264	1	.264	.384	.539
	Within Groups	26.116	38	.687		
	Total	26.380	39			

Since the ANOVA analysis results have $F(1,39) = 0.336$, $F(1,39) = 3.849$, $F(1,39) = 0.001$, and $F(1,39) = 0.384$ ($F_{\alpha=.05}(1,39) = 4.08$), p-value > 0.05; then H_o cannot be rejected for any of the UCD components. Therefore, based on the sample, it can be concluded that there is no statistical evidence of a significant difference between novices and experts. Therefore, based on this sample, it can be concluded that a novice can evaluate a product just as well as an expert using the product assessment tools. However, the industrial design assessment tool should be evaluated further due to the proximity of the p-value to 0.05.

Table 20 displays the results obtained from the ANOVA analysis conducted to test for the robustness of the product assessment tools developed. The ANOVA analysis tests for the null hypothesis H_o of the product variances comparing the differences between novices and experts:

$$H_o: \sigma^2_{Novices} = \sigma^2_{Experts}$$

$$H_a: \sigma^2_{Novices} \neq \sigma^2_{Experts}$$

Where:

H_o: Null hypothesis

H_a: Alternative hypothesis

$\sigma^2_{Novices}$: the variance of the results obtained by the novices

$\sigma^2_{Experts}$: the variance of the results obtained by the experts

Table 20 ANOVA analysis of product variances comparing Novices vs Experts using the User Centered Design Assessment Tools

		Sum of Squares	df	Mean Square	F	Sig.
PD	Between Groups	3.316	1	3.316	2.039	.161
	Within Groups	61.794	38	1.626		
	Total	65.110	39			
ID	Between Groups	.396	1	.396	.290	.593
	Within Groups	51.855	38	1.365		
	Total	52.252	39			
CD	Between Groups	.016	1	.016	.027	.869
	Within Groups	22.301	38	.587		
	Total	22.317	39			
UE	Between Groups	.067	1	.067	.071	.791
	Within Groups	35.797	38	.942		
	Total	35.864	39			

Since the ANOVA analysis results have $F(1,39) = 2.039$, $F(1,39) = 0.290$, $F(1,39) = 0.027$, and $F(1,39) = 0.071$ ($F_{\alpha=.05}(1,39) = 4.08$), p-value > 0.05; then H_o cannot be rejected for each of the UCD components. Therefore, it can be concluded, based on the sample size, that there is no significant difference in the product assessment variances between novices and experts.

To assess the robustness of the instruments, the interaction between type of product and level of expertise was assessed by means of a 2x5 mixed factorial design. The independent variables are:

- Level of expertise with two levels (novice and expert) between groups
- Type of products with 5 levels (5 types of product) within groups

The dependent variable is represented by the weighted scores obtained in the previous analysis conducted with UCD factors. Therefore, four different mixed factorial designs were performed accordingly (physical design, user experience, industrial design, and cognitive design).

Physical Design

Table 21 Tests of within-subjects effects for Physical Design tool

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
product	Sphericity Assumed	8.041	4	2.010	2.562	.064
	Greenhouse-Geisser	8.041	1.598	5.033	2.562	.134
	Huynh-Feldt	8.041	2.449	3.284	2.562	.103
	Lower-bound	8.041	1.000	8.041	2.562	.161
product * Expertise	Sphericity Assumed	2.113	4	.528	.673	.617
	Greenhouse-Geisser	2.113	1.598	1.323	.673	.500
	Huynh-Feldt	2.113	2.449	.863	.673	.554
	Lower-bound	2.113	1.000	2.113	.673	.443
Error(product)	Sphericity Assumed	18.831	24	.785		
	Greenhouse-Geisser	18.831	9.586	1.964		
	Huynh-Feldt	18.831	14.693	1.282		
	Lower-bound	18.831	6.000	3.138		

The interaction between product type and subject expertise within subject's effects of product type on tool-use performance at the 0.05 level was not statistically significant. Therefore, based on the p-value scores there was no statistical evidence of a significant interaction between product type and subjects experience for the physical design assessment tool [$F(1, 7) = 0.673$; $p > 0.05$].

Table 22 Tests of between-subjects effects for Physical Design tool

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	297.734	1	297.734	117.511	.000
Expertise	3.499	1	3.499	1.381	.284
Error	15.202	6	2.534		

Tests between subjects effects showed that there was no significant effect in the user's level of expertise on test scores [F (1, 7) = 1.381; p > 0.05]. Therefore, there was no supporting statistical evidence that showed a difference between a novices and an expert's ability to evaluate a product using the physical design assessment tool.

User Experience

Table 23 Tests of within-subjects effects for User Experience Design tool

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
product	Sphericity Assumed	3.199	4	.800	2.038	.121
	Greenhouse-Geisser	3.199	1.853	1.727	2.038	.178
	Huynh-Feldt	3.199	3.092	1.035	2.038	.142
	Lower-bound	3.199	1.000	3.199	2.038	.203
product * Expertise	Sphericity Assumed	2.065	4	.516	1.315	.293
	Greenhouse-Geisser	2.065	1.853	1.114	1.315	.304
	Huynh-Feldt	2.065	3.092	.668	1.315	.300
	Lower-bound	2.065	1.000	2.065	1.315	.295
Error(product)	Sphericity Assumed	9.420	24	.392		
	Greenhouse-Geisser	9.420	11.118	.847		
	Huynh-Feldt	9.420	18.553	.508		
	Lower-bound	9.420	6.000	1.570		

The interaction between product type and subject expertise within subject's effects of product type on tool-use performance at the 0.05 level was not statistically significant. Therefore, based on the p-value scores there was no statistical evidence of a significant interaction between product type and subjects experience for the user experience design assessment tool [F (1, 7) = 1.315; p > 0.05].

Table 24 Tests of between-subjects effects for User Experience Design tool

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	718.341	1	718.341	407.467	.000
Expertise	.504	1	.504	.286	.612
Error	10.578	6	1.763		

Tests between subjects effects showed that there was no significant effect on level of expertise on test scores [F (1, 7) = 0.286; p > 0.05]. Therefore, there was no supporting statistical evidence that showed a difference between a novices and an experts' ability to evaluate a product using the user experience design assessment tool.

Industrial Design

Table 25 Tests of within-subjects effects for Industrial Design tool

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
product	Sphericity Assumed	2.006	4	.501	1.550	.220
	Greenhouse-Geisser	2.006	2.177	.922	1.550	.249
	Huynh-Feldt	2.006	4.000	.501	1.550	.220
	Lower-bound	2.006	1.000	2.006	1.550	.260
product * Expertise	Sphericity Assumed	1.236	4	.309	.955	.450
	Greenhouse-Geisser	1.236	2.177	.568	.955	.417
	Huynh-Feldt	1.236	4.000	.309	.955	.450
	Lower-bound	1.236	1.000	1.236	.955	.366
Error(product)	Sphericity Assumed	7.763	24	.323		
	Greenhouse-Geisser	7.763	13.060	.594		
	Huynh-Feldt	7.763	24.000	.323		
	Lower-bound	7.763	6.000	1.294		

The interaction between product type and subject expertise within subject's effects of product type on tool-use performance at the 0.05 level was not statistically significant. Therefore, based on the p-value scores there was no statistical evidence of a significant interaction between product type and subjects experience for the industrial design assessment tool [$F_{(1,7)} = 0.955$; $p > 0.05$].

Table 26 Tests of between-subjects effects for Industrial Design tool

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	323.704	1	323.704	154.524	.000
Expertise	5.753	1	5.753	2.746	.149
Error	12.569	6	2.095		

Tests between subjects effects showed that there was no significant effect on level of expertise on test scores [$F_{(1, 7)} = 2.746$; $p > 0.05$]. Therefore, there was no supporting statistical evidence that showed a difference between a novices and an experts' ability to evaluate a product using the industrial design assessment tool.

Cognitive Design

Table 27 Tests of within-subjects effects for Cognitive Design tool

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
product	Sphericity Assumed	20.574	4	5.144	6.018	.002
	Greenhouse-Geisser	20.574	1.556	13.220	6.018	.026
	Huynh-Feldt	20.574	2.352	8.749	6.018	.010
	Lower-bound	20.574	1.000	20.574	6.018	.050
product * Expertise	Sphericity Assumed	.883	4	.221	.258	.902
	Greenhouse-Geisser	.883	1.556	.568	.258	.724
	Huynh-Feldt	.883	2.352	.376	.258	.809
	Lower-bound	.883	1.000	.883	.258	.629
Error(product)	Sphericity Assumed	20.513	24	.855		
	Greenhouse-Geisser	20.513	9.338	2.197		
	Huynh-Feldt	20.513	14.110	1.454		
	Lower-bound	20.513	6.000	3.419		

The interaction between product type and subject expertise within subjects' effects of product type on tool-use performance at the 0.05 level was not statistically significant. Therefore, based on the p-value scores there was no statistical evidence of a significant interaction between product type and subjects experience for the cognitive design assessment tool [$F(1, 7) = 0.258$; $p > 0.05$].

Table 28 Tests of between-subjects effects for Cognitive Design tool

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	504.597	1	504.597	142.694	.000
Expertise	.390	1	.390	.110	.751
Error	21.217	6	3.536		

Tests between subjects effects showed that there was no significant effect on level of expertise on test scores [$F(1, 7) = 0.110$; $p > 0.05$]. Therefore, there was no supporting statistical evidence that showed a difference between a novices and an experts' ability to evaluate a product using the cognitive design assessment tool.

User-Centered Design Index Model Development

The user-centered design index model was developed using two types of systems (an audio system and a cluster system) from four different vehicle models (See Figures 22-29).

Figure 22 Audio system evaluated - Product (1A)

Figure 23 Audio system evaluated - Product (2A)

Figure 24 Audio system evaluated - Product (3A)

Figure 25 Audio system evaluated - Product (4A)

Figure 26 Cluster system evaluated - Product (1B)

Figure 27 Cluster system evaluated - Product (2B)

Figure 28 Cluster system evaluated - Product (3B)

Figure 29 Cluster system evaluated - Product (4B)

The assessments for model development and validation for the user-centered design index were individually conducted by two participants and two subject matter experts. Since the assessments were conducted at car dealerships, the number of vehicles and participants were constrained by accessibility of vehicle models.

Membership Functions

The degrees of memberships per product were determined using the weighted averages from the assessments conducted by the participants. The weighted averages were then mapped with the degree of membership, in the [0, 1] interval. The fuzzy sets allow the representation of vague concepts. The type of membership function was determined from the concept and the context in which it was used. The functions are represented with different shapes of the graphs. It should be considered that many applications are not overly sensitive to shape variations; therefore, it may be convenient to use a simple shape (Klir and Yuan, 1995). Therefore, the membership shape for the UCD index model components was determined to be linear.

Figure 30 is a graphical representation of the physical design membership function of the products evaluated in each vehicle, where two of the product degrees of membership values had relatively high values.

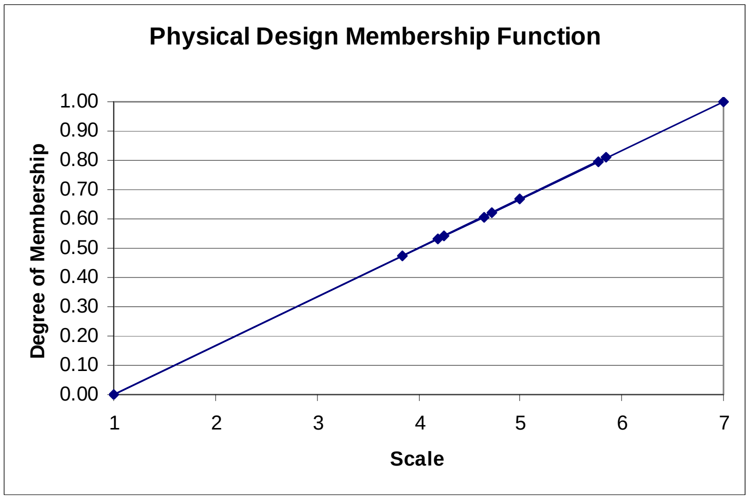

Figure 30 Physical Design Membership Function

Figure 31 is a graphical representation of the industrial design membership function of the products evaluated in each vehicle, where it shows that several of the systems had a degree of membership value close to 0.70.

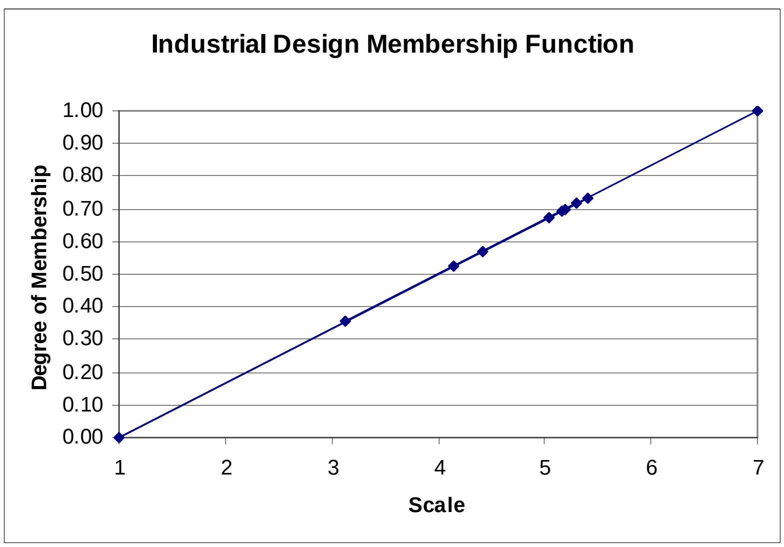

Figure 31 Industrial Design Membership Function

Figure 32 is a graphical representation of the cognitive design degree of membership for the products evaluated in each vehicle, in which, most of the product degree of membership values were above 0.50.

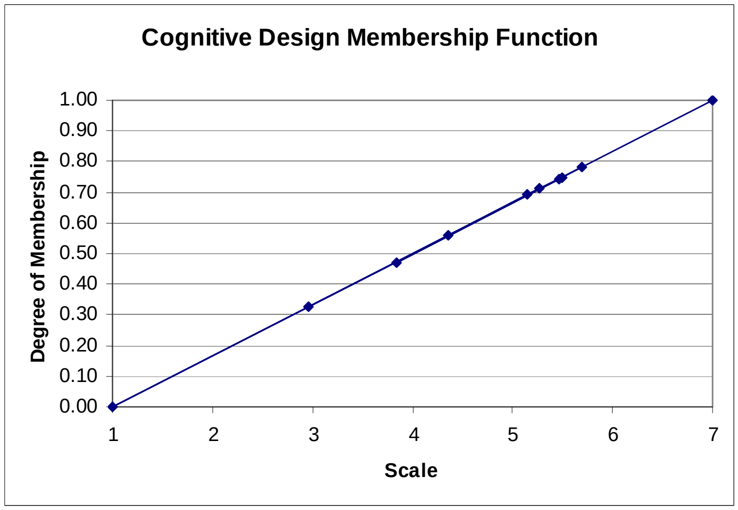

Figure 32 Cognitive Design Membership Function

Figure 33 is a graphical representation of the user experience design membership function of the products evaluated in each vehicle, where all of the product degree of membership values were above 0.50.

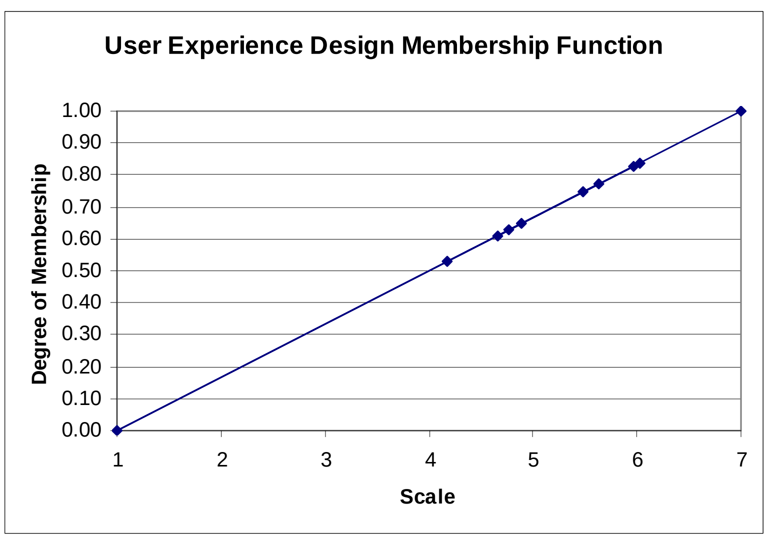

Figure 33 User Experience Design Membership Function

Table 29 illustrates a summary of all the product degree of membership functions for each of the UCD components.

Table 29 Summary of Membership Functions

Degree of Membership	Audio				Cluster			
	1A	2A	3A	4A	1B	2B	3B	4B
Physical Design	0.531	0.607	0.667	0.808	0.542	0.619	0.472	0.794
Industrial Design	0.354	0.571	0.525	0.673	0.717	0.693	0.733	0.699
Cognitive Design	0.326	0.472	0.560	0.712	0.782	0.750	0.692	0.744
User Experience Design	0.529	0.837	0.627	0.746	0.828	0.647	0.610	0.772

The degree of membership values were used to develop the UCD index model for each of the products used in this research. The values range between 0 and 1, which means that the greater the value, the stronger the degree of membership for that particular factor on the evaluated product. For example, product 2A-Audio had the strongest degree of membership in cognitive design.

Relative Weights

The participation of three subject matter experts was required to calculate the relative weight of variables used to determine the overall UCD index. The relative weights were calculated using Expert Choice, See Figure 34 for results.

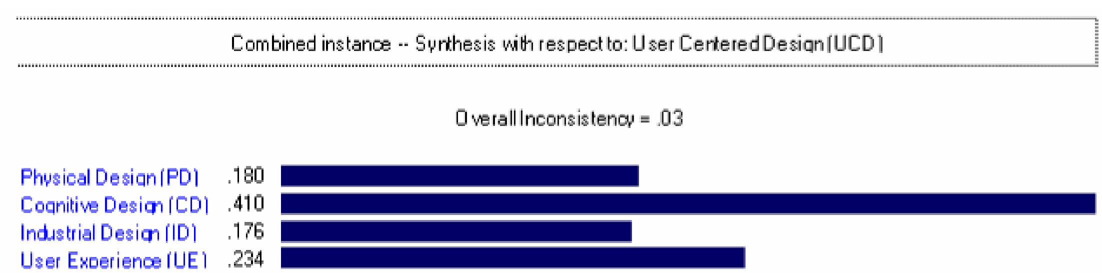

Figure 34 AHP analysis results of User-Centered Design model using Expert Choice

Therefore, the following are the overall user-centered design (UCD) component relative weights based on the pairwise comparisons conducted by the subject matter experts:

Physical Design (PD) (L: 0.180)

Cognitive Design (CD) (L: 0.410)

Industrial Design (ID) (L: 0.176)

User Experience (UE) (L: 0.234)

The values show that of the four components, cognitive design had the strongest relative weight. In addition to the relative weights, the software also provided an inconsistency rating of the AHP analysis conducted by comparing the pairwise comparison values of the subject matter experts. Table 30 illustrates the inconsistency rating of the subject matter experts that conducted the AHP analysis for user-centered design.

Table 30 Inconsistency rating for User Centered Design AHP analysis

Inconsistency Ratio	
SME 1	0.1829
SME 2	0.0000
SME 3	0.5544
Combined	**0.0261**

The consistencies of the combined and individual inputs were determined by analyzing the inconsistency ratio, which should be below 0.10. The inconsistency ratio is a measure that consistency, not randomness was used when making paired comparisons. The inconsistency ratio was calculated for each set of judgments. It follows the transitive property, for example, if an evaluator states that A > B, and B > C, then states that C > A, then there would be inconsistency in the evaluation. A set of perfectly consistent judgments would produce a consistency index of 0, whereas a consistency ratio of 1 indicates consistency similar to that which would be achieved if judgments were made randomly rather than based on sound judgment or intellect. Thus it can be concluded that the larger the value, the more inconsistent the judgments. The differences in the judgments may be the result of the SME backgrounds because they may have conducting the pairwise comparisons with different goals or applications in mind. For instance, SME 1 is from the academia and was perhaps considering a general application. Although SME 2 is not from the academia, her work environment is such that requires the design and development of different product types, which explains why she would assign equal values to all of the components, thus resulting in perfect consistency in her pairwise comparison. SME 3 however, has a background in the automotive industry and may have performed the pairwise comparisons without clear and specific intended applications. Expert Choice, a frequently used software tool for developing the relative weights also reports an overall inconsistency ratio, which is a ratio between the inconsistency from the individual assessment compared to the expected inconsistency from a matrix with the number of variables evaluated. The software calculates a combined as well as individual weight based on each and all of the subject matter experts' AHP analysis. For the purpose of this research, the combined results were used, which incorporates the feedback from all of the subject matter experts. The combined relative weights also have a combined inconsistency rating calculated from a weighted average of the inconsistency ratios. The program initially assumes all of the pairwise comparisons to have equal relative weights and allows the user to modify the relative weights assigned to each person's responses or to remove any of the evaluations performed. However, due to the number of subject matter experts performing the pairwise comparisons and considering the individual participants' background (industry and academia), all of the individual responses were included and each was assumed of equal importance. As represented in Table 30, the inconsistency ratio of the combined calculated relative weight is 0.0261, which is within the desired 0.10 score. Therefore, it may be concluded that the combined AHP analysis conducted by the subject matter experts to determine the relative weights for the user-centered design index model was determined with consistency, not randomness.

User-Centered Design Index Model

The user-centered design (UCD) index model was developed using equation 4.1.

$$\text{UCD Index} = W_{PD}\,(PD) + W_{ID}\,(ID) + W_{CD}\,(CD) + W_{UED}\,(UED) \qquad (4.1)$$

Where:

UCD Index = the level or measure of total user-centered design characteristics present in the product or system

PD = the degree of membership for the physical design

W_{PD} *= weighting factors for the physical design factor*

CD = the degree of membership for the cognitive design

W_{CD} *= weighting factors for the cognitive design factor*

ID = the degree of membership for the industrial design

W_{ID} *= weighting factors for the industrial design factor*

UED = the degree of membership for the user experience design

W_{UED} *= weighting factors for the user experience design factor*

Audio System

The following is the UCD index rating for the audio system in vehicle 1.

$$UCD_{1A} = (0.180)(0.531) + (0.176)(0.354) + (0.410)(0.326) + (0.234)(0.529)$$
$$UCD_{1A} = 0.096 + 0.145 + 0.057 + 0.124$$
$$UCD_{1A} = 0.422$$

The following is the UCD index rating for the audio system in vehicle 2.

$$UCD_{2A} = (0.180)(0.607) + (0.176)(0.571) + (0.410)(0.472) + (0.234)(0.837)$$
$$UCD_{2A} = 0.109 + 0.234 + 0.083 + 0.196$$
$$UCD_{2A} = 0.622$$

The following is the UCD index rating for the audio system in vehicle 3.

$$UCD_{3A} = (0.180)(0.667) + (0.176)(0.525) + (0.410)(0.560) + (0.234)(0.627)$$
$$UCD_{3A} = 0.120 + 0.215 + 0.099 + 0.147$$
$$UCD_{3A} = 0.581$$

The following is the UCD index rating for the audio system in vehicle 4.

$$UCD_{4A} = (0.180)(0.808) + (0.176)(0.673) + (0.410)(0.712) + (0.234)(0.746)$$
$$UCD_{4A} = 0.146 + 0.276 + 0.125 + 0.174$$
$$UCD_{4A} = 0.721$$

Cluster System

The following is the UCD index rating for the cluster system in vehicle 1.

$$UCD_{1B} = (0.180)(0.542) + (0.176)(0.717) + (0.410)(0.782) + (0.234)(0.828)$$
$$UCD_{1B} = 0.098 + 0.294 + 0.138 + 0.194$$
$$UCD_{1B} = 0.723$$

The following is the UCD index rating for the cluster system in vehicle 2.

$$UCD_{2B} = (0.180)(0.619) + (0.176)(0.693) + (0.410)(0.750) + (0.234)(0.647)$$
$$UCD_{2B} = 0.111 + 0.284 + 0.132 + 0.151$$
$$UCD_{2B} = 0.679$$

The following is the UCD index rating for the cluster system in vehicle 3.

$$UCD_{3B} = (0.180)(0.472) + (0.176)(0.733) + (0.410)(0.692) + (0.234)(0.610)$$
$$UCD_{3B} = 0.085 + 0.301 + 0.122 + 0.143$$
$$UCD_{3B} = 0.650$$

The following is the UCD index rating for the cluster system in product 4.

$$UCD_{4B} = (0.180)(0.794) + (0.176)(0.699) + (0.410)(0.744) + (0.234)(0.772)$$
$$UCD_{4B} = 0.143 + 0.286 + 0.131 + 0.181$$
$$UCD_{4B} = 0.741$$

Once the models for each product were completed, a rating scale was developed to defuzzify the results obtained. Table 31 illustrates the rating scale and cut-off values that were developed based on a variation of the scale used by J.D. Powers, which is the current leader in product assessment rating scales.

Table 31 Rating scale to defuzzify the UCD index model results

Rating	Scale
Unacceptable	(0, 0.49)
Average	(0.50, 0.79)
Outstanding	(0.80, 1.00)

Table 32 summarizes the results from the UCD index model and their respective ratings obtained from the scale provided in Table 31.

Table 32 Summary of UCD index model rating results

Products	Audio				Cluster			
	1A	2A	3A	4A	1B	2B	3B	4B
UCD Index Model	0.422	0.622	0.581	0.721	0.723	0.679	0.650	0.741
Index Rating	Unacceptable	Average	Average	Average	Average	Average	Average	Average

Based on the rating scale, all of the user-centered design index models for the evaluated products were rated to be at an average level.

User-Centered Design Index Model Validation

Several methods to validate fuzzy models are available. For instance, a traditional method of fuzzy model validation would consist of comparing the results obtained from the developed model with the results obtained from using a “gold standard”. The UCD index model validation was limited by the accessibility of the data. For the purpose of this research, a “gold standard” that was sufficiently comprehensive for the large number of variables considered in the UCD model was not available. Therefore, the data partitioning method was performed for validation, where half of the participant responses were used for model development, and the second half was used for model validation. However, due to the limited access to the vehicles, it is emphasized that future research should consider the application in a larger, diverse product sample. The primary significance of this research consists of the development of the models. Future research efforts should include a more extensive validation approach with a larger sample size.

Membership Functions for UCD index model validation

A second group of participants conducted product assessments to validate the results obtained from the evaluations conducted by the first group of participants. The degrees of membership for the assessments conducted by the second group were calculated and reported in this section separately from the values used to develop the model. The membership functions for validation were developed by calculating the weighted average of the product assessments. Figures 30-33 illustrate the membership functions for each UCD component (physical design, industrial design, cognitive design, and user experience design).

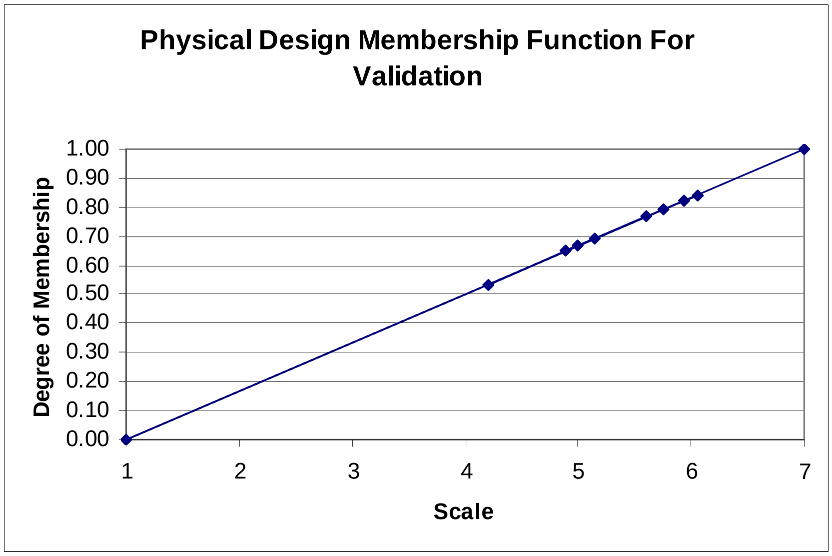

Figure 35 Physical Design Membership Function (model validation)

Figure 36 is a graphical representation of the industrial design membership function of the products evaluated in each vehicle. The graph illustrates all the degree of membership values were above 0.50.

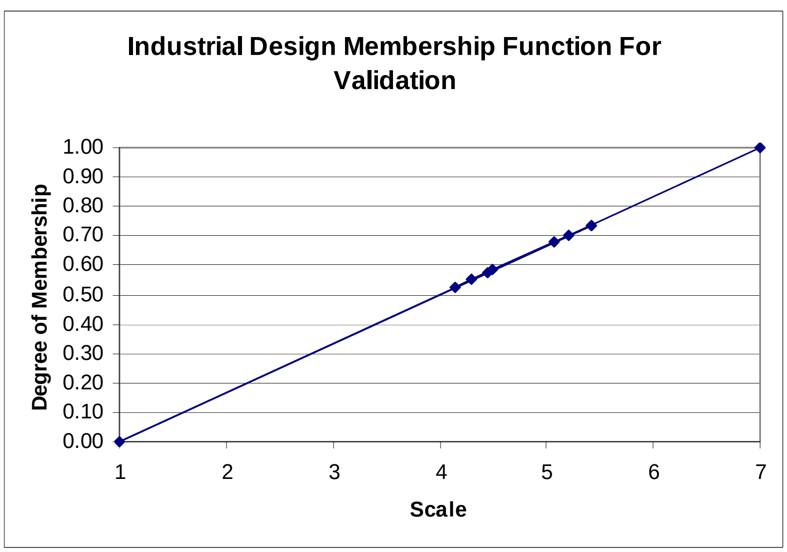

Figure 36 Industrial Design Membership Function (model validation)

Figure 37 is a graphical representation of the cognitive design membership function of the products evaluated in each vehicle. The graph illustrates one of the products' degrees of membership values to be below 0.50.

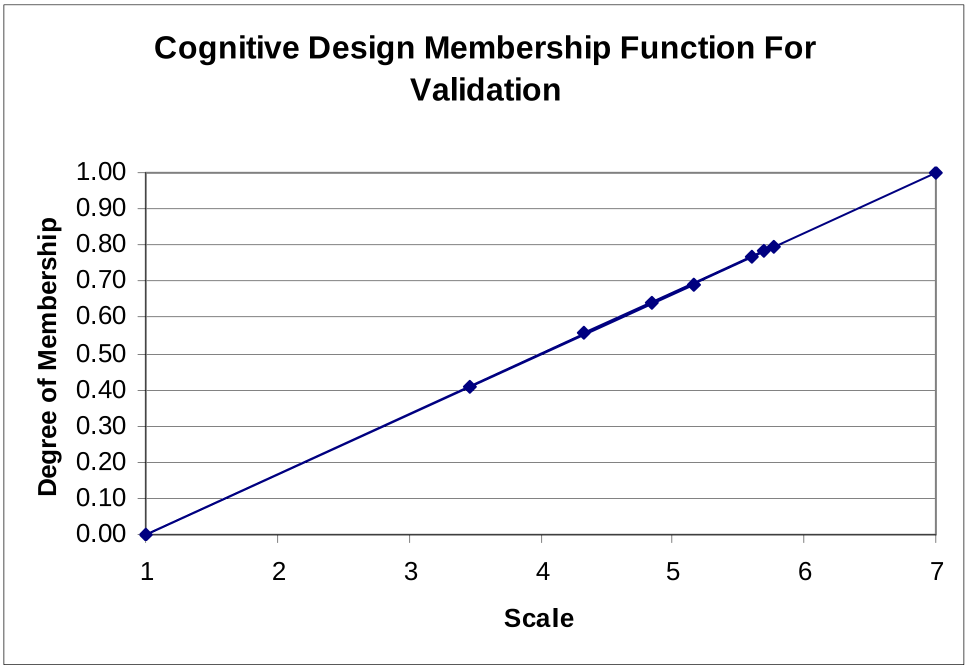

Figure 37 Cognitive Design Membership Function (model validation)

Figure 38 is a graphical representation of the user experience design membership function of the products evaluated in each vehicle. The graph illustrates one of the products' degrees of membership values to be below 0.40.

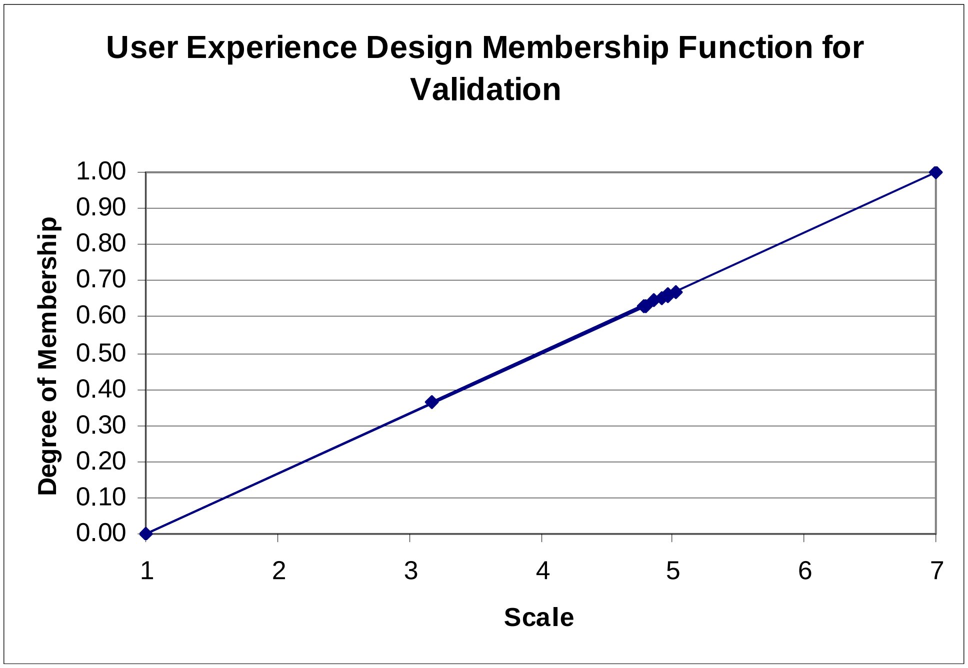

Figure 38 User Experience Design Membership Function (model validation)

Table 39 illustrates a summary of all the product degrees of membership for each of the UCD components.

Table 33 Summary of Degrees of Membership (model validation)

Degree of Membership	Audio				Cluster			
	1A	2A	3A	4A	1B	2B	3B	4B
Physical Design	0.767	0.533	0.648	0.843	0.690	0.667	0.792	0.824
Industrial Design	0.678	0.524	0.701	0.575	0.583	0.550	0.737	0.737
Cognitive Design	0.556	0.410	0.795	0.693	0.767	0.782	0.641	0.693
User Experience Design	0.631	0.362	0.670	0.653	0.644	0.661	0.632	0.660

Relative Weights

The relative weights for the model validation were the same as the relative weights developed to calculate user-centered design index model, which were based on the AHP analysis conducted by the subject matter experts:

Physical Design (PD) (L: 0.180)

Cognitive Design (CD) (L: 0.410)

Industrial Design (ID) (L: 0.176)

User Experience (UE) (L: 0.234)

The following is the user-centered design index validation model equation.

$$UCD = W_{PD}\,(PD) + W_{ID}\,(ID) + W_{CD}\,(CD) + W_{UED}\,(UED) \qquad (4.2)$$

Audio System

The following is the UCD index validation rating for the audio system in vehicle 1.

$$UCD_{1A} = (0.180)(0.767) + (0.176)(0.678) + (0.410)(0.556) + (0.234)(0.631)$$
$$UCD_{1A} = 0.138 + 0.278 + 0.098 + 0.148$$
$$UCD_{1A} = 0.661$$

The following is the UCD index validation rating for the audio system in vehicle 2.

$$UCD_{2A} = (0.180)(0.533) + (0.176)(0.524) + (0.410)(0.410) + (0.234)(0.362)$$
$$UCD_{2A} = 0.117 + 0.288 + 0.140 + 0.157$$
$$UCD_{2A} = 0.701$$

The following is the UCD index validation rating for the audio system in vehicle 3.

$$UCD_{3A} = (0.180)(0.648) + (0.176)(0.701) + (0.410)(0.795) + (0.234)(0.670)$$
$$UCD_{3A} = 0.124 + 0.239 + 0.135 + 0.151$$
$$UCD_{3A} = 0.649$$

The following is the UCD index validation rating for the audio system in vehicle 4.

$$UCD_{4A} = (0.180)(0.843) + (0.176)(0.575) + (0.410)(0.693) + (0.234)(0.653)$$
$$UCD_{4A} = 0.143 + 0.302 + 0.113 + 0.148$$
$$UCD_{4A} = 0.705$$

Cluster System

The following is the UCD index validation rating for the cluster system in vehicle 1.

$$UCD_{1B} = (0.180)(0.690) + (0.176)(0.583) + (0.410)(0.767) + (0.234)(0.644)$$
$$UCD_{1B} = 0.096 + 0.215 + 0.072 + 0.085$$
$$UCD_{1B} = 0.468$$

The following is the UCD index validation rating for the cluster system in vehicle 2.

$$UCD_{2B} = (0.180)(0.667) + (0.176)(0.550) + (0.410)(0.782) + (0.234)(0.661)$$
$$UCD_{2B} = 0.152 + 0.236 + 0.122 + 0.153$$
$$UCD_{2B} = 0.662$$

The following is the UCD index validation rating for the cluster system in vehicle 3.

$$UCD_{3B} = (0.180)(0.792) + (0.176)(0.737) + (0.410)(0.641) + (0.234)(0.632)$$
$$UCD_{3B} = 0.120 + 0.226 + 0.138 + 0.155$$
$$UCD_{3B} = 0.638$$

The following is the UCD index validation rating for the cluster system in vehicle 4.

$$UCD_{4B} = (0.180)(0.824) + (0.176)(0.737) + (0.410)(0.693) + (0.234)(0.660)$$
$$UCD_{4B} = 0.148 + 0.302 + 0.122 + 0.154$$
$$UCD_{4B} = 0.727$$

Once the models for each product were completed, a rating scale was developed to defuzzify the results obtained. Table 34 illustrates the rating scale and cut-off values that were developed based on a variation of the scale used by J.D. Powers, which is the current leader in product assessment rating scales.

Table 34 Rating scale to defuzzify the UCD Validation model results

Rating	Scale
Unacceptable	(0, 0.49)
Average	(0.50, 0.79)
Outstanding	(0.80, 1.00)

Table 35 summarizes the results from the UCD index model and their respective ratings obtained from the scale provided in table 34.

Table 35 Summary of UCD Validation model rating results

Products	Audio				Cluster			
	1A	2A	3A	4A	1B	2B	3B	4B
UCD Index Model Validation	0.661	0.468	0.701	0.662	0.649	0.638	0.705	0.727
Index Rating	Average	Average	Average	Average	Average	Average	Average	Average

Based on the rating scale, all of the user-centered design validation models for the evaluated products were rated to be at an average level.

User-Centered Design Index Model Validation Assessment

The measures of accuracy, sensitivity, and specificity were calculated to validate the UCD index model. A comparison between the results obtained with the UCD index model and the assessment obtained by the second set of evaluations performed was conducted. Table 36 illustrates the comparative results between the UCD index models and the validation assessments.

Table 36 Comparative results between UCD Index Models and the validation assessments

Products	Audio				Cluster			
	1A	2A	3A	4A	1B	2B	3B	4B
UCD Index Model	Unacceptable	Average	Average	Average	Average	Average	Average	Average
UCD Index Model Validation	Average	Average	Average	Average	Average	Average	Average	Average

The results provided in Table 36 were used to calculate the accuracy, sensitivity, and specificity (adapted from Table 13 and illustrated in Tables 37 and 38) of the UCD index model compared to the assessments conducted by the second set of evaluators.

Table 37 Accuracy, Sensitivity, and Specificity results

		Condition (from "Gold" standard)			
		Outstanding	Average	Unacceptable	
Test Outcome	Outstanding	True Positive (Accurate)		False Positive	
	Average	False Negative	True Positive (Accurate)	Type I Error	
	Unacceptable	Type II Error		True Positive (Accurate)	
		Sensitivity TP/(TP+FN)		Specificity TN/(TN+FP)	Accuracy = (TP+TN)/ TP+FP+FN+TN

Table 37 is the result of adapting the characterization of accuracy, sensitivity, and specificity calculations to a three-level rating scale.

Table 38 Accuracy, Sensitivity, and Specificity results for User-centered design

		Condition (from "Gold" standard)			
		Outstanding	Average	Unacceptable	
Test Outcome	Outstanding	TP = 0	TP = 0	FP = 0	
	Average	FN = 0	TP = 7	FP = 0	
	Unacceptable	FN = 0	FN = 1	TN = 0	
		Sensitivity TP/(TP+FN) = 87.5%		Specificity TN/(TN+FP) = 0	Accuracy = (TP+TN)/ TP+FP+FN+TN = 87.5%

Accuracy looks at the degree that a measured or calculated quantity is to its actual (true) value; sensitivity measures the rate of how well a test correctly identifies a condition, and specificity measures how well a test correctly identifies the negative cases. The results reflect a specificity rate of 0% as well as an accuracy and sensitivity rate of 87.5%

User-Centered Design Index Model Validation Assessment – Nonparametric Test

Due to the sample size, nonparametric analysis was applied as an additional validation method. The Wilcoxon rank sum test was used to validate the models because it compares the variable distributions not just the median; two populations were analyzed by performing matched-pairs tests set up as follows:

H_o: Populations have the same distribution

H_a: one distribution is shifted (either to the right or left) of the other

Wilcoxon Signed Rank Test: UCD-model-Valid

```
Test of median = 0.000000 versus median not = 0.000000

                    N
                   for   Wilcoxon          Estimated
               N  Test  Statistic       P     Median
UCD-model-Valid  8     8       19.0  0.944   0.005750
```

Figure 39 Wilcoxon Signed Rank Test for UCD index model validation

Since the p-value is > 0.50, then it can be concluded that based on the sample size, there was no significant difference between the UCD index model values and the UCD index model validation values.

Customer Benefits

The customer benefits index model was validated using a data set obtained from a company in the automotive industry. The study collected feedback from 64 participants.

Customer Benefits Index Model Development

Since the customer benefits index model requires the feedback of participants that own the product, then historical data was obtained from the company. The data used originated from a study the company previously conducted that was also in relation to user-centered design. The study consisted of participants rating each variable using a scale from 1-7, which is the same scale used within this research. A mapping between the survey questions developed in this research effort and the data obtained was conducted. Only the data from the two types of systems (an audio system and a cluster system) of the four vehicle models used to develop the UCD index models were included to develop the customer benefits index models.

Membership Functions

The degrees of memberships per product were calculated using weighted averages of the assessments conducted by the participants. The weighted averages were then mapped with the degree of membership, in the [0, 1] interval. The membership function shape for the customer benefits index model components was determined to be linear.

Table 39 illustrates the mapping between the survey questions developed to characterize safety and the data collection factors used to develop the customer benefits index model.

Table 39 Mapping of identified Customer Satisfaction factors with data collection factors

Component	Sub-component	Factor	Data collection factors
Safety	Injuries	Bodily reaction (to chemicals)	
		Rubbing or abrasions	
		Exposure to extreme temperatures	
		Repetitive strain	
	Illnesses	Muscle and tendon disorders (tendonitis, muscle damage)	
		Tunnel syndromes (carpal tunnel, radial tunnel)	
	Warnings	Size	Illegible features
		Shape	Detectable parts
		Color	
		Contrast	Distinguishable elements
		Placement	Accessible
		Use of 'active' attention getters	Uninviting
		Physical durability	

Although some of the identified factors for the safety component were not collected in the data collection, the factors identified were the most applicable for the products used to develop the model. The sub-component injuries and illnesses do not have a strong application for an audio system and a cluster system, unlike the warnings sub-component which is more critical for the design of the two evaluated systems. Therefore, the results of the customer benefits index model were not expected to be negatively impacted by the unmeasured factors.

Figure 40 is a graphical representation of the safety degree of membership for the products evaluated in each vehicle. The graph illustrates most of the product degree of membership values to be above 0.50.

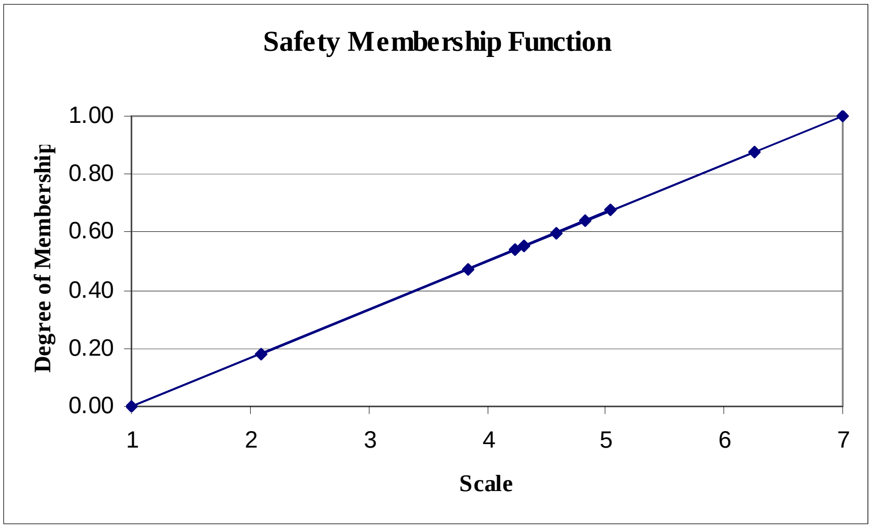

Figure 40 Safety Membership Function

Table 40 illustrates the mapping between the survey questions developed to characterize quality product and the data collection factors used to develop the customer benefits index model. Although some of the identified factors for the quality component were not collected in the data collection, the factors available are sufficient to develop the model. Therefore, the results of the customer benefits index model were not expected to be negatively impacted by the unmeasured factors.

Table 40 Mapping of identified Quality Product factors with data collection factors

Component	Sub-component	Factor	Data collection factors
Quality product	Quality index	Reliability	
		Accuracy	Controllable
		Conformance	
		Stability	Uncertain
		Effectiveness	Responsive
		Efficiency/Productivity	Complex
		Functionality	
		Repeatability	Unpredictable

Figure 41 is a graphical representation of the safety degree of membership for the products evaluated in each vehicle. The graph illustrates most of the product degree of membership values to be relatively high values.

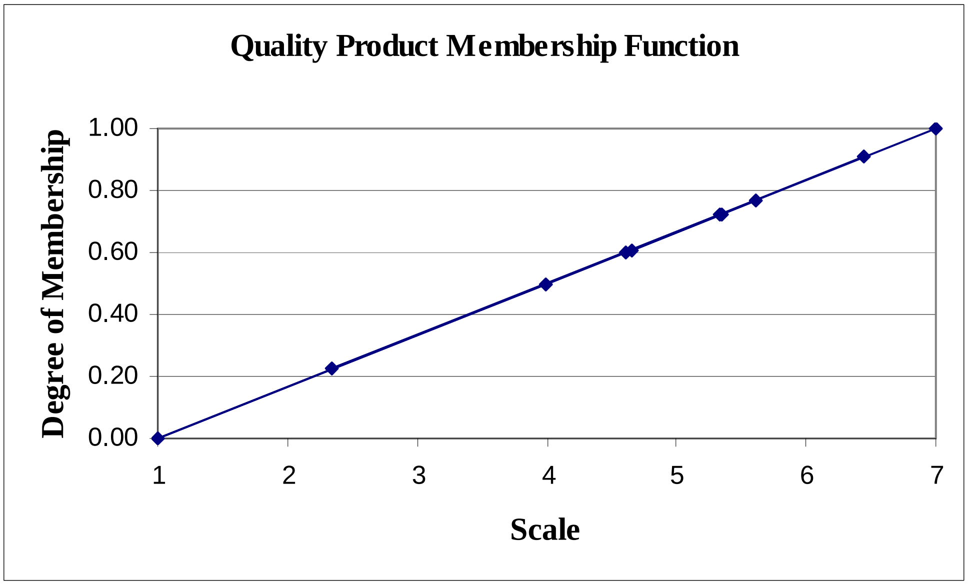

Figure 41 Quality Product Membership Function

Table 41 illustrates the mapping between the survey questions developed to characterize customer satisfaction and the data collection factors used to develop the customer benefits index model. Only two of the identified factors for the customer satisfaction component were not collected in the data collection. The results of the customer benefits index model were not expected to be negatively impacted by the unmeasured factors.

Table 41 Mapping of identified Customer Satisfaction factors with data collection factors

Component	Sub-component	Factor	Data collection factors
Customer satisfaction	Customer perception	Significance of use	Impractical
		Usefulness of product	Useful
		Expected perceived value	Worthless
	Durability/ Reliability	Length of usable life	
		Time to failure	
		Consistent performance	Inconsistent
	Appeal	Aesthetics	I like it rating
		Joy level	I am displeased rating
		Motivation level	Encouraged
		Satisfaction level	Disappointed rating

Figure 42 is a graphical representation of the customer satisfaction degree of membership function for the products evaluated in each vehicle. The graph illustrates one of the product degree of membership values to be a relatively high value.

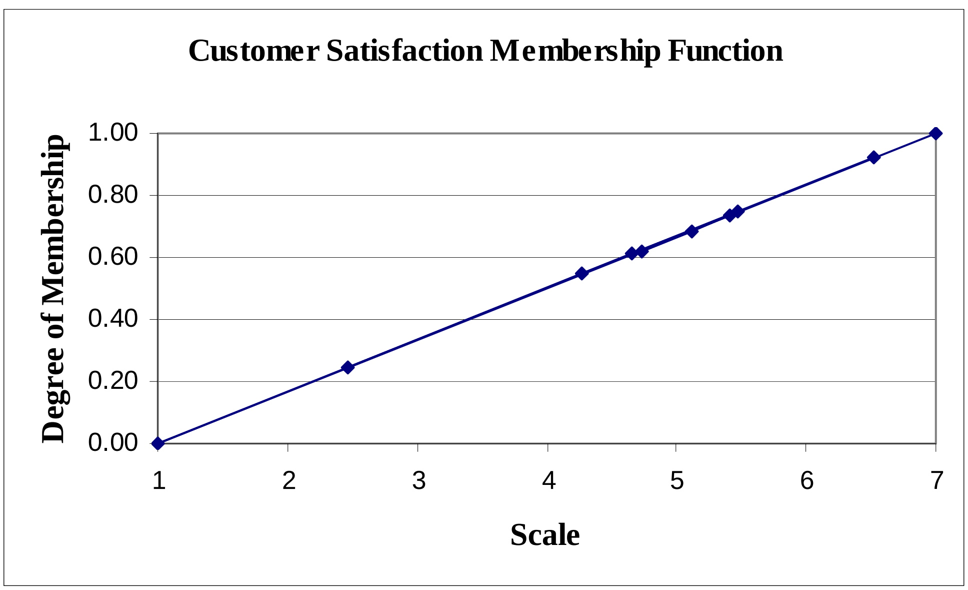

Figure 42 Customer Satisfaction Membership Function

Table 42 illustrates a summary of all the product degree of membership for each of the customer benefits components.

Table 42 Summary of Membership Functions

Customer Benefits Model	Audio				Cluster			
	1A	2A	3A	4A	1B	2B	3B	4B
Safety	0.138	0.036	0.180	0.095	0.106	0.134	0.118	0.120
Quality Product	0.261	0.079	0.327	0.175	0.207	0.282	0.271	0.215
Customer Satisfaction	0.297	0.096	0.367	0.212	0.233	0.298	0.283	0.242

The degree of membership values were used to develop the customer benefits index model for each of the products used in this research.

Relative Weights

The overall customer benefits component relative weights were determined based on AHP analysis conducted of pairwise factor comparisons using four subject matter experts. The Expert Choice software was used to conduct the AHP analysis (See Figure 37 for output results).

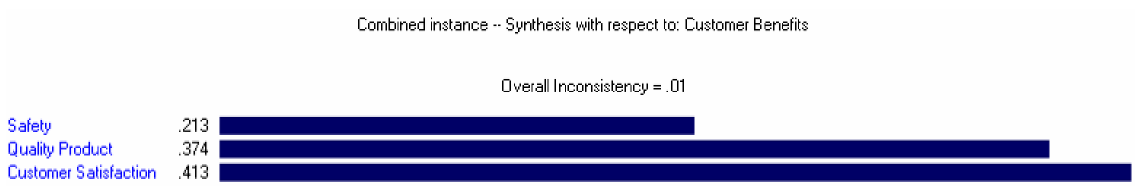

Figure 43 AHP analysis results of Customer Benefits model using Expert Choice

The following are the resulting relative weights for the customer benefits index model:

Safety (L: 0.213)

Quality Product (L: 0.374)

Customer Satisfaction (L: 0.413)

The values show that of the three components, customer satisfaction has the strongest relative weight. In addition to the weights, the software also provided an inconsistency rating of the AHP analysis conducted by comparing the pairwise comparison values of the subject matter experts. Table 43 illustrates the inconsistency rating of the subject matter experts that conducted the AHP analysis for customer benefits.

Table 43 Inconsistency rating for Customer Benefits AHP analysis

Inconsistency Ratio	
SME 1	0.4151
SME 2	0.0000
SME 3	0.0000
SME 4	0.0367
Combined	**0.0122**

The consistencies of the combined and individual inputs were determined by analyzing the inconsistency ratio, which should be below 0.10. The inconsistency ratio is a measure that consistency, not randomness was used when making paired comparisons. The inconsistency ratio was calculated for each set of judgments. It follows the transitive property, for example, if an evaluator states that A > B, and B > C, then states that C > A, then there would be inconsistency in the evaluation. A set of perfectly consistent judgments would produce a consistency index of 0, whereas a consistency ratio of 1 indicates consistency similar to that which would be achieved if judgments were made randomly rather than based on sound judgment or intellect. Thus it can be concluded that the larger the value, the more inconsistent the judgments. The differences in the judgments may be the result of the SME backgrounds because they may be conducting the pairwise comparisons with different goals or applications in mind. For instance, SME 1 has a background in the automotive industry and may have performed the pairwise comparisons without clear and specific intended applications. SME 2 however, is from the academia and was perhaps considering a general application. SME 3 is from the industry and perhaps had a clear application in mind while performing the pairwise comparisons. Although SME 4 is not from the academia, her work environment is such that requires the design and development of different product types, which explains why she would assign equal values to all of the components, thus resulting in perfect consistency in her pairwise comparison. Expert Choice, a frequently used software tool for developing the relative weights also reported an overall inconsistency ratio, which is a ratio between the inconsistency from the individual assessment compared to the expected inconsistency from a matrix with the number of variables evaluated. In addition to the individual inconsistency ratings calculated for each individual's pairwise comparisons, the software also provided a set of relative weights combining the responses from the participants. The combined relative weights also have a combined inconsistency rating calculated from a weighted average of the inconsistency ratios. The program initially assumes all of the pairwise comparisons to have equal relative weights and allows the user to modify the relative weights assigned to each person's responses or to remove any of the evaluations performed. However, due to the number of subject matter experts performing the pairwise comparisons and considering the individual participants' background (industry and academia), then all of the individual responses were included and each was assumed of equal importance. The inconsistency ratio was used to determine which model relative weights should be used. Although the inconsistency ratio from SMEs 2 and 3 were the lowest, the combined inconsistency ratio of 0.0122 was selected because it also considers the feedback from SMEs 1 and 4. The combined inconsistency scoring is within the 0.10 desired score. Therefore, it may be concluded that the combined AHP analysis conducted by the subject matter experts to determine the relative weights for the customer benefits index model was determined with consistency, not randomness.

Customer Benefits Index Model

The customer benefits (CB) index model is developed using equation 4.3.

$$CB = W_S\,(S) + W_{QP}\,(QP) + W_{CS}\,(CS) \qquad (4.3)$$

Where:

CB = the benefits associated with the customer benefits characteristics

QP = the degree of membership for the quality product

W_{QP} *= weighting factor for each quality product factor*

S = the degree of membership for the safety

W_S *= weighting factor for each safety factor*

CS = the degree of membership for the customer satisfaction

W_{CS} *= weighting factor for each customer satisfaction factor*

Audio System

The following is the customer benefits index rating for the audio system in vehicle 1.

$$CB_{1A} = W_S(S) + W_{QP}(QP) + W_{CS}(CS)$$
$$CB_{1A} = 0.213(0.65) + 0.374(0.70) + 0.413(0.72)$$
$$CB_{1A} = 0.138 + 0.261 + 0.297$$
$$CB_{1A} = 0.696$$

The following is the customer benefits index rating for the audio system in vehicle 2.

$$CB_{2A} = W_S(S) + W_{QP}(QP) + W_{CS}(CS)$$
$$CB_{2A} = 0.213(0.17) + 0.374(0.21) + 0.413(0.23)$$
$$CB_{2A} = 0.036 + 0.079 + 0.096$$
$$CB_{2A} = 0.212$$

The following is the customer benefits index rating for the audio system in vehicle 3.

$$CB_{3A} = W_S(S) + W_{QP}(QP) + W_{CS}(CS)$$
$$CB_{3A} = 0.213(0.84) + 0.374(0.87) + 0.413(0.89)$$
$$CB_{3A} = 0.180 + 0.327 + 0.367$$
$$CB_{3A} = 0.874$$

The following is the customer benefits index rating for the audio system in vehicle 4.

$$CB_{4A} = W_S(S) + W_{QP}(QP) + W_{CS}(CS)$$
$$CB_{4A} = 0.213(0.44) + 0.374(0.47) + 0.413(0.51)$$
$$CB_{4A} = 0.095 + 0.175 + 0.212$$
$$CB_{4A} = 0.482$$

Cluster

The following is the customer benefits index rating for the cluster system in vehicle 1.

$$CB_{1B} = W_S(S) + W_{QP}(QP) + W_{CS}(CS)$$
$$CB_{1B} = 0.213(0.50) + 0.374(0.55) + 0.413(0.56)$$
$$CB_{1B} = 0.106 + 0.207 + 0.233$$
$$CB_{1B} = 0.546$$

The following is the customer benefits index rating for the cluster system in vehicle 2.

$$CB_{2B} = W_S(S) + W_{QP}(QP) + W_{CS}(CS)$$
$$CB_{2B} = 0.213(0.63) + 0.374(0.75) + 0.413(0.72)$$
$$CB_{2B} = 0.134 + 0.282 + 0.298$$
$$CB_{2B} = 0.714$$

The following is the customer benefits index rating for the cluster system in vehicle 3.

$$CB_{3B} = W_S(S) + W_{QP}(QP) + W_{CS}(CS)$$
$$CB_{3B} = 0.213(0.55) + 0.374(0.72) + 0.413(0.69)$$
$$CB_{3B} = 0.118 + 0.271 + 0.283$$
$$CB_{3B} = 0.672$$

The following is the customer benefits index rating for the cluster system in vehicle 4.

$$CB_{4B} = W_S(S) + W_{QP}(QP) + W_{CS}(CS)$$
$$CB_{4B} = 0.213(0.56) + 0.374(0.57) + 0.413(0.59)$$
$$CB_{4B} = 0.120 + 0.215 + 0.242$$
$$CB_{4B} = 0.577$$

Once the models for each product were completed, a rating scale was developed to defuzzify the obtained results. Table 44 illustrates the rating scale and cut-off values that were developed based on a variation of the scale used by J.D. Powers, which is the current leader in product assessment rating scales.

Table 44 Rating scale to defuzzify the Customer Benefits Index model results

Rating	Scale
Unacceptable	(0, 0.49]
Average	(0.50, 0.89]
Outstanding	(0.90, 1.00]

Table 45 summarizes the results from the customer benefits index model and their respective ratings obtained from the scale provided in Table 44.

Table 45 Summary of Customer Benefits Index model rating results

Products	Audio				Cluster			
	1A	2A	3A	4A	1B	2B	3B	4B
CB Index Model	0.696	0.212	0.874	0.482	0.546	0.714	0.672	0.577
Index Rating	Average	Unacceptable	Average	Unacceptable	Average	Average	Average	Average

Based on the rating scale, two of the customer benefits index models for the evaluated products were rated to be at an unacceptable level.

Customer Benefits Index Model Validation

To validate the customer benefits index models, the "gold standard" selected consisted of the results from an assessment conducted by JD Powers, a company that evaluates the opinions people have about products and ranks them by preference, quality, and ease of use, among others. The Ckpt: IP Design score was used to validate the cluster system models and the Sound Sys: Overall Rating score was used to validate the audio system models.

Table 46 Customer Benefits Index Model Gold Standard (JD Powers)

JD Power Models	Cluster System	Audio System
1	8.24	7.95
2	8.49	8.47
3	8.59	8.42
4	9.23	8.85

JD Powers used a scale of 1-10, ranging between unacceptable and outstanding. Table 47 illustrates the JD Powers rating scale.

Table 47 Rating scale to defuzzify the Customer Benefits Index model

Rating	Scale
Unacceptable	(1, 4)
Average	(5, 9)
Outstanding	(10)

Table 48 summarizes the results from the customer benefits index model and their respective ratings obtained from the scale provided in Table 47.

Table 48 Summary of Customer Benefits Validation model rating results

Products	Audio				Cluster			
	1A	2A	3A	4A	1B	2B	3B	4B
CB Gold Standard (JD Powers)	8.514	7.900	9.024	8.584	8.490	8.244	9.228	8.591
Index Rating	Average	Average	Average	Average	Average	Average	Average	Average

Based on the rating scale, all of the customer benefits validation models for the evaluated products were all rated to be at an average level.

The measures of accuracy, sensitivity, and specificity were calculated to validate the customer benefits index model. A comparison between the results obtained with the customer benefits index model and the assessment obtained with the "gold standard" was conducted. Table 49 illustrates the comparative results between the customer benefits index models and the "gold standard".

Table 49 Comparative results between Customer Benefits Index models and the "gold standard"

Products	Audio				Cluster			
	1A	2A	3A	4A	1B	2B	3B	4B
CB Index Model	Average	Unacceptable	Average	Unacceptable	Average	Average	Average	Average
CB Validation	Average	Average	Average	Average	Average	Average	Average	Average

The results provided in Table 49 were used to calculate the accuracy, sensitivity, and specificity (illustrated in Table 50) of the UCD index model compared to the results obtained from the "gold standard".

Table 50 Accuracy, Sensitivity, and Specificity results for Customer benefits

		Condition (from "Gold" standard)			
		Outstanding	Average	Unacceptable	
Test Outcome	Outstanding	TP = 0	TP = 0	FP = 0	
	Average	FN = 0	TP = 6	FP = 0	
	Unacceptable	FN = 0	FN = 2	TN = 0	
		Sensitivity TP/(TP+FN) = 75%		Specificity TN/(TN+FP) = 0	Accuracy = (TP+TN)/ TP+FP+FN+TN = 75%

Accuracy looks at the degree that a measured or calculated quantity is to its actual (true) value, sensitivity measures the rate of how well a test correctly identifies a condition, and specificity measures how well a test correctly identifies the negative cases. The results reflect a sensitivity rate and an accuracy of 75%, as well as a specificity of 0%. A suggestion for future research is to expand the data sample that includes more products to reach additional conclusions in terms of the accuracy of the results, as well as the application in a diversity of industries and products.

Customer Benefits Index Model Validation Assessment – Nonparametric Test

Due to the sample size, nonparametric analysis was applied as an additional validation method. The Wilcoxon rank sum test was used to validate the models because it compares the variable distributions not just the median; two populations were analyzed by performing matched-pairs tests set up as follows:

H_o: Populations have the same distribution

H_a: one distribution is shifted (either to the right or left) of the other

Wilcoxon Signed Rank Test: CB-JD-All

Test of median = 0.000000 versus median not = 0.000000

	N	N for Test	Wilcoxon Statistic	P	Estimated Median
CB-JD-All	8	8	1.0	0.021	-0.2458

Figure 44 Wilcoxon Signed Rank Test to validate the customer benefits index model with gold standard (JD Powers)

Since the p-value is < 0.50, then it can be concluded that based on the sample size, there is significant difference between the customer benefits index model values and the gold standard (JD Powers). The primary reason for the differences between the customer benefits index model results and the values obtained from the JD Powers study is that although JD was selected as the gold standard, it should be noted that no "true" gold standard currently exists to truly compare the customer benefits model. The variables measured by JD Powers were not all the same as the variables measured in the customer benefits index model, the JD Powers study was used because it is the closest available for comparison.

Organizational Benefits

For the purpose of this research, the membership functions for the organizational benefits were calculated for the vehicle model or manufacturer. Since the customers interact with the evaluated products on a daily basis, it can be assumed that there is a strong relationship between the opinion about the individual products the user interacts with and the vehicle as a whole.

Organizational Benefits Index Model Development

The organizational benefits data is obtained from organizational reports such as consumer reports, market research studies, financial reports, etc. However, due to data accessibility and confidentiality concerns regarding nonpublic information, the organizational benefits index model was developed using data obtained from public information reporting such as 10K/A corporate annual reports, balance sheets, consumer reports, and JD Powers's studies. Since the data available is an aggregate value, then it is only a reference to the vehicle models not specific to the type of products evaluated (audio system and cluster system) in the previous sections. Therefore, this portion of the research was analyzed in terms of the four vehicle models used to develop the UCD index models and the customer benefits index models.

Membership Functions

The degree of membership was determined using the some of the variables provided in Table 51. The percentage of customer complaints was obtained from a J.D. Powers Vehicle Dependability study that reports the dependability problems identified per 100 vehicles (Greywitt and Tews, 2004). The study used a scale up to 550, where vehicle 3 had a score of

267/550, vehicle 4 had a score of 297/550, and the industry average was determined to be 269/550 or 49%.

Table 51 Company Image factors

Company Image	Product X
What percentage of customer complaints does the company receive related to their products per year?	
What percentage of unfavorable media does the company receive per year?	
How is your company doing in terms of customer service responsiveness? (i.e average amount of time customer waits to have an issue solved)	
What is the percentage of new customers obtained per year?	
What percentage of customers purchase products based on Credibility/brand recognition?	

Due to data availability limitations, the company image membership function was determined with the use of the percentage of customer complaints received per year and the percentage of new customers obtained per year. The data provided in Table 52 was implemented by comparing the performance of the evaluated vehicles with other industry leaders such as Ford, Nissan, Toyota, and Honda, among others.

Table 52 Customer Complaints

Customer Complaints		
Company	***X***	***Y***
Lexus	29.455	1.000
Buick	34.000	0.987
Infiniti	34.364	0.985
Lincoln	35.273	0.979
Cadillac	35.636	0.976
Honda	38.000	0.954
Acura	38.545	0.948
Toyota	39.273	0.939
Mercury	40.727	0.920
Porsche	43.636	0.873
Chevrolet	47.636	0.792
GMC	47.636	0.792
BMW	48.000	0.783
Saab	48.182	0.779
Saturn	48.545	0.771
Ford	50.182	0.730
Nissan	50.909	0.710
Chrysler	51.818	0.685
Mazda	51.818	0.685
Subaru	52.364	0.670
Plymouth	52.545	0.664
Audi	53.636	0.652
Pontiac	54.000	0.637
Dodge	54.182	0.630
Jaguar	56.364	0.546
Jeep	57.091	0.520
Oldsmobile	57.091	0.520
Mercedes-Benz	59.455	0.438
Mitsubishi	59.455	0.438
Volvo	62.909	0.330
Suzuki	66.364	0.238
Hyundai	68.182	0.196
Volkswagen	70.182	0.154
Isuzu	71.455	0.130
Daewoo	74.727	0.077
Kia	78.545	0.033
Land Rover	85.818	0.000

The percentage of new customers obtained per year was determined from the remainder of the percentage of returning customers, which was obtained from a JD Powers Customer Retention Study (Greywitt, M., Tews, J., 2004). Table 53 provides a list of the vehicles used to determine the membership function.

Table 53 Percentage of New Customers

Percentage of New Customers		
Company	***X***	***Y***
Toyota	39.4	0.344
Lexus	40.5	0.388
Chevrolet	41.1	0.413
Hyundai	42.4	0.470
Honda	44.8	0.581
Ford	45.5	0.614
Cadillac	47.2	0.693
Mercedes-Benz	48.4	0.747
BMW	48.6	0.756
Kia	49.1	0.778
Jaguar	51.7	0.879
Subaru	52	0.889
Audi	54	0.947
Saturn	55	0.969
Dodge	55.5	0.978
Buick	55.6	0.979
GMC	55.9	0.984
Lincoln	56	0.985
Nissan	57.7	0.999
Porsche	58.2	1.000
Land Rover	58.7	0.999
Acura	60.2	0.989
Chrysler	60.5	0.985
Volvo	60.7	0.982
Jeep	61.7	0.965
Mercury	65.6	0.850
Volkswagen	66.3	0.823
Pontiac	66.5	0.815
Mitsubishi	68.2	0.743
Infiniti	68.6	0.725
Suzuki	68.6	0.725

Saab	69.5	0.684
Mazda	76.9	0.352
Isuzu	93	0.027
Oldsmobile	95.1	0.017

Based on the percentage of new customers' industry data and characteristics, The Gaussian membership function is applied. The Gaussian membership function is one of several membership functions with the characteristics of being smooth nonlinear functions.

$$gaussian(x;c,\sigma) = e^{-\frac{1}{2}(\frac{x-c}{\sigma})^2} \tag{4.4}$$

The Gaussian membership function was selected for new customers because having a small percentage of new customers as well as a large percentage of new customers is an indication of low customer loyalty. The degree of membership was determined by the parameters *c* and σ, where *c* represents the center of the membership function, and σ determines the width of the membership function (Jang, et. al., 1997).

The percentage of customer complaints related to the products were obtained from a dependability study performed by J.D. Powers, where vehicles were rated on a scale up to 550, and the industry average was determined to be 269 out of 550 or 49% (Greywitt and Tews, 2004). The customer complaints industry data has the characteristics of a sigmoidal membership function, which is inherently open right or left. The sigmoidal membership function is most frequently used to represent concepts such as "very large" or very negative. The sigmoidal membership function is defined by equation 4.5, where α is the zero membership function, γ is the complete membership function, and β is the point where the domain value is 50% true (inflection or crossover point). The value for the curve in domain point *x* is provided in the following (Cox, 1994).

$$sig(x;\alpha,\beta,\gamma)=\begin{bmatrix} 0 \rightarrow x \leq \alpha \\ 2((x-\alpha)/(\gamma-\alpha))^2 \rightarrow \alpha \leq x \leq \beta \\ 1-2((x-\gamma)/(\gamma-\alpha))^2 \rightarrow \beta \leq x \leq \gamma \\ 1 \rightarrow x \geq \gamma \end{bmatrix} \quad (4.5)$$

The company image membership function (C) is derived from the union of the new customers' membership function (A) and the customer complaints membership function (B). The union of two fuzzy sets is defined as C = A ∪ B or C = A OR B, where the membership function of C is related to A and B by

$$\mu_C(x) = \max((\mu_A(x), \mu_B(x)) = \mu_A(x) \vee \mu_B(x) \quad (4.6)$$

Zadeh pointed out that an equivalent definition for the union between two fuzzy sets is the "smallest" fuzzy set that contains both A and B (Jang, et. al., 1997). Therefore, Figure 38 illustrates the resulting company image membership (bold line) included in the development of the organizational benefits model.

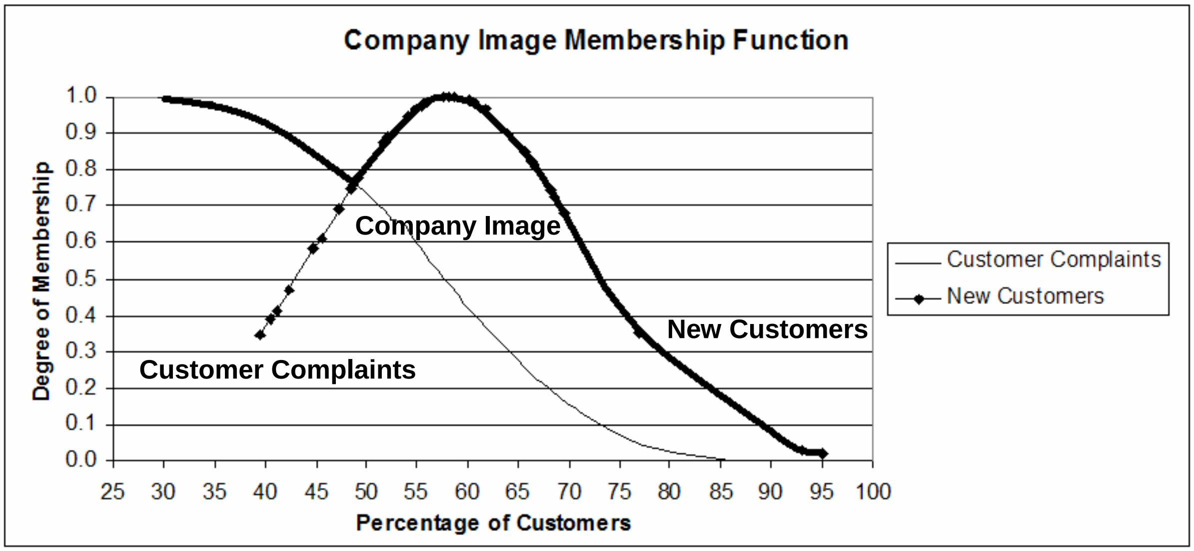

Figure 45 Company Image Membership Function

Once the values for each degree of membership (customer complaints and new customers) were obtained, the highest value is selected to obtain the new degree of membership for company image. The resulting degrees of membership for company image are provided in Table 54.

Table 54 Company Image Degree of Membership

Vehicle Number	New Customer Degree of Membership	Customer Complaints Degree of Membership	Company Image Degree of Membership
1	0.413	0.792	0.792
2	0.979	0.987	0.987
3	0.969	0.771	0.969
4	0.815	0.637	0.815

Table 55 illustrates the customer loyalty factors identified to develop the organizational benefits Index model. The percentage of returning customers was obtained from the JD Powers Customer Retention Study, where the industry average was determined to be 48.4%. The 2004 Customer Retention Study is based on responses from over 171,000 new-vehicle buyers and lessees, of which 103,088 replaced a vehicle that was originally purchased new (Greywitt and Tews, 2004).

Table 55 Customer Loyalty factors

Customer Loyalty	Product X
What is the percentage of customer referrals received per year?	
What percentage of Customer perception feedback is positive?	
What percentage of Customer experience feedback is positive?	
What is the percentage of returning customers per year?	

Due to data availability limitations, the customer loyalty membership function was developed considering the customer perception and percentage of returning customers per year. However, for further application, the inclusion of the percentage of customer referrals and customer experience feedback is recommended for the development of a more accurate membership function. The percentage of returning customers data was obtained from the 2004 customer retention study performed by JD Powers, where the industry average was determined to be 43.4 (Greywitt and Tews, 2004). Table 56 provides a list of the vehicles used to determine the membership function.

Table 56 Customer Retention

Customer Retention		
Company	***X***	***Y***
Oldsmobile	4.9	0.000
Isuzu	7	0.003
Mazda	23.1	0.214
Saab	30.5	0.422
Infiniti	31.4	0.453
Suzuki	31.4	0.453
Mitsubishi	31.8	0.466
Pontiac	33.5	0.527
Volkswagen	33.7	0.535
Mercury	34.4	0.561
Jeep	38.3	0.679
Volvo	39.3	0.708
Chrysler	39.5	0.713
Acura	39.8	0.721
Land Rover	41.3	0.760
Porsche	41.8	0.772
Nissan	42.3	0.784
Lincoln	44	0.822
GMC	44.1	0.824
Buick	44.4	0.831
Dodge	44.5	0.833
Saturn	45	0.843
Audi	46	0.863
Subaru	48	0.898
Jaguar	48.3	0.902
Kia	50.9	0.939
BMW	51.4	0.945
Mercedes-Benz	51.6	0.948
Cadillac	52.8	0.961
Ford	54.5	0.976
Honda	55.2	0.981
Hyundai	57.6	0.994
Chevrolet	58.9	0.998
Lexus	59.5	0.999
Toyota	60.6	1.000

The customer perception data was obtained from consumer reports, which analyzed the overall vehicle rating based on more than 50 test evaluations. Some of the evaluations performed were predicted reliability, owner satisfaction, predicted depreciation, accident avoidance, fuel economy, safety, performance, comfort/convenience, and specifications [94]. Table 57 provides a list of the vehicles used to determine the membership function.

Table 57 Customer Perception

Customer Perception		
Company	***X***	***Y***
Suzuki	36	0.000
Saturn	38	0.003
Pontiac	39	0.006
Dodge	46	0.071
Chrysler	48	0.103
Buick	56	0.285
GMC	57	0.314
Mitsubishi	63	0.519
Subaru	64	0.558
Volvo	70	0.743
Mercedes-Benz	73	0.818
Kia	75	0.860
Ford	75	0.860
Hyundai	76	0.880
Mazda	76	0.880
Mercury	77	0.897
Chevrolet	83	0.974
Cadillac	84	0.982
Nissan	85	0.989
Toyota	87	0.997
Honda	88	0.999
Volkswagen	89	1.000

Figure 57 illustrates the customer retention membership function that is represented by a sigmoidal shape with a 41.75 mean, and the customer perception membership function, which is represented with a sigmoidal shape that has a 65.36 mean. The two sigmoidal functions become a close and asymmetrical membership function. Several methods of obtaining these types of membership functions may be implemented such as taking the difference $|y_1-y_2|$, calculating the addition, and determining the product y_1y_2. The customer loyalty degree of membership was determined by calculating the product between the two membership functions.

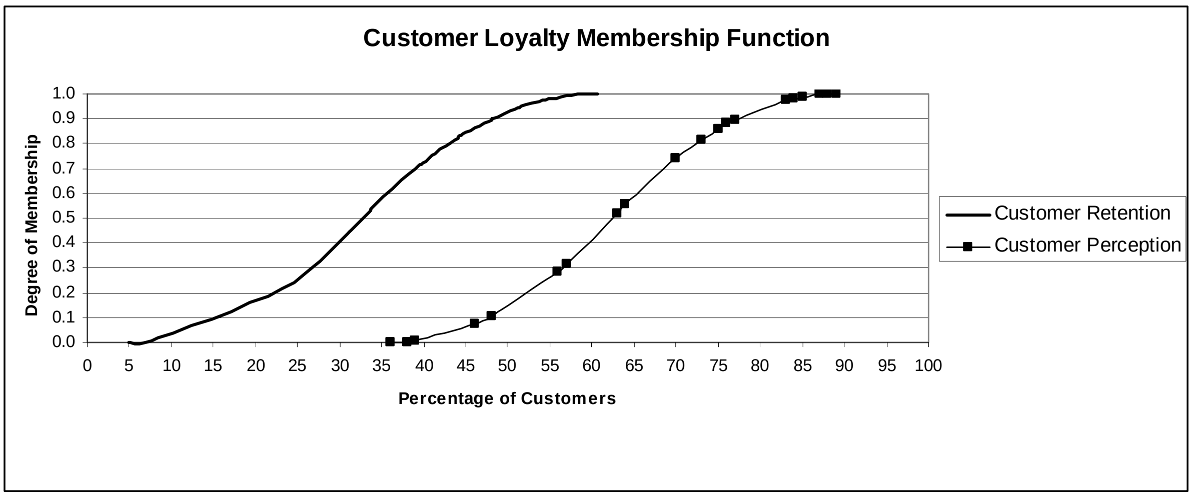

Figure 46 Customer Loyalty Membership Function

The following table is developed with the resulting customer loyalty degree of membership once the values for the percentage of customer perception and customer retention were mapped to their perspective degree of membership. The customer perception and customer retention values for vehicle 3 were 38 and 45, respectively. The customer perception and customer retention values for vehicle 4 were 39 and 33.5, respectively. The customer loyalty degree of membership values were implemented in the development of the organizational benefits model.

Table 58 Customer Loyalty Degree of Membership

Vehicle Number	Customer Perception Degree of Membership	Customer Retention Degree of Membership	Customer Loyalty Degree of Membership
1	0.974	0.998	0.972
2	0.285	0.831	0.237
3	0.003	0.843	0.002
4	0.006	0.527	0.003

Table 59 illustrates the profitability factors used to measure the organizational benefits. Due to data accessibility limitations, the factors used to determine profitability were the revenues made from sales and the amount of money spent on research and development; however, to obtain more accurate values for the profitability degrees of membership, the factors identified (provided in Table 11) should be applied. The company annual reports were used to quantify the identified factors. According to the Center of Automotive Industry (2006), "Automobiles are developed over three years (approximately), before production begins. In electronics the development phase for many technologies (especially consumer electronics that might be used for infotainment and telematics) is often under twelve months." However, since the companies may work on infotainment and telematics during different phases of the development process, then for simplification purposes, the R&D expenses values from the same year were used. For the purpose of this research, the research and development expenses were calculated by assuming that all of the vehicles spend a percentage of the overall sales revenues. However, future research should include a broader industry sample data.

Table 59 Profitability Factors

Profitability	**Product X**
How much money is spent on product development? (i.e Research and Development)	
What percentage of the product development costs are spent on Training?	
What percentage of the product development costs are spent on equipment?	
How much money is spent on capital expenses?	
How much money is spent on tech support?	
How much money is spent on operating expenses?	
How much money is spent on outsourced expenses?	
How much money is being made from sales?	
How much money is spent on capital investment?	

Figure 40 illustrates the resulting membership function for profitability associated with research and development (R&D).

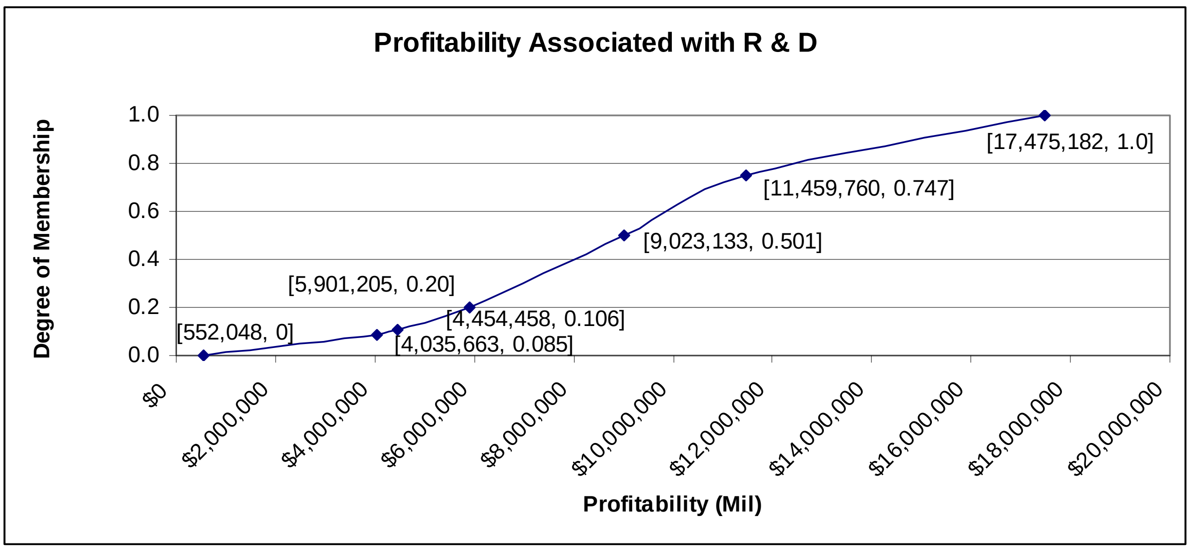

Figure 47 Profitability Membership Function

The following table was developed with the resulting profitability degree of membership. The profitability degree of membership values were implemented in the development of the organizational benefits model.

Table 60 Profitability Degree of Membership

Vehicle	*Sales Revenue*	*Research and Development Expenses*	*Profitability associated with R&D*	*Profitability Degree of Membership*
1	$18,082,764	$607,582	$17,475,182	1.000
2	$6,106,380	$205,175	$5,901,205	0.106
3	$4,175,976	$140,313	$4,035,663	0.085
4	$9,336,852	$313,719	$9,023,133	0.501

Although some of the identified factors for the customer loyalty, company image, and profitability components were not collected, the factors available were the most applicable for the products used to develop the model. For instance, the factor unfavorable media does not have a strong application for an audio system and a cluster system, unlike the R&D expenses which is more critical for the design of the two evaluated systems. Therefore, the results of the organizational benefits index model should not be negatively impacted by the unmeasured factors; however, the validation of the results may be impacted by the number of product types evaluated. Table 61 illustrates a summary of all the degree of membership values for each of the organizational benefits components.

Table 61 Summary of Degree of Membership for Organizational Benefits Components

	Degree of Membership		
Vehicle Number	**Profitability**	**Customer Loyalty**	**Company Image**
1	1.000	0.972	0.792
2	0.200	0.237	0.987
3	0.085	0.002	0.969
4	0.501	0.003	0.815

The degree of membership values were used to develop the organizational benefits index model for each of the vehicles used in this research.

Relative Weights

Overall organizational benefits component relative weights based on AHP analysis conducted by subject matter experts. The Expert Choice software was used to conduct the AHP analysis (See Figure 48 for output results).

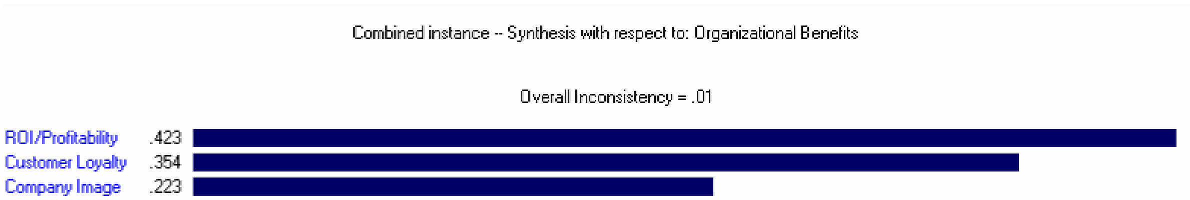

Figure 48 AHP analysis results of Organizational Benefits model using Expert Choice

The following are the resulting relative weights for the organizational benefits index model:

ROI/Profitability (L: 0.423)

Customer Loyalty (L: 0.354)

Company Image (L: 0.223)

The values show that of the three components, ROI/Profitability had the strongest relative weight. In addition to the weights, the software also provided an inconsistency rating of the AHP analysis conducted by comparing the pairwise comparison values of the subject matter experts. Table 62 illustrates the inconsistency rating of the subject matter experts that conducted the AHP analysis for organizational benefits.

Table 62 Inconsistency rating for Organizational Benefits AHP analysis

Inconsistency Ratio	
SME 1	0.4151
SME 2	0.0000
SME 3	0.1292
Combined	**0.0085**

The consistencies of the combined and individual inputs were determined by analyzing the inconsistency ratio, which should be below 0.10. The inconsistency ratio is a measure that consistency, not randomness was used when making paired comparisons. The inconsistency ratio was calculated for each set of judgments. It follows the transitive property, for example, if an evaluator states that A > B, and B > C, then states that C > A, then there would be inconsistency in the evaluation. A set of perfectly consistent judgments would produce a consistency index of 0, whereas a consistency ratio of 1 indicates consistency similar to that which would be achieved if judgments were made randomly rather than based on sound judgment or intellect. Thus it can be concluded that the larger the value, the more inconsistent the judgments. The differences in the judgments may be the result of the SME backgrounds because they may be conducting the pairwise comparisons with different goals or applications in mind. For instance, SME 1 has a background in the automotive industry and may have performed the pairwise comparisons without clear and specific intended applications. The pairwise comparisons from SME 2 may be perfectly consistent because she is a VP in a major manufacturing company that perhaps had clear and specific applications when completing the pairwise analysis. SME 3 is from the academia and was perhaps considering a general application while completing the pairwise analysis. Expert Choice, a frequently used software tool for developing the relative weights also reported an overall inconsistency ratio, which is a ratio between the inconsistency from the individual assessment compared to the expected inconsistency from a matrix with the number of variables evaluated. In addition to the individual inconsistency ratings calculated for each individual's pairwise comparisons, the software also provided a set of relative weights combining the responses from the participants. The combined relative weights also have a combined inconsistency rating calculated from a weighted average of the inconsistency ratios. The program initially assumes all of the pairwise comparisons to have equal relative weights and allows the user to modify the relative weights assigned to each person's responses or to remove any of the evaluations performed. However, due to the number of subject matter experts performing the pairwise comparisons and considering the individual participants' background (industry and academia), then all of the individual responses were included and each was assumed of equal importance. Although the inconsistency ratio from SME 1 is high, the combined inconsistency ratio of 0.0085 was selected because it also considers the feedback from SMEs 2 and 3. The combined inconsistency scoring was within the 0.10 desired score. Therefore, it may be concluded that the combined AHP analysis conducted by the subject matter experts to determine the relative weights for the organizational benefits index model was determined with consistency, not randomness.

Organizational Benefits Index Model

The organizational benefits (OB) index model is developed using equation 4.7.

$$OB = W_{PT}\,(PT) + W_{CL}\,(CL) + W_{CI}\,(CI) \quad (4.7)$$

Where:

OB = the benefits associated with the organizational benefits

PT = the degree of membership for the profitability

W_{PT} *= weighting factor for each profitability factor*

CI = the degree of membership for the company image

W_{CI} *= weighting factor for each company image factor*

CL = the degree of membership for the customer loyalty

W_{CL} = weighting factor for each customer loyalty factor

Vehicle 1

The following is the organizational benefits index rating for vehicle 1.

$$OB_1 = W_{PT}(PT) + W_{CL}(CL) + W_{CI}(CI)$$
$$OB_1 = 0.423(1.00) + 0.354(0.972) + 0.223(0.792)$$
$$OB_1 = 0.423 + 0.344 + 0.177$$
$$OB_1 = 0.944$$

Vehicle 2

The following is the organizational benefits index rating for vehicle 2.

$$OB_2 = W_{PT}(PT) + W_{CL}(CL) + W_{CI}(CI)$$
$$OB_2 = 0.423(0.200) + 0.354(0.237) + 0.223(0.987)$$
$$OB_2 = 0.085 + 0.084 + 0.220$$
$$OB_2 = 0.388$$

Vehicle 3

The following is the organizational benefits index rating for vehicle 3.

$$OB_3 = W_{PT}(PT) + W_{CL}(CL) + W_{CI}(CI)$$
$$OB_3 = 0.423(0.085) + 0.354(0.002) + 0.223(0.969)$$
$$OB_3 = 0.036 + 0.001 + 0.216$$
$$OB_3 = 0.253$$

Vehicle 4

The following is the organizational benefits index rating for vehicle 4.

$$OB_4 = W_{PT}(PT) + W_{CL}(CL) + W_{CI}(CI)$$
$$OB_4 = 0.423(0.501) + 0.354(0.003) + 0.223(0.815)$$
$$OB_4 = 0.212 + 0.001 + 0.182$$
$$OB_4 = 0.395$$

Once the models for each vehicle were completed, a rating scale was developed to defuzzify the obtained results. Table 64 illustrates the rating scale and cut-off values that were developed based on a variation of the scale used by J.D. Powers, which is the current leader in product assessment rating scales

Table 63 Rating scale to defuzzify the Organizational Benefits index model results

Rating	Scale
Unacceptable	(0, 0.33)
Average	(0.34, 0.66)
Outstanding	(0.67, 1.00)

Table 64 summarizes the results from the customer benefits index model and their respective ratings obtained from the scale provided in Table 63.

Table 64 Summary of Organizational Benefits Index model rating results

	Vehicles			
	1	**2**	**3**	**4**
OB Index Model	0.944	0.388	0.253	0.395
Index Rating	Outstanding	Unacceptable	Unacceptable	Unacceptable

Based on the rating scale vehicle 1 obtained the highest rating score and vehicle 3 obtained the lowest rating score for the organizational benefits index model.

Organizational Benefits Index Model Validation

To validate the organizational benefits index models, the "gold standard" selected was the Forbes Global 2000, which includes non-US companies. Like Fortune 500 and Forbes 500 (American companies), the Forbes Global 2000 looks at size and growth; the ranking is based on sales, profit, assets, and market value, as opposed to Forbes 500 (American companies) that only looks at American companies and Fortune 500 which ranks based only on revenue. Table 65 provides the ranking of the company participating in this research.

Table 65 Organizational Benefits Index model Gold Standard (Forbes Global 2000)

Rank	Company	Country	Industry	Sales ($bil)	Profits ($bil)	Assets ($bil)	Market Value ($bil)
513	X	United States	Consumer Durables	207.35	-1.98	153.23	18.04

Based on the ranking obtained from Forbes Global 2000, the company is considered to be in the top 26th percentile, which based on the rating scale provided in Table 65 is average. Table 66 illustrates the rating scale and cut-off values were developed based on a variation of the scale used by J.D. Powers, which is the current leader in product assessment rating scales.

Table 66 Rating scale to defuzzify the Gold Standard scale

Rating	Scale
Outstanding	(1, 500)
Average	(501, 1000)
Poor	> 1001

Table 67 summarizes the results from the organizational benefits index model and their respective ratings obtained from the scale provided in Table 66.

Table 67 Summary of Organizational Benefits Validation model rating results

	Vehicles			
	1	**2**	**3**	**4**
Gold Standard	513	513	513	513
Index Rating	Average	Average	Average	Average

Based on the rating scale, all of the organizational benefits validation models for the evaluated products were rated to be at an average level.

The measures of accuracy, sensitivity, and specificity were calculated to validate the organizational benefits index model. A comparison between the results obtained with the organizational benefits Index model and the assessment obtained with the "gold standard" was conducted. Table 68 illustrates the comparative results between the customer benefits index models and the "gold standard".

Table 68 Comparative results between Organizational benefits index models and the "gold standard"

	Vehicles			
Results	**1**	**2**	**3**	**4**
CB Index Model	Outstanding	Unacceptable	Unacceptable	Unacceptable
Gold standard	Average	Average	Average	Average

The results provided in Table 68 were used to calculate the accuracy, sensitivity, and specificity (illustrated in Table 69) of the organizational benefits index model compared to the results obtained from the "gold standard".

Table 69 Accuracy, Sensitivity, and Specificity results for Organizational benefits

		Condition (from "Gold" standard)			
		Outstanding	Average	Unacceptable	
Test Outcome	Outstanding	TP = 0	FP = 1	FP = 0	
	Average	FN = 0	TP = 0	FP = 0	
	Unacceptable	FN = 0	FN = 3	TN = 0	
		Sensitivity TP/(TP+FN) = 0		Specificity TN/(TN+FP) = 0	Accuracy = (TP+TN)/ TP+FP+FN+TN = 0

Accuracy looks at the degree that a measured or calculated quantity is to its actual (true) value, sensitivity measures the rate of how well a test correctly identifies a condition, and specificity measures how well a test correctly identifies the negative cases. The results reflect accuracy and sensitivity as well as a specificity rate of zero. This outcome may be the result of an inappropriate gold standard. Currently, no gold standard was available to conduct a suitable validation analysis of the organizational benefits model. Therefore, a suggestion for future research is to expand the data sample that includes more products to reach additional conclusions in terms of the accuracy of the results, as well as the application in a diversity of industries and products.

Organizational Benefits Index Model Validation Assessment – Nonparametric Test

Due to the sample size, nonparametric analysis was applied as an additional validation method. The Wilcoxon rank sum test was used to validate the models because it compares the variable distributions not just the median; two populations were analyzed by performing matched-pairs tests set up as follows:

H_o: Populations have the same distribution

H_a: one distribution is shifted (either to the right or left) of the other

The following figure illustrates the results from the conducted Wilcoxon rank sum test.

Wilcoxon Signed Rank Test: Diff_OBModel_Validation

Test of median = 0.000000 versus median not = 0.000000

	N	N for Test	Wilcoxon Statistic	P	Estimated Median
Diff_OBModel_Validation	4	4	1.0	0.201	-0.3503

Figure 49 AHP analysis results of Organizational benefits index model

Since the p-value is > 0.50, then it can be concluded that based on the sample size, there was no significant difference between the organizational benefits index model values and the gold standard (Forbes 2000). However, due to sample size less than 7 in OBModel_Validation, the p-value is an imperfect approximation. This outcome may be the result of the level of evaluation performed for the organizational benefits model. The limitations of data accessibility may have impacted the results. Particularly, the fact that the data was unavailable for each product within the evaluated vehicles model may be in part the cause of the obtained results. However, it should also be considered that the model focuses on product development and design, instead of the company performance as a whole, which emphasizes other factors.

Relationship between User-Centered Design, Customer Benefits and Organizational Benefits

The final portion of this research consists of analyzing the relationship between user-centered design, customer benefits, and organizational benefits. Figure 50 illustrates the results obtained from conducting a relationship analysis of the developed model results.

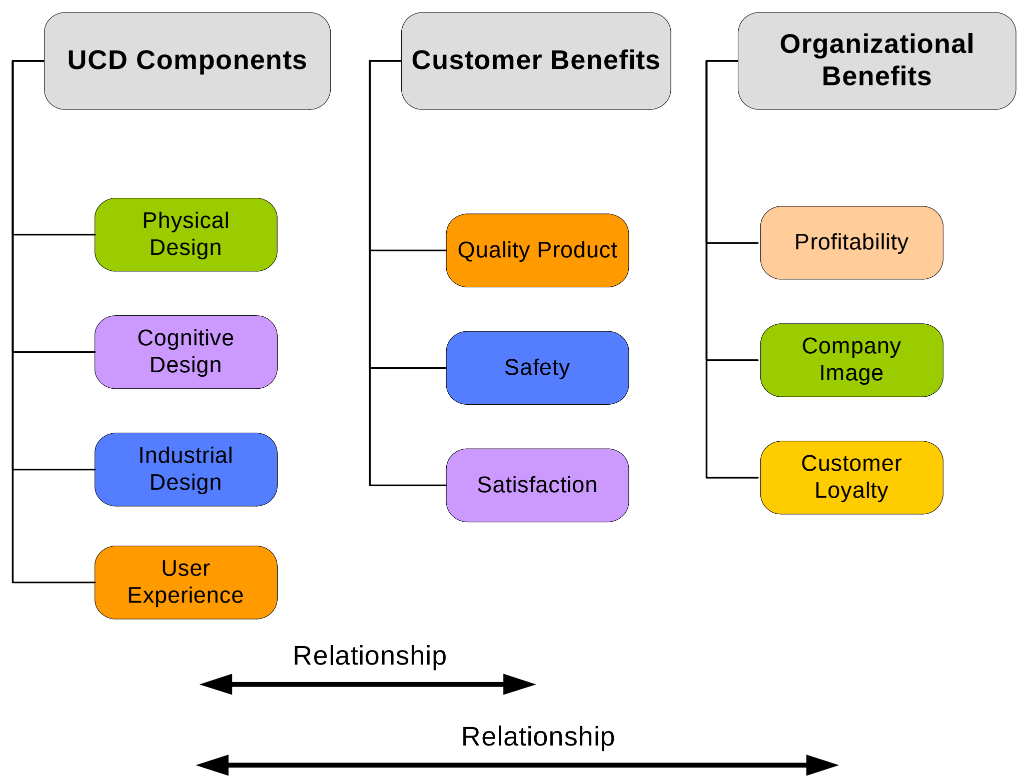

Figure 50 Relationship between UCD, customer benefits, and organizational benefits

Nonparametric test was applied because the confidence intervals and test of hypotheses were unsuitable as a result of data sample. Therefore, Milton Friedman's test for a randomized block design was applied to determine the relationship between user-centered design, customer benefits, and organizational benefits because it is used when dealing with three or more populations. The Friedman test was used to validate a relationship between the models, user-centered design, customer benefits, and organizational benefits and it is set up as follows:

H_o: Populations have the same distribution

H_a: one distribution is shifted (either to the right or left) of the other

Friedman Test: Scores_1 versus Metric_1 blocked by Product_1

```
S = 1.00  DF = 2  P = 0.607

                            Sum
                             of
Metric_1  N  Est Median   Ranks
CB        8     0.58975    16.0
OB        8     0.48525    14.0
UCD       8     0.66925    18.0

Grand median = 0.58142
```

Figure 51 Friedman test to determine relationship between UCD, customer benefits, and organizational benefits

Since the p-value is > 0.50, then it can be concluded that based on the sample size, there is a relationship between user-centered design, customer benefits, and organizational benefits. A suggestion for future research is to expand the data sample to conduct a correlation analysis the will determine the amount of relationship between user-centered design, customer benefits, and organizational benefits.

CHAPTER V: CONCLUSION

This chapter begins by summarizing the approach used to answer the research questions. Next, the findings of this research are reviewed. Finally, this dissertation concludes by listing the contributions of this research and future research opportunities.

User-centered design is a strategic asset that companies can use to improve their customer relationships and learn more about their customers and how to serve them better. Therefore, it is highly valuable to transform theoretical user-centered design efforts into quantifiable organizational benefits. Boar stated that 60-80% of the systems' problems originate from inaccurate requirements specifications, which justifies the need for UCD evaluation tools (Boar, 1984). Therefore, it is imperative that the design requirement specifications of newly developed products and systems be based on the user and the intended use of the product as well as the environment in which the product will be used. This dissertation considers the problem of providing designers with product assessment tools that lead to the mathematical quantification of user-centered design considerations in product or system design.

The emphasis of this research was to provide an evaluation tool for the level of user-centered design characteristics incorporated in products or systems that could be used to support product developers and capable of improving the effectiveness and efficiency of the product development process. The design evaluation tools would help reduce development costs by using predefined methods and tools while guaranteeing conformity of the user interface with standards for quality assurance. The specific questions answered with this research include the following:

What are the critical user-centered design requirements?

What are the measures to assess/evaluate these user-centered design factors?

What are the measures to evaluate customer benefits and organizational benefits?

How do user-centered design components relate to customer benefits and organizational benefits?

Summary of Approach

The approach used in this research was divided between assessment tool creation and mathematical model development and validation. The overview of the research approach is provided in the following figure.

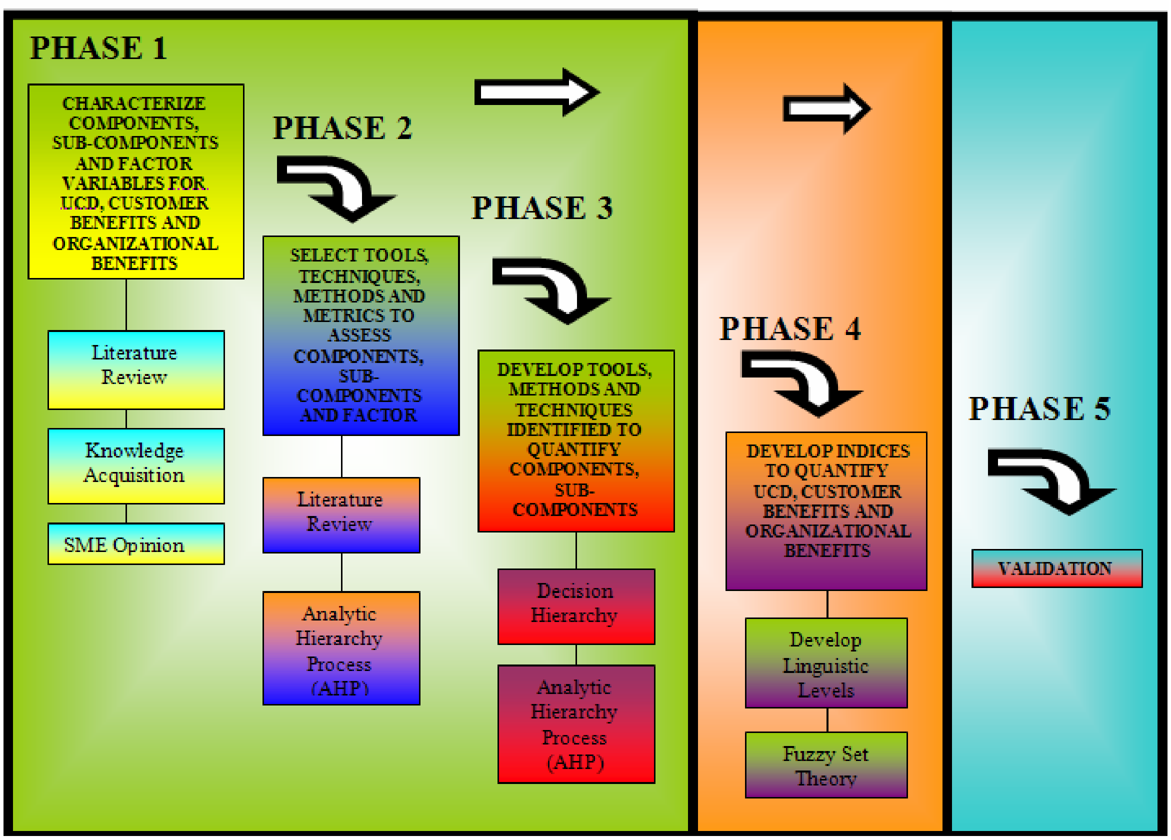

Figure 52 Overview of Research Approach

The taxonomy approach was developed to capture the interrelationships among components, sub-components, and factor variables in this study. A taxonomy was completed for all components identified to influence user-centered design, organizational benefits and customer benefits. The user-centered design components identified consist of the following: physical design, industrial design, cognitive design, and user experience design. The customer benefits components identified consisted of product quality, safety, and customer satisfaction. The organizational benefits components identified consisted of ROI/Profitability, customer loyalty, and company image. The components were then measured using an assessment tool that evaluates the consideration of the variables in the product design. The taxonomies were developed by applying analytic hierarchy process for variable definition, which led to the development of the product assessment tools. The validity and usability of the tools were evaluated experimentally by testing 5 product types. The assessments were done by novices and experts. Once the tools were developed, mathematical indices for user-centered design, customer benefits, and organizational benefits were created. The mathematical models were using AHP analysis and fuzzy set theory. The relationship between the three models; user-centered design, customer benefits, and organizational benefits was evaluated with Friedman's test. The findings of this analysis were used to guide recommendations for the next generation of product design.

Summary of Findings

The following is a summary of the research findings. It is divided into the development of each model: User-centered design, customer benefits, and organizational benefits, as well as the relationship between them. This section will also include some of the limitations encountered while conducting this investigation, as well as resulting contributions to the scientific body of knowledge.

User-Centered Design Index Model

The user-centered design index model was validated using two types of systems (an audio system and a cluster system) from four different vehicle models. The assessments for model development and validation were individually conducted by two participants and two subject matter experts. Since the assessments were conducted at car dealerships, the number of vehicles and participants were constrained by accessibility of vehicle models. The degrees of memberships per product were determined using the weighted averages from the assessments conducted by the participants. The weighted averages were then mapped with the degree of membership, in the [0, 1] interval. The participation of three subject matter experts was required to calculate the relative weights of the variables used to determine the overall UCD index. Once the models for each product were completed, a rating scale was developed to defuzzify the results obtained. The UCD index model validation was limited by the accessibility of the data. For the purpose of this research, a "gold standard" that is sufficiently comprehensive for the large number of variables considered in the UCD model was not currently available. Therefore, data partitioning used to validate the developed UCD model. However, due to the limited access to the vehicles, it needs to be emphasized that future research should consider the application in a larger, diverse product sample. Future research efforts should include a more extensive validation approach with a larger sample size. The measures of accuracy, sensitivity, and specificity were calculated to validate the UCD index model, where accuracy looks at the degree that a measured or calculated quantity is to its actual (true) value, sensitivity measures the rate of how well a test correctly identifies a condition, and specificity measures how well a test correctly identifies the negative cases. A comparison between the results obtained with the UCD index model and the assessment obtained by the second set of evaluations performed was conducted. The results reflect a specificity rate of 0% as well as an accuracy and sensitivity rate of 87.5%. Nonparametric analysis was also applied as an additional validation method. The Wilcoxon rank sum test was used to validate the models because it compares all the distributions not just the median; two populations are analyzed by performing matched-pairs tests. The obtained p-value was 0.94, which is greater than 0.50; therefore, it can be concluded that based on the sample size, there was no significant difference between the UCD index model values and the UCD index model validation values. Thus the UCD index model created in this research study appears to be valid.

Customer Benefits Index Model

Since the customer benefits index model requires the feedback of participants that own the product, historical data was obtained from the company. The data used originated from a study the company previously conducted that was also in relation to user-centered design. A mapping between the survey questions developed in this research effort and the data obtained was conducted. The overall customer benefits component relative weights were determined based on AHP analysis conducted of pairwise factor comparisons using four subject matter experts. To validate the customer benefits index models, the "gold standard" selected were results from an assessment conducted by JD Powers, a company that evaluates the opinions people have about products and ranks them by preference, quality, and ease of use, among others. The measures of accuracy, sensitivity, and specificity were calculated to validate the customer benefits index model, where accuracy looks at the degree that a measured or calculated quantity is to its actual (true) value, sensitivity measures the rate of how well a test correctly identifies a condition, and specificity measures how well a test correctly identifies the negative cases. A comparison between the results obtained with the customer benefits index model and the assessment obtained with the "gold standard" was conducted. The results reflect a sensitivity rate and an accuracy of 75%, as well as a specificity of 0%. A suggestion for future research is to expand the data sample that includes more products to reach additional conclusions in terms of the accuracy of the results, as well as the application in a diversity of industries and products. Due to the sample size, nonparametric analysis was applied as an additional validation method. The Wilcoxon rank sum test was used to validate the models because it compares all the distributions not just the median; two populations were analyzed by performing matched-pairs tests. The resulting p-value was 0.21, which is less than 0.50; therefore, it can be concluded that based on the sample size, there is significant difference between the customer benefits index model values and the gold standard (JD Powers). The primary reason for the differences between the customer benefits index model results and the values obtained from the JD Powers study is that although JD was selected as the gold standard, it should be noted that no "true" gold standard currently exists to truly compare the customer benefits model. The variables measured by JD Powers were not all the same as the variables measured in the customer benefits index model, the JD Powers study was used because it is the most similar available for comparison.

Organizational Benefits Index Model

Since the organizational benefits index model focuses on business aspects of the company, the data was obtained from reports such as consumer reports, market research studies, and financial reports, which reflect the performance of the organization. However, due to data accessibility and confidentiality concerns regarding nonpublic information, the organizational benefits index model was developed using data obtained from public information reporting such as 10K/A corporate annual reports, balance sheets, consumer reports, and JD Powers's studies. Since the data available is an aggregate value, then it is only a reference to the vehicle models not specific to the type of products evaluated (audio system and cluster system) in the previous sections. Therefore, this portion of the research is analyzed in terms of the four vehicle models used to develop the UCD index models and the customer benefits index models. The factors used to determine profitability were the revenues made from sales and the amount of money spent on research and development. To validate the organizational benefits index models, the "gold standard" selected was the Forbes Global 2000, which includes non-US companies and looks at size and growth; the ranking is based on sales, profit, assets, and market value. The validation measures of accuracy, sensitivity, and specificity were calculated to validate the organizational benefits index model, where accuracy looks at the degree that a measured or calculated quantity is to its actual (true) value, sensitivity measures the rate of how well a test correctly identifies a condition, and specificity measures how well a test correctly identified the negative cases. A comparison between the results obtained using the organizational benefits index model and the values obtained from the "gold standard" were conducted. The results reflected accuracy and sensitivity as well as a specificity rate of zero. This outcome may be the result of an inappropriate gold standard. Currently, no gold standard is available to conduct a suitable validation analysis of the organizational benefits model. Due to the sample size, nonparametric analysis was applied as an additional validation method. The Wilcoxon rank sum test was used to validate the models because it compares all the distributions not just the median; two populations were analyzed by performing matched-pairs tests. Since the p-value (0.201) is greater than 0.50, then it can be concluded that based on the sample size, there was no significant difference between the organizational benefits index model values and the gold standard (Forbes 2000). However, due to sample size less than seven in OBModel_Validation, the p-value is an imperfect approximation. This outcome may be the result of the level of evaluation performed for the organizational benefits model and limitations from data accessibility. Particularly, the fact that the data was unavailable for each product within the evaluated vehicles model may be in part the cause of the obtained results. However, it should also be considered that the model focuses on product development and design, instead of the company performance as a whole, which emphasizes other factors.

Lastly, Milton Friedman's test for a randomized block design was applied to determine the relationship between user-centered design, customer benefits, and organizational benefits. Since the resulting p-value was of 0.607, then it can be concluded that based on the sample size, there is a relationship between user-centered design, customer benefits, and organizational benefits. A suggestion for future research is to expand the data sample to conduct a correlation analysis the will determine the level of impact between user-centered design, customer benefits, and organizational benefits.

Research Contributions

The following are some of the research contributions resulting from this investigation:

- A characterization taxonomy of critical user-centered design, customer benefits, and organizational benefits components
- Development of specific product design evaluation tools to assess UCD aspects of products and systems
- Creation of assessment measures to evaluate customer benefits and organizational benefits
- Generation of mathematical models to quantify user-centered design, customer benefits, and organizational benefits. The developed predictive models can be used to make informed design decisions because they link usability experience to overall customer satisfaction and system design characteristics to usability experience
- Development of measurement scales that can be used at various stages of component design and vehicle development cycles
- Development of a methodology for measuring the relationship between user-centered design, customer benefits, and organizational benefits
- Development of a UCD characterization and quantification process plan that is included in APPENDIX D as an implementation guide for companies.
- Development of a customer benefits characterization and quantification process plan that is included in APPENDIX E as an implementation guide for companies to evaluate the relationship between the UCD index model rating and the customer benefits index model rating.

The following figure illustrates the research gaps identified in the literature review and contributions to the body of knowledge resulting from this research investigation.

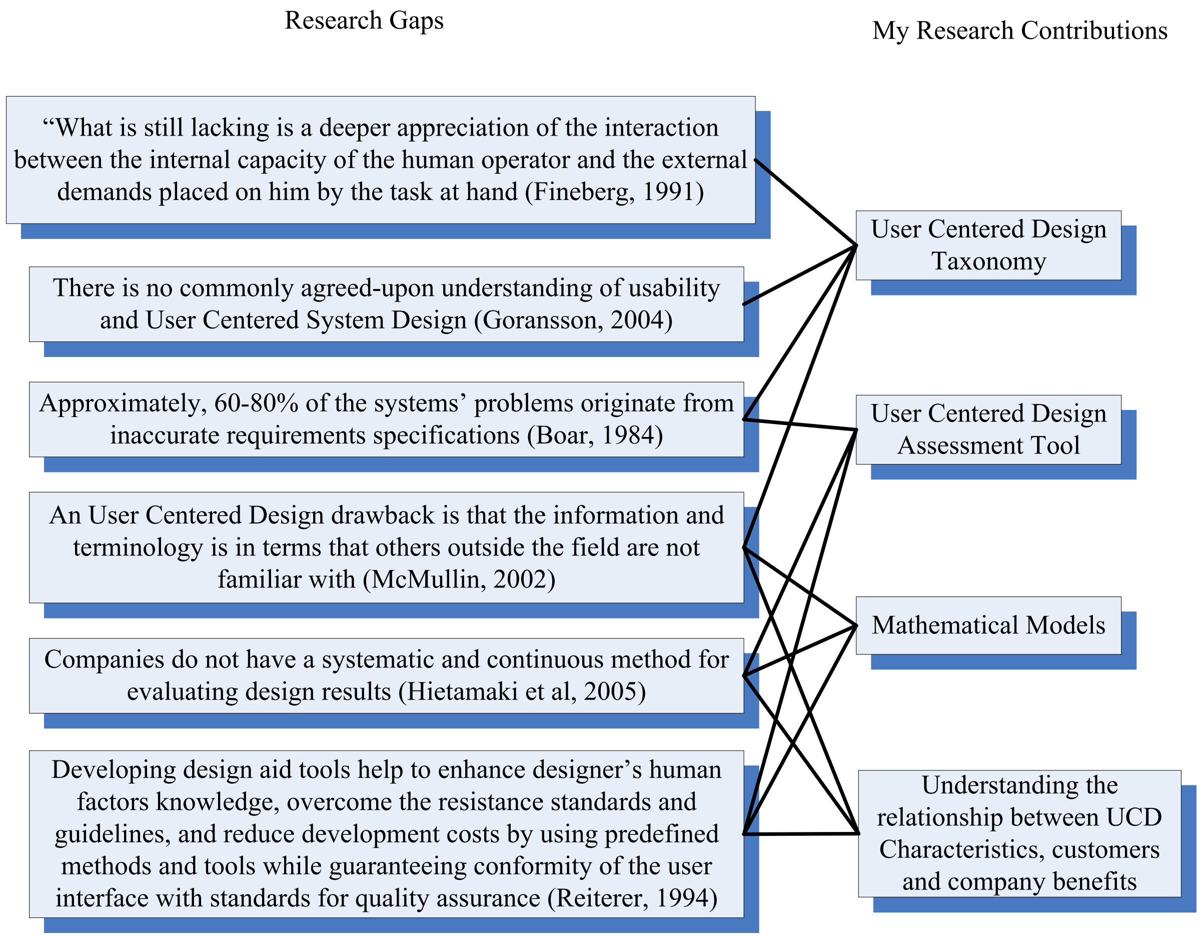

Figure 53 Research gaps and contributions

In summary, this research provides many findings that will be useful to companies in the design industry; it helps to characterize and develop the best descriptors for estimating critical components, sub-components, and factors influencing user-centered design. This research has generated more specific conclusions regarding variables of UCD that directly relate to customer benefits and organizational benefits.

This research has successfully identified the factors that influence user experience and providing tools and techniques to measure and quantify the user experience resulting from interacting with a product or system.

These research efforts produced definitive information regarding the weighting/impact of various factors on user-centered design, customer benefits and organizational benefits. In addition, the development of specific tools, techniques, and instruments for assessing and quantifying user-centered design, customer benefits and organizational benefits were generated for use by practitioners.

Lastly, formulas for aggregating/combining information on various factors of UCD are available as a result of this research for engineers, scientists, planning staff, and other key personnel. Results of this research will help to predict, prevent, control and mitigate the occurrence of product development factors that negatively influences customer and organizational benefits. Thus this research effort provides tools and information to rapidly augment decision making related to product development.

Overall, the limitations encountered during the investigation primarily consisted in the availability of data and existing gold standard for model validation. The primary problems encountered with the data were in relation to the sample size. In the development and validation of the user-centered design index model, the sample size was limited by vehicle accessibility. While, the validation of the customer benefits index model was limited by the gold standard, used at this present time, currently JD Powers is the only available index for validation, and the variables used in this index are not the same as the variables identified to be critical in assessing customer benefits of using products or systems in this investigation; therefore, a variation in the results was found. Lastly, in the development and validation of the customer benefits index model, the sample size was limited by data confidentiality, format, and availability. Also, the validation was limited because no true gold standard is currently available.

Future Research

This research effort can be used as the foundation for further research in this field, given that some of the limitations of this research were primarily the availability and accessibility of additional data to develop and validate the mathematical models that quantify the identified factors. Therefore, future research should include the implementation of a larger data sample size to further valid conclusions and findings of this work. Diversity should also be considered for applicability to multiple products within same industry. Diversity should also be considered for applicability in multiple types of industries. For instance, the next step would include a larger set of products from a few leading companies, followed by the application within several different industries to obtain additional conclusions regarding the model accuracy and robustness. Additionally, further research should be conducted to measure the level of relationship between User-centered design, customer benefits, and organizational benefits. Finally, the contributions of this work can be used to develop software tools for the assessment and rapid calculation of a model index values can be readily used in an industrial facility.

APPENDIX A USER CENTERED DESIGN VALIDATION FORM

Please rate how important each variable is when designing a product for the human user. Enter your values in the column labeled "level of importance" in the table below. Please use the following scale in your rating for each variable in the tables below:

4: Vitally Important
3: Strongly Important
2: Moderately Important
1: Mildly Important
0: Not Important

For example, if you believe that considering "Physical Design" is not important then you would enter a "0". If you believe that considering "Industrial Design" is extremely important, then you would enter a "4".
You may use the Comments/Additions column to enter any comments regarding your rating for a variable or to add any additional variable that you feel should be considered when designing products for human users.

EXAMPLE TABLE ONLY

Variable	Definition	Level of Importance	Level of Importance	Level of Importance
Physical Design	User's physical interaction with the product such as muscular activity and strength. It unifies the design process to generate a product that not only meets functional requirements but also creates the visual/tactile form that relates the product to the user.	**0**	**0**	**0**
Industrial Design	Product characteristics such as texture, dimensions, and form. It focuses on defining the form/function interface.	**4**	**4**	**4**
Cognitive Design	Product features dealing with human-product interaction in which the human must use a mental process including aspects such as awareness, perception, and reasoning. It focuses on developing designs that are within human information processing capabilities and limitations.	**3**	**3**	**3**
User Experience Design	Emotions experienced by the user resulting from interacting with the product/system. User experience is a term used to describe the overall experience and satisfaction a user has when using a product or system.	**2**	**2**	**2**

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Variable	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Physical Design	User's physical interaction with the product such as muscular activity and strength. It unifies the design process to generate a product that not only meets functional requirements but also creates the visual/tactile form that relates the product to the user.	4	3	4
Industrial Design	Products characteristics such as texture, dimensions, and form. It focuses on defining the form/function interface.	4	3	3
Cognitive Design	Product features dealing with human-product interaction in which the human must use a mental process including aspects such as awareness, perception, and reasoning. It focuses on developing designs that are within human information processing capabilities and limitations.	4	4	4
User Experience Design	Emotions experienced by the user resulting from interacting with the product/system. User experience is a term used to describe the overall experience and satisfaction a user has when using a product or system.	4	4	3

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Primary variables associated with Physical Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Anthropometry	The measurement of the size and proportions of the human body.	3	4	4
Strength Needed	Strength required to perform or complete a task.	4	3	4
Repetitive Motion	The act of performing the same physical movement several times.	4	3	2
Muscular Activity	Physical actions that require the use of the muscles	4	2	2
Body Posture	Refers to a posture of the human body	4	2	3
Body Position	Refers to a position of the human body	3	3	3

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Primary variables associated with Industrial Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Form	Shape or structure. The external appearance of a clearly defined area, as distinguished from color or material	4	3	2
Sound/Noise Level	Refers to the noise power	4	3	3
Illumination/ Lighting	Something that makes things visible or affords illumination. The intensity of light falling at a given place on a lighted surface; the luminous flux incident per unit area, expressed in lumens per unit of area.	4	3	4
Vibration	The act of vibrating. the oscillating, reciprocating, or other periodic motion of a rigid or elastic body or medium forced from a position or state of equilibrium	4	3	2
Temperature	A measure of the warmth or coldness of an object or substance with reference to some standard value.	4	3	2
Function	The kind of action or activity proper to a person, thing, or institution; the purpose for which something is designed.	4	4	4

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Primary variables associated with User Experience Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Useful	Being of use or service; serving some purpose; advantageous, helpful, or of good effect	4	4	4
Usable	Available or convenient for use. Fit for use; convenient to use	4	4	4
Desirable	Something worth having or seeking, as by being useful, advantageous, or pleasing	4	3	3
Findable	Easy to locate, attain, or obtain by search or effort	4	3	3
Credible	Worthy of being believed or plausible	4	3	1
Accessible	Able to be reached or approached easily	3	4	3
Valuable	Having considerable qualities of worth	4	3	4

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Primary variables associated with Cognitive Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Ease of Use	Refers to the property of a product or thing that a user can operate without having to overcome a steep learning curve. Things with high ease of use will be intuitive to the average user in the target market for the product.	4	4	4
Memorability	Easily remembered	4	2	3
Usability	The effectiveness, efficiency, and satisfaction with which users can achieve tasks in a particular environment of a product. High usability means a system is: easy to learn and remember; efficient, visually pleasing and fun to use; and quick to recover from errors.	4	4	4

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Secondary variables associated with Physical Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Body segment dimensions (length, width, circumference)	Length of specific parts of the bodies (forearm, arm, torso, etc.)	3	3	2
Body segment mass (volume, weight, density)	Mass of specific part of the body (forearm, arm, torso, etc.)	3	3	2
Body segment center of mass	Center of mass for the specific body segment (also called center of gravity)	3	3	2
Range of motion	The range of translation and rotation of a joint for each of its degrees of freedom	3	3	2
Strength capabilities	Capability to generate muscular tension and to apply it to an external object through the skeletal lever system	3	3	2
Moments	Quantity necessary to cause or resist rotation of a body, usually expressed in Newton-meters	3	2	2
Muscular activity	Muscle contractions to develop tension to move body segments or support loads	3	3	2
Isometric contraction	Muscular effort which causes tension but no movement	3	3	3
Isotonic contraction	Muscular effort in which the muscles contract and shortens under a constant load	3	3	3

Secondary variables associated with Physical Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Isokinetic contraction	Muscular effort in which the muscle contracts and shortens at constant speed	3	3	
Static strength	Refers to the force that can be held at one place by a specific muscle	3	4	
Isoinertial condition	Condition where muscles move a constant mass	3	3	
Tendons	Fibrous cord joining a muscle to a bone	3	2	0
Tendon sheaths	Tubular structure through which tendons run	3	2	0
Muscles	A tissue bundle of fibers, able to contract or be lengthened	3	2	0
Ligaments	Fibrous band between two bones at a joint. They are flexible but inelastic	3	2	0
Joints	Location where two or more bones make contact	3	2	0
Nerves	Elements of the nerve system that transmits stimuli from the sensors to the central nervous system and vice versa	3	2	0
Static loading	Loading condition where the load is constant in its magnitude at rest or in equilibrium	3	3	0
Endurance	Ability to exert through aerobic or anaerobic exercise for relatively long periods of time.	3	3	0
Repetition	Performing the same activity more than once	3	3	3
Frequency	Measurement of the number of occurrence of repeated event per unit of time	3	3	0

Secondary variables associated with Physical Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Body Plane	Imaginary lines that divide the body in different areas (Sagital plane divides the body or any of its part in right and left. The coronal or frontal plane divides the body or any of its parts in anterior or posterior. The transverse plane divides the body or its parts in upper and lower)	3	3	0
Extension	Position that a limb assumes when it is straightened	3	2	0
Flexion	The position that a limb assumes when it is bent.	3	2	0
Abduction	Moving of a body part away from the central axis of the body.	3	2	0
Adduction	Moving of a body part toward the central axis of the body.	3	2	0
Neutral posture	The posture when the joints are not bent and the spine is aligned and not twisted. Working in neutral postures is preferable to working while twisting the back or bending the wrists.	3	2	2
Sitting	Rest position supported by the buttocks or thighs where the torso is more or less upright	3	3	2
Standing	Position where the body constantly is in an orthostatic state	3	3	2
Stooping	The action to bend forward and down from the waist or the middle of the back to walk or stand	3	4	2

Secondary variables associated with Physical Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Crouching	Action of lowering the body stance especially by bending the legs. To lie close to the ground with the legs bent	3	4	2
Supine (lying down)	The position of the body when lying face upward	3	3	2
Kneeling	Position in which the weight is distributed on the knees and feet on a surface close to horizontal	4	3	2
Walking	Movement over a surface by taking steps with the feet at a pace lower than running	4	3	2
Easy to activate	How easy it is to activate or start a product or process	4	4	3
Overhead reaching	Reach by moving and positioning arms on the range of angles over the shoulders	4	3	2
Extended reach	Reach by extending adjacent body segments so that the angle between them is increased	4	3	2

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Secondary variables associated with Industrial Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Color contrast (wavelength, luminance, saturation)	Difference in color and light between parts of an image	4	3	2
Flexibility (design allowances, tolerances, universal design considerations)	Ability to bend or adapt to different circumstances	4	4	2
Handicapped accessibility	Available accessibility for users that are handicapped	3	3	1
Shape (length, width, height)	Dimensions of any object	4	1	0
Texture (coarse, fine, even)	The properties held and sensations caused by the external surface of objects received through the sense of touch.	4	3	0
Sound frequency	An audio frequency (AF) is any frequency from about 20 Hz to about 20 kHz, which is the approximate range of sound frequencies audible to humans.	4	3	1
Phon/Son	A unit for measuring the apparent loudness of a sound, equal in number for a given sound to the intensity in decibels of a sound having a frequency of 1000 cycles per second when, in the judgment of a group of listeners, the two sounds are of equal loudness.	4	3	1

Secondary variables associated with Industrial Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Impulse noise	A short burst of an acoustic energy consisting of either a single impulse or a series of impulses.	4	3	0
Ultrasonic noise	Temporary beats that can occur in on-and-off repeating patterns such as jack hammers or punch presses	4	1	0
Acoustic factors	Physical factors that affect the propagation of sound waves	4	3	1
Sound duration	Amount of time or a particular time interval	4	3	0
Noise spectrum	The range of frequencies occurring in the noise emitted by a source.	4	2	1
Light adaptation	Regulation by the pupil of the quantity of light entering the eye.	4	3	0
Radiant energy	Energy transmitted in wave motion, especially electromagnetic wave motion.	4	1	0
Irradiance	Incident flux of radiant energy per unit area.	4	2	0
Glare	To shine with or reflect a very harsh, bright, dazzling light.	4	3	0
Luminance	The quality or condition of radiating or reflecting light	4	3	0
Contrast	To set in opposition in order to show or emphasize differences	4	3	0

Secondary variables associated with Industrial Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Brightness	The luminance of a body, apart from its hue or saturation, which an observer uses to determine the comparative luminance of another body. Pure white has the maximum brightness, and pure black has the minimum brightness.	4	3	0
Reflectance	The ratio of the intensity of reflected radiation to that of the radiation incident on a surface.	4	2	0
Energy	Define by the amount of photons in the light spectrum	4	0	0
Vibration frequency	Rate at which an object tends to vibrate with when hit, struck, plucked, strummed or somehow disturbed is known as the natural frequency of the object	4	?	0
Intensity	The amount or degree of strength per unit area or volume.	4	?	1
Amplitude	The absolute value of the maximum displacement from a zero value during one period of an oscillation.	4	?	1
Displacement	Magnitude of vibration	4	?	1
Velocity	Defines the magnitude of oscillations	4	?	0
Acceleration	Rate of change of velocity	4	?	0

Secondary variables associated with Industrial Design of Products	**Definition**	**Level of Importance (SME 1)**	**Level of Importance (SME 2)**	**Level of Importance (SME 3)**
Vertical	Being in a position or direction perpendicular to the plane of the horizon; upright	0	?	0
Horizontal	Being in a position or direction perpendicular to the vertical plane	0	?	0
Rotational	The force of attraction between any two masses	0	?	0
Environment temperature	External conditions, resources, stimuli etc. with which an organism interacts	4	3	0
Surface temperature	The outside hull of a tangible object	4	?	0
Consistency	The agreement, harmony, or compatibility in performance, especially correspondence or uniformity among the parts of a complex thing	4	3	3
Durability	Ability to resist wear, decay, etc., well; lasting; enduring	4	3	0
Cleanability	The ability to be cleaned, especially easily or without damage	4	3	0
Precision	The state of being accurate	4	2	0
Comfort	To make physically comfortable.	4	3	1
Predictability	To declare or tell in advance. To anticipate the result	4	4	3

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Secondary variables associated with User Experience Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Helpful	The act of giving or rendering aid or assistance; of service	4	2	3
Supporting	To aid the cause, policy, or interest	4	1	2
Enjoyable	Giving or capable of giving joy or pleasure	4	3	2
Impractical	Not practical or useful	4	1	3
Frustrating	Discouraging by hindering	2	1	3
Sympathetic	Characterized by, proceeding from, exhibiting, or feeling sympathy; sympathizing; compassionate	4	1	0
Controllable	The situation of being under the regulation, domination, or command of another	4	2	3
Emotionally fulfilling	That generates pleasing emotions when interacting with	4	3	1
Satisfying	To fulfill the desires, expectations, needs, or demands of (a person, the mind, etc.); give full contentment to something	4	3	2
Motivating	To provide with a motive or motives; incite; impel.	4	3	3
Aesthetically pleasing	It means that you like the way something looks. Finding an object appealing.	4	4	1
Entertaining	To hold the attention of with something amusing or diverting.	4	3	1

Secondary variables associated with User Experience Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Controllable	The situation of being under the regulation, domination, or command of another	4	3	2
Emotionally fulfilling	That generates pleasing emotions when interacting with	4	3	1
Satisfying	To fulfill the desires, expectations, needs, or demands of (a person, the mind, etc.); give full contentment to something	4	3	2
Motivating	To provide with a motive or motives; incite; impel.	4	3	2
Aesthetically pleasing	It means that you like the way something looks. Finding an object appealing.	4	3	3
Entertaining	To hold the attention of with something amusing or diverting.	4	3	3
Controllable	The situation of being under the regulation, domination, or command of another	4	2	2
Emotionally fulfilling	That generates pleasing emotions when interacting with a product	4	3	4
Satisfying	To fulfill the desires, expectations, needs, or demands of (a person, the mind, etc.); give full contentment to something	4	2	4
Motivating	To provide with a motive or motives; incite; impel.	4	3	4
Aesthetically pleasing	It means that you like the way something looks. Finding an object appealing.	4	3	3

Secondary variables associated with User Experience Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Entertaining	To hold the attention of with something amusing or diverting.	4	3	1
Rewarding	Affording satisfaction, valuable experience, or the like; worthwhile.	4	3	2
Impressive	Having the ability to impress the mind; arousing admiration, awe, respect, etc.; moving; admirable	4	2	1
Innovative	Being or producing something like nothing done or experienced or created before	4	2	1
Good	Right; proper; fit	4	3	2
Supportive of creativity	That encourage innovation when operating an object	4	2	1

Secondary variables associated with Cognitive Design of Products	Definition	Level of Importance	Level of Importance	Level of Importance
Population stereotypes	Particular options or concepts that are chosen by a large proportion of a given population	4	4	0
Cluttered	A confused or disordered state or collection	4	1	2
Consistency	Mental agreement, harmony, or compatibility, especially correspondence or uniformity among the parts of a complex thing.	4	3	3
Intuitiveness	Perceived by, resulting from, or involving intuition	4	3	2

Secondary variables associated with Cognitive Design of Products	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)	Level of Importance (SME 3)
Familiarity	Knowledge or mastery of a thing, subject, etc.	4	2	3
Sensory storage-encoding (visual, tactile, auditory, taste, smell)	Translation of stimuli into neurological codes for storage to be used by the working memory	4	3	4
Working memory (short term - capacity, duration: visual, phonetic, semantic)	Refers to the structures and processes used for temporarily storing and manipulating information. It stores items for only around 30 seconds	4	3	4
Long term memory	Refers to the system for permanently storing, managing, and retrieving information for later use. Items of information stored as long-term memory may be available for a lifetime.	4	3	4
Performance time	Time required for a user to complete a specific task with an object	4	2	3
Understandable	Easy to understand	4	3	3
Learnability	Easy to learn	4	3	3
Uncertainty	State of being uncertain; doubt; hesitancy	4	0	2
Time recovery from errors	Time spend to correct a failed action when interacting with an object or interface	4	3	2
Errors rate	Number of incorrect responses related to the total number of items	4	3	2
Output/Input	Refers to the communication between an interactive object and the outside world or human	4	2	2

APPENDIX B CUSTOMER BENEFITS TAXONOMY VALIDATION FORM

Please rate how important each variable is when considering the Customer Benefits resulting from designing excellent products for consumers. In the table below you only need to enter your values in the column labeled "level of importance". Please use the following scale in your rating for each variable in the tables below:

4: Vitally Important
3: Strongly Important
2: Moderately Important
1: Mildly Important
0: Not Important

For example, if you believe that considering "Safety" is not important then you would enter a "0". If you believe that considering "Quality product" is extremely important, then you would enter a "4".

You may use the Comments/Additions column to enter any comments regarding your rating for a variable or to add any additional variable that you feel should be considered when designing products for human users.

EXAMPLE TABLE ONLY

Variable	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
Safety	Condition or state of being safe; freedom from danger or hazard; exemption from injury or loss	**0**	
Quality product	The degree to which the product or service meets desired design specifications and customer demands	**4**	
Customer satisfaction	The fulfillment or gratification of a desire or need, as well as the pleasure or contentment that is derived from such gratification	**3**	

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Variable	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
Safety	Condition or state of being safe; freedom from danger or hazard; exemption from injury or loss	1	2
Quality product	The degree to which the product or service meets desired design specifications and customer demands	3	3
Customer satisfaction	The fulfillment or gratification of a desire or need, as well as the pleasure or contentment that is derived from such gratification	4	3

Primary variables associated with Safety	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
Injuries	An act that damages or hurts	4	3
Illnesses	An unhealthy condition of body or mind	4	1
Warnings	Something that warns or serves to warn; especially a notice or bulletin that alerts the public to an imminent hazard	2	2

Primary variables associated with Quality product	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
Performance	The execution of an action. The ability to perform efficiently. The manner in which a mechanism performs	2	3

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Primary variables associated with Customer satisfaction	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
Customer perception	A customer's mental image or physical sensation interpreted in the light of experience	5	3
Durability/Reliability	Does the product meet or surpass customer expectations, increase appeal to the product and maximize acceptability	4	2
Serviceability	Fit for use	0	0
Appeal	Attractiveness	4	3

Secondary variables associated with Quality product	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
Reliability	That may be relied on; dependable in achievement, accuracy, honesty	4	3
Accuracy	The condition or quality of being true, correct, or exact; freedom from error or defect; precision or exactness; correctness.	3	3
Stability	The state or quality of being stable, especially: a. Resistance to change, deterioration, or displacement. b. Constancy of character or purpose; steadfastness. c. Reliability; dependability.	3	3
Effectiveness	Adequate to accomplish a purpose; producing the intended or expected result	4	4
Efficiency/Productivity	Accomplishment of or ability to accomplish a job with a minimum expenditure of time and effort	3	3
Functionality	Serving a utilitarian purpose; capable of serving the purpose for which it was designed	4	3
Repeatability	A duplicate or reproduction of something.	3	3

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Secondary variables associated with Safety	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
Bodily reaction (to chemicals)	Physical reaction of the human skin to products such as chemicals	2	4
Rubbing or abrasions	A wearing, grinding, or rubbing away by friction	2	3
Exposure to extreme temperatures	Exposure to temperatures that are too high or too low for the body	2	4
Exposure to radiation / acoustics	Exposure of the human body to radiation	4	2
Repetitive strain - Tunnel syndromes (carpal tunnel, radial tunnel)	Any of various musculoskeletal disorders (i.e. carpal tunnel syndrome or tendonitis) caused by cumulative damage to muscles, tendons, ligaments, nerves, or joints from highly repetitive movements	4	2
Muscle and tendon disorders (tendonitis, muscle damage)	Chronic overuse of tendons	4	1
Graphical design (size, shape, color, contrast)	Refers to the design specifications of the products' graphical aspects	3	2
Placement	Location	2	3
Use of 'active' attention getters	Does the product use 'active' attention getters (sound alarms, waving flags, blinking lights)	3	2
Physical durability	Able to exist for a long time without significant deterioration	3	1
Appearance	Sense impression or aspect of a thing	2	1

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Secondary variables associated with Customer satisfaction	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
Significance of use	The value of using a product or feature to accomplishing a goal or task	4	2
Usefulness of product	the quality of having utility and especially practical worth or applicability	4	3
Expected perceived value	Value the customers believe can to be expected from the product	3	4
Length of usable life	The amount of time a product or feature is expected to function properly	4	2
Time to failure	Number of failures per hour	3	2
Consistent performance	Continuous product performance	4	2
Way of servicing the product	How the product is serviced	0	0
Customer service and support	Level of customer service and support provided by the company	0	0
Joy level	Level of great happiness	4	4
Motivation level	Refers to the reason or reasons for engaging in a particular behavior	4	2
Satisfaction level	Level of gratification or contentment	4	2
Aesthetics	Sensory or sensori-emotional values, sometimes called judgments of sentiment and taste	4	3

APPENDIX C ORGANIZATIONAL BENEFITS TAXONOMY VALIDATION FORM

Please rate how important each variable is when considering the Organizational Benefits resulting from designing excellent products for consumers. In the table below you only need to enter your values in the column labeled "level of importance". Please use the following scale in your rating for each variable in the tables below:

4: Vitally Important
3: Strongly Important
2: Moderately Important
1: Mildly Important
0: Not Important

For example, if you believe that considering "ROI/Profitability" is not important then you would enter a "0". If you believe that considering "Customer loyalty" is extremely important, then you would enter a "4".

You may use the Comments/Additions column to enter any comments regarding your rating for a variable or to add any additional variable that you feel should be considered when designing products for human users.

EXAMPLE TABLE ONLY

Variable	**Definition**	**Level of Importance (SME 1)**	**Level of Importance (SME 2)**
ROI/Profitability	Referring specifically to product design research and development	**0**	**0**
Customer loyalty	The degree to which the company is capable of maintaining customer commitment to the company or product/repeated business	**4**	**4**
Company image	Composite mental picture or impression held by customers about a specific company or a brand's product or service	**2**	**2**

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Variable	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
ROI/Profitability	Referring specifically to product design research and development	3	4
Customer loyalty	The degree to which the company is capable of maintaining customer commitment to the company or product/repeated business	4	4
Company image	Composite mental picture or impression held by customers about a specific company or a brand's product or service	4	4

Primary variables associated with ROI/Profitability	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
Expenses	Referring specifically to product design research and development	3	3
Revenue	Amount spent on the body of persons engaged in working for wages in research and development.	3	4
Primary variables associated with Customer loyalty	**Definition**	**Level of Importance (SME 1)**	**Level of Importance (SME 2)**
Repeated business	The body of persons engaged in such activity, esp. those working for wages. There are, in general, three types of costs you capitalize: 1. Going into business 2. Business assets 3. Improvements.	4	4

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Primary variables associated with Company image	**Definition**	**Level of Importance (SME 1)**	**Level of Importance (SME 2)**
Public opinion	Costs for having tech support (salary, equipment expenses, etc.)	4	4

Secondary variables associated with Customer loyalty	**Definition**	**Level of Importance (SME 1)**	**Level of Importance (SME 2)**
Customer buying pattern	Number or percentage of returning customers	4	4
Customer perception	Customers' awareness or understanding	4	4
Customer experience	The customers' experience with this product and other previously purchased products	4	4
Likelihood that the customer refers others to buy the product	Based on the customers' interaction and satisfaction with the product, what is the likelihood that the customer refers others to buy the product	4	4

Secondary variables associated with Company image	**Definition**	**Level of Importance (SME 1)**	**Level of Importance (SME 2)**
Customer complaints	Number of problems and complaints received from the customers regarding the product or system	4	4
Credibility/Brand recognition	Trustworthiness, how believable	4	4
Unfavorable media	Negative publication and information about the company or company products	4	4
New customers	Number or percentage of new customers	4	4
Customer service responsiveness	Responsiveness to providing customers with product customization and design improvement recommendations	4	2

PLEASE COMPLETE THE "LEVEL OF IMPORTANCE" COLUMN FOR THE TABLES BELOW

Secondary variables associated with ROI/Profitability	Definition	Level of Importance (SME 1)	Level of Importance (SME 2)
Capital expenses	The body of persons engaged in such activity, especially those working for wages. Three typical types of costs you capitalize: 1. Going into business 2. Business assets 3. Improvements.	3	3
Tech support costs	Costs for having tech support (i.e. salary and equipment expenses)	2	2
Operating expenses	Expenses associated with running a business but not considered directly applicable to the current line of goods and services being sold (i.e. sales and marketing, R&D, and general and administrative costs (including the salaries).	2	2
Training	Acquisition of knowledge, skills, and competencies	2	2
Insurance	Form of risk management primarily used to hedge against the risk of a contingent loss	0	1
Outsourced expenses	Expenses associated with additional needs for prototype development	4	4
Development costs (labor, materials)	Development costs can be seen as the overheads i.e. costs of market analysis, R&D, advertising, machine tools, storage, plant maintenance, etc. All the cost that cannot be apportioned to one particular product but are needed for the company to be successful.	3	3
Equipment	Equipment used to develop product prototypes	3	2
Sales	Activities involved in selling products or services in return for money or other compensation	4	4
Capital input	A measure of the flow of services available for production from the stock of capital goods	2	2

APPENDIX D UCD CHARACTERIZATION AND QUANTIFICATION PROCESS PLAN

Step 1 – Define product design requirements based on the intended user, the tasks to be performed with the product, and the environment where the product will be used.

Step 2 – Verify UCD taxonomy factors to be considered based on the intended use of the product to be designed.

Step 3 – Identify subject matter experts to recalculate relative weights by adjusting pairwise comparisons between components based on the intended user, the tasks to be performed with the product, and the environment where the product will be used.

Step 4 – Evaluate the product design using each of the four user-centered design assessment tools developed (physical design, cognitive design, industrial design, and user experience design).

Step 5 – Within each of the four user-centered design assessment tools, count the frequency of each factor value for each rating level (1-7). Sum the total for each rating level (1-7). Calculate the weighted average of the product design scores assigned to each component (physical design, cognitive design, industrial design, and user experience design).

Step 6 – Determine the degree of membership using the membership functions for each of the four user-centered design components (physical design, cognitive design, industrial design, and user experience design).

Step 7 – Calculate the UCD index model by multiplying each of the component relative weights (obtained in Step 3) to their individual component degree of membership (obtained in Step 6). Add each of the values calculated for the four user-centered design components (physical design, industrial design, cognitive design, and user experience design).

Step 8 – Determine where the UCD index model score for the product design falls in the following rating scale:

Rating	Scale
Unacceptable	(0, 0.49)
Average	(0.50, 0.79)
Outstanding	(0.80, 1.00)

Based on the rating score obtained, determine if design modifications should be considered.

Step 9 – If design modifications need to be performed, evaluate each of the UCD component values from the assessment tools to identify which of the four design components has the lowest value to determine which should be redesigned.

Step 10 – If design modifications were performed, go back to Step 4 and repeat steps 4-10.

APPENDIX E CUSTOMER BENEFITS CHARACTERIZATION AND QUANTIFICATION PROCESS PLAN

Step 1 – Verify customer benefits factors to be considered in taxonomy based on the intended use of the designed product.

Step 2 – Identify subject matter experts to recalculate relative weights by adjusting pairwise comparisons between components based on the type of product, intended user, the tasks to be performed with the product, and the environment where the product will be used.

Step 3 – Evaluate the customer benefits using customer benefits survey developed to assess the three components: product quality, safety, and customer satisfaction.

Step 4 – Within each of the three customer benefits components (product quality, safety, and customer satisfaction) in the customer benefits survey, count the frequency of each factor value for each rating level (1-7). Sum the total for each rating level (1-7). Calculate the weighted average of the product design scores assigned to each component (product quality, safety, and customer satisfaction).

Step 5 – Determine the degree of membership using the membership functions for each of the three customer benefits components (product quality, safety, and customer satisfaction).

Step 6 – Calculate the customer benefits index model by multiplying each of the component relative weights (obtained in Step 2) to their individual component degree of membership (obtained in Step 5). Add each of the values calculated for the three customer benefits components (product quality, safety, and customer satisfaction).

Step 7 – Determine where the customer benefits index model score falls in the following rating scale:

Rating	**Scale**
Unacceptable	(0, 0.49]
Average	(0.50, 0.89]
Outstanding	(0.90, 1.00]

Step 8 – Determine the relationship between UCD index model rating and the customer benefits index model rating by performing correlation analysis.

APPENDIX F UCF INSTITUTIONAL REVIEW BOARD (IRB) APPROVAL

University of Central Florida

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

Notice of Expedited Initial Review and Approval

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

To : **Katherine Meza**

Date : **October 11, 2007**

IRB Number: **SBE-07-05049**

Study Title: **An Investigation of Organizational Benefits gained from implementing Holistic User-Centered Design considerations in product and system development**

Dear Researcher:

Your research protocol noted above was approved by **expedited** review by the UCF IRB Vice-chair on 10/10/2007. **The expiration date is 10/9/2008.** Your study was determined to be minimal risk for human subjects and expeditable per federal regulations, 45 CFR 46.110. The category for which this study qualifies as expeditable research is as follows:

7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

The IRB has approved a **consent procedure which requires participants to sign consent forms.** Use of the approved, stamped consent document(s) is required. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Subjects or their representatives must receive a copy of the consent form(s).

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

To continue this research beyond the expiration date, a Continuing Review Form must be submitted 2 – 4 weeks prior to the expiration date. Advise the IRB if you receive a subpoena for the release of this information, or if a breach of confidentiality occurs. Also report any unanticipated problems or serious adverse events (within 5 working days). Do not make changes to the protocol methodology or consent form before obtaining IRB approval. Changes can be submitted for IRB review using the Addendum/Modification Request Form. An Addendum/Modification Request Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at http://iris.research.ucf.edu .

Failure to provide a continuing review report could lead to study suspension, a loss of funding and/or publication possibilities, or reporting of noncompliance to sponsors or funding agencies. The IRB maintains the authority under 45 CFR 46.110(e) to observe or have a third party observe the consent process and the research.

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

Signature applied by Joanne Muratori on 10/11/2007 08:57:59 AM EDT

Joanne Muratori

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