

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

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### 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

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

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

## 74 BACKGROUND OF THE SCHOOL FURNITURE 75 PROBLEM IN COSTA RICA

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

87 The most important considerations of this study  
88 were mismatches between the children's anthropo-  
89 metrics and the dimensions of the school furniture that  
90 could cause pain and discomfort or chronic muscle-  
91 skeletal disorders. School children are particularly at  
92 risk, because of the wide range of body size, the  
93 prolonged seated posture, and the possible adverse  
94 developmental effects of prolonged exposure to postural  
95 stresses. In this study, we have tried to determine whether  
96 the reports of discomfort can be related to mismatches  
97 between anthropometrics of the children and the  
98 dimensions of the tables and chairs. Two hundred and  
99 twenty-four students from four schools were studied.  
100 These students were from three different grades (ages  
101 approximately 12, 14, and 16 years, respectively). Seven  
102 anthropometric measures were made on each student.  
103 The students answered a questionnaire, which asked  
104 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 anthropo-  
metric 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

## Quality Function Deployment

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105 necessary to tie it all together. Finally, it is an excellent  
 106 method for assuring that the customer obtains high value  
 107 from the product. Mizuno and Akao (1994), in their  
 108 book, indicate that QFD is far more than has previously  
 109 been disclosed. It is clearly the mechanism for deploying  
 110 quality, reliability, cost, and technology throughout the  
 111 product, the project to bring forth the product, and the  
 112 enterprise as a whole.

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

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

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

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

154 Sullivan (1986) says that the main objective of any  
 155 manufacturing company is to bring products to market  
 156 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 Aberyssekera, 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

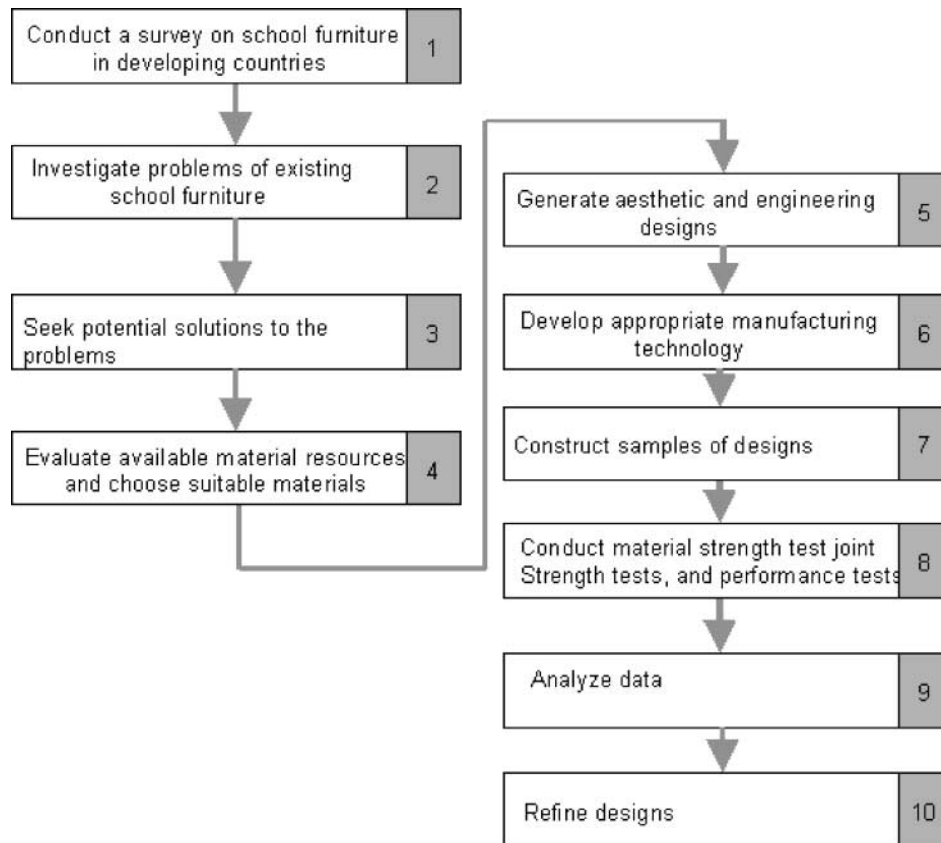


Figure 1. Methodology applied.

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

## Quality Function Deployment

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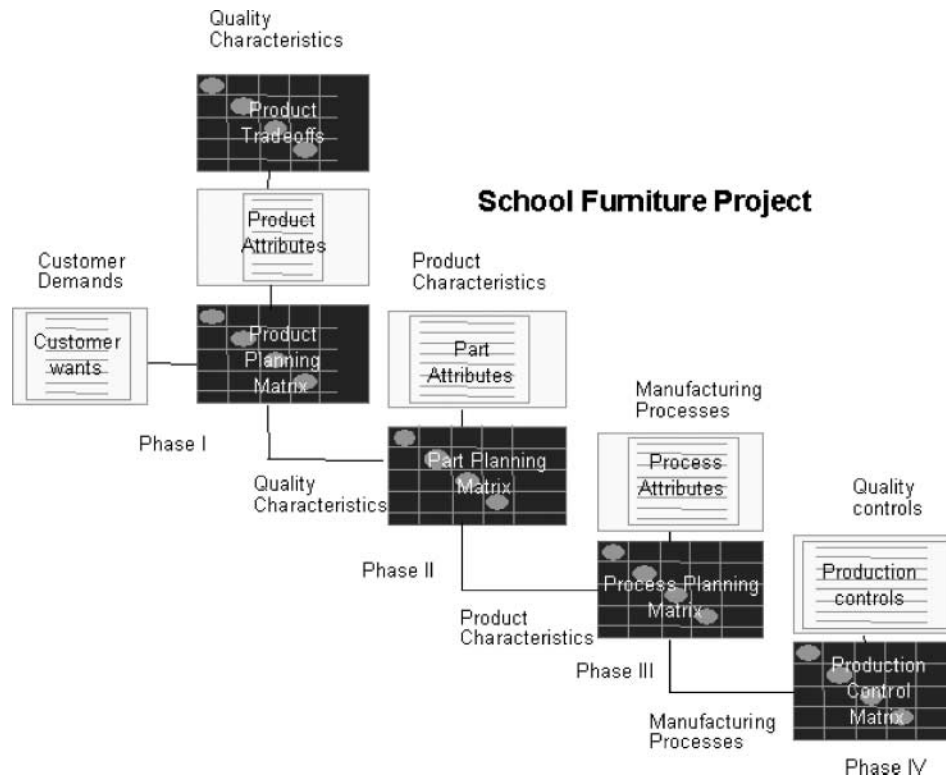
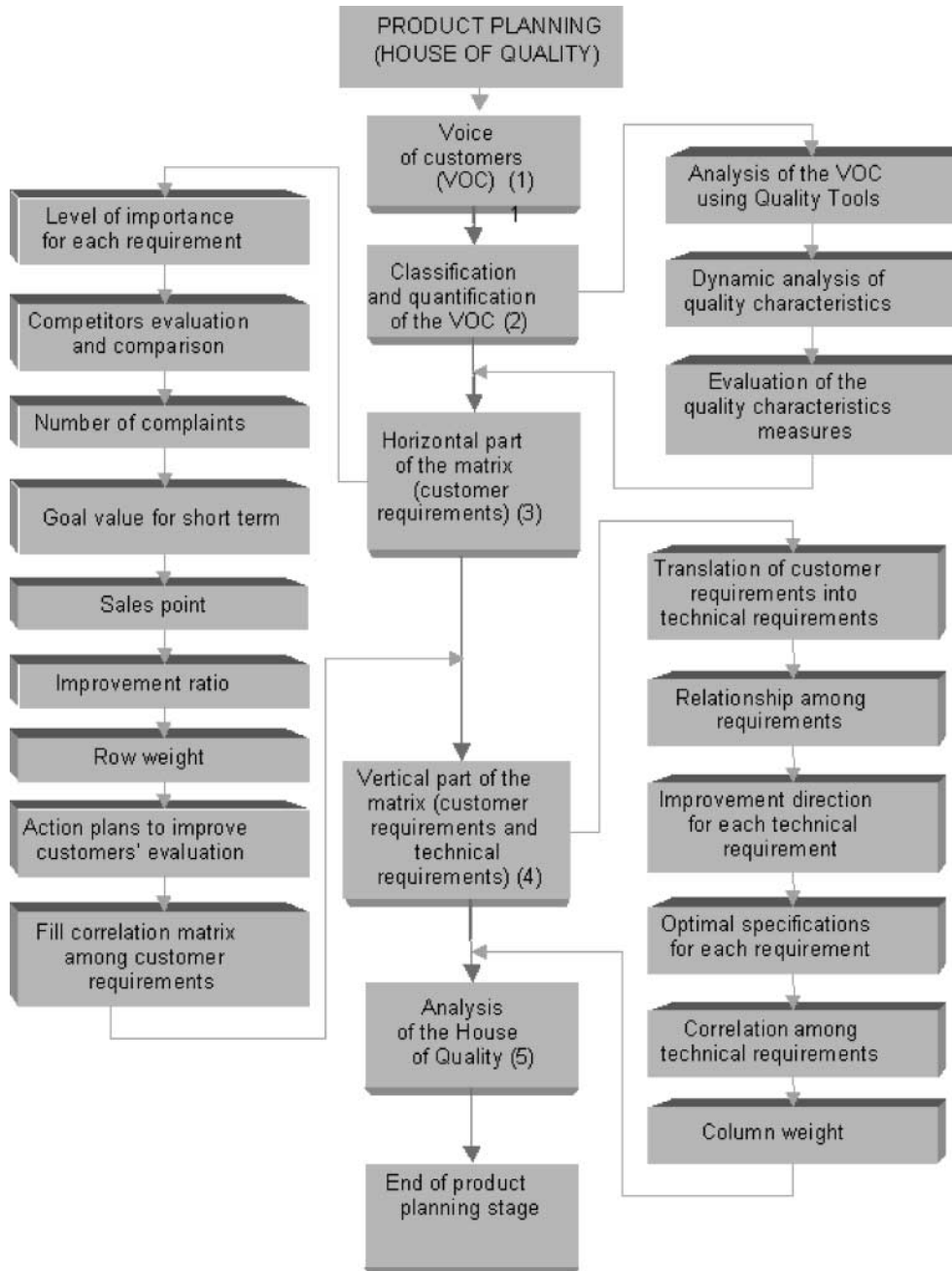


Figure 2. Roadmap of the QFD project.

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 included 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



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

306 quality. This stage is very important since we will  
307 determine which customer requirements will be  
308 implemented into the process as technical requirements  
309 due to their importance for the customers. There will be  
310 some customer requirements that are really impossible or  
311 very expensive to implement in the process; therefore, a  
312 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

313 furniture process. The detailed scientific analysis was  
 314 accomplished with the aid of QFD (phase I, II, III, and  
 315 IV). The common requirements, characteristics, and  
 316 parameters of change management were entered into a  
 317 full QFD matrix as what's and how's ("what" needs to be  
 318 done and "how" it can be achieved). This led to a list of  
 319 factors ranked in order of importance and prioritized. The  
 320 importance number (weighting factor) entered into the  
 321 QFD matrix for the what's was calculated based on a  
 322 survey gathered from 400 Costa Rican school students  
 323 responding from seven different states (provinces). This  
 324 research provided valuable information on the most  
 325 important parameters, identified methods that needed to  
 326 be changed, and secured the commitment of management  
 327 to quality.

### 330 THE QFD APPLICATION

332 One of the major difficulties of using QFD is the  
 333 large size of the charts, which increases as it increases the  
 334 number of variables involved in the process. Even for a  
 335 simple product design, the size can grow rapidly. This  
 336 requires a large amount of time to fill out the QFD charts.  
 337 The modeling approach presented in Fig. 3 provides a  
 338 formal structure and solution approach to QFD for the  
 339 school furniture problem. The model starts with the voice  
 340 of the customer, which is translated into the house of  
 341 quality as customer requirements. We used a survey  
 342 applied to users (elementary, middle, and high school  
 343 students). From the survey and personal interviews, we  
 344 reunited 480 customer requirements (step 1 in Fig. 3).  
 345 However, it is not possible nor understandable to include  
 346 all of them in the matrix. Therefore, we performed  
 347 different statistical analyses, such as dynamic analysis  
 348 and factor analysis, in order to classify and decrease  
 349 those customer requirements (step 2 in Fig. 3). In Table 1,  
 350 we can see a middle step of the classification process,  
 351 since we show how the 480 customer requirements were  
 352 put into 28 variables. However, further data reduction is  
 353 needed, as we will see in the final house of quality. For  
 354 this stage, we used dynamic analysis, factor analysis, and  
 355 the Delphi method (with the help of the manufacturer's  
 356 design and production areas, the QFD team, and the  
 357 people involved in the educational system). We ended up  
 358 with two factors (chair-related requirements and table-  
 359 related requirements), as shown in Fig. 4 under customer  
 360 requirements, which are grouping 12 variables in total  
 361 that conceive the 28 variables we mentioned before.  
 362 Table 1 depicts the customer requirements that the QFD  
 363 team selected from the first screening and the number of  
 364 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

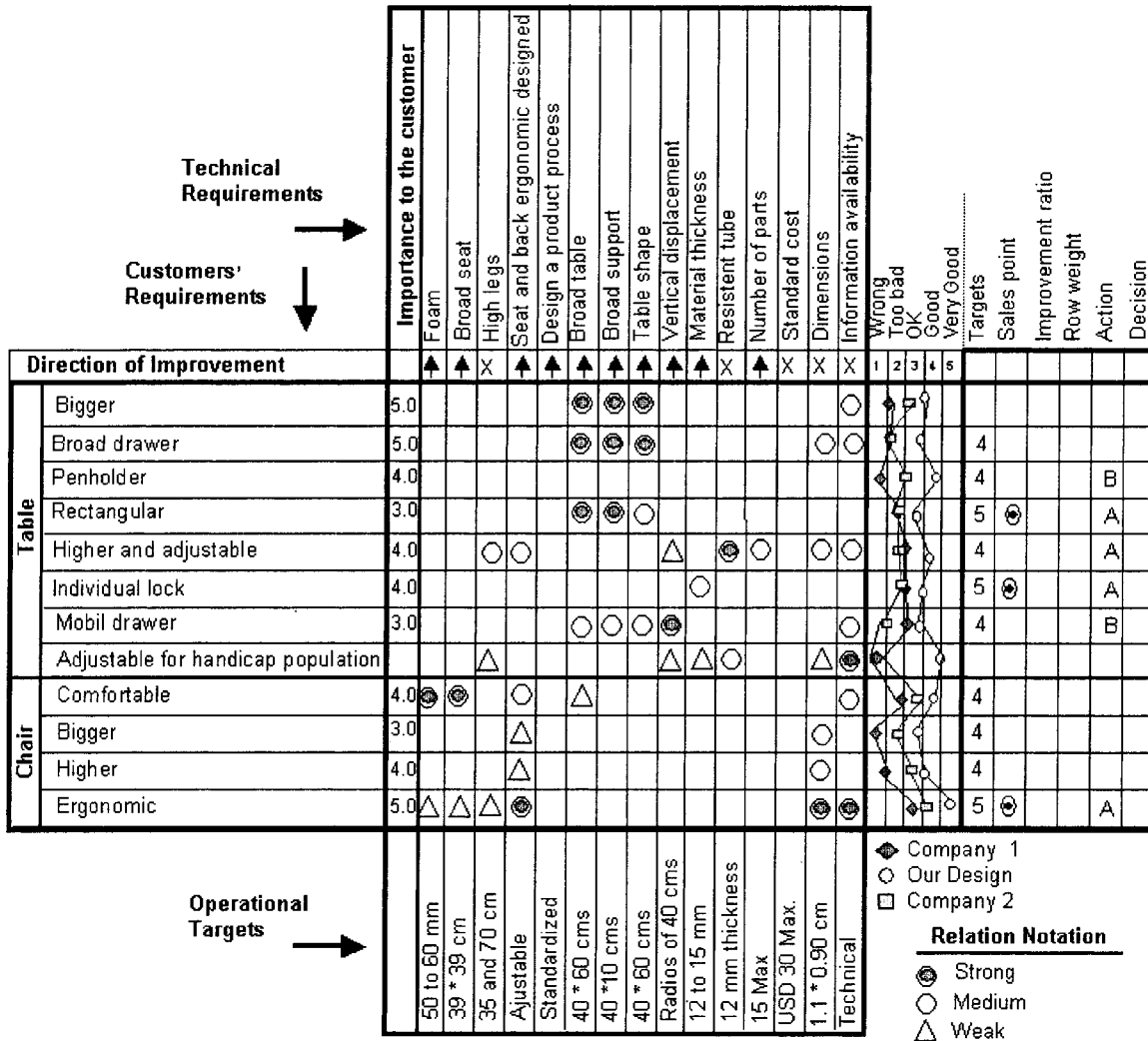


Figure 4. Users demands and prioritization.

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 F5 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 F6 customer expectations defined in the first matrix. Figure 6



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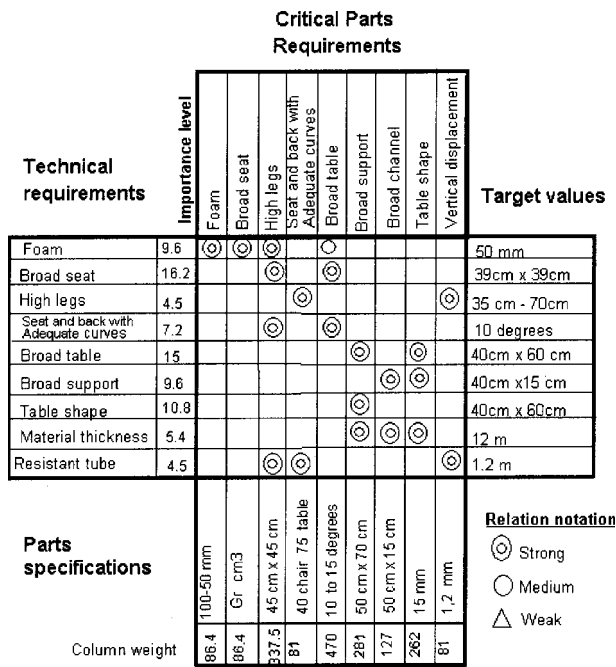


Figure 5. Characteristic part matrix.

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.

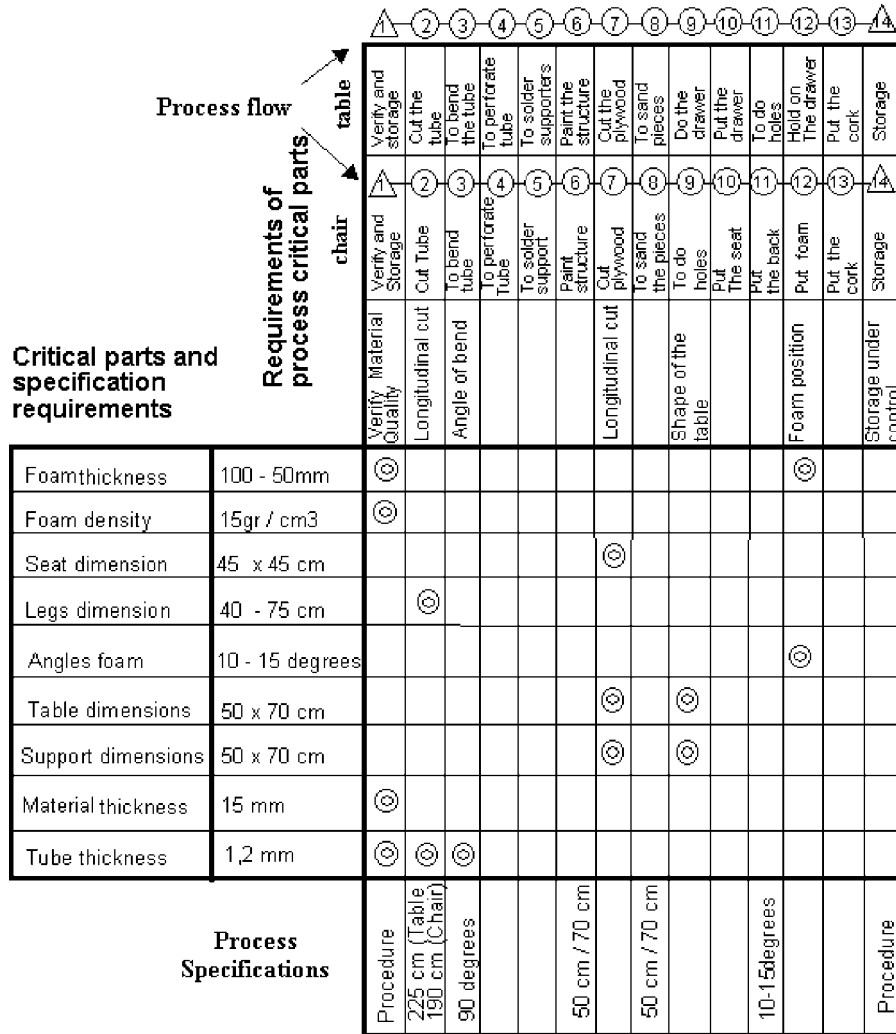


Figure 6. Process planning matrix.

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

Quality Function Deployment

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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	
CHAIR	TABLE		Occurrence	Security	Detection difficulty	Risk factor	Tools		Manufacturing		Quality Control					
							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.

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