Creating a Market Paradigm Shift with Quality Function Deployment

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Abstract

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The objective of this research is to develop and document the methodology of creating a process for quality function deployment into the product management process in the disc jockey market. The disc jockey product market has been selected due to its smaller relative size to traditional firms developing QFD processes. This market also is unique such that the functions deployed integrate new technology developments with existing standardized features concurrently. The development methodology as well as the methodology for determining the value of QFD is documented. This research applies Kano's Theory as well as the use of the House of Quality. The relationships between quality functions and customer requirements are scientifically expressed with the interrelationships between the quality functions. A case study is performed at Numark Industries to develop a new product which will cause a paradigm shift in the marketplace. The procedure methodology for this process is documented.

Approved: Charles Parks

Professor and Chair of Industrial and Manufacturing Systems Engineering

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Introduction

Since the 1960's, Quality Function Deployment (QFD) has been implemented in various industries worldwide providing a tool to aid in the research, development, and production of various products and systems that they are developed in (Karlsson, 1997).

QFD often utilized matrices in the form of competitive analysis charts as well as house of quality diagrams. The combination of these tools aid in new product development, and show companies where new hybrid products can be developed to maximize profits (Bergquist and Abeysekera, 1996). QFD keeps the customer focus through all sections of the process.

QFD has typically been used in larger corporations and has been integrated across all products. Recently, QFD has been implemented in smaller firms with more specified markets (Chan and Wu, 2002). The purpose of this research is to perform a case study in a smaller market to a new product in the development stage where there are many constraints to the traditional model that are not typically present in larger corporations. This research is also intended to provide a clear methodology of implementing QFD into the disc jockey product market. Upon completion the results of the QFD implementation will be measured based on comparing the output results to historical data for similar projects.

Problem Statement

The professional disc jockey industry is a specialized market where isolating the customers needs is of great concern. Learning, and satisfying customer requirements is challenging to any industry but what makes this industry different from the others is the actual customer identification process is unclear. Unlike the automotive industry, where the customer is well defined and products are marketed towards a specific client, the disc jockey industry has many different types of customers. Some of the customers are known and some are unknown.

The breakdown of the customers by ranking per product is hard to calculate as well. There is an area of opportunity in the disc jockey market to provide industrial engineering tools in the form of quality function deployment to help identify customer needs and wants and convert those needs and wants into feasible and profitable finished goods to be sold worldwide.

Numark, a professional disc jockey audio company in Cumberland, RI, has expressed their interest and need for the improved method of product development. Specifically, Numark would like to reduce the number of engineering changes during the product development process thus reducing costs and production lead time. Numark has also expressed interest in developing relationships between disc jockey (DJ) product features and their customer requirements to aid in paradigm shift decisions.

Currently the DJ market includes older technology items such as turntables and vinyl and also includes innovative technology products such MP3 media, computer controllers, and hard drive integration. These market behaviors suggest a paradigm shift to include the technologies of today, as well as the interface of the past, which must be identified and evaluated. The QFD process has been selected for this evaluation due to the historical and theoretically potential QFD benefits to the project. This selection of QFD must be evaluated and justified to create a new paradigm that satisfies the DJ products market. The following literature review will show that QFD is state of the art. Following that, the methodology used is shown, including a justification for QFD, and the detailed implementation procedure.

Literature Review

This literature review has been categorized into three basic categories in regards to the primary use to this research. Much of this literature, however, has useful information in regards to all of the categories.

Overview Literature

Salheigh and Monplaisir discuss ways the marketplace has shifted towards global operations. Their work goes into detail regarding how the Internet has been able to integrate the market from global perspectives. It is suggested that design engineering should be based on methodologies that can analyze current practices to then estimate the capabilities of performing certain operations concurrently with collaborative efforts (Salheigh and Monplaisir, 2003). The framework suggested consists of six modules that provide a plan for computer-supported collaboration.

Gonzalez et al. discuss the concept of incorporating intelligence on markets, consumers, and technologies in strategy environments are discussed (Gonzalez et al., 2004). The paper links marketing and manufacturing strategies by developing continuous improvements strategies. The idea of putting marketing and manufacturing together to provide the competitive advantage in the market is discussed. This paper is very important to the proposed research because it provides the solid groundwork for keeping the organizations goals and the end customer in mind. The work provides a good start to showing how to bridge marketing and manufacturing in a technology driven industry. Customer feedback is also discussed.

Tan and Shien discuss how the quality of a product or service is directly correlated to customer satisfaction (Tan and Shien, 2000). QFD is implemented in their research specifically in the form of competitive analysis charts and methodologies which can be implemented in the proposed research. There is also an example of how to use customer perception with the Kano model. The Kano categories include rating features as ‘must-be’, ‘one-dimensional’ and ‘attractive’ which is used to describe features in consideration for products in development. This model is illustrated further in regards to its implementation with this specific QFD study.

Bergquist and Abeysekera discuss how to use QFD to determine the importance of product characteristics (Bergquist and Abeysekera, 1996). The paper discusses target values for product characteristics as well as relationships. Scaling scores and weighting methodology for relationships are referenced which lead to the desired outcomes. Their case study is a shoe design ergonomics study conforming to customer requirements as well as meeting required safety standards.

Matzler and Hiterhuber discuss how to use Kano’s model of customer satisfaction for use in product development projects to increase success rate (Matzler and Hiterhuber, 1998). The approach described comes from a management background as compared to an engineering background. Concepts of competition, customer retention, and customer satisfaction are described. Easy to follow steps are also presented to use the method including: identifying the product requirements, constructing a Kano questionnaire, conducting interviews, and evaluation. The paper gives a brief overview of the QFD approach and provides benefits to combining Kano’s method with the QFD approach.

Griffin and Hauser discuss patterns of communication among marketing, engineering, and manufacturing using the QFD process (Griffin and Huaser, 1992). At the time of printing, scientific research suggested that new product teams for development are more successful if the communication between different areas of the development process is increased. A comparison of new-product strategies is presented in a figure which illustrates the placement of projects based on their success rate verses the percent of company sales from new products. There is also a figure showing OEM-to-Supplier communication changes as a result of the implementation of QFD.

According to Natter et al., incentive schemes are affecting firms that do not use QFD more than firms that use the QFD process (Natter et al., 2001). Incentive schemes can determine the weights for performance measures. In other words, as the QFD process proposes implemented features, it is expected that there are less changes as compared to trial and error testing (Natter et al., 2001). Searching strategies, product evaluation methods, learning environments, and performance measures in relationships to QFD are also discussed.

Housel and Kanevsky discuss the promise of business process reengineering (BPR) and how it needs to relate to return on investment process (ROP). ROP is the process for which the return on investment (ROI) is calculated. The ideology of reducing unnecessary operational costs is a critical element to providing competition in any market (Housel and Kanevsky, 1995). Their paper provides sections that cover topics in regard to BPR and ROP. A relationship to thermodynamics is illustrated with the concept of entropy, allowing changes in the environment can be controlled by numerous elementary changes. This paper provides information to QFD by helping to answer the question "Where and how much investment should be made by a company's processes results in a significant increase in return on investment in the process final consumable product/service?" (Housel and Kanevsky, 1995)

Methods Literature

Reich and Levy discuss developing a single intuitive method for using non-linear programming to manage product development projects under active and constantly changing constraints (Reich and Levy, 2004). Their model is an improvement on existing models that use QFD, while extending the capabilities of the house of quality even further. There is a brief description on good company profiles for candidates to use the method in a real project. No case study is provided. The software developed to use this methodology has been used in computerized manufacturing industries.

Rajala and Savolainen discuss a new approach for applying QFD methods with the addition of the IDEF0 business modeling (Rajala and Savolainen, 1996). Five basic steps are presented which include: modeling the business process and transforming it into a simulation model form; determining the customer's preferences and requirements; performing statistical analysis to model the customer preference distributions; choosing variables to be varied in simulation experiments; and comparing the results from the experiments with the customer preferences. The paper also discusses how to separate the voice of the customer into categories based on the business process.

Tu et al. show how to implement the house of quality using Microsoft Excel software combined with Lindo linear programming software (Y. L. Tu et al., 2003). The roof of the house of quality is used in the optimization of customer requirements and technical attributes to the products for decision making purposes.

Rangaswamy and Lilien discuss various software tools used in product development (Rangaswamy and Lilien, 1997). The software tools reviewed are specifically used for product development decision making. Multiple software packages are summarized with a useful list of benefits and limitations. The actual software packages named in this paper may be outdated. However, the methods described for selecting appropriate software is useful information for product development software evaluation.

Govers' discusses the value of the QFD process separate from the value of QFD as a tool. (Govers, 1996). The paper covers the importance of team building and roles of team members. The house of quality is explained and the process of implementation is compared with the Kano model showing how functions can satisfy customers relative to what amount of investment goes into the respective functions. This directly relates to the ability of functions to satisfy customers. There are also remarks on implementation requirements of the company for successful QFD implementation.

Tang et al. describe how to take into account financial factors and uncertainties in the product design process using fuzzy optimization and genetic algorithms (Tang et al., 2002). This is primarily used to develop resource allocation to meet the goals of the organization. Fuzzy formulation for costs and budget constraints are modeled to maximize the overall customer satisfaction. The difference between overall satisfaction and enterprise satisfaction is discussed as well.

Cristiano et al. discuss the results of over 400 companies using QFD for product development to show the positive impact (Cristiano et al., 2001). Useful data show percentage of success rates for QFD as well as team size. The importance of the cross-functional team understanding the importance of the relationship between independent activities is stressed. They also show how companies who had a stronger and broader set of reasons to use QFD were more likely to report reduced lead-time as a result of the QFD exercise.

One alternative to QFD found in literature is developing taxonomies for design requirements in a corporate environment (Gershenson and Stauffer, 1999). Taxonomies are used to classify large bodies of information. They can provide order to massive amounts of data and can be arrange in a variety of ways as discussed in the paper. According to the abstract, they claim for it to be able to facilitate a “broader and clearer form of QFD…” (Gershenson and Stauffer, 1999). This theory seems very similar to IDEF0. It also seems to be a good tool to provide QFD meeting notes on subjective decisions in the matrix and why the decisions have been made for validation purposes.

Crow illustrates a step by step process for going through the QFD method for his company which uses the technique when consulting for clients (Crow, 2002). This work is listed online and has been noted in various papers including a literature review by Chan and Wu (Chan and Wu, 2002) as legitimate. There are many valuable explanations on how to implement the theoretical QFD process in real world exercises. The main points include: gathering customer needs; product planning; conceptual development; and developing the deployment matrix. Specific areas of interest are suggested in real world experience which is valuable to any QFD case study (Crow, 2002)

Karlsson discusses using QFD to manage software requirements in regards to issues and explanations for forming cross-functional teams, as well as additional notes on every step of the QFD process using the house of quality (Karlsson, 1997). An interesting point discussed is how the complete traditional framework is not always applicable to software development and integration into all companies. It is mentioned that evaluating QFD can be used to pick the useful concepts and then customize a framework for the specific needs of the organization.

Kaulio discusses seven different methods used in the product development process of different business world wide in the spirit of focusing on customers in the total quality management approach (Kaulio, 1998). The seven selected methods which are discussed include QFD, user-oriented product development, concept testing, beta testing, the consumer idealized design method, the lead user method, and participatory ergonomics. These seven methods are compared and contrasted. Many of them have been adopted by firms to use with product development and most are related in at least one respect.

Reich and Levy published a paper improving previous models for QFD by incorporating realistic cost functions and allowing continuous use of these functions throughout the project (Reich and Levy, 2004). The shortcomings of the roof of the house of quality have also been reduced through weighting importances based on the voice of the customer. There are many specific case studies compared as well as illustrated methods to use their improvements. One specific area of importance to this paper is that Reich and Levy address engineering constraints which can have partial investments allowing the amount of investment to a specific engineering constraint to be variable in the QFD process.

Case Studies and Applications

Angeli, Jones, and Sabir discuss their three year joint research study to find out what it takes to bring about change in senior management culture to improve the leadership qualities of their firm and how to best execute decisions (Angeli et al., 1998). QFD is mentioned as one of the methods to assist in prioritization. The QFD method was documented in a case study where a company used a 72 by 165 matrix to help identify product feature elements unique to the specific markets which the firm operated. Angeli et al. provide a business approach that is very similar to the presented QFD process for Numark. Both identify the specific demands of the customer that products are targeted towards.

Lowe, Ridgway and Atkinson developed a QFD tool to be used in a semi-solid metal processing application (as well as others) which provides abilities to insert sections from the house of quality into a software package for evaluation (Lowe et al., 2000). This tool has the most potential to evaluate products to pursue relative to other potential products. This paper provides a specific user interface which can be easily interpreted by the various backgrounds found in diverse cross-functional teams. The relationship in the roof of the house of quality is not used in the scoring method. It is used for discussion purposes only.

Buyukozkan and Feyzioglu explain uncertainties with new product development and how they can be modeled using modern techniques such as fuzzy logic and neural networks (Buyukozkan and Feyzioglu, 2004). Inputs to their system include customers and employees through one channel and designers and product managers through another channel. The marketing team is implemented through the process and the overall results describe weighted risk analysis, benefit indices, and strategic impacts for potential products. Their method has been proposed to a toy manufacturing firm which had a reliable historical database which is required for neural networks.

Methodology

Why QFD?

Current Methods for Product Development

In this research, a method for determining the voice of the customer (VOC) is needed to provide the best quality products to the market. Customer focus is one of the key components in a total quality management approach (Kaulio, 1998). There are various methods that firms use to develop products. These methods can be classified by specific components included with the methodology. Some of the basic classification points include: specification phases; concept development phases; and prototyping phases (Kaulio, 1998).

There are many procedures used in practice which fit into multiple classifications. "The issue of selecting methods for customer involvement in product development is, however, not a matter of selecting a specific method, but a matter of designing a whole system of methods linked together in an overall process that focuses design efforts on the customer's future satisfaction." (Kaulio, 1998)

Feasible solutions found in the literature include: QFD; user-oriented product development; concept testing; beta testing; consumer idealized design; the lead user method; participatory ergonomics; IDEF0 programming; and taxonomies.

QFD has been described as a customer-oriented approach to product innovation (Govers, 1996). According to Govers, the roots of the method are based on a slightly different concept of Total Quality Control (TQC), which was introduced by Feigenbaum. This separate version utilizes "Company Wide Quality Control" (Govers, 1996). This method allows the voice of the customer to be implemented throughout the entire process in relationship to various aspects of the business model including the entire product development process from idea conception through manufacturing.

Traditional QFD provides a house of quality which relates customer requirements, and design requirements as shown in Figure 1. Figure 1 also shows how the matrix provides a competitive analysis which makes QFD a very useful tool when trying to pick features that provide direct competition to an existing competitor's product while adding features that are shown as a breakthrough opportunity (ReVelle et al., 1998). A breakthrough opportunity provides a competitive advantage to the firm relative to the customer requirements. There are many ways to calculate the values of the customer requirements and different heuristics to select features depending on the specifics of the problem, providing flexibility to the model. QFD can also accommodate projects with large parameter sets including hundreds of technical attributes and hundreds of customer requirements (Angeli et al., 1998).

Figure 2, from the Qimpro Standards Association, shows how different matrices are formed to compare customer requirements to design requirement, design requirements to part requirements, part requirements to process requirements, and process requirements to the output of the customer satisfaction. The bottom line to this relationship is outputting customer satisfaction.

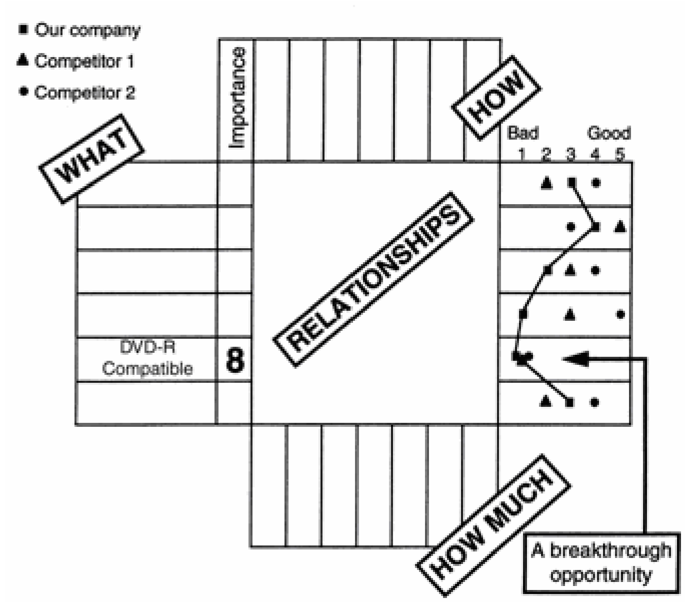

Figure 1: Basic QFD relationship. (ReVelle et al., 1998)

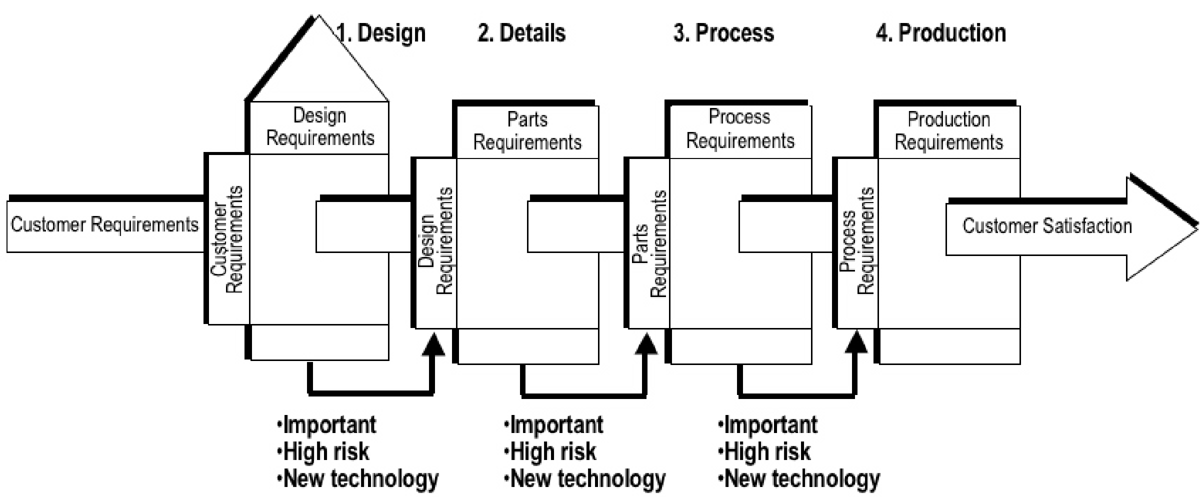

Figure 2: QFD Progression. (Qimpro Standards Association)

QFD offers a specification phase which directly relates the customer requirements with customer satisfaction through four or more basic phases. For this project at Numark Industries, only the design process and the details are needed. However, the process for manufacturing and production are handled through an OEM manufacturer so modification will be needed to the QFD model to account for this. The concept development category of QFD as shown in Figure 2 is through the first and second step. There is not a means for cycling concepts suggested back into the process for further evaluation and refinement.

Numark Industries typically receives a prototype for mass production approval. However at this stage, the tooling for the product is complete and there is not the budget to provide engineering changes at this point. In this case, the prototype is used to only to verify the specifications, as compared to a prototype that is used to reevaluate the concept development, where new changes may be made for a new prototype.

The following methods provide additional tools that have been used in product development processes.

The **user-oriented product development process** uses human factors and ergonomics to develop the design of the product (Kaulio, 1998). The primary characteristics of this process include providing an analysis of the problem or opportunity suggested by customers as a starting point to create a set of user requirements. Similar to the QFD approach, the user requirements are transformed into quantifiable engineering requirements. At this point in the process, prototypes are tested by users and modified by designers.

This specification process in user-oriented product development typically requires the combination of high volume sales with low production costs. This method has been applied to areas such as designing work and military clothing, hand tools, public systems, and public transports (Kaulio, 1998). These examples either have very large research and development budgets, or the cost of prototyping is relatively low. To manufacture different prototypes of a hammer, for example, is much cheaper than to manufacture a computer controlled device. However, public systems are very expensive. The difference being that public systems have a larger budget for product development as compared to a manufacturing a computer controlled device or a DJ device that Numark Industries designs. The life expectancy of public systems is measured in decades as compared to a computer based product, such as DJ equipment, which may be obsolete by the time it comes to market.

Concept testing is similar to the user-oriented product development process in that customers are used in the concept stage. However, concept testing uses more of an integrated approach for prototyping and specification phases. In concept testing, focus groups may be created to come together, and asked to react to stimulating drawings, models, and non functioning prototypes. The major component missing from this process is engineering and manufacturing constraints. This method does not provide communications channels between different functions of the firm. Concept testing provides direct customer feedback to the area of the company that is performing the process. With the DJ market being such a volatile one with highly competitive firms fighting for market share, the engineering and design forces must work together concurrently.

Beta testing is a back end testing procedure frequently used in software engineering (Kaulio, 1998). Beta testing specification capabilities are completely in a back end approach where designers provide the original specifications, engineers produce design specifications and technical requirements, and manufacturing will implement the proposed product from the chain. At this point, customers evaluate the product and propose changes after all of the design has occurred. Beta testing is very useful for the electronic portion of DJ product development such that software written or audio preferences can be altered by programming changes. In other words, beta testing is very useful for fine tuning a product, rather than designing the product. It is very similar to a guess and check method, which would increase the time to market, unless the first product is good enough to pass the checks.

Consumer idealized design can be described as a process for having customers involved in the actual design of new to market goods or services (Kaulio, 1998). This process involves focus groups similar to concept testing. In this case, the focus group session begins with a blank sheet of paper and the members of the focus group develop the product as compared to a focus group evaluating the product. A design is formed, technical requirements are formed, and validation for the decisions is documented. The specification phase of the consumer idealized process includes 100% of the focus group's decisions and does not take into account the engineering or technical requirements to make that happen. For simple products, such as hand tools, the technical requirements to make these focus group recommendations are not a critical factor in the development. However, for complex products, such as computer software, like what Numark needs in the DJ industry, focus groups might develop products which are not feasible to produce under the cost constraints. There is no prototyping phase with this process.

Generally, focus groups will provide an excellent voice of the customer (VOC) if the sampling for the focus group fairly represents the customer market. However, customers always want a feature loaded product at a featureless price point. This presents a contradiction in focus groups developing products. If the focus group does not weight the features that they are specifying, then the designers and engineers do not have enough information to accurately rate these features when features need to be removed for costing reasons. There are methods to obtain cost-benefit trade-offs in new products, however, this can be difficult to validate for new technologies which are not easily understandable by average users because they have not been previously introduced into the market.

The lead user method is very similar to the consumer idealized design method except that users are selected for a focus group based on their specific needs that are ahead of the product technology curve (Kaulio, 1998). The customers in a focus group for the lead user method are selected because they are users who face the needs of the market months or years before the majority of customers in that market. This method has similar relationships to the specification phases, concept development phases, and prototyping phases as the consumer idealized design method. The major difference is the selection of users. One advantage of this method over the consumer idealized design method is that the information is a forecast into the future. The disadvantage is the risk involved. Many products are designed with the intentions of reaching the masses with only penetrating a small section of the market. The reason for this risk is that the select focus group members do not necessarily represent what the entire customer base will want or need int the future. There is a higher product risk involved with the lead user method because of the uncertainty in the ability of the focus group to accurately predict trends in the disc jockey market..

Participatory ergonomics uses customers in the design phase to actively work as designers (Kaulio, 1998). This method is primarily used in workspace design and has not been reported as a method that has been used with the design of mass market products (Kaulio, 1998).

Rajala and Savolainen applied the IDEF0 technique (Integration Definition language 0 for modeling function) to the QFD model. As shown in Figure 3, IDEF0 sets up a model of the business process and transforms it into a simulation model form (Rajala and Savolainen, 1996). Figure 4 shows how this model has been used in a specific business example with inputs, outputs, constraints, and resources expended (Rajala and Savolainen, 1996). The specification phases with IDEF0 are very useful for setting up the relationships in an easy to use graphical representation. The concept development phase is unclear with IDEF0. Prototyping may occur at the conclusion of the IDEF0 process.

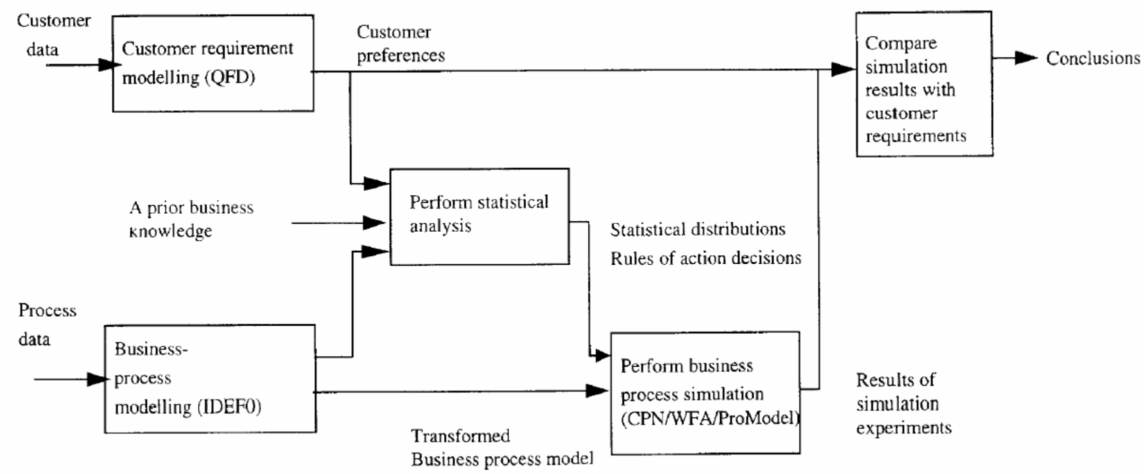

Figure 3: IDEF0 Example (Rajala and Savolainen, 1996).

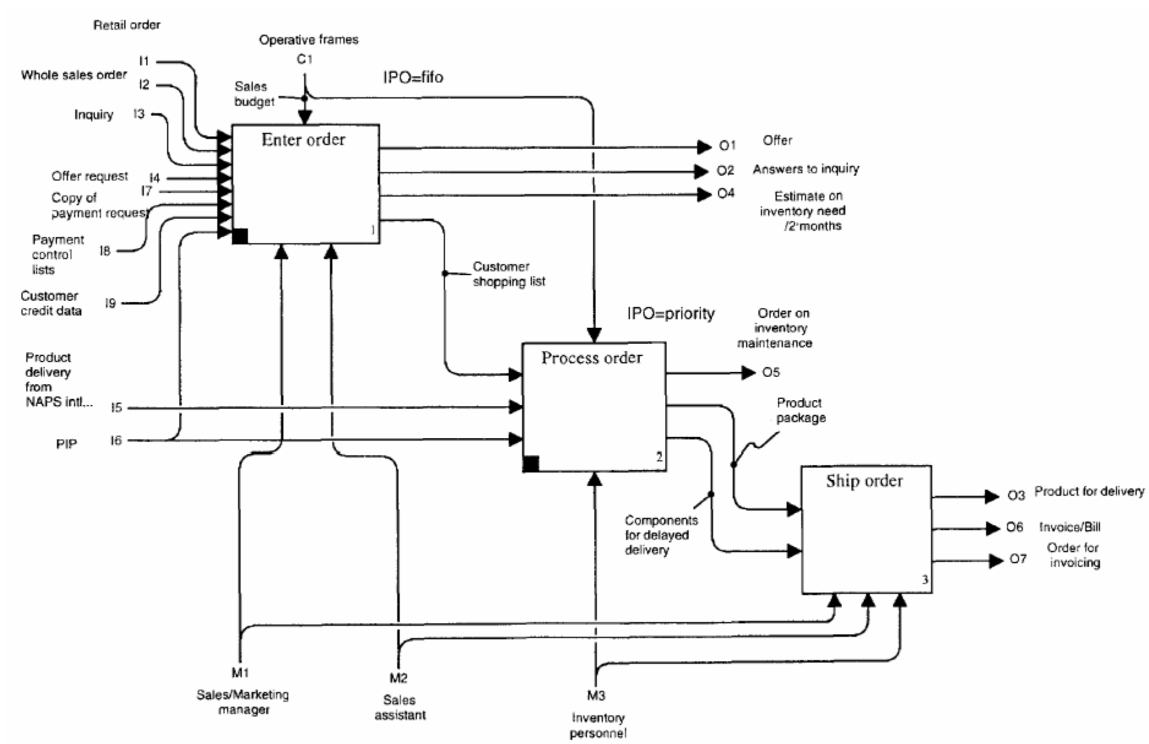

Figure 4: IDEF0 Example (Rajala and Savolainen, 1996).

An additional method found is using taxonomies to meet the design requirements. This method is a business method commonly used to describe large bodies of information (Gershenson and Stauffer, 1999). This method has also been used in many different fields of science to classify anything that has two common threads. “Derr states that classes must be mutually exclusive and exhaustive.” (Gershenson and Stauffer, 1999) This method is a very effective way for all sections of the business function to break down marketing, strategies, financial considerations, manufacturing, and any other area of business, into easy to read categories. The specifications using this method come from breaking down each area into sub categories until there are no more relationships between elements to consider. There is not much discussion regarding the specifics of concept development or prototyping with this method. Gershenson and Stauffer mention that at a manufacturing level, a fishbone diagram is made to break down the definition of product attributes.

With these methods, various software platforms have come about to assist in the modeling of these methods including but not limited to: QFD software; fuzzy logic software; IDEF0 modeling; neural networking software; and taxonomy software.

Creating a Method Tailored for the DJ Industry

From the methods currently used in business practices, industries often take valuable parts of certain methods to design a specific method that works based on possible objective functions and historical data. As mentioned, the size of the firm, the budget available for product development, the technological requirements of the products and the constraints when developing are used to determine the best set of methods used.

When selecting methods based on the criteria of specification process capability, concept development capabilities, and prototyping phases, the QFD, IDEF0, and lead user method processes have the best application. IDEF0 can organize relationships between the customer requirements and the technical attributes as does QFD. The lead user method simply provides the strongest concept development with the customer because the actual customer is drawing the product. The shortcomings of the lead user method are that engineering and sales are not properly represented and there is no formal way to translate the voice of the customer to each separate attribute based on price decisions, quality decisions, and feature tradeoffs customers generally do not understand. In other words, the customer in a focus group can provide all of the desired features of tomorrow. However, a focus group is not capable of providing engineers and designers with the underlying goals and rankings of those features in the traditional sense without explicitly including these issues into the focus group.

The QFD method has been selected because it has robust capabilities and it can be applied to a variety of situations and customized for the specific application. For the

Numark project, the entire QFD process, in traditional terms, will not be fully used. Numark needs a good mix of other strategies to appropriately meet the goals of the specific project on hand. QFD case study data also supports that customer focus and process improvements are more pronounced in smaller firms when using the QFD process (Cristiano et al., 2001).

The DJ industry as a whole uses both push and pull marketing strategies. According to Numark, pushing products to customers through the distribution channels by satisfying expectations of price, product development time, and product quality allow Numark to increase business. The remainders of the product development projects contain pull features where the customer asks for a particular feature and that feature is implemented in a new or existing product. For example, home electronics consumers have standardized the MP3 audio format in home products. DJ customers are now expecting their products to be compatible with these audio formats to follow the home audio trends. Numark will pull that information from the customer to provide them with that specific need as identified.

Numark as well as other major manufacturers in the DJ industry now support MP3 media in CD players, and other playback devices. However, Numark needs to evaluate different features to create an optimum feature set based on their individual relationships with the rated customer requirements <u>which QFD provides the best fit and is the selected method</u>.

Key Factors for Success

Numark decided to pilot the QFD program based on the proven potential of the QFD process combined with the volatile DJ market with constant changes in technology and fierce competition.

Figure 5 shows the QFD effect on product development lead time when successful. These results are accomplished when marketing and technology are integrated (Griffin and Hauser, 1992). The success rate is shown in Figure 6.

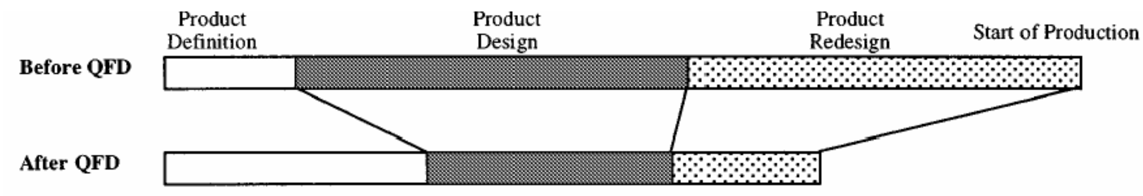

Figure 5: Effect of QFD on lead time (Cristiano et al., 2001).

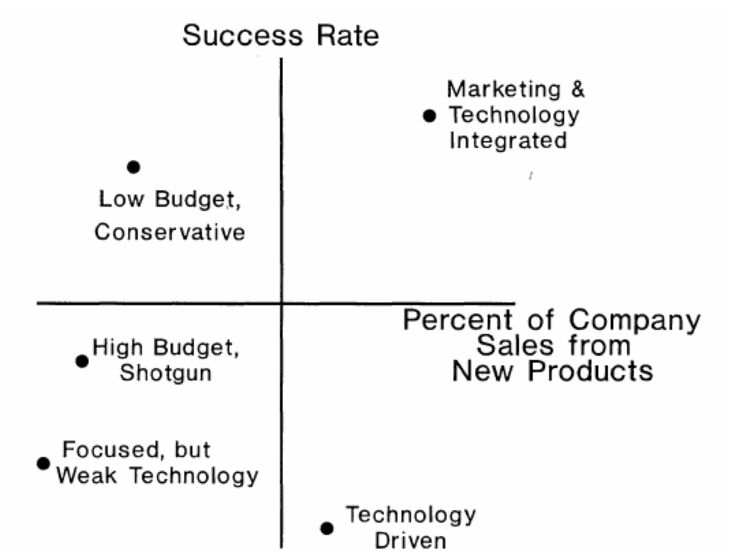

Figure 6: Success rate comparison (Griffin and Hauser, 1992).

It is important for top management to understand the process and the goals. Note that the time for product definition is longer with the QFD process. Numark traditionally has created a list of features which were sent to the design phase, then to the manufacturer. There are many deviations to the original product definition with this existing process. QFD will increase the initial analysis and development portion, but by integrating the different areas of business, less time will be needed for the design due to a more focused set of features and direction and less redesign time will be needed because manufacturing and sales constraints such as feasibility and cost are implemented in the QFD design stage.

Griffin and Hauser discuss the addition to team productivity with QFD. They also introduce the concept that a good product development process should enhance the OEM-supplier relationship (Griffin and Hauser, 1992). Figure 7 is a result of a case study where two identical products were evaluated side by side with a QFD team size of 9 members (two from the supplier and seven from the OEM) and a phase-review team consisting of 12 members (five from the supplier and seven from the OEM). The authors note caution while evaluating Figure 7 because the phase-review team had 5 extra members. Griffin and Hauser suggest that OEM-to-supplier links have not been fully evaluated with the QFD process which should be investigated in the future.

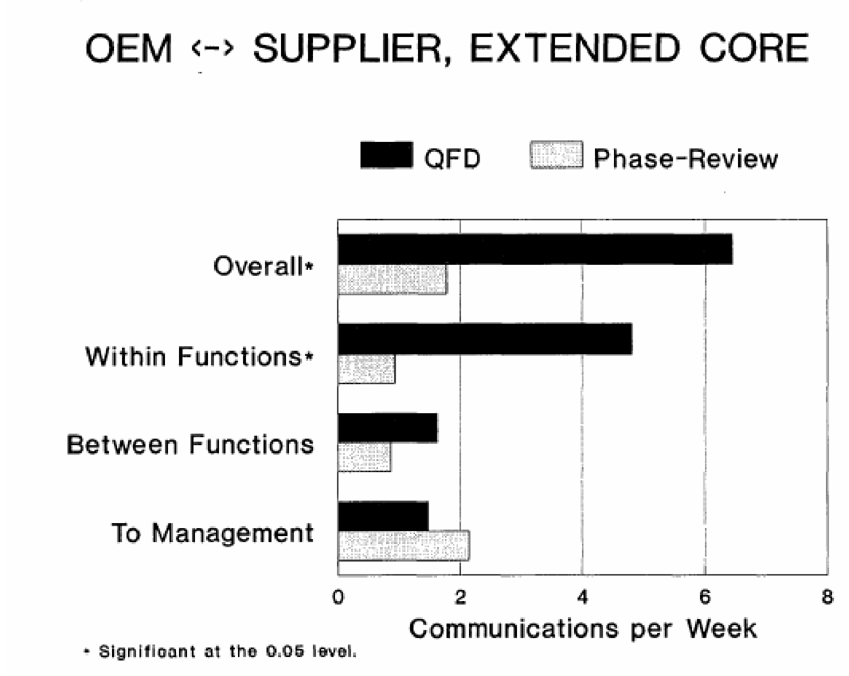

Figure 7: OEM-to-Supplier Communications (Griffin and Hauser, 1992).

Cristiano et al. concluded that "Those who had a broader and stronger set of reasons for using QFD were more likely to report reduced lead-time as a result of the QFD study." (Cristiano et al., 2001) Numark has demonstrated their broad and strong case for using QFD due to the robust market and fierce competition as mentioned.

Another key to success to QFD is the concept of developing cross functional teams.

> "Team structures are superior to sequential organizations. Team organizations can significantly benefit from the use of the House of Quality methodology. The relative advantage of the House of Quality increase with shorter life cycles, increased product complexity, and smaller development teams" (Natter et al., 2001)

Numark, like any company piloting a new technique, had concerns and questions regarding the results and what it would mean to the bottom line. A key to success with the QFD process at Numark is that they understand that it is easy to forget that QFD is merely a tool to provide quality feature sets (Cristiano et al., 2001). According to Cristiano et al., "What matters the most seems to be management fundamentals like top management support, investing sufficient resources in understanding what the customer wants from the product, and keeping those customer desires in front of engineers as they design the product."

Upon completion of this process, an estimation of the return on investment in process can be calculated from differences between this project and similar project historical data (Housel and Kanevsky, 1995). For Numark, the project selected was specifically selected for the potential benefits of QFD as mentioned previously. It also has been selected because it is similar to previous projects which the QFD process results can be compared to the traditional approach. Having comparable results to provide a return on investment to upper management is a key to proving the success of the QFD process in a business process reengineering project.

Kano's Model

All companies need to produce the right feature set to provide a competitive advantage over the competitive products. Kano's model shown in Figure 8 illustrates the three classifications of features: basic; performance; and excitement (Govers, 1996). Basic features and excitement features are not spoken by the customer. Performance features have a direct trade off with the degree of achievement of engineering and design and customer satisfaction.

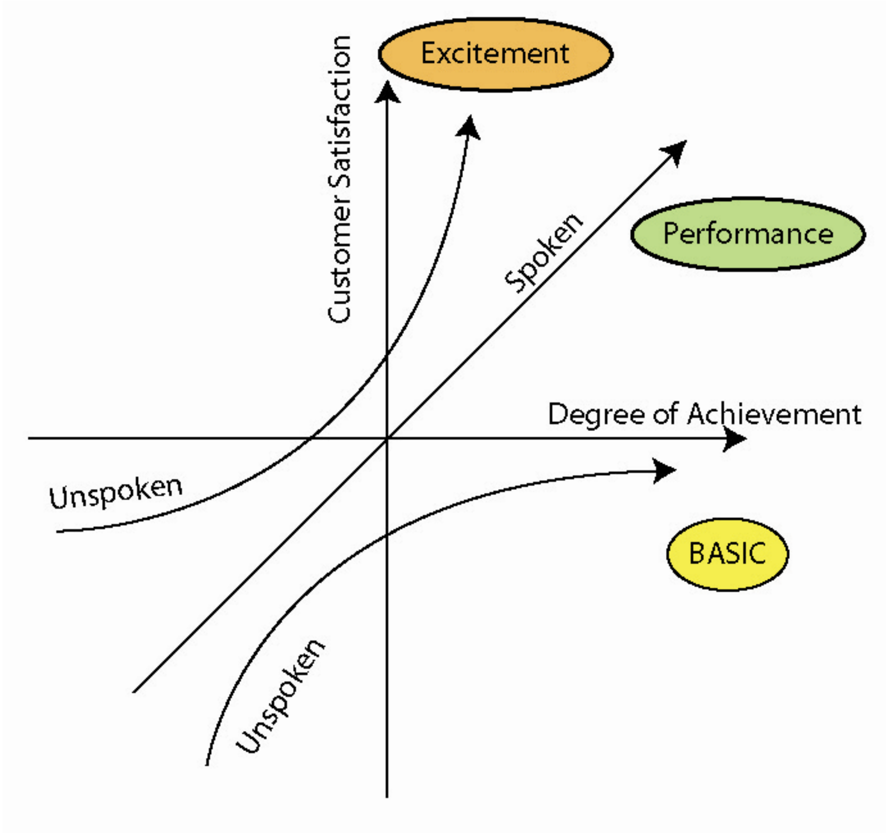

Figure 8: Kano's Model.

For example, if a customer is surveyed in regards to purchasing an alarm clock, the customer is not going to report that they want an alarm clock that can correctly show the time. It is expected that showing the time is a basic function of an alarm clock therefore it is not spoken. The clock customer is also not going to ask that their clock automatically sets the contrast of the digital display depending on the lighting in the room. This feature may be very simple and provide the user a better night's rest which they can get excited about. However, it is not a currently available feature on alarm clocks; therefore the customer may not be asking for it.

A performance feature for the alarm clock example would be having a radio. The radio could be an analogue device which would cause lower customer satisfaction than a radio that was digital and included the emergency weather broadcast frequencies. These additions to the radio are spoken and would require more achievement to get the higher customer satisfaction where the excitement feature of having an auto dimmer could require a low degree achievement with a high value of customer satisfaction.

Time will push excitement features to performance features or to basic features. For the radio example, having the auto dimmer could be determined as a breakthrough opportunity from the house of quality (HOQ). However, the cost of the degree of achievement needed to make the auto dimmer is relatively low. Once the competition can get that feature into their product, it will become either a performance feature or will become a standard feature.

Implementation

Project Definition

As mentioned in the methodology, QFD is an overall concept that translates customer requirements into the appropriate technical attributes which can then be designed and engineered (Chan and Wu, 2001). This method will be used in the traditional sense to provide the translation. In addition, it will be customized to account for different customer segments and variable costs and times to production due to OEM relationships.

Objectives, their variables, and their subjective constraints are provided in the project definition. The objective was set from upper management and confirmed during the first QFD meeting with the team.

Objectives

With the release of a competitor product that provides opportunity advantages to a current existing Numark product line, the project's objective is to provide a feature set for the new product.

The feature set must provide direct competition to competitors by optimizing the features needed by the target customers, providing excitement features, and to meet a price point set by sales and marketing management. This new product must provide Numark with the competitive advantage, within appropriate production costs to meet sales price points.

The objective function is to maximize overall product quality by selecting the feature set subject to the constraints.

Variables

Variables for the project include all of the possible customers which the project will be marketed towards, all of the feasible technical attributes, as well as data defining, specifying, and relating these variables.

Constraints

Explicit constraints for this project include the total production cycle time and the total cost of the product. The man hours available is a constraint, however it is not included in this QFD model.

Numark provided support for this QFD approach from top level management down. Management supported this initial project as a pilot to introduce the concept of quality into their product development process. Numark has not set a constraint on the time allocated to develop the feature sets. However, for future projects at Numark, historical data on QFD development and manufacturing deadlines will add the additional constraint of the time allowed for research on the variables to improve the accuracy of the data set for variables.

Once the project is defined, the process can be developed to meet the demands of the specific project.

Process

The process to implement QFD at Numark to meet project objectives includes:

1. Forming the cross functional QFD team.
2. Selecting the user interface to communicate with the team including software selection.
3. Developing the house of quality.
4. Developing a model to output the quality with fixed variables.
5. Maximizing the quality by changing variables within the constraints.

These steps in the process are further illustrated and start with forming the cross functional QFD team.

Forming the Cross Functional Team

The initial activity to start the QFD process once the project definition is completed is to form a cross functional team which will gather people representing different functions of the organization (Karlsson, 1996). For Numark, this includes representation from sales, marketing, engineering, product development, and design. The QFD leader is also included in this group to direct the team.

Including expertise from different functional areas has been shown to contribute to the decision making process in QFD projects (Cristiano et al., 2001). Various literature sources have stated that this is one of the most critical elements to successful QFD projects.

The Numark QFD team consisted of seven members from the engineering, marketing, sales, management, and product development divisions of Numark:

- QFD Facilitator: (Project Manager).
- Upper Level Management. (Senior V.P. of Sales and Marketing).
- Product Development (Experienced Product Developer).
- Sales (National Sales Manager).
- Marketing/Advertising (Senior V.P. of Sales and Marketing).
- Industrial Design (Industrial Designer; Industrial Design Manager).
- Engineering (Director of Engineering and Product Development).

The team size has proven to be appropriate considering the size of Numark. In a study performed in 1986, 66% of Japanese QFD teams reported to be ten people or less (Cristiano et al., 2001). This information validates that there is no reason to suspect that seven member team is not an appropriate size.

The **QFD facilitator** is responsible for the QFD process generation and the management and direction of the team.

The Senior Vice President of Sales and Marketing has a dual role representing Numark's **Marketing/Advertising** department as well as providing the leadership and support for the QFD project from **upper level management**. Strong positive relationships between upper level management support and QFD success have been concluded in various surveys with QFD success rates (Cristiano et al, 2001).

Product development's expertise to the cross functional team brings historical data on the Numark historical products, information on competitive products, as well as expertise from the DJ market. Numark's product developer is also a mobile DJ with over 20 years experience which is helpful for defining and describing variables in the QFD model as well as providing customer insight to the product.

The **sales** division is represented by Numark's national sales manager with over 20 years experience in selling products to dealers as well as communication channels between the finished products and the customers. Sales is a vital role to the QFD matrix development because many features have a technical nature that needs to be marketable, such that the sales department can successfully produce sales and procure the products in a timely manner. Numark's national sales manager also travels to dealers and trade shows which provide valuable expertise in QFD process discussions.

Two team members are from the **industrial design** department. One member is a Numark industrial designer. The other member is the manager of the industrial design department. The designer is responsible for providing the form for the product once the quality function deployment process provides the feature set. The industrial design manager is responsible for providing general expertise in regards to the voice of the customer and how customer requirements relate to technical attributes.

In planning for this project, Numark plans to use an OEM for much of the engineering work to be completed. However, Numark does employ in house engineers for certain components. The **engineering** function is represented by the director of engineering and product development. This member's expertise is in costing and feasibility of the technical attributes suggested and listed in the HOQ.

Once the team has been formed, the project manager is responsible for selecting an appropriate user interface for the QFD development process and searching and selecting possible software packages capable to meet the demands of this project.

User Interface and Software Selection

The interface for the QFD method is critical to ensure that the team understands the customer requirements quickly and accurately (Tu et al., 2003). Key factors in the decision process for choosing the correct interface for Numark include the size of the team, the location of the team members, and the knowledge/experience with the QFD process.

In order to clearly illustrate the concept of QFD, an interface which has the capabilities of providing easy to understand notations and pictorial representations is desirable. A search for software was performed with the following review.

Rangaswamy and Lilien provided a thorough review in 1997 of software tools available for new product development from a marketing perspective (Rangaswamy and Lilien, 1997). Tu et al. provide an example using Excel with Lindo optimization software which has been used for resource allocation in a QFD manner (Tu et al., 2003). In 1996, Moskowitz and Kim developed a program QFD Optimizer. According to their findings in a case study, QFD Optimizer provided a novice friendly means for better understanding the complex interrelationships between customer needs and the engineering characteristics (Moskowitz and Kim, 1997). A similar tool is presented in 2000 by Lowe et al. allows novice users to enter the voice of the customer, technical attributes, their relationships. The software also provides scorings.

An internet search was also performed to identify current QFD software packages available for evaluation. Quality Associates International's, QFD Designer software was evaluated as well as International TechneGroup Incorporated's QFD Capture software. Both software packages provided a novice-friendly interface and showed the basic HOQ and allowed the user to enter in the relationships with basic templates. These software packages all allow a low to fair amount of customization for developing custom heuristics to evaluate the data.

Software was downloaded when available for further testing. Much of the software provided the user interface requirements for Numark. Software that provided colors and easily identifiable shapes for relationships helps to keep the team focused on the relationships instead of being confused about the numbering scheme. This is very important when working with a team that is new to the concept. The software must be able to graphically show how the relationship process is working.

However, optimization is not included with any of the software tested or reviewed except for QFD Optimizer. The problem with the QFD Optimizer software is that the optimization is not customizable. Customization is desirable to implement improved methods or custom methods for specific applications. For example, this project uses custom functions to relate the quality of a technical attribute based on the amount of investment. If there is a change in the function to calculate these quality changes, the selected software package should be able to adapt to those changes. Rating systems to account for single products which would be sold to different customers was not available in the QFD software packages either. At this point the decision was made to go with customizable software. There were two clear options for customizable software.

The first option for customizable software is to create a relational database system and create the HOQ with a programming language such as Visual Basic, C++, etc. For this option, the calculations has to be manually programmed. The amount of resources needed for this option made it infeasible. However, with sufficient resources, this software would be very beneficial for a firm that is practicing multiple projects with the QFD process.

The second option for customization, Microsoft Excel with integrated optimization software, was selected to be used at Numark for the QFD implementation. Excel was chosen because it is familiar to the team members, and the QFD model can be fully customized for a specific case. Though it does not allow easy to understand shapes to be entered into the HOQ, it does have features like data validation and conditional formatting which allow a sufficient graphical user interface (GUI) for the team members.

Excel also allows the data to be exported in a variety of formats to be used in other software applications for optimizing the feature set required. An additional benefit not mentioned in any of the literature is that team members can not open up the file on their computers without a license for the software. All of the Numark team members were able to open up QFD excel files on their computer. The location of team members was also a requirement for a software selection. With one of the team members working remote, it made the team meetings very efficient by having that team member simply opening up the Excel file on their computer to follow along in discussions.

Though the team members did not have the optimization software, they could still review the QFD model and suggest changes and review others work in a familiar format. Only the facilitator had the optimization software, and because the facilitator was the only one qualified to use the software, it did not pose a problem.

Developing the House of Quality

The What's, How's, and Relationships Between

The house of quality (HOQ) was developed during the first QFD team meeting. Once the team was selected and confirmed, the team was formally introduced to the QFD process and was provided with a schedule of the process with milestones and an itinerary for the first meeting. The itinerary for the first meeting included:

1. Provide an introduction to QFD.
2. Confirm the project definition.
3. Rank the importance of the three customers to the project.
4. Define and rate each customer requirement against each of the three customers for the product.
5. Create a weighted voice of the customer for the product.
6. Rank competitive products to the voice of the three customers.
7. Define the technical attributes (TAs).
8. Provide relationships between the technical attributes and the weighted customer requirements which in turn provides rankings and weightings of the TAs listed based on the data entered.

All members of the team were present at the start of the meeting. Only the product developer, the engineer, the industrial designer, and the QFD facilitator participated in steps 7 and 8.

Voice of the Customer

In the specific market for the product used with the QFD process, there are three different customers that Numark would like to market their products to. Two of the customers have similar characteristics and the third represents a small portion of the market and has unique demands for the product which differ from the other two types of customers.

Figure 9 shows the nine VOCs which are classified into the three groups on the right side. Across the top are the three customers, their respective importance ratings, 70%, 25%, and 5% respectively, and the weighted ratings. The importance ratings for the customer sum 100%. Therefore the weighted rating for the VOC for all three customers can be illustrated in the following equation:

$$\text{Weighted Rating}(\text{VOC}_\text{i}) = \sum_{j=1}^{n} (VC_{ij})(IR_j)$$

Equation 1: Weighted Importance Ratings.

Where:

VOC_i = i^{th} Voice of the Customer where i=1 to m. (m=9 in this example).

VC_{ij} = the relationship between of the i^{th} voice of the customer (customer requirement) and the j^{th} customer where j=1 to m (n=3 in this example).

IR_j = the importance rating of Customer j where j=1 to m.

The results of the weighted rating in the Numark example are shown in Figure 9.

The cross functional Numark team decided on weighting to give the relationships to all of the VOCs based on the customer type based on marketing and sales strategies. The relationships between the VOCs and the three customers are based on a 1 to 5 scale where 1 being a low importance and 5 being extremely important. All of the ratings are relative to each other.

To develop the list of customer requirements from the VOC, the product developer and the industrial design team listed all of the top requirements. The industrial designer worked on a psychoanalysis profile of the three types of customers that would be using the product prior to the initial team QFD meeting. This analysis was used to clarify the VOCs such that the team can best compare them with the relationships with the three different customers, the relationships between the competitive products, and the list of TAs.

			Importance Ratings			
		% Importance	70%	25%	5%	OK
			Customer 1	Customer 2	Customer 3	**Weighted Rating**
Voice of Customer (VOC)	**Group 1**	*Group 1, VOC 1*	**4**	**4**	**2**	**3.9**
		Group 1, VOC 2	**4**	**5**	**3**	**4.2**
		Group 1, VOC 3	**3**	**5**	**5**	**3.6**
	Group 2	*Group 2, VOC 1*	**3**	**5**	**5**	**3.6**
		Group 2, VOC 2	**2**	**5**	**4**	**2.85**
		Group 2, VOC 3	**4**	**5**	**5**	**4.3**
	Group 3	*Group 3, VOC 1*	**5**	**4**	**1**	**4.55**
		Group 3, VOC 2	**5**	**3**	**3**	**4.4**
		Group 3, VOC 3	**4**	**3**	**3**	**3.7**

Figure 9: VOC with Weighted Customer Ratings.

Competitive Analysis

Once the weighted ratings are complete, the competitive analysis is formed. For this project there were three main competitor products that needed to be compared to the VOCs. Each competitor product was rated by the same 1 to 5 scale used previously (shown in Figure 10) to show the achievement of the competitive product meeting the specific VOC relative to other competitors.

These ratings are graphed to show the traditional competitive analysis as shown in Figure 11. This has been the standard method proposed by all evaluated software platforms and literature. The graph is intended to provide the team with an easy to see picture of opportunities for competitive advantages with the project relative to the determined competition. The problem with Figure 11 is that the importance of the VOC it relates to is not factored in. For example, in Figure 11, Competitor 2 shows excellent relationships between their product and (Group 1, VOC 3) as well as (Group 2, VOC 2) with scores of excellent (5) in both. This excellent rating is compared only to the VOC which it is compared to and there is no way to relate how much better a competitive product is to the bottom line without taking into account the weighted ratings for the VOCs.

As shown in Figure 12, Competitor 2 still has the relative advantage to Competitor 1 and Competitive 3. However, the actual rating for the VOC is multiplied by the weighted rating and divided by the maximum score (5) which provides results to see where the main competition can be found which leads to the greatest overall customers satisfaction for the product.

The results in this from Figure 11 in this case would show that (Group 1, VOC 3), (Group 2, VOC 2), (Group 3, VOC 1), and (Group 3, VOC 3) showed the highest peaks which would lead the team to believe that these are either opportunity areas or areas where the competition has the upper hand. Figure 12 shows the same competitive relative information for comparing one competitor to another. However it also shows the relative importance to the entire project. Figure 11 would show that four VOCs have very high ratings and should be evaluated. From Figure 12, the team concluded that though there were four areas with excellent ratings, only (Group 3, VOC 1), and (Group 3, VOC 3) provided areas of opportunity and those VOCs had a larger weight to the overall quality rating of the QFD project.

These two VOCs shown in Figure 12 ((Group 3, VOC 1), and (Group 3, VOC 3)), were immediately identified as strong areas for success in the project.

			Importance Ratings	Competitive Analysis					
		% Importance	OK	*Subjective Analysis (1-5)*			*Weighted*		
			Weighted Rating	Competitor 1	Competitor 2	Competitor 3	Competitor 1	Competitor 2	Competitor 3
Voice of Customer (VOC)	**Group 1**	*Group 1, VOC 1*	**3.9**	5	3	4	3.9	2.34	3.12
		Group 1, VOC 2	**4.2**	4	3	2	3.36	2.52	1.68
		Group 1, VOC 3	**3.6**	4	5	4	2.88	3.6	2.88
	Group 2	*Group 2, VOC 1*	**3.6**	4	4	4	2.88	2.88	2.88
		Group 2, VOC 2	**2.85**	3	5	4	1.71	2.85	2.28
		Group 2, VOC 3	**4.3**	2	4	3	1.72	3.44	2.58
	Group 3	*Group 3, VOC 1*	**4.55**	5	1	1	4.55	0.91	0.91
		Group 3, VOC 2	**4.4**	1	1	1	0.88	0.88	0.88
		Group 3, VOC 3	**3.7**	3	1	5	2.22	0.74	3.7

Figure 10: Competitive Analysis Data.

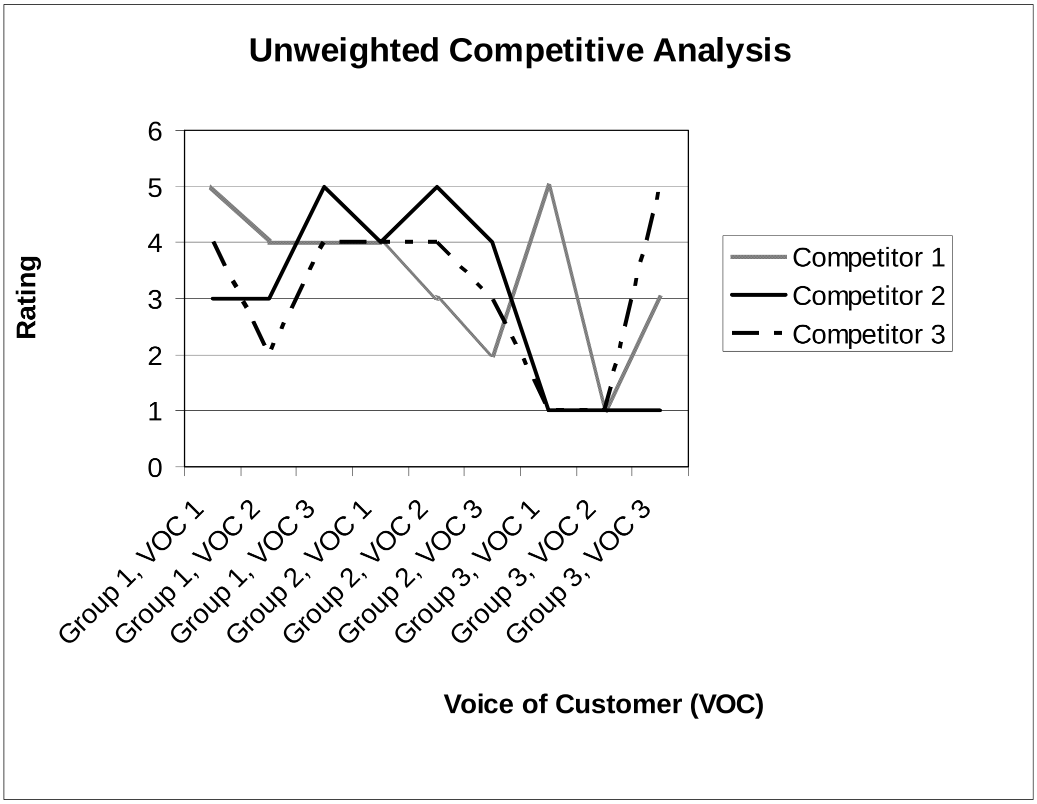

Figure 11: Unweighted Competitive Analysis.

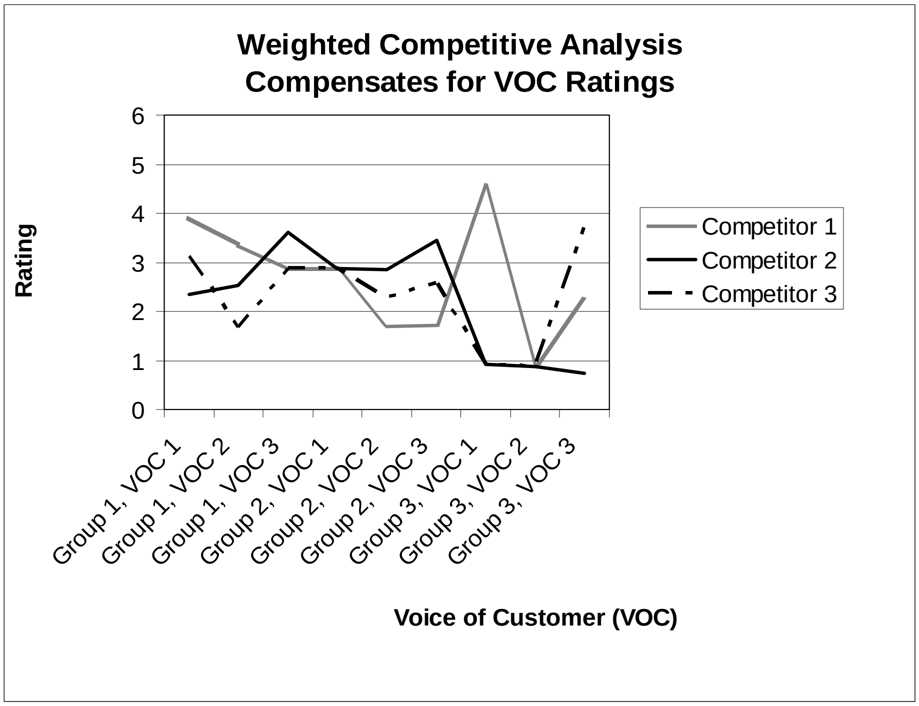

Figure 12: VOC Rated Competitive Analysis.

Upon conclusion of the competitive analysis, the QFD team moved to steps 7 and 8 of the meeting objectives. As mentioned, those without technical expertise were excused. It was not time-efficient to have management and sales involved with implementation of the technical aspects of the QFD process. However, management and sales received a copy of the completed HOQ for verifications purposes once the chart was completed.

The expertise of Numark's management and national sales manager is the most valuable for items at a macro level which is why their input was needed for the description of the customers, the weighting of the customers, and the competitive analysis. The technical attributes are at a micro level where only team members with the technical expertise are qualified to evaluate. Having their involvement also gave confirmation of the projects direction and increased the communications between departments and management. Now management understands what the development and engineering is doing and why they are doing it.

Technical Attributes

To create a list of technical attributes, the product developer consulted with other team members before the first meeting to create an extensive list of all possible technical attributes which would be considered in this QFD project.

Many of the technical attributes created were interrelated. All of the relationships have been noted in comments in meeting minutes. Some of the technical attributes were found to be basic features referring Kano's model (Figure 8). These technical attributes are assumed to exist in the project, and were removed from the QFD selection model. The associated resources required to develop and manufacture these assumed basic features have been deducted from the available resource constant in the model.

The goal of the QFD exercise is to determine which technical attributes will be included and what resources (if applicable) should be spent investing into the corresponding TA to maximize the overall quality of the product within the constraints listed.

Relationships and Corresponding TA Ratings

The rating system between TAs and VOCs include:

- 0 – No Relationship.
- 1 – Weak Relationship.
- 3 – Strong Relationship.
- 9 – Very Strong Relationship.

This rating system has been suggested by Nilsson in 1990 because 9 is three times stronger than 3 and 3 is three times stronger than 1 (Bergquist et al., 1996). Bergquist et al. also suggested that other types of scales can be used as long as a stronger relationship is given a higher rating.

Figure 13 shows 5 of the 26 total TAs, and their relationships with the corresponding VOCs. Figure 14 shows the corresponding weight, percentile of weight of final product, and ranking. Note that only the first five TAs are shown and the rankings were calculated based on the 26 TAs. Refer to Appendix A for the full chart. Reich and Levy explain that the ratings are taken from a product of the quality sums shown in the following equation (Reich and Levy, 2004):

$$\sum_{i=1}^{n} P_i \bullet C_{ij}$$

Equation 2: TA Quality Sums.

Where P_i is the weighted rating of VOC_i and C_{ij} is the relationship between the TA_i and the VOC_j.

		% Importance	Importance Ratings OK	Technical Attributes				
			Weighted Rating	TA 1	TA 2	TA 3	TA 4	TA 5
Voice of Customer (VOC)	Group 1	Group 1, VOC 1	3.9	9	3	9	1	3
		Group 1, VOC 2	4.2	9		9	9	9
		Group 1, VOC 3	3.6	9	9	9	1	9
	Group 2	Group 2, VOC 1	3.6	9	9	9	3	
		Group 2, VOC 2	2.85	9	9	9	9	3
		Group 2, VOC 3	4.3	9	3	9		
	Group 3	Group 3, VOC 1	4.55	3	3	9		
		Group 3, VOC 2	4.4	1				
		Group 3, VOC 3	3.7	9		3		

Figure 13: Relationships between TAs and VOCs.

			Importance Ratings	Technical Attributes				
		% Importance	OK					
			Weighted Rating	TA 1	TA 2	TA 3	TA 4	TA 5
Voice of Customer (VOC)	Group 1	Group 1, VOC 1	3.9	9	3	9	1	3
		Group 1, VOC 2	4.2	9		9	9	9
		Group 1, VOC 3	3.6	9	9	9	1	9
	Group 2	Group 2, VOC 1	3.6	9	9	9	3	
		Group 2, VOC 2	2.85	9	9	9	9	3
		Group 2, VOC 3	4.3	9	3	9		
	Group 3	Group 3, VOC 1	4.55	3	3	9		
		Group 3, VOC 2	4.4	1				
		Group 3, VOC 3	3.7	9		3		
			Overall Weighting	253	129	254	82	90
			Percentage	8.0%	4.1%	8.0%	2.6%	2.9%
			Ranking	3	10	2	20	18

Figure 14: TA Rankings.

With the rankings and weightings completed, the first meeting was concluded after discussions regarding the results of the meeting. The team came in to the meeting new to the QFD development concept. Following the meeting, they had already begun to take ownership of the model and were starting to realize what the capabilities of this project could be.

All of the desired goals for the first meeting were accomplished at this point and tasks were assigned to each team member for the next meeting as listed:

- **QFD Facilitator**: Begin development of the model to output the overall quality of the product based on resources invested in TAs.
- **Industrial Design Team**: Develop concepts for top rated features as result of the meeting.
- **Engineering Team**: Develop specifications for the TAs and complete the roof of the HOQ showing the interrelationships between TAs.

- **All Others**: Review the minutes from the remainder of the meeting for which they were absent and review the updated HOQ Excel chart to provide comments.

Interrelationships between TAs in the Roof of the HOQ

Procedure

Karlsson describes the roof of the HOQ as a correlations matrix describing the relationship of each TA as how the deployment of one TA affects another (Karlsson, 1997). Figure 15 shows the relationships between 26 TAs. This has been recorded into Excel. Any comments regarding questionable relationships have been noted in the cell relating the two TAs for later reference.

The equivalent relationship of one TA compared another TA is recorded in the roof of the HOQ. A value of ‘1’ indicates a positive relationship, blank cells represent no apparent relationship, and ‘-1’ values represent a negative relationship.

This chart was completed by the engineering team. Where questionable relationships existed, they were noted by comments and given the best score. When two TAs are selected in the feature set and they have a positive relationship, there is an additional quality from this relationship which is summed into the product quality function.

For this project, it is assumed that the relationship that TA X has to TA Y is the same relationship that Y has to X.

Roof of the HOQ

	TA 1	TA 2	TA 3	TA 4	TA 5	TA 6	TA 7	TA 8	TA 9	TA 10	TA 11	TA 12	TA 13	TA 14	TA 15	TA 16	TA 17	TA 18	TA 19	TA 20	TA 21	TA 22	TA 23	TA 24	TA 25	TA 26
TA 1																										
TA 2																										
TA 3																										
TA 4	1		1																							
TA 5	-1			-1																						
TA 6			1																							
TA 7	1		1	1	-1	1																				
TA 8	1		1		-1	1	1																			
TA 9	1		1	1	-1	1	1	1																		
TA 10	1		1	1	-1	1	1	1	1																	
TA 11	1			1			1	1	1	1																
TA 12	1			1				1	1		1															
TA 13			1				1		1		1	1														
TA 14	1		1			1		1																		
TA 15	1		1			-1		1																		
TA 16				-1		1	-1	-1	-1				1	1	1											
TA 17		1		-1			1		-1							1										
TA 18			1	1	-1	1	1	1	1	1	1	1		1	1	-1	-1									
TA 19	1	1	1	1		1	1	1	1	1	1	1			1	1	1	1								
TA 20	1	1	1			1	1	1	-1	-1				1	1			1	1							
TA 21			1			1									1	1			1	1						
TA 22	1	1	1	1	-1	1	1	1	1	1	1	1		1				1	1	1	1					
TA 23							1						1								1	1				
TA 24								1				1						1	1			1				
TA 25			1	1								1							1			1				
TA 26			1	1			1		1	1	1							1	1			1			1	

Figure 15: Roof of HOQ.

Additional Notes

Reich and Levy show that the current method that was used in this QFD project, which has been a standard method for various QFD projects, is deficient (Reich and Levy, 2004). They go on to state that TAs are not symmetrical to each other as was stated as an assumption in this example. The upper level of the matrix is equal to the lower level therefore it has not been filled in. Reich and Levy are suggesting that there are different relationships which should be identified. They go further to state that a matrix should exist for every VOC. All of the matrices should be weighted accordingly to provide a weighted output of the HOQ roof. This is very similar to the ideology used when changing the traditional competitive analysis to account for every VOC.

The problem with going through this method is that with 26 TAs and 9 VOCs, their method would require 6,084 instances to compare. The current method shown in Figure 15 required 338 instances to evaluate.

Evaluating over 6,000 instances is assumed to take more costs in resources than additional benefit provided to the model. It is recommended that with smaller projects, the full roof is investigated as suggested by Reich and Levy. However for larger projects, their proposed method is not feasible.

Developing the Model

To develop the optimization model, the following variables needed to be defined: weighted scoring of the TAs; interrelationships between TAs; the characteristics for the TAs; and quality returns in a TA from resources invested.

The **weighted scoring of the TAs** has been delivered from the first meeting to fill in the HOQ. **Interrelationships between TAs** is also considered part of the HOQ but would need to be determined by the engineering team as a task assigned at the end of the first QFD meeting. The **characteristics for the TAs** include: possible price ranges; time to production; resources needed; and the quality returned based on the resources invested. **Quality returns in a TA from resources invested** must be determined based on a set of possible functions which the engineering team would have to estimate based on historical data which helps define the characteristics for the TA.

Modeling Quality vs. Investment with Technical Attributes

Reich and Levy propose separating functions to show the quality of a TA as a function of investment as shown in Figure 16. The relationship is that without any initial investment, the basic quality of the feature is set at H_j. After a set minimal direct investment into the TA shown at x_{j0}, the investment function follows a non-linear improvement function described by $g(x_j)$.

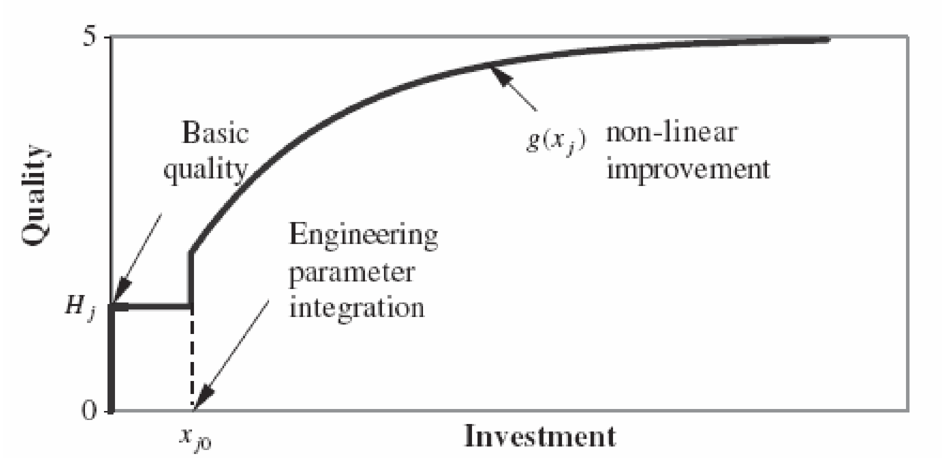

Figure 16: Quality vs. Investment (Reich and Levy, 2004).

These two g(x) functions are taken directly from Reich and Levy.

First g(x):

$$g(x_j) = \begin{cases} H_j & x_j < x_{j0} \\ (5 - H_j) \bullet (1 - e^{-t_j x_j}) + H_j & x_j \geq x_{j0} \end{cases}$$

Equation 3: Quality of TA (Reich and Levy, 2004).

$$t_j = -\frac{1}{A_{b\%,j}} \ln\left(\frac{100 - b\%}{100}\right)$$

Equation 4: Quality of TA Sub-Equation (Reich and Levy, 2004).

Second g(x)

$$g(x_j) = \begin{cases} H_j & x_j < x_{j0} \\ (5 - H_j) \bullet (1 - \frac{t_j}{(x_j + t_j)}) + H_j & x_j \geq x_{j0} \end{cases}$$

Equation 5: Alternative Quality of TA (Reich and Levy, 2004).

$$t_j = A_{b\%,j}\left(\frac{100 - b\%}{100}\right)$$

Equation 6: Alternative Quality of TA Sub-Equation (Reich and Levy, 2004).

Where:

H_j is the initial quality of the TA.

$A_{b\%,j}$ is the direct investment required in order to improve the quality of the TA by b%.

x_j is the investment made in the TA.

x_{j0} is the minimal direct investment in the TA to allow its integration into the product.

These functions are displayed in Figure 17 with the solid lines representing the first g(x) equation and the dashed lines representing the second g(x) equation with $H = 0$, $x_{j0} = 0$, $A_{b\%,j} = 10$, and different values for $b_{\%}$.

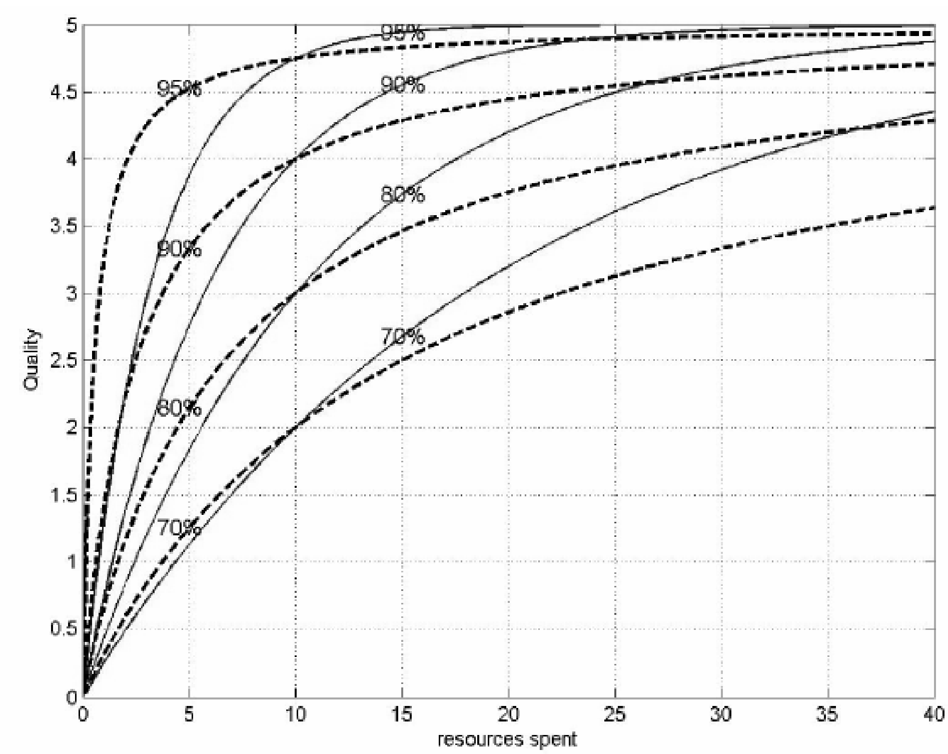

Figure 17: Quality vs. Resources Spent (Reich and Levy, 2004).

These functions show quality on a scale of 0 to 5. For the Numark QFD study, quality was represented as a percentage which will change the g(x) to the following which will set the output quality levels ranges from 0 to 1. Note that t_j does not change for the respective equations.

$$\text{First } g(x_j) = \begin{cases} H_j \\ (1-H_j)\bullet(1-e^{-t_j x_j}) + H_j \end{cases} where \begin{cases} x_j < x_{j0} \\ x_j \geq x_{j0} \end{cases}$$

Equation 7: Modified Quality of TA Function.

$$\text{Second } g(x_j) = \begin{cases} H_j \\ (1-H_j)\bullet\left(1-\frac{t_j}{(x_j+t_j)}\right) + H_j \end{cases} where \begin{cases} x_j < x_{j0} \\ x_j \geq x_{j0} \end{cases}$$

Equation 8: Alternative Modified Quality of TA Function.

The slope and behavior of these curves are the same as the previous equations. The only difference is the scaling factor. More information along with the Excel sheet with these curves is illustrated in Appendix B.

The Quality Function to Maximize

Reich and Levy provide the final optimization problem (which equals the total quality of the product) as:

$$\max \sum_{i=1}^{n} P_i \sum_{j=1}^{m} C_{ij} \left[g(x_j) + \sum_{k=1, k \neq j}^{m} g(x_k) \bullet D_{jk} \right]$$

$$s.t. \sum_{j=1}^{m} x_j \leq X$$

$$\mathrm{x_j} \geq 0, \ \mathrm{j} = 1, \ldots, \mathrm{m}.$$

Equation 9: Reich and Levy's Final Optimization Problem (Reich and Levy, 2004).

Where:

P_i = the weighted importance ratings of VOC_i.

C_{ij} = the impact of TA_j on VOC_i.

$g(x_j)$ = the quality of TA_j due to the amount of direct investment x_j.

D_{jk} = the relationship in the roof of the house of quality.

X = maximum investment available in project.

Numark's quality function will follow the same form with some modifications. The first modification is with the following selection relating the roof of the HOQ to the overall quality of VOC_i. The original equation sums the product of the other investments in VOCs *k* through m by the relationship between them and VOC_j as shown.

$$\sum_{k=1, k \neq j}^{m} g(x_k) \cdot D_{jk}$$

Equation 10: Reich and Levy's Quality Function (Reich and Levy, 2004).

The problem with this calculation for Numark is that the qualities are outputted as a percentage of the maximum rating score.

The second modification is adding constraints. There are two limits with the Numark case, investment in resources (X), and the added cost of features in the Bill of Materials.

To compensate for this, to better model the Numark situation, Reich and Levy's equation has been modified to:

$$\max \sum_{i=1}^{n} P_i \sum_{j=1}^{m} C_{ij} \left[g(x_j) + \sum_{k=1, k \neq j}^{m} g(x_k) \bullet (0.1)(D_{jk}) \right]$$

Equation 11: Modified Quality Function for Numark.

This new equation changes the interrelationship weighting when calculating the overall output quality by for TA_j. Reich and Levy's equation will sum the quality score between 0 and 5 of the related TA, x_k, to $g(x_j)$.

At Numark, g(x) always provides the quality score for 'x' as a percentage. The value of $g(x_k)$ is multiplied by a constant of 0.1 which allows the maximum increase or decrease to the total quality score of TA_j to be 10% of the sums of $g(x_k)$ where there is a relationship between TA_j and TA_k. D_{jk} determines the relationship between TA_j and TA_k.

This 10% score was selected as an approximation of the average maximum influence that one TA could have on another. This constant 10% in the Numark model remains constant; however, it could be variable and determined for each relationship in the roof of the HOQ shown in Figure 1. As noted in the roof of HOQ additional notes, the amount of time required to do this in this example would not be efficient to the progress of the QFD project. However in smaller models, this would be a recommended area of research.

The calculation for the D_{jk} influence is also another area of suggested research. Maximum changes based on D_{jk} relationships should be investigated. In this Numark model, this method has been selected by approximating the relative differences between total TA scoring based on the choice for the D_{jk} relationship.

Software Implementation

OptWorks Genetic Algorithm software has been selected due to its ability to work with various model sizes. Other software available may provide better solutions. Optimization software which can be run as an Excel add-in included: Lindo's What's Best software; Jorma Kuha's Direct Optimizer; and the Excel Solver included with Microsoft Excel.

Software which could not be used as an Excel add-in has not been evaluated due to the interface requirements of the cross-functional team. Having an easy to understand and robust to change interface provides an overall improvement in the method of product development (Govers, 1996). OptWorks provided that solution. All Excel add-in software was tested concurrently on the same model for direct and fair comparisons.

Lindo was initially thought to be the best solution due to the availability of creating hard, non-varied, constraints. Implementation of this software created problems due to the limitations of excels formulas that were recognized by the software. Reference formulas provided the greatest problem area in the What's Best Excel add-in and workarounds became difficult at best. Results were also continuously wrong in even the smallest examples. Technical support from the company mentioned issues with using functions to calculate values. A different solution was needed.

OptWorks provided all of the tools and controls needed for the Numark example as well as a variety of searching methods for the genetic algorithm (GA). OptWorks provides: custom GA searching; automatic GA searching; simulated annealing; automated simulated annealing; coordinate patter searching; random walking; grid searching; and random searching to provide results. Each method allows for discrete variables. However, multiple methods should be used to find the best solution. More information on the OptWorks algorithm software as well as screen shots can be found in Appendix C.

The results from the OptWorks software provided the best solutions available for the costs that should be spent on corresponding TA's maximizing the overall quality of the product while keeping within constraints which leads to the implemented solution

Implemented Solution

The solution to the model from OptWorks provided optimum investment costs that will be applied to the final product. This information has been used to develop the potential feature set for the product. The information has been presented to the QFD team for discussion. This model will be the foundation for the product features set and it robust enough to allow as changes in data as they occur in the product development process. Typical expected changes include: pricing for TAs; feasibility of the TAs due to development constraints (which were not explicitly expressed as a constraint); new technology introduction; increased competition; and changes in direction from management in the project.

Limitations

Resource Constraints and Allocation

This model does not explicitly account for available resources and how those resources can be allocated. Additional constraints in the model can be determined to limit the total amount of time and manpower available.

This poses a specific area of interest for Numark due to the OEM relationships with manufacturing. Additional functions would be required to approximate the investment in 'cost per unit' into 'man hours' needed for development.

Tooling costs in addition to any other overhead that is a function of the features selected can also be modeled by adding functions to show the amount of time and money needed from the 'cost per unit.'

In this case, the delivered results are subject to feasibility under the constraints that are not accounted for the model. In the case that such constraints pose a problem for the suggested feature set, the model will be manually configured to include a feature at a fixed cost which will not vary in the GA calculations.

Quality Returns from QFD Investment

Housel discusses the importance of understanding how the value generating capabilities of all component process may be affected under a business process reengineering effort such as the QFD effort implemented at Numark (Housel and Kanevsky, 1995). This project has created historical data which needs to be compared with previous and future project to determine the quality from investment in the QFD process. Not having this data provides a limitation for this QFD process. However, this limitation is expected for a first time QFD implementation.

Conclusions

This paper presented a methodology, discussed the implementation and deployment of the methodology, and calculated optimum results using genetic algorithm software for the feature set of a new product currently being developed at Numark Industries in the disc jockey market using a modified version of the traditional QFD process.

The QFD process has been modified by including multiple customers for the product with respective ratings, providing an enhanced competitive analysis which includes the ratings for the VOC's relative importance to the product, the interrelationship between TAs, and the method of communication between the cross functional team.

As mentioned, the QFD process has been identified as a tool to aid in the product development. The QFD process has improved the method of product development at Numark by reducing the lead time to a finalized feature set, reducing costs in engineering changes by implementing quality into the product, and developing the relationship between features and customer requirements to aid in a paradigm shift decisions.

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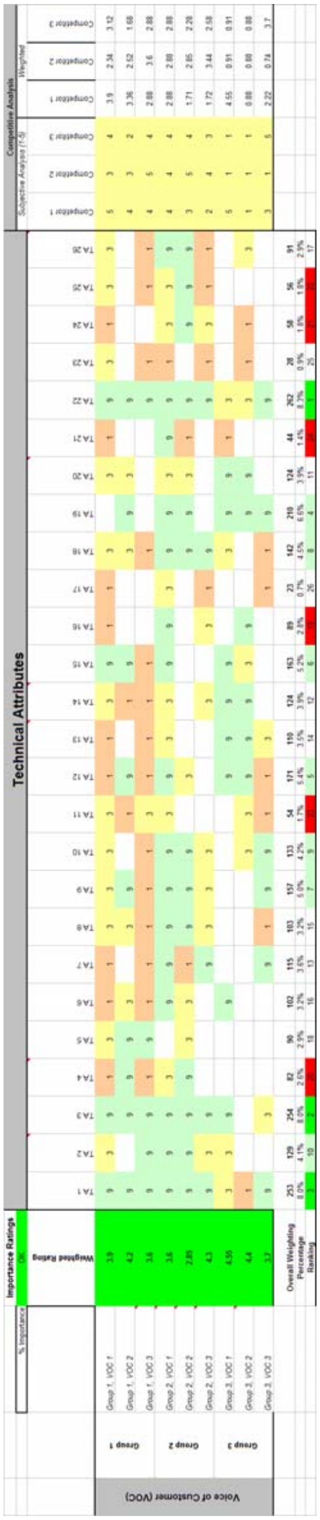
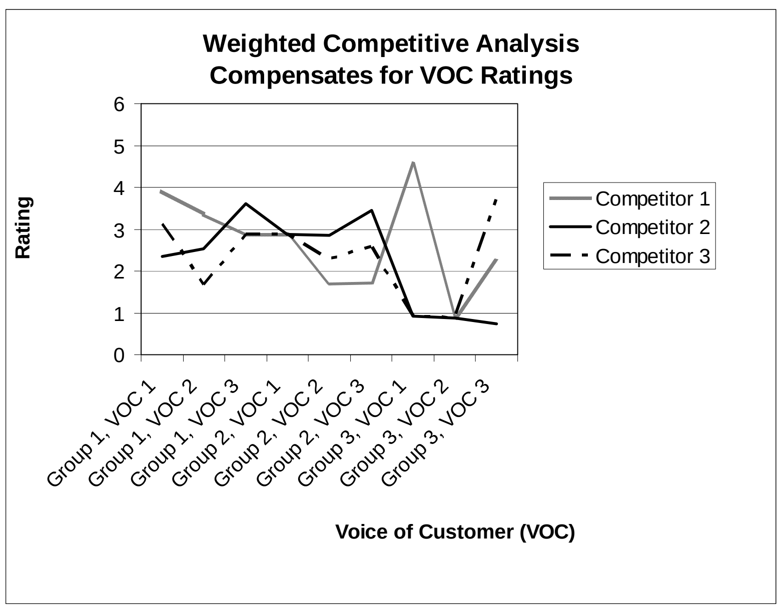
Appendix A: HOQ Excel Sheet



Roof of the HOQ

	TA 1	TA 2	TA 3	TA 4	TA 5	TA 6	TA 7	TA 8	TA 9	TA 10	TA 11	TA 12	TA 13	TA 14	TA 15	TA 16	TA 17	TA 18	TA 19	TA 20	TA 21	TA 22	TA 23	TA 24	TA 25	TA 26
TA 1																										
TA 2																										
TA 3																										
TA 4	1		1																							
TA 5	-1			-1																						
TA 6			1																							
TA 7	1		1	1	-1	1																				
TA 8	1		1		-1	1	1																			
TA 9	1		1	1	-1	1	1	1																		
TA 10	1		1	1	-1	1	1	1	1																	
TA 11	1			1			1	1	1	1																
TA 12	1			1				1	1		1															
TA 13			1				1		1		1	1														
TA 14	1		1			1		1																		
TA 15	1		1			-1		1																		
TA 16				-1		1	-1	-1	-1				1	1	1											
TA 17		1		-1			1		-1							1										
TA 18			1	1	-1	1	1	1	1	1	1	1		1	1	-1	-1									
TA 19	1	1	1	1		1	1	1	1	1	1	1			1	1	1	1								
TA 20	1	1	1			1	1	1	-1	-1				1	1			1	1							
TA 21			1			1									1	1			1	1						
TA 22	1	1	1	1	-1	1	1	1	1	1	1	1		1				1	1	1	1					
TA 23							1						1								1	1				
TA 24								1				1						1	1			1				
TA 25			1	1								1							1			1				
TA 26			1	1			1		1	1	1							1	1			1			1	

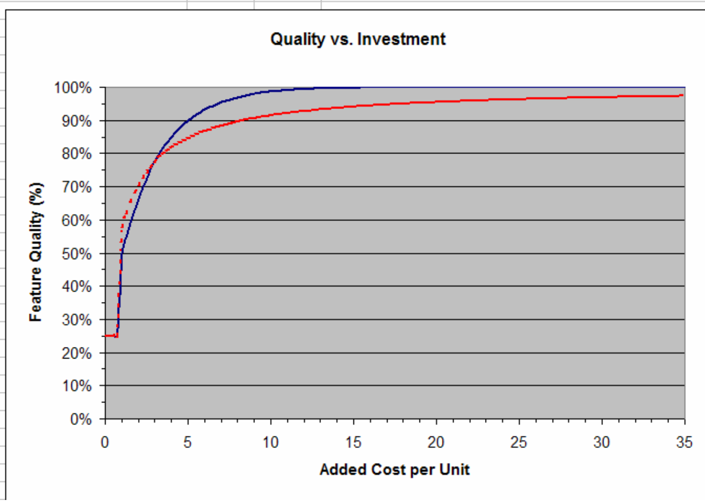


Appendix B: Quality vs. Investment Excel Sheet

KEY
Variables Set By Engineering
Computer Minimizes
Computer Maximizes

1 for g(x) 1 (Blue), 2 for g(x)2 (red)	2
Investment (Cost per Unit)	10
Quality (% of maximum)	91.5%

Description	Notation	Value	Units
The direct investment requred in order to improve the quality of the TA j by b%)	A(b%,j)	3.0	Percent
the improved qulaity of the TA	b%	70.0	%
Basic quality without investment	Hj	25%	%
The minimal direct investment in a TA to allow its integration into the product	xj0	1	Cost per Unit
EQ 8improvement rate of the quality of the TA (DO NOT ADJUST, TEMP CALC)	tj1	0.4013	
EQ 10 improvement rate of the quality of the TA (DO NOT ADJUST, TEMP CALC)	tj2	1.2857	
ROI (the amount of returned quality percentage vs. the amount of invested time percentage		2333%	



	EQ 8	EQ 10
0	25%	25%
0.25	25%	25%
0.5	25%	25%
0.75	25%	25%
1	50%	58%
1.25	55%	62%
1.5	59%	65%
1.75	63%	68%
2	66%	71%
2.25	70%	73%
2.5	73%	75%
2.75	75%	76%
3	78%	78%
3.25	80%	79%
3.5	82%	80%
3.75	83%	81%
4	85%	82%
4.25	86%	83%
4.5	88%	83%
4.75	89%	84%

This excel sheet has been used to determine the quality characteristics of TAs based on the amount of resources invested. This investment is measured cost per unit. For Numark, the cost per unit can be approximated into overhead expenses and development time. Overhead and resource allocation is not looked at in this QFD model.

This excel sheet was used in engineering team meetings by adjusting the highlighted values on the right hand side highlighted to adjust the two curves in the excel chart. This sheet provided an easy to use graphing calculator to best pick the curve characteristics. When the curve was determined an appropriate estimation of the technical attribute, the highlighted values were stored into the model for the respective TA.

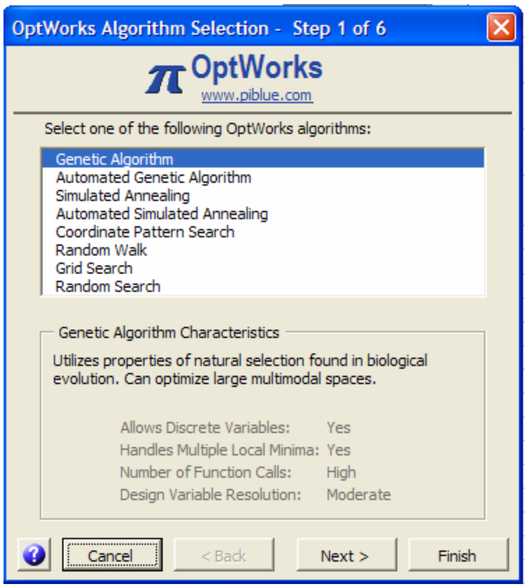
Appendix C: OptWorks Model in Excel

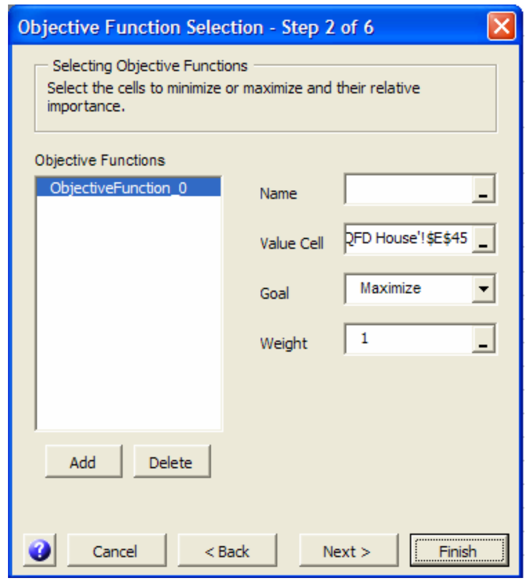
The following is a screen shot from the Excel Model including three of the TA showing how they are formulated. Investments are calculated by OptWorks as shown in the OptWorks Screen Shots following. Constraints are listed in the bottom left in the Solver box.

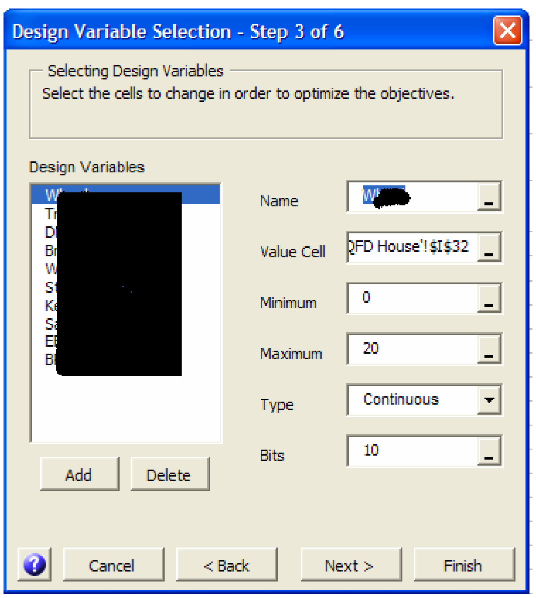
	Importance Ratings				Technical Attributes		
% Importance	70%	25%	5%	OK			
	Customer 1	Customer 2	Customer 3	Weighted Rating	VOC 1	VOC 2	VOC 3
Group 1, VOC 1	4	4	2	3.9	9	3	9
Group 1, VOC 2	4	5	3	4.2	9		9
Group 1, VOC 3	3	5	5	3.6	9	9	9
Group 2, VOC 1	3	5	5	3.6	9	9	9
Group 2, VOC 2	2	5	4	2.85	9	9	9
Group 2, VOC 3	4	5	5	4.3	9	3	9
Group 3, VOC 1	5	4	1	4.55	3	3	9
Group 3, VOC 2	5	3	3	4.4	1		
Group 3, VOC 3	4	3	3	3.7	9		3
				Overall Weighting	253	129	254
				Percentage	8.0%	4.1%	8.0%
				Ranking	3	10	2
				Investment	$ 6.08	$ 2.91	$ 6.82
				Min	$ 8.00	$ 8.00	$ 8.00
				Max	$ 20.00	$ 20.00	$ 20.00
			Quality vs Investment Variables	A(b%,j)	3.0	3.0	3.0
				b%	70.0	70.0	70.0
				Hj	25%	25%	25%
				xj0	1	1	1
				tj1	0.4013	0.4013	0.4013
				tj2	1.2857	1.2857	1.2857
				Type of curve	1	2	1
			Quality	g(x)	93%	77%	95%
			Total TA Quality		236.8	99.1	241.8

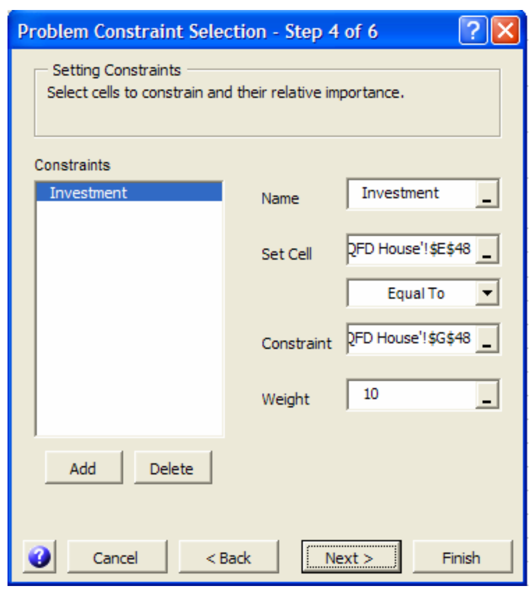
Solver			
	Quality		
Maximize	1495.0		
	Total	Relationsh	Constraint
Investment	$ 40.25	<=	$ 50.00

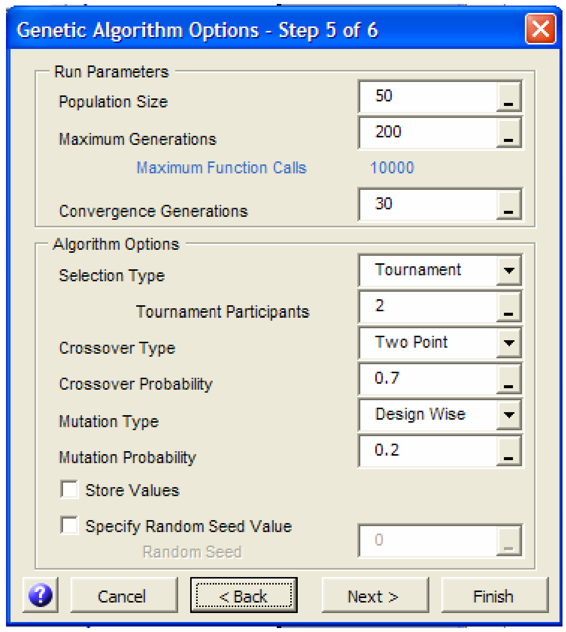
The following screen shots show the options in the OptWorks Software Package.



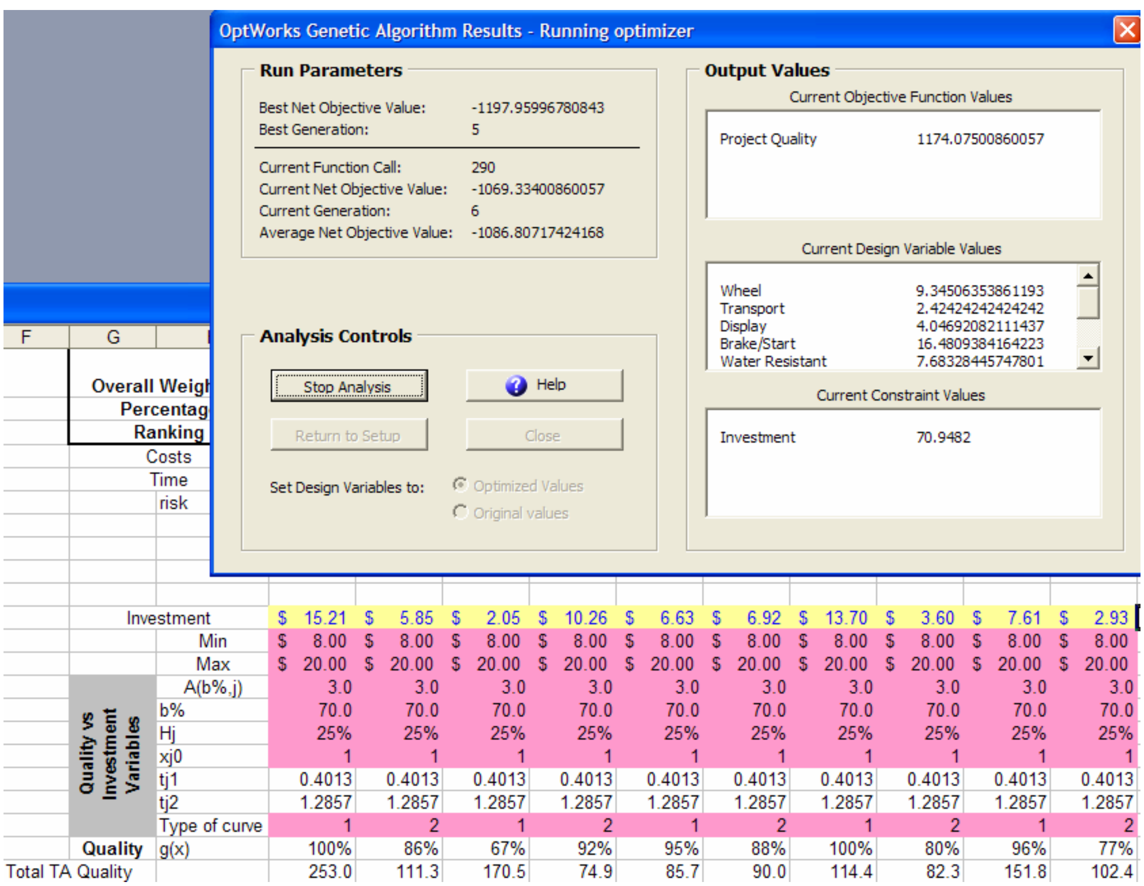




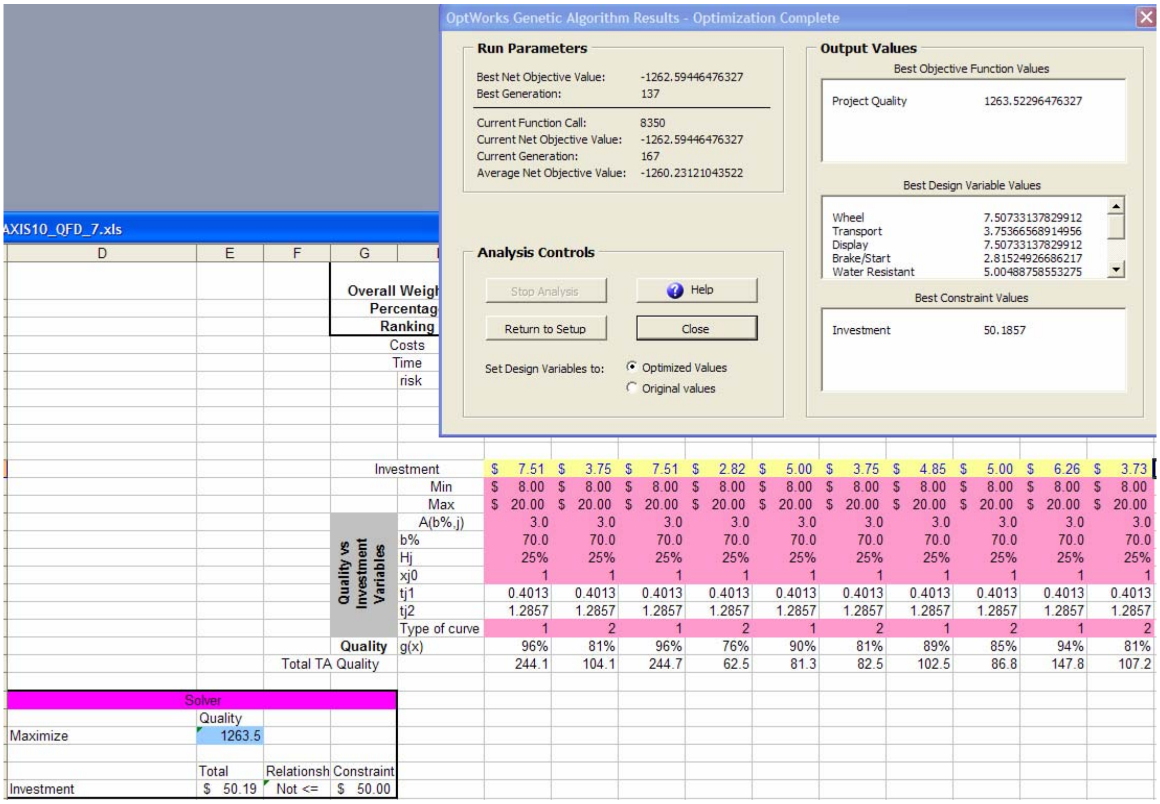




Sample Snap Shot While OptWorks is Solving



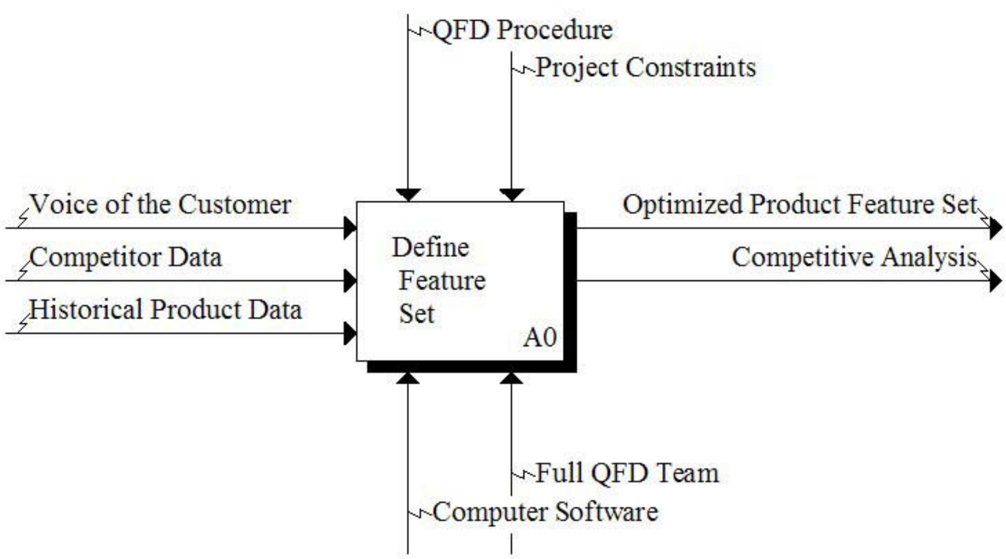
Sample Optimum Solution

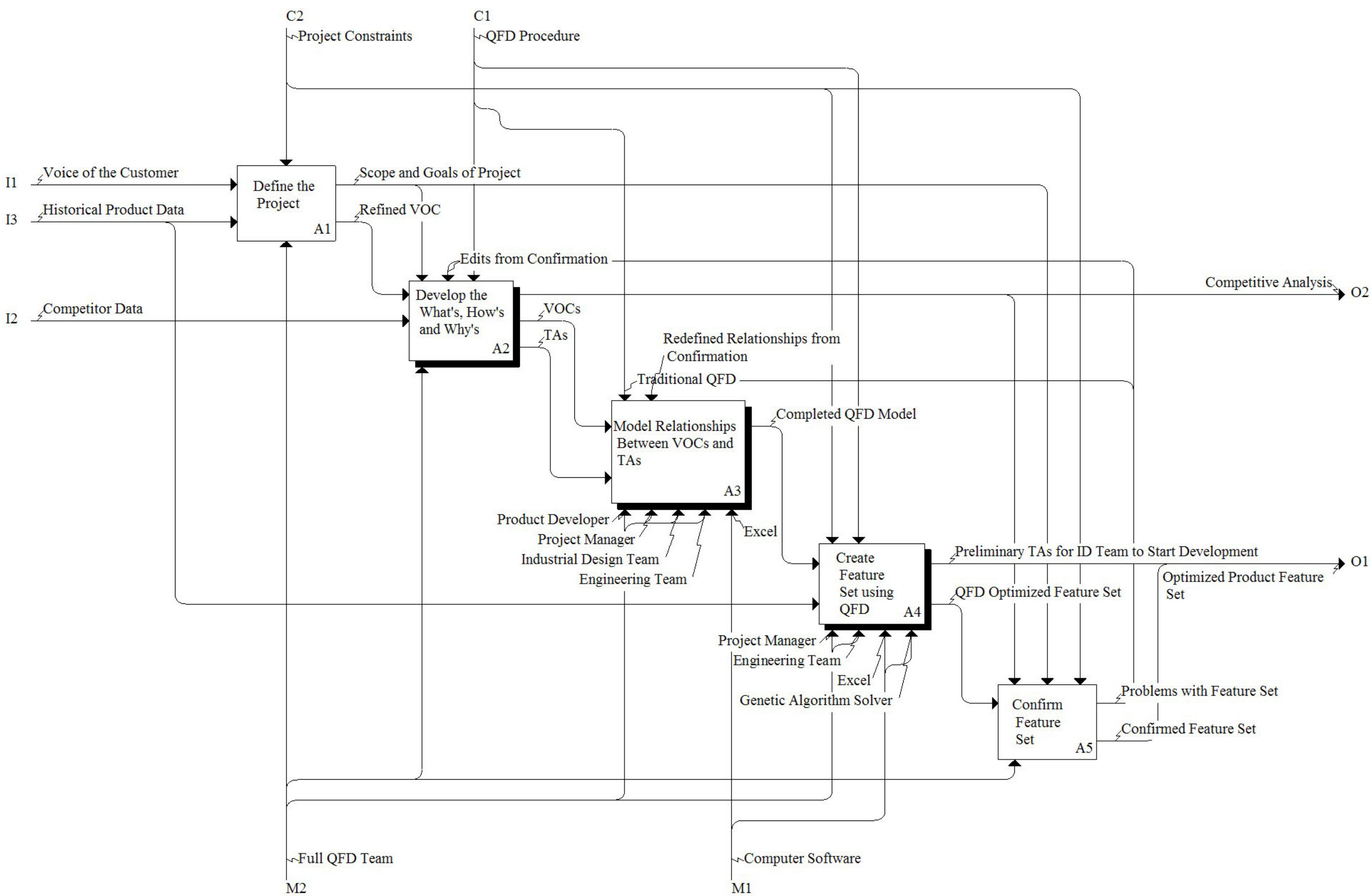


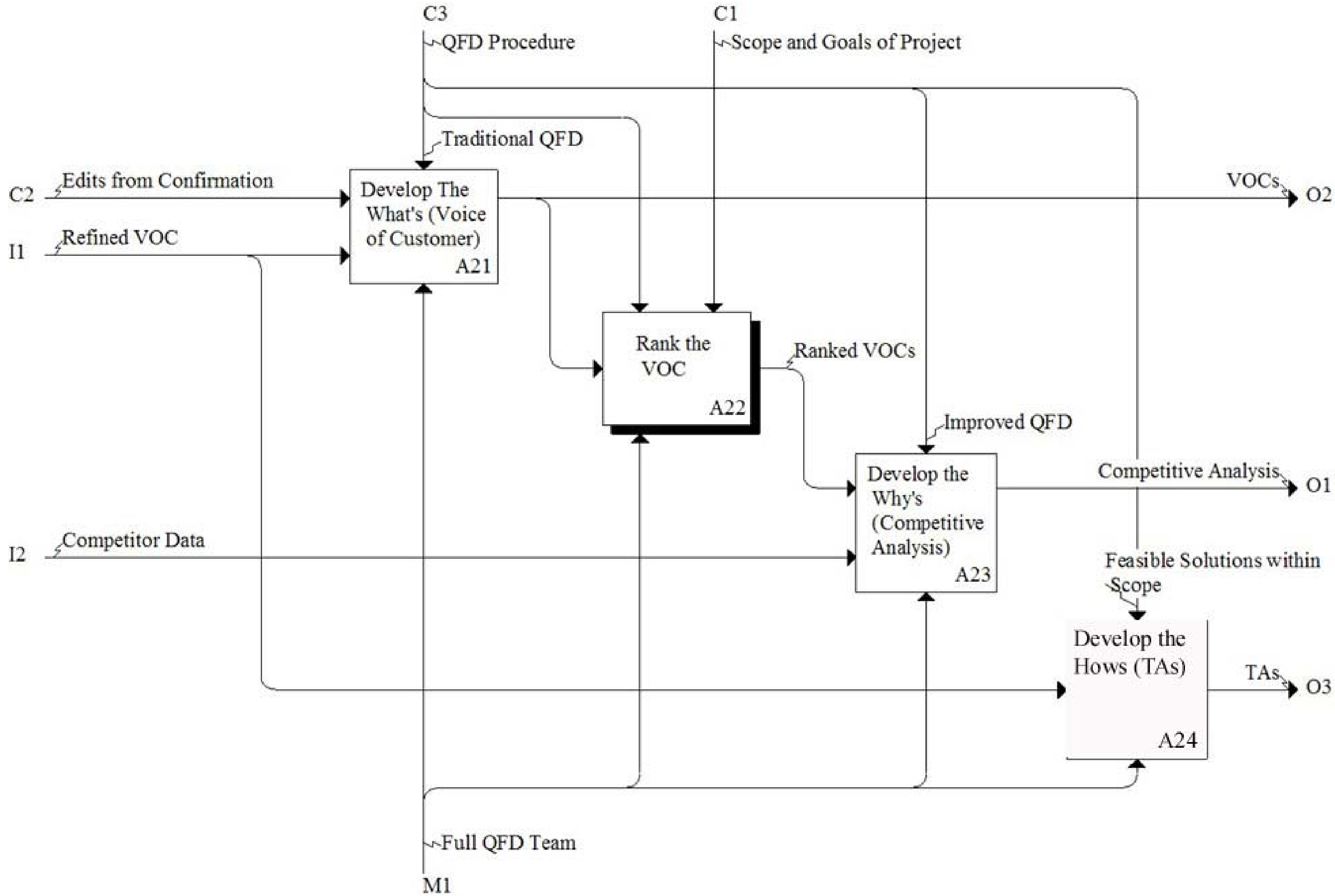
Appendix D: IDEF0 Model.

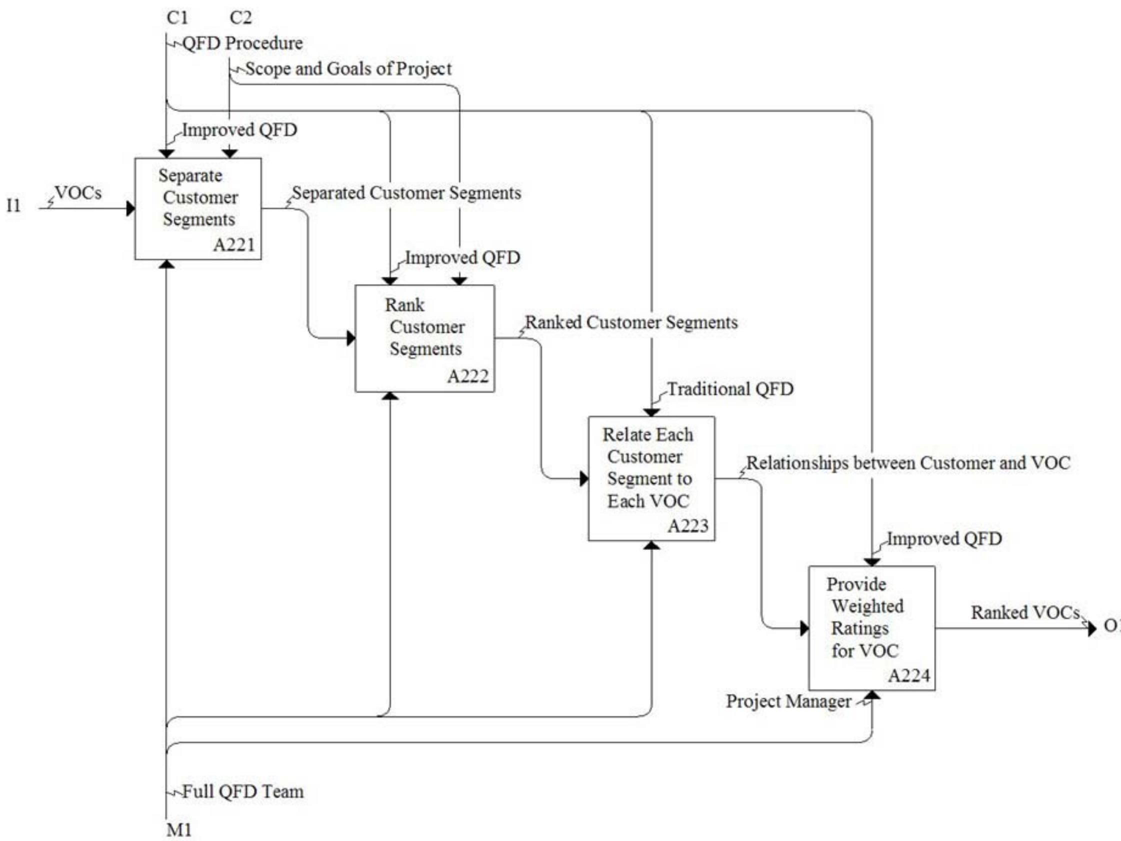
The following diagrams can be used to describe the activities conducted to define a feature set using the QFD Procedure. Inputs to the model include the voice of the customer, competitor data, and historical product data. The QFD procedure, traditional and modified, and project constraints control the defined feature set. The QFD team and computer software are the mechanisms. The goal is to output the optimized feature set and a detailed competitor analysis.

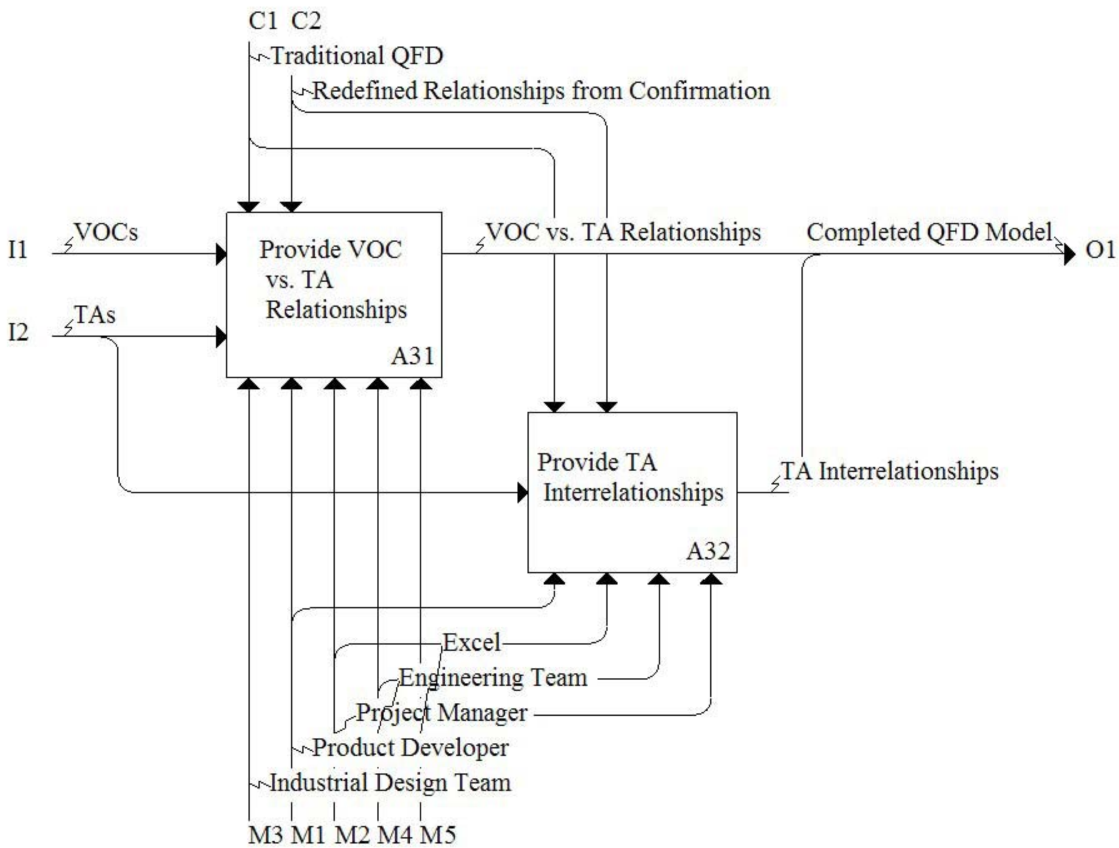
All block diagrams are a breakdown of the respective parent diagram. For example, block A2 is broken down in the diagram containing blocks A2X where X is 1 to 4. The inputs, controls, mechanisms, and outputs can be bundled together or split but are all a part of the items contained in block A0 listed below.

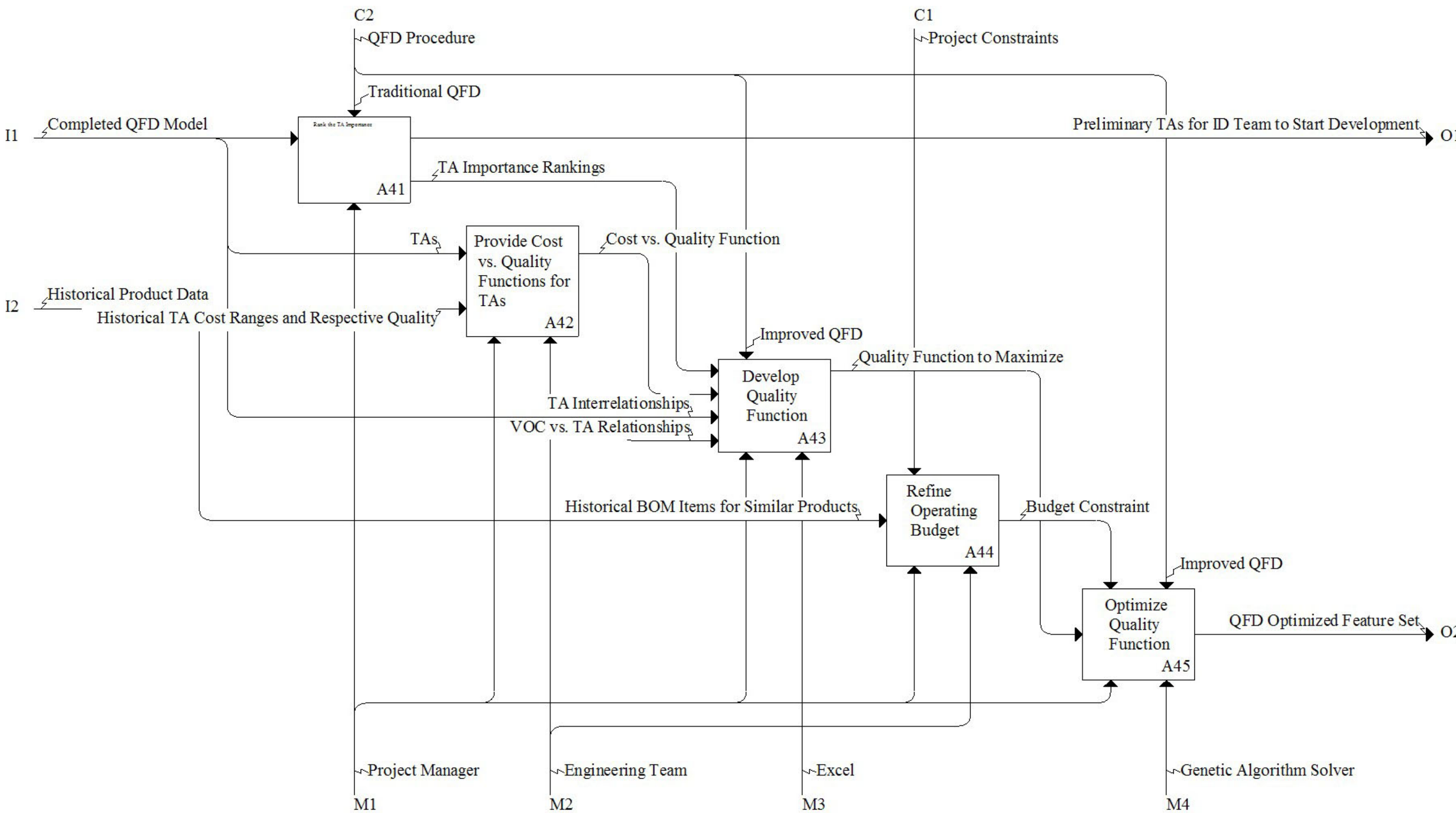



C2
Project Constraints
C1
QFD Procedure
I1
Voice of the Customer
I3
Historical Product Data
I2
Competitor Data
Define the Project
A1
Scope and Goals of Project
Refined VOC
Edits from Confirmation
Develop the What's, How's and Why's
A2
Competitive Analysis
O2
VOCs
TAs
Redefined Relationships from Confirmation
Traditional QFD
Model Relationships Between VOCs and TAs
A3
Completed QFD Model
Product Developer
Project Manager
Industrial Design Team
Engineering Team
Excel
Create Feature Set using QFD
A4
Preliminary TAs for ID Team to Start Development
O1
Optimized Product Feature Set
QFD Optimized Feature Set
Project Manager
Engineering Team
Excel
Genetic Algorithm Solver
Confirm Feature Set
A5
Problems with Feature Set
Confirmed Feature Set
Full QFD Team
M2
Computer Software
M1


C3
QFD Procedure
C1
Scope and Goals of Project
Traditional QFD
C2
Edits from Confirmation
Develop The What's (Voice of Customer)
A21
VOCs
O2
I1
Refined VOC
Rank the VOC
A22
Ranked VOCs
Improved QFD
Develop the Why's (Competitive Analysis)
A23
Competitive Analysis
O1
I2
Competitor Data
Feasible Solutions within Scope
Develop the Hows (TAs)
A24
TAs
O3
Full QFD Team
M1


C1
C2
QFD Procedure
Scope and Goals of Project
Improved QFD
I1
VOCs
Separate Customer Segments
A221
Separated Customer Segments
Improved QFD
Rank Customer Segments
A222
Ranked Customer Segments
Traditional QFD
Relate Each Customer Segment to Each VOC
A223
Relationships between Customer and VOC
Improved QFD
Provide Weighted Ratings for VOC
A224
Ranked VOCs
O1
Project Manager
Full QFD Team
M1


C1 C2
Traditional QFD
Redefined Relationships from Confirmation
I1
VOCs
I2
TAs
Provide VOC vs. TA Relationships
A31
VOC vs. TA Relationships
Completed QFD Model
O1
Provide TA Interrelationships
A32
TA Interrelationships
Excel
Engineering Team
Project Manager
Product Developer
Industrial Design Team
M3 M1 M2 M4 M5



C2
QFD Procedure
C1
Project Constraints
Traditional QFD
I1
Completed QFD Model
Rank the TA Importance
A41
Preliminary TAs for ID Team to Start Development
O1
TA Importance Rankings
TAs
Provide Cost vs. Quality Functions for TAs
A42
Cost vs. Quality Function
I2
Historical Product Data
Historical TA Cost Ranges and Respective Quality
Improved QFD
Quality Function to Maximize
Develop Quality Function
A43
TA Interrelationships
VOC vs. TA Relationships
Historical BOM Items for Similar Products
Refine Operating Budget
A44
Budget Constraint
Improved QFD
Optimize Quality Function
A45
QFD Optimized Feature Set
O2
Project Manager
M1
Engineering Team
M2
Excel
M3
Genetic Algorithm Solver
M4