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Improving Product Design Using Quality Function Deployment: The School Furniture Case in Developing Countries

Marvin E. González,[1,*] Gioconda Quesada,[2] and A. Terry Bahill[3]

[1]Operations and Technology, Instituto de Empresa, Madrid, Spain
[2]Information Systems and Operations Management Department, The University of Toledo, Toledo, Ohio, USA
[3]Systems and Industrial Engineering, University of Arizona, Tucson, Arizona, USA

ABSTRACT

This paper presents a quality function deployment (QFD) analysis of the design of school furniture in developing countries, using Costa Rica as the baseline. The dynamic hierarchy process model for QFD was used to help the product development team make effective decisions in satisfying the requirements of the customer constrained by limited resources.

A number of total quality management (TQM) tools were employed during the development of the school furniture solution. A dynamic, cross-functional team organization was used. A simple form of quality function deployment was used to identify the desirable product design, safety, and service features.

Key Words: Quality function deployment (QFD); Concurrent engineering; Sensitivity analysis; Total quality management.

INTRODUCTION

Educating children has long been regarded as an important element of economic improvement in developing countries. Although well-designed school furniture has been shown to contribute to the learning process, school furniture used in these countries often hobbles rather than facilitates education. Moreover, the furniture is of low quality, has rough writing surfaces, falls apart quickly, and does not fit the children, yet it is relatively costly and consumes a disproportionate amount of limited educational budgets. A detailed description of the school furniture problem in Costa Rica is described later in this paper.

The purpose of this project is to address the school furniture problem in the areas of functionality, material, structure, production, ergonomics, and aesthetics. The specific objective of the project is identifying the most

*Correspondence: Marvin E. González, Operations and Technology, Instituto de Empresa, Madrid, Spain 28006; Fax: 34-91-561-0930; E-mail: Marvin.Gonzalez@ie.edu.

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important variables in order to create designs that are ergonomically correct, strong, durable, low maintenance, low cost, and can be made by local industries from locally available materials.

The organization of the paper is as follows. First, we describe the general problem of the school furniture in Costa Rica. After this, we explain the methodology used in the present study along with general concepts of quality function deployment (QFD), followed by a literature review that will help theoretically support our practical results. Then, we describe the QFD application in the school furniture problem. It is important to emphasize that we describe in detail the development of the house of quality (first stage in a QFD project) since the following houses or stages follow a similar procedure. Therefore, for the last three stages or houses, we briefly mention them and present them in the figures. Finally, we present the conclusions reached by the project.

BACKGROUND OF THE SCHOOL FURNITURE PROBLEM IN COSTA RICA

A recent study of school furniture in Costa Rica by González et al. (1998) showed that only 0.005% of the National Budget for Education is used for new furniture. A shortage of 100,000 pieces of furniture was found. Costa Rican children spend 7 hours per day (35 hours per week) in classrooms. Therefore, the Costa Rican national government is looking for better, faster, and cheaper solutions for school furniture design and manufacturing, in order to reduce stress on the children and optimize school budgets.

The most important considerations of this study were mismatches between the children's anthropometrics and the dimensions of the school furniture that could cause pain and discomfort or chronic muscle–skeletal disorders. School children are particularly at risk, because of the wide range of body size, the prolonged seated posture, and the possible adverse developmental effects of prolonged exposure to postural stresses. In this study, we have tried to determine whether the reports of discomfort can be related to mismatches between anthropometrics of the children and the dimensions of the tables and chairs. Two hundred and twenty-four students from four schools were studied. These students were from three different grades (ages approximately 12, 14, and 16 years, respectively). Seven anthropometric measures were made on each student. The students answered a questionnaire, which asked about pain and discomfort experienced at school, habitual study, sports and other activities, and whether the pain had restricted any activities. The classroom furniture used by each group of students was measured, and these measurements were linked to the related anthropometric measures (e.g., seat depth and thigh length, seat height and lower-leg length). The data were analyzed using chi-square and t-tests. There was a high incidence of reported pain and discomfort, 55% at the 5% level of confidence (González et al., 1998).

The most important relationships were due to mismatches between thigh length and seat depth, which was significantly related to general seated discomfort, and mismatches between the seated elbow height and the desk height, which was significantly related to pain in the shoulders and neck. The high level of reported pain and discomfort is a matter for considerable concern and warrants further investigation. The failure of anthropometric mismatches to fully account for the expressed pain suggests that other factors contributing to postural discomfort need to be found.

LITERATURE REVIEW

Quality function deployment has been used to translate customer needs and wants into technical requirements in order to increase customer satisfaction (Akao, 1990). Quality function deployment utilizes the house of quality, which is a matrix providing a conceptual map for the design process, as a construct for understanding customer requirements (CRs) and establishing priorities of technical requirements (TRs) to satisfy them (Gonzalez, 2001).

According to Gonzalez (2001), QFD is a product development process that stresses cross-functional integration. Kim et al. (1998) stated that QFD brings the following advantages to companies: fewer and earlier design changes, reduced product development cycle time, fewer startup problems, and, above all, customer satisfaction. Armacost et al. (1992) describe an analytic hierarchy process (AHP) framework that has been established for prioritizing requirements. Franceschini and Rupil (1999) illustrate how the priority rank of design characteristics can change depending on the type of scales used. According to Ghiya et al. (1999), most Americans associate QFD with the "house of quality." As discussed here, QFD contains far more. Clausing and Pugh (1991) and Kim et al. (1998) provide more extensive and complete views. Dean (1993) views QFD as a system engineering process, which transforms the desires of the customer into the language required for implementing a product. It also provides the glue necessary to tie it all together. Finally, it is an excellent method for assuring that the customer obtains high value from the product. Mizuno and Akao (1994), in their book, indicate that QFD is far more than has previously been disclosed. It is clearly the mechanism for deploying quality, reliability, cost, and technology throughout the product, the project to bring forth the product, and the enterprise as a whole.

Using QFD, there are two issues in the analysis of the customer requirements. First, customer requirements are often described informally using vague terms (remember that the source of information in our case is children). However, lack of a formal method for interpreting the semantics of these requirements makes it difficult to determine if a realization of the system meets its customer's needs. Second, identifying relationships between requirements is often time consuming. Sometimes, it is difficult to arrive at a group consensus on a particular relationship between requirements (Mazur, 1991a,b).

Quality, as well as ergonomics, aims at meeting the demands of the customer. A high-quality product therefore may be regarded as an ergonomic product—a product adapted to human abilities and limitations (González et al., 1998). According to Nakui (1991), a number of methods have been developed aimed at simplifying and making the product development more efficient. These methods could be used in ergonomics. Quality function deployment is a well-known and systematic method based on the idea of adapting technology to people, a method that determines the voice of the customers and examines the company response to this voice through and organized team approach (Day, 1993).

Quality function deployment adopts a customer-driven approach and provides a structured way to ensure that the final product meets customer requirements (Parasuraman et al., 1985). The first QFD chart links customer attributes and technical requirements through a two-dimensional diagram.

Akao (1990) introduced QFD in Japan in 1966. He said QFD is a method for translating the consumer's demand into design targets and major quality assurance points to be used throughout the production phase. Quality function deployment is a way to assure the design quality while the product is still in the design stage (Armacost et al., 1992). As an important side benefit, Akao (1990) states that QFD has produced reductions in development time of one half to one third.

Sullivan (1986) says that the main objective of any manufacturing company is to bring products to market sooner than the competition with lower cost and improved quality and that QFD can help do this. Quality function deployment provides a means of translating customer requirements into the appropriate technical requirements for each stage of product development (i.e., marketing strategies, planning, product design and engineering, prototype evaluation, production process development and production, sales). In QFD, all operations are driven from the *voice of the customer*; QFD therefore represents a change from manufacturing-process quality control to product-development quality control. Quesada (1997) showed several examples of using TQM tools in order to discover the customer needs and designed a methodology for prioritization of these expectations.

Sullivan (1986) notes that QFD has been used by Toyota since 1977, following four years of training and preparation. Results have been impressive. Between 1977 and 1984, Toyota Auto-body introduced four new van-type vehicles. Using 1977 as a base, Toyota reported a 20% reduction in startup costs on the launch of the new van in 1979, a 38% reduction in 1982, and a cumulative 61% reduction at 1984. During this period, the product development cycle (time to market) was reduced by one third with a corresponding improvement in quality, because of a reduction in the number of engineering changes.

Most of the literature on QFD is too simplified to learn what it is or how to use it. On the other extreme, it is difficult for a novice to launch into the real thing [See Mizuno and Akao (1994)]. The Japanese articles tell us where they were some years ago and where we need to be now in the development and improvement of QFD applications. Addresses for a number of companies providing QFD software can be found in Scheurell (1992) and Sorli et al. (1993) provide guidelines for implementing QFD.

Several researchers have been working on approaches for quality function deployment (Anon, 1994; Day, 1991; Mazur, 1991; Parasuraman et al., 1988; Quinlan, 1991) and developed a number of interesting Q1 models and applications using QFD as solution tool. Also, several researchers have been publishing different applications in QFD (Bahill and Chapman, 1993; Berglund, 1993; Bergquist and Aberysekera, 1996).

RESEARCH METHODOLOGY

The methodology used in the project presented in F1 this paper is shown in Fig. 1. During the stages described in the methodology, we used people from several disciplines so that we could gather important information

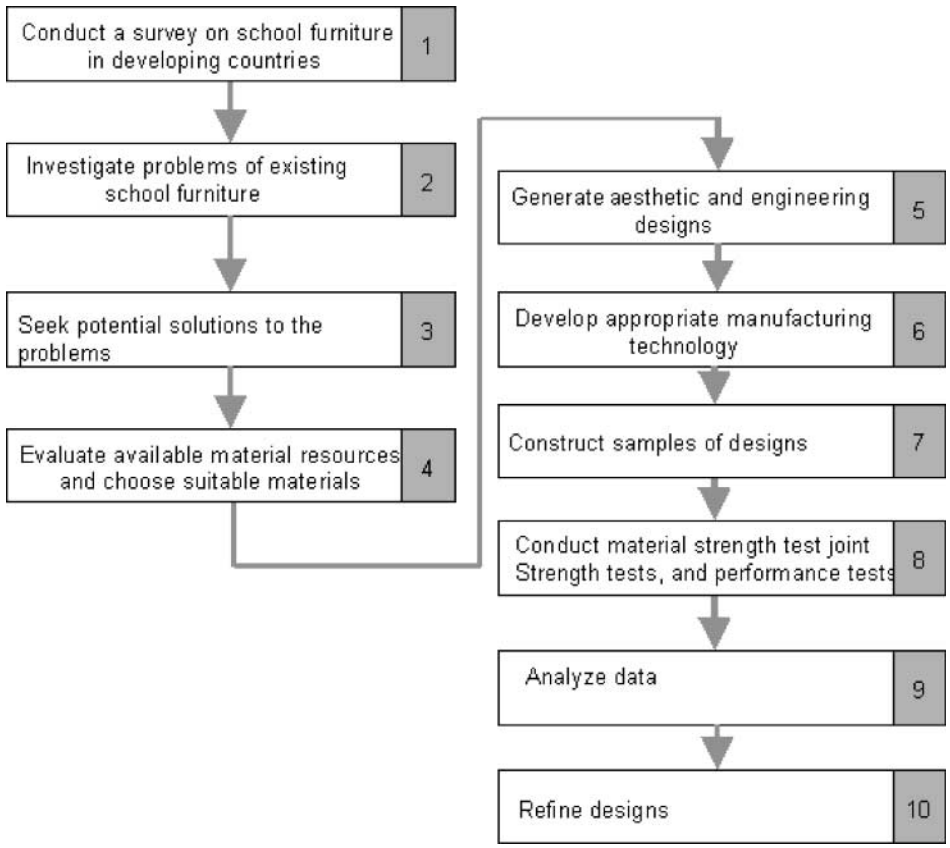

Figure 1. Methodology applied.

from all perspectives, from engineering to design. In this paper, we are focusing in stage 2 and stage 3, since it is in these two stages that we implemented the QFD methodology. The purpose of applying QFD was to define the most important variables and characteristics for the final product based on the customers' voice. As it is known worldwide, QFD is a tool for ensuring that the voice of the customer is deployed throughout the product planning and design stages (Franceschini and Rupil, 1999).

Quality function deployment uses four "houses" (represented in Fig. 2 by stages) to integrate the informational needs of marketing, engineering, research and development, and manufacturing and management (Gonzalez, 2001) and is most commonly known by its first phase or house, usually called "the house of quality." We are specifically interested in describing the first stage of QFD for the scope of this paper, since it translates customer needs for a product into technical requirements (i.e., product design specifications). The following houses or stages are presented in the figures without detailed description of the development process, since they are built in a similar way as the first house. Further explanation of the construction of all four stages of QFD is found in Gonzalez (2001). The challenges presented by the QFD team were combined with identified design for assembly and design for manufacturing principles to create the project schedule and a flow plan for concurrent engineering. Statistical process control of critical machined dimensions was introduced to avoid tolerance stack-up and performance variability. In order to help the product development team make effective decisions in satisfying the requirements of the customer within the constraints of limited resources, the dynamic hierarchy process model for QFD was used (Gonzalez, 2001). This model fully utilizes all the information of the house of quality, including the planning matrix for customer requirements, the relation matrix between customer requirements and technical requirements, and the correlation matrix of technical requirements (see Fig. 3).

The development of the house of quality can be considered as a five-step process, as described in Fig. 3. The first step, voice of the customers (VOC), is a direct retrieval of the customer requirements. This could be

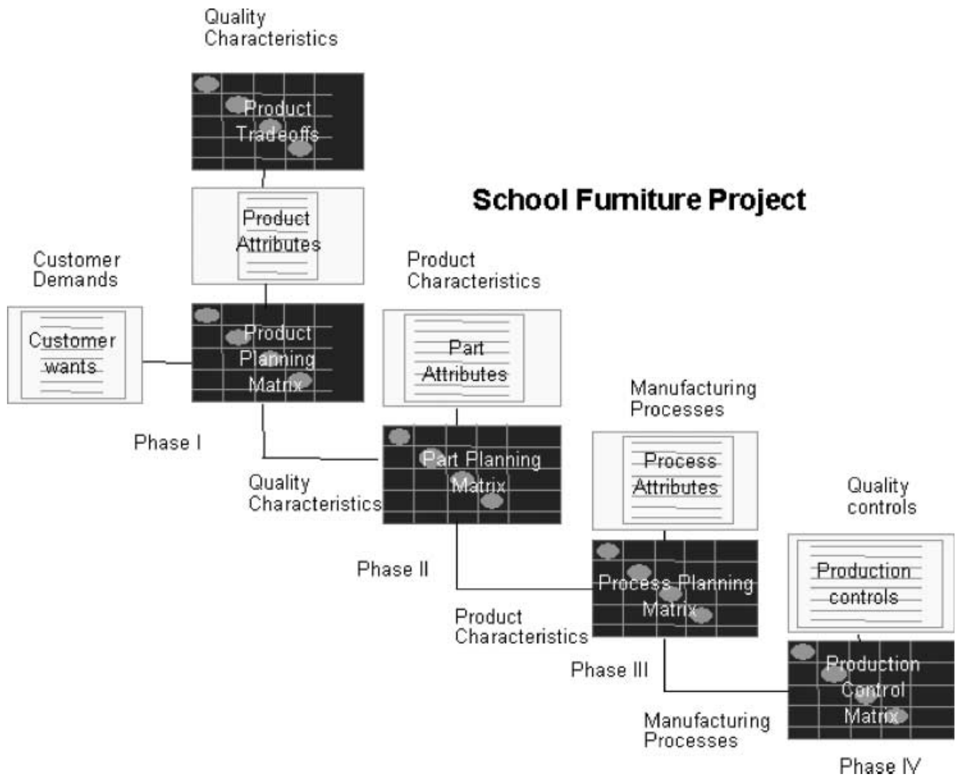

Figure 2. Roadmap of the QFD project.

done by opened or closed interviews or surveys. It is important not to lead the customers to the desired answers but to allow them to express to the company what they really want. The second step, "classification and quantification of the VOC," is a concise and applicable qualitative description and the corresponding quantitative presentation of the customers' requirements. We propose both dynamic analysis and factor analysis methods in order to obtain the final importance ratings of the customer needs. As expressed by Hair et al. (1998), a factor analysis can be utilized to examine the underlying patterns or relationships for a large number of variables (as the ones given by the customers) and to determine whether the information can be condensed or summarized in a smaller set of factors or components. Applied to our case, we used factor analysis in order to classify the different requirements of the customers so that we could decrease the number of variables in the house of quality. Regarding the dynamic analysis method, we can assign a numerical value to the different relationships among variables. Therefore, the use of factor analysis in conjunction with dynamic analysis will allow us to organize the customer requirements in groups of variables that will be easy to identify and define and that will have numerical meaning for further quantitative analysis. There are other methods for technical requirements prioritization, as shown by Franceschini and Rossetto (1995) and Franceschini and Rupil (1999), instead of dynamic analysis; however, the innovative approach of our analysis is to merge two strong statistical tools such as factor analysis and dynamic analysis.

The third step in the development of the house of quality is building the horizontal part of the matrix, which is related to the customer requirements. This step is based on the information analyzed in the previous step and is to be include in a structured way into the matrix. Other information is required such as level of importance, competitor evaluation on these requirements versus our evaluation from the customers, and other ratios that are explained in detail in Quesada (1997). The fourth step is to build the vertical part of the matrix that concerns the customer requirements and technical requirements. More specifically, we translate the customer requirements into technical requirements understandable by the engineering and design experts. We also assign the degree of the relationship between customer and technical requirements (strong, moderate, and weak) in the middle of the matrix. Finally, the fifth and last step is to analyze the house of

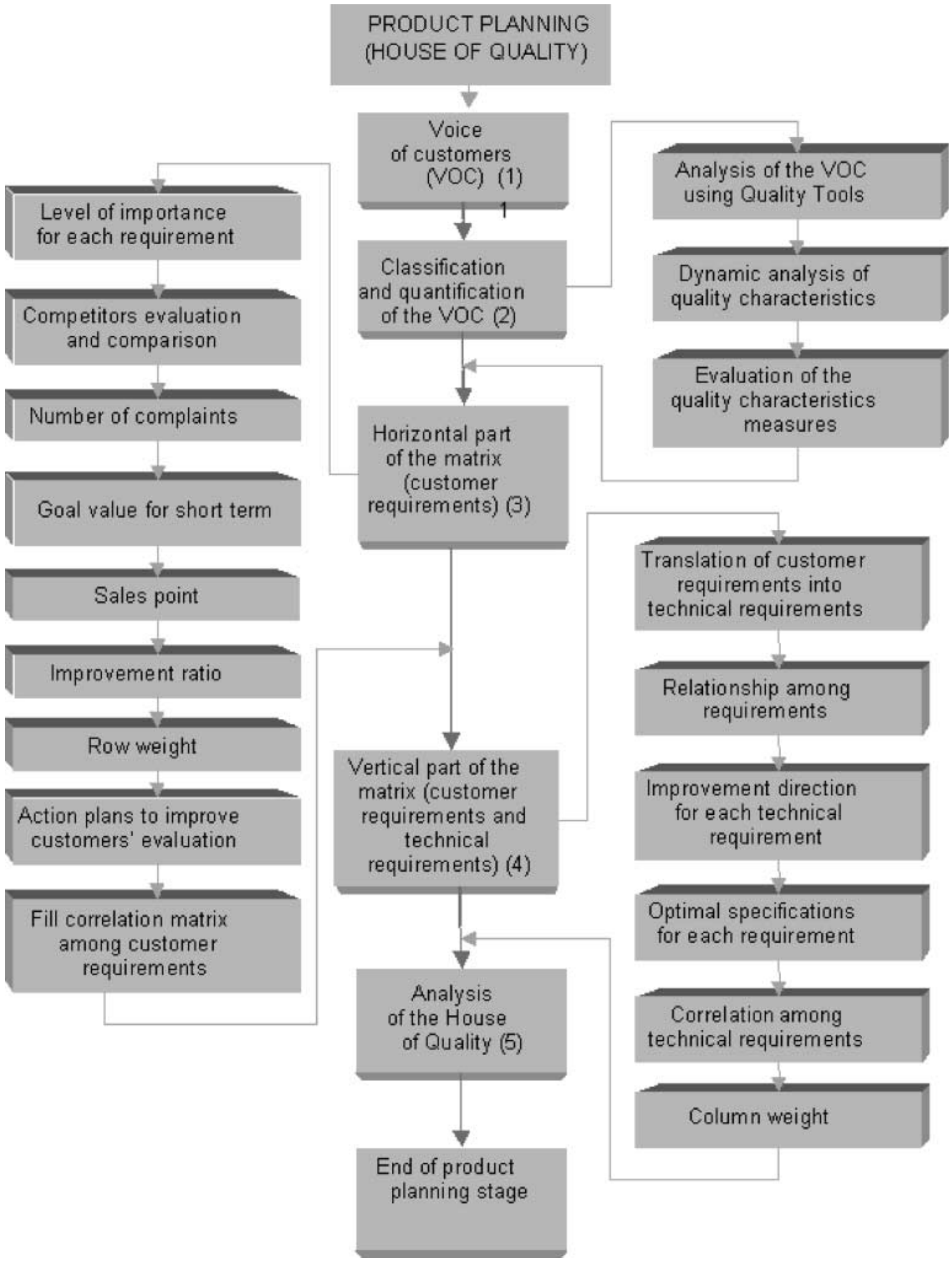

Figure 3. The house of quality methodology (Quesada, 1997).

quality. This stage is very important since we will determine which customer requirements will be implemented into the process as technical requirements due to their importance for the customers. There will be some customer requirements that are really impossible or very expensive to implement in the process; therefore, a decision should be made in order to determine which technical requirements will continue in the analysis of the other matrixes of QFD. A more detailed explanation of the process of building the house of quality is found in Quesada (1997).

This paper suggests a knowledge-based approach to building a QFD project and the identification and presentation of the most important factors in the school furniture process. The detailed scientific analysis was accomplished with the aid of QFD (phase I, II, III, and IV). The common requirements, characteristics, and parameters of change management were entered into a full QFD matrix as what's and how's ("what" needs to be done and "how" it can be achieved). This led to a list of factors ranked in order of importance and prioritized. The importance number (weighting factor) entered into the QFD matrix for the what's was calculated based on a survey gathered from 400 Costa Rican school students responding from seven different states (provinces). This research provided valuable information on the most important parameters, identified methods that needed to be changed, and secured the commitment of management to quality.

THE QFD APPLICATION

One of the major difficulties of using QFD is the large size of the charts, which increases as it increases the number of variables involved in the process. Even for a simple product design, the size can grow rapidly. This requires a large amount of time to fill out the QFD charts. The modeling approach presented in Fig. 3 provides a formal structure and solution approach to QFD for the school furniture problem. The model starts with the voice of the customer, which is translated into the house of quality as customer requirements. We used a survey applied to users (elementary, middle, and high school students). From the survey and personal interviews, we reunited 480 customer requirements (step 1 in Fig. 3). However, it is not possible nor understandable to include all of them in the matrix. Therefore, we performed different statistical analyses, such as dynamic analysis and factor analysis, in order to classify and decrease those customer requirements (step 2 in Fig. 3). In Table 1, we can see a middle step of the classification process, since we show how the 480 customer requirements were put into 28 variables. However, further data reduction is needed, as we will see in the final house of quality. For this stage, we used dynamic analysis, factor analysis, and the Delphi method (with the help of the manufacturer's design and production areas, the QFD team, and the people involved in the educational system). We ended up with two factors (chair-related requirements and table-related requirements), as shown in Fig. 4 under customer requirements, which are grouping 12 variables in total that conceive the 28 variables we mentioned before. Table 1 depicts the customer requirements that the QFD team selected from the first screening and the number of variables related to them from the original data.

Table 1. Process planning matrix.

Customer need	Variables related	Customer weighting
Unsatisfactory or unfit for intended uses	17	15
Inconveniences for changing room settings	19	16
Poor, wrong, or nonexistent production methods	17	28
Cannot serve for multiple purposes	16	14
Storing and transportation problems	15	13
Expensive imported materials	14	27
Split or delaminated boards	18	26
Rough working surfaces	18	12
Loose joints	16	23
Weak structures	14	24
Deformed shapes	14	25
Plain color	16	22
Plain shape	12	21
Flat seats	16	9
Inadequate back support	18	10
Seats, working surfaces only one height	12	11
Availability	10	17
Handicap population	22	6
Technical features	24	4
Heavy	26	3
According to population measurements	28	7
Standard design	20	18
Standardized materials	26	19
Quality control procedures	21	20
Easy to handle	25	1
Wide drawer	26	5
Wide support	24	8
Seat with foam	25	2
Total	480	

Using dynamic analysis (Gonzalez, 2001), a level of importance was assigned to each requirement. In this section of the product planning stage (step 3 in Fig. 3), the number of complaints, the different goals (targets), and the evaluation of the different competitors were considered. This matrix shows a comparison of our company's capabilities of satisfying the customer requirements with the capabilities of other companies that manufacture school furniture. Other information is summarized in the house of quality such as the sales point (the requirements in which the company has the ability to

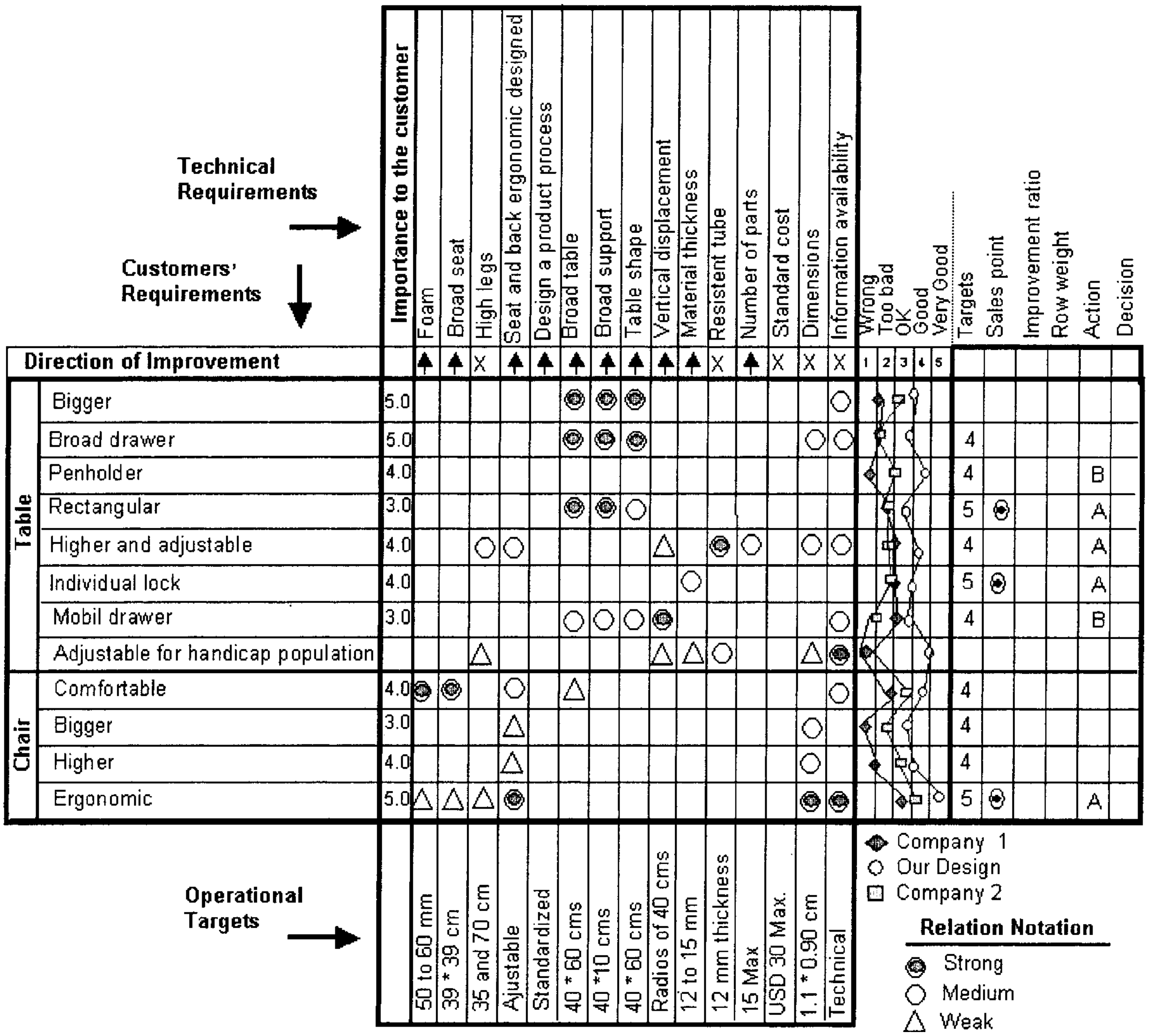

Figure 4. Users demands and prioritization.

sell the product, based on how well each customer requirement is met), the improvement ratio (relates the goal or target with the current performance measure in a specific requirement), and the raw weight (a computed value relating the importance to customer, the improvement ratio, and the sales point). All of this information will help us in determining what kind of actions to take in order to improve our customer ratings in the different customer requirements. Finally, in step 4 of Fig. 3, we translate the customer requirements (called the what's in the QFD language) into technical requirements (called the how's in the QFD language). The technical requirements are placed at the top of the house of quality. In order to determine the how's, we asked the manufacturers: This is *what* the customer wants, now *how* can we measure it? We will often associate operational target values with these measures.

The second QFD matrix is the characteristic part matrix (Fig. 5). For building this matrix, the most important input comes from the technical requirements in the house of quality (also called the planning matrix), since they become the left side of this new matrix. The importance of this matrix is that we can show a relationship among critical part characteristics, part tolerance, and also technical requirements and their respective objectives. In summary, we can show in this matrix how and in what amount the customer requirements can be a part of the process.

The QFD solution for this problem provides a structure for the manufacturing process, in order to meet the customer expectations defined in the first matrix. Figure 6

Technical requirements	Importance level	Foam	Broad seat	High legs	Seat and back with Adequate curves	Broad table	Broad support	Broad channel	Table shape	Vertical displacement	Target values
Foam	9.6	◎	◎	◎		○					50 mm
Broad seat	16.2			◎		◎					39cm x 39cm
High legs	4.5				◎					◎	35 cm - 70cm
Seat and back with Adequate curves	7.2			◎		◎					10 degrees
Broad table	15						◎		◎		40cm x 60 cm
Broad support	9.6							◎	◎		40cm x15 cm
Table shape	10.8						◎				40cm x 60cm
Material thickness	5.4						◎	◎	◎		12 m
Resistant tube	4.5			◎	◎					◎	1.2 m
Parts specifications		100-50 mm	Gr cm3	45 cm x 45 cm	40 chair 75 table	10 to 15 degrees	50 cm x 70 cm	50 cm x 15 cm	15 mm	1,2 mm	
Column weight		86.4	86.4	337.5	81	470	281	127	262	81	

Critical Parts Requirements

Relation notation: ◎ Strong; ○ Medium; △ Weak

Figure 5. Characteristic part matrix.

depicts the process planning matrix for the school furniture problem in which the technical requirements from the previous matrix (characteristic part matrix) become the new input for the left column. Here the QFD team defined the process specifications for each critical requirement and assessed the relationship between the critical requirements and specifications. Another important part in this matrix is the definition of the critical requirement process specifications. For now, a standardized design process can be used in Costa Rican furniture industries in the development and manufacture of the school furniture.

Finally, using the information that comes from matrices 1, 2, and 3 (Figs. 4, 5, and 6, respectively), the production requirement matrix can be created and a detailed production plan for the elaboration of any amount of school furniture can be done. This matrix shows the different stages of the manufacturing process for both chairs and tables (see Fig. 7). Figure 7 also provides a risk analysis for each activity. Complete requirement planning is provided on this matrix along with the production organization of material and human resources needed on the construction of any piece of school furniture.

CONCLUSIONS

The school furniture case revealed that QFD theory could be a very inspiring source for improvements in a manufacturing system, helping out not only in the cost reduction but also the design of products, processes, and procedures. This paper has presented a methodology that includes nontraditional approaches in the QFD theory, such as the joint use of factor analysis and dynamic analysis. Several methods used for product development depend on cooperation between the designer and the user. In the present study, the customer requirements were crucial to the final design of the furniture. By using the QFD methodology, the customer requirements are mapped out and integrated into the total product development process.

The use of factor analysis allowed us to reduce the amount of customer requirements in a structured form, considering the previous analysis and the relationships discovered in the dynamic analysis—another concept introduced in our methodology that allowed a detailed analysis of each customer expectation. Both concepts were of great value in our analysis because they permitted us to know in detail the process and the real requirements of the customers and, in combination with other tools, to select the right groups of requirements for the house of quality analysis.

The analysis presented in this paper allowed us to find details of the design and production of new school furniture. Specifically, details related to technical parts and production requirements. This will permit us to do better strategic planning of the materials, stages, and processes required for the production of the school furniture, while minimizing the cost and improving the quality and the productivity of both the product and the process.

This paper was written for two classes of readers: QFD practitioners and school furniture designers. The QFD practitioners should have learned the use of nontraditional tools in the challenging process of finding homogeneity in the customer requirements. These tools include the hierarchy dynamic process. Quality function deployment never ends in the product-planning matrix. It goes beyond to the development of the four matrices that will make it possible to design not only a product that satisfies and exceeds customer expectations but a product that considers the limitations of the production process. The design of the four QFD matrices empowers the generation of important product and process specifications, which will impact the final product cost. The initial cost of traditional school furniture is between \$50 and \$56. The new design, based on the results of QFD, brings the cost down approximately 50% to \$29.87.

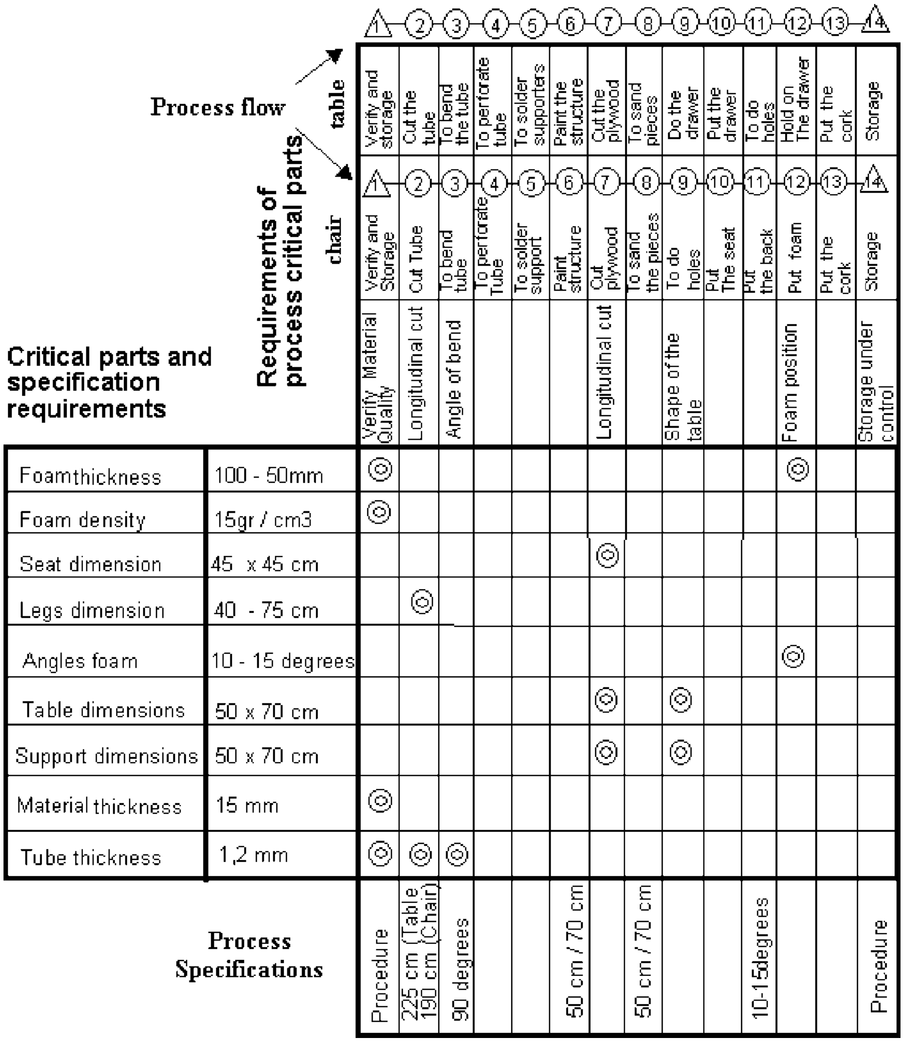

Figure 6. Process planning matrix.

The school furniture designers should have learned the following. Mismatches between thigh length and seat depth cause discomfort and mismatches between seated elbow height and desk height cause pain in the shoulders and neck. A set of product and process specifications that improve cycle times and general costs can be derived from the use of QFD. Quality function deployment also involves a production process that considers both the customers' expectations and the technical requirements for the product, design, and materials of the furniture. It is undoubtedly a design tool that addresses both the desires of the customer and the real limitations of the production process.

ABOUT THE AUTHORS

Dr. Gonzalez is a professor at the Instituto de Empresa. He received his Ph.D. from Purdue University; MIS from ITESM, Mexico; and B.S. in industrial engineering from ITCR, Costa Rica. He is the author of the book, *QFD: A Road for Listening the Customer Expectations*. He is currently engaged as investigator on the IMSS project that involves an evaluation on best manufacturing strategies and practices in the world.

Gioconda Quesada, M.S., is an ABD in manufacturing management and information systems

MODEL # _____ PRODUCT NAME: :Furniture School, New Model 2000 DATE : 12/12/99

PROCESS STAGES		Key factor to be considered on the process	Risk analysis				Planning needs							Notes	Person in charge	Date
							Tools	Manufacturing			Quality Control					
CHAIR	TABLE		Occurrence	Security	Detection difficulty	Risk factor	Training Maintenance	Trained operator	Instruction of operator	Adequate technology	Supplier agreement	Parts dimension	Procedure			
Verify and storage	Verify and storage	Verify the material when arrive	1	5	2	10		●	●		●		●	To do a report	Storage manager	
Cut tube	Cut tube	Cut longitude	1	5	2	10	●	●	●	●		●	●		Production manager	
To bend tube	To bend tube	Degree to bend	1	5	2	10	●	●	●	●		●	●		Production manager	
To perforate tube	To perforate tube															
To solder supports	To solder supports															
Structure paint	Structure paint															
Cut plywood	Cut plywood	Degree to bend	1	5	2	10	●	●	●	●		●	●		Production manager	
To sand pieces	To sand pieces															
To do holes	To do drawer	Geometrical shape of the table	1	3	1	3		●	●			●	●		Production manager	
Put seat	Put drawer															
Put back	To do holes															
Put the foam	Hold on the drawer	Degree position of the foam	3	3	1	9		●	●			●	●		Production manager	
Put the cork	Put the cork															
Storage	Storage	Storage using the procedure	1	3	1	3		●	●				●		Storage manager	

● Person in charge

Figure 7. Production requirement matrix.

at the University of Toledo. During the last two years, she has worked as an adjunct professor at the graduate business school in Instituto de Empresa, Spain. She focuses her current research in information systems and supply chain management.

Dr. Terry Bahill is a professor at the University of Arizona. He received his Ph.D. from the University of California, his M.S. from San Jose State University, and his B.S. from the University of Arizona. Bahill has over 200 publications. Over the past decade, he has spent 36 months working on IPD and systems engineering with several industrial companies in Arizona, New Mexico, Minnesota, Washington, and Idaho.

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