QUALITY FUNCTION DEPLOYMENT

How Useful Is QFD?

by **John L. Sanford**

Quality function deployment (QFD), also known as the house of quality, is a process pioneered by Yoji Akao at Mitsubishi's Kobe, Japan, shipyard in the 1960s and 1970s. Many major companies use it as a design tool that enables engineers to resolve customer needs with what can be achieved both logically and practically.

QFD was introduced at my company, Cincinnati-Lamb, in 1998 as part of our design for Six Sigma initiative. Cincinnati-Lamb is a large domestic designer and builder of high volume and flexible machining and assembly systems as well as stand-alone production equipment.

I have often wondered about the usefulness of QFD in a work environment. This concern is largely due to my opinion that many engineers have preconceived ideas that would steer the QFD to foregone conclusions or perhaps have egos that would convince them they already know what is needed. Engineers frequently exhibit reluctance to

In 50 Words Or Less

- The author mentors a high school team in a multinational robotics competition.
- In the second year, the team used quality function deployment (QFD) in both the strategy and design phases.
- QFD sped up the process and is expected to help even more in the future.

WINNING ROBOT: The team mentored by John Sanford won first place in its division at the championship event in 2004. The winning robot and trophy are pictured.

CHAMPIONSHIP COMPETITION: The competition was intense during the championships in Atlanta in 2004, where more than 7,000 students on 295 teams participated.

use tools like this on even the most complex design challenges. We simply love to get busy right away without giving adequate thought to what we really need to be building in the first place.

QFD With High Schoolers

Recently, I had the chance to experience a successful implementation of QFD with a group of high school students. Given a group with open minds and some complementary tools and techniques (Pareto charts, impact vs. effort diagrams, brainstorming and a type of nominal group technique), I found QFD a very useful tool indeed, but its power comes from the process that involves its use rather than from the tool itself.

In late 2002, I had volunteered to mentor high school students who wanted to build a robot for a 2003 competition. Having spent 24 plus years assembling and testing machine tools for the aerospace industry, I thought I might be able to offer some assistance teaching the use of basic hand tools, measuring equipment and parts manufacturing.

FIRST Robotics Team #1038 from Lakota East High School in West Chester, OH, was a rookie team made up of more than 30 sophomores, juniors and seniors of all intellectual levels. (FIRST stands for **F**or **I**nspiration & **R**ecognition of **S**cience & **T**echnology.) Mentors guide the students through the design, manufacturing and programming of the robot. The students learn basic engineering, mechanical, programming and animation skills while having fun and competing (see "Competition"). The team is divided into five main groups: machine, computer aided design, animation, leadership and programming.

From the time the rules for each year's FIRST robotics competition are announced, each team has just six weeks to deliver a finished robot to compete at a regional event. This seemed all too much like any project we would undertake at work. We determine our strategy and then move to ideation, design, manufacturing, programming and debugging—all while meeting an impossible delivery deadline.

Our first season was frantic to say the least. We were into our third week and had still not settled on a design. As a result, we worked extra long hours and weekends to get done on time, but had virtually no time to debug.

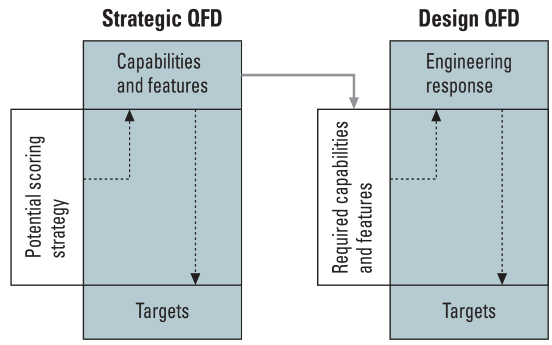
The 2003 competition involved moving and stacking plastic storage boxes, plus playing king of the hill against competing robots. Although we did not place with the top finishers at regional competition, we had a tremendously successful first season. The students won several of the judge's awards at a regional competition, including Leaders in Controls, Best Website and Autodesk Visualization (for animation). The Leaders in Controls award was prestigious enough to win us a place at the national competition in Houston.

After we finished our season and finally had a chance to breathe, I reflected on our use of time and wondered what we could do to get through the design phase and begin manufacturing sooner.

My background in quality engineering and Six Sigma had me thinking about using QFD as a means of arriving at the right design in less time. But I faced some serious concerns:

- Would this process really be effective in reducing our design time?
- Could a group of high school students stay focused enough to get through this process in a timely manner?
- How would I deal with trying to reach consensus with such a large group?
- How would we deal with matching our top priority technical responses to our limited available resources?

FIGURE 1 Scoring and Capabilities Spreadsheet



QFD = quality function deployment

The 2004 Competition

For the 2004 competition, I convinced the team coordinator QFD would work, and we decided to give it a go. As it turns out, it was a great learning experience for all of us.

Rather than go into the process of QFD cold, we held a one-hour training class to review the different components of the tool. It was easy to see the students were a bit intimidated, and I'm certain this was not what they expected when they joined the robotics team.

Simply explaining the name as "qualities (features, attributes) function deployment" seemed to help. We reviewed the different components of the

Competition

The FIRST Robotics Competition is a multinational event that teams professionals and young people to solve an engineering design problem.

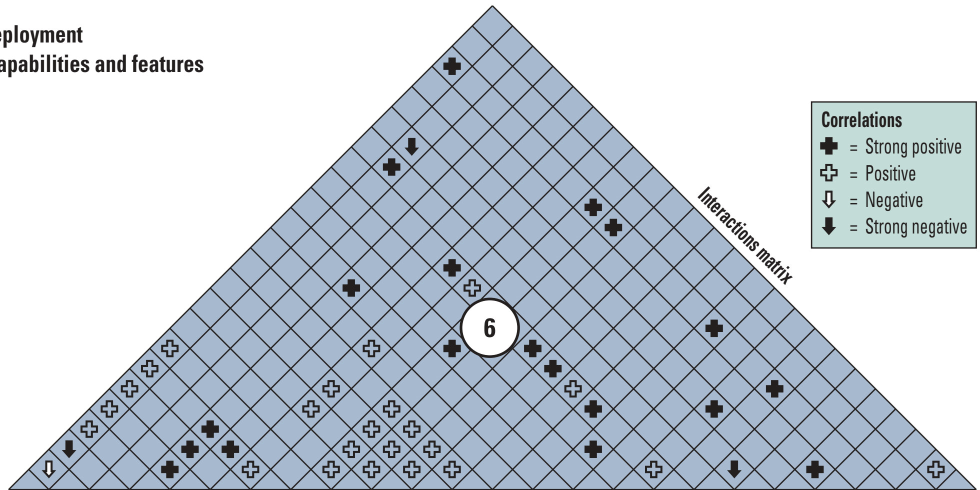
Teams come from Canada, Brazil, Ecuador, Mexico, Great Britain and almost every U.S. state. Colleges, universities, corporations, businesses and individuals provide scholarships to participants.

In 2004, more than 14,000 volunteer mentors assisted more than 50,000 youths and 900 teams competing in 26 regional events. In the championship event at the Georgia Dome in Atlanta, more than 7,000 students on 295 teams competed.

For additional information, go to www.usfirst.org.

FIGURE 2 Technical Responses

Strategic quality function deployment
Determines importance of capabilities and features



Correlations
- ✚ = Strong positive
- ✙ = Positive
- ⇩ = Negative
- ⬇ = Strong negative

Relationships
- ◉ = Strong 5
- ○ = Medium 3
- △ = Weak 1

Scoring opportunities and necessary attributes / Capabilities and features	Strategic importance	Accurate autonomous	Speed of autonomous	Multiple aut[illegible]ous	Extended r[illegible]	Punch/swat 2x ball	Grab/hold 2x ball	Stuff the goal with the 2x ball	Herd multiple balls	Corral and move small balls through narrow opening	Pick up and hold bonus balls	Pick up and hold small balls	Ability to throw balls	Couple/hitch with short goal	Hook/grab 10-foot bar and support weight of robot	Ability to spread out the robot	Climb variable heights (6 inches or 12 inches)	Operator friendly controls	Driving speed	Drive torque	Traction	Immovable	Maneuverability	Durability	Serviceability
Release balls first.	3	◉	○	○	○						△								○		△		△		
Uncap 2x ball from goals.	5				○	○	○						△		○										
Control short goal.	3	○	○	○			△							◉				○	△	○	○		△	△	
Deliver balls to the shooter.	5								◉	◉	○	◉	○			△		○					△		
Cap 2x balls into goals.	4				◉		◉								△			○					○		
Moving small balls to your side.	5								◉	◉	○	◉	◉			○		△	△				△		
Chin-up (50 points).	4				◉										◉		◉	○			◉	○	◉	◉	
Dominate all space under chin-up bar (keep others away).	[illegible]				△										△	○	△			◉	◉	◉	○	◉	
Be able to get onto the platform.	4				△										△		◉	○		◉	◉		○		
Be anywhere in playing field quickly.	5		○	○													◉	○	◉		○		◉		
Unscore stuffed cap.	3				◉	○	○	○							△			○							
Control 2x balls.	4	◉	○	◉	◉	△	◉	○	○						△			○						△	
Block opponent's goal.	3	○	○	◉	◉	○	◉	◉										○							
Block opponent's doggy door.	1	△	△	◉										○		◉		△	○	○	○	◉		◉	
Be reliable.	5																							◉	◉
Control bonus balls.	1	◉	○	◉	◉				○		◉	○	○					○							
Difficulty rating (impact vs. effort) 5 = high impact/little effort																									
Absolute importance (score)		59	58	78	126	37	82	36	65	50	38	[illegible]	[illegible]	18	53	34	68	114	45	47	85	32	94	72	25
Relative importance		4.2%	4.1%	5.5%	8.9%	2.6%	5.8%	2.5%	4.6%	3.5%	2.7%	3.7%	3.4%	1.3%	3.7%	2.4%	4.8%	8.0%	3.2%	3.3%	6.0%	2.3%	6.6%	5.1%	1.8%

QFD and how scoring was done. Surprisingly, the students had no trouble understanding the matrix, probably because most of them had done considerable work with spreadsheets.

When the rules were announced for the 2004 season, we were quite intimidated. The robots first had to run in autonomous mode for 15 seconds while attempting to trip sensors to release playground size balls onto the playing court. After 15 seconds, the drivers had to take control of their robots and herd the balls to human players who would attempt to shoot baskets into goals (one stationary and one mobile).

To double the score tally of a goal, a robot could lift and cap each goal with a 3-foot diameter ball. Bonus points would be awarded if a robot could climb steps, reach up and grasp a 10-foot high chin-up bar, lift itself off of the court (up to 130 pounds) and stay suspended when power was cut at the end of the allotted playing time.

With just six weeks to design, build and test our robot, we did not want to waste time building a robot that did not address the design challenges well enough to be competitive in a match.

QFD provides a structured process for identifying the critical to quality features, attributes and deliverables. Normally, there are four phases of product development (product planning, part deployment, process planning and production requirements). For the purpose of building our robot, we streamlined the process to just two phases: strategy and design.

We began identifying our scoring opportunities on the vertical axis of a spreadsheet and answers on the horizontal axis by listing the capabilities and features required to support our strategies. Once we established the capabilities and features, these items moved to the vertical axis of our second level spreadsheet and were answered by engineering responses (see Figure 1, p. 53). The rest of the matrix was used for identifying relationships and correlations and scoring the importance of features and responses.

During our first QFD session, all the students participated in a brainstorming session to identify all the scoring opportunities or tasks our robot would need to perform to play the game (Figure 2, step one). Next, we voted on the strategic importance of each item (Figure 2, step two). This completed the vertical columns on the left side of the matrix.

TEAMMATES: The high schoolers who used quality function deployment to design a robot that won a divisional trophy at the FIRST robotics championships in Atlanta in 2004 are shown with some of the volunteers and teachers who assisted them. These adults include David Campbell (program coordinator and mentor), David McKain, Doug Noxsel, Mary Jo Oliver, Rick Oliver, Norm Reiboldt, Todd Statt and Bill Vinnage. Other mentors and volunteers, not pictured, are Dale Barker, John Sanford, John Severns and Dave Williamson.

For our second session, we broke into small groups to discuss the capabilities and features each group determined were necessary to play the game according to its strategy. Some groups role-played: Students walked through a simulated game as if they were the robot, while other students played the opponent and tried to determine how they would counter.

Afterward, the students regrouped to present their ideas, and we filled in the technical response portion of the QFD (Figure 2, step three).

Dealing With a Large Group

We made a terrible mistake on our third session when we tried to get more than 30 students to reach consensus in placing values in the relationship matrix (Figure 2, step four). We quickly realized we needed to get the group size down to a manageable level. Now the problem was that if we worked only with a representative group, how would the other students have a voice in the QFD?

I asked the team leader to select a cross functional group of about eight to 10 students. This group was able to quickly fill in the relationship matrix and calculate the scores for each capability and feature (Figure 3). We then produced a 24-inch by 36-inch printout of the completed section of the matrix with the calculated scores (Figure 2, step five), plus a Pareto chart of the capabilities and features by relative score. The printed matrix was tacked to a bulletin board.

Scoring was a simple matter of multiplying the importance rating in the vertical column with each score in the relationship matrix. The absolute importance score at the bottom is the sum of the products. Dividing each absolute score by the sum of all scores allowed us to determine the relative importance,

FIGURE 3 Relational Matrix

Relationships		
⦿	= Strong	5
○	= Medium	3
△	= Weak	1

Scoring opportunities and necessary attributes \ Capabilities and features	Strategic importance	Accurate autonomous	
Release balls first.	3	⦿	3 x 5 = 15
Uncap 2x ball from goals.	5		
Control short goals.	3	○	3 x 3 = 9
Deliver balls to the shooter.	5		
Cap 2x balls into goals.	4		
Moving small balls to your side.	5		
Chin-up (50 points).	4		
Dominate all space under chin-up bar (keep others away).	3		
Be able to get onto the platform.	4		
Be anywhere in playing field quickly.	5		
Unscore stuffed cap.	3		
Control 2x balls.	4	⦿	4 x 5 = 20
Block opponent's goal.	3	○	3 x 3 = 9
Block opponent's doggy door.	1	△	1 x 1 = 1
Be reliable.	5		
Control bonus balls.	1	⦿	1 x 5 = 5
Difficulty rating (impact vs. effort) 5 = high impact/little effort			
15 + 9 + 20 + 9 + 1 + 5 = 59 …nce (score)		59	
Relative importance		4.2%	

which was then charted in a Pareto diagram.

Other activities were planned for the rest of the evening, but all 30 students were encouraged to study the QFD results. If they thought an item was rated too high or low, they could trace their way back through the matrix to see where the problem was. They would then place a semitransparent sticky note over the item they thought needed adjustment and enter the score they thought was appropriate.

Near the end of the evening, it was gratifying to see the matrix was covered with change proposals on sticky notes. The students' participation without direction indicated to me they had begun to take ownership of the QFD. When we regrouped to discuss the proposed changes, it was time to let them run with it. One of the students now took my place as facilitator and led the group through the changes. Each student was given the opportunity to plead his or her case for a proposed adjustment. Majority vote would decide whether the change was valid—perhaps based on a strategy not thought of earlier—and the change would be made or not made depending on the outcome.

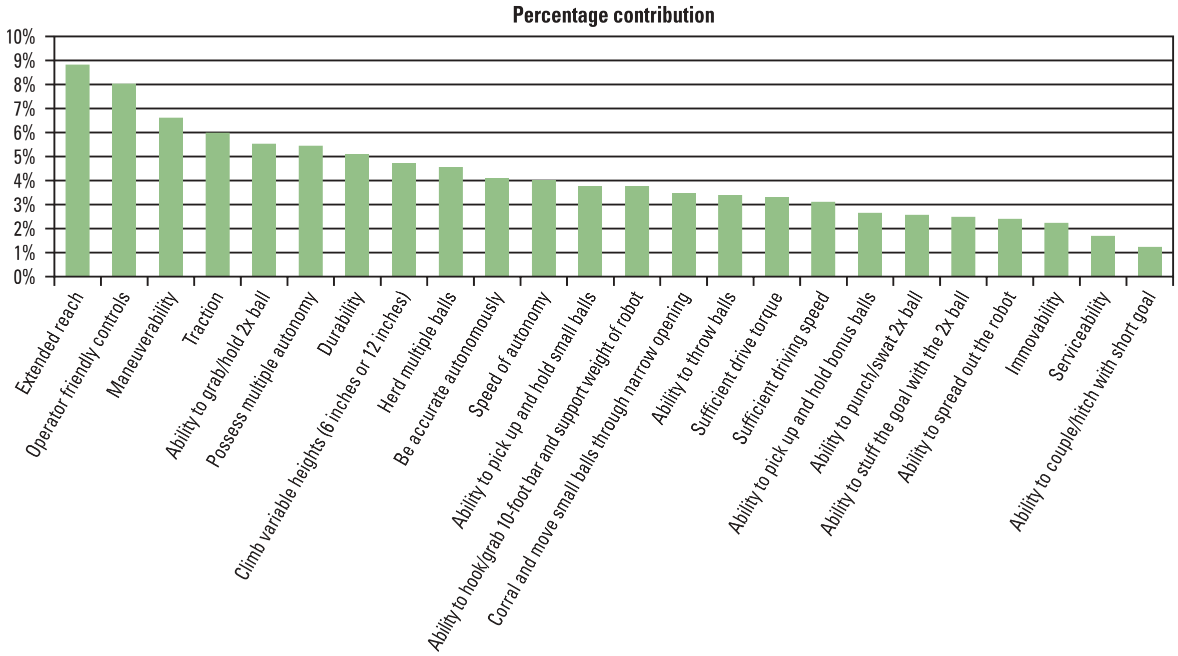
Considering Resources

Once the students had tabulated the scores at the bottom of the QFD (a simple task performed with some basic spreadsheet formulas), we made a Pareto chart to illustrate the relative importance of each feature (see Figure 4).

As powerful a tool as a Pareto chart is, it is important to keep in mind what the diagram is not telling us as well as what it is revealing. Most companies have limited resources. Our team was even more limited in this regard than most companies. We had only a small machine shop, limited material and a tight budget. However, we had a group of mentors rich in manufacturing experience. We relied heavily on the mentors to help us determine the amount of effort necessary to attain specific capabilities and features based on our available resources. We scored the effort required on a scale of one to three.

Finally, we divided the Pareto chart into thirds. The items on the left would have the greatest impact and those on the right would have the least. Now it was a simple matter of entering the capabilities and features into an impact vs. effort diagram (see Figure 5). The items with highest impact and the least amount of effort would score the highest;

FIGURE 4 Capabilities and Features Pareto Chart



those that had the least impact and required the most effort would score the lowest.

When dividing the Pareto chart into thirds, it's important to be careful dealing with mutually exclusive items. For instance, if there are three different drives and only one can be used, do not let the drives alone dominate the most important third of the matrix.

The correlations matrix or roof of the QFD (Figure 2, step six) was completed offline by a small group of students. This helped us group or package features.

We did not do a competitive analysis that is often seen on the right-hand side of the matrix. While we could justify excluding this part of the QFD because we had nothing to compare our design to, the truth is it could easily have been added to compare our various design concepts.

More Than Halfway There

With the strategy QFD, Pareto diagram and impact vs. effort matrix complete, the students were feeling good about their accomplishment. Unfortunately, there was another QFD to design and complete. Cries of "you mean we have to do this all over again?" were heard.

FIGURE 5 Impact vs. Effort Diagram

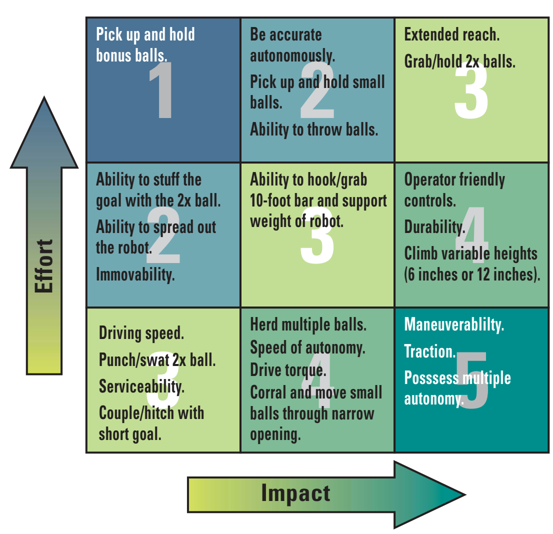
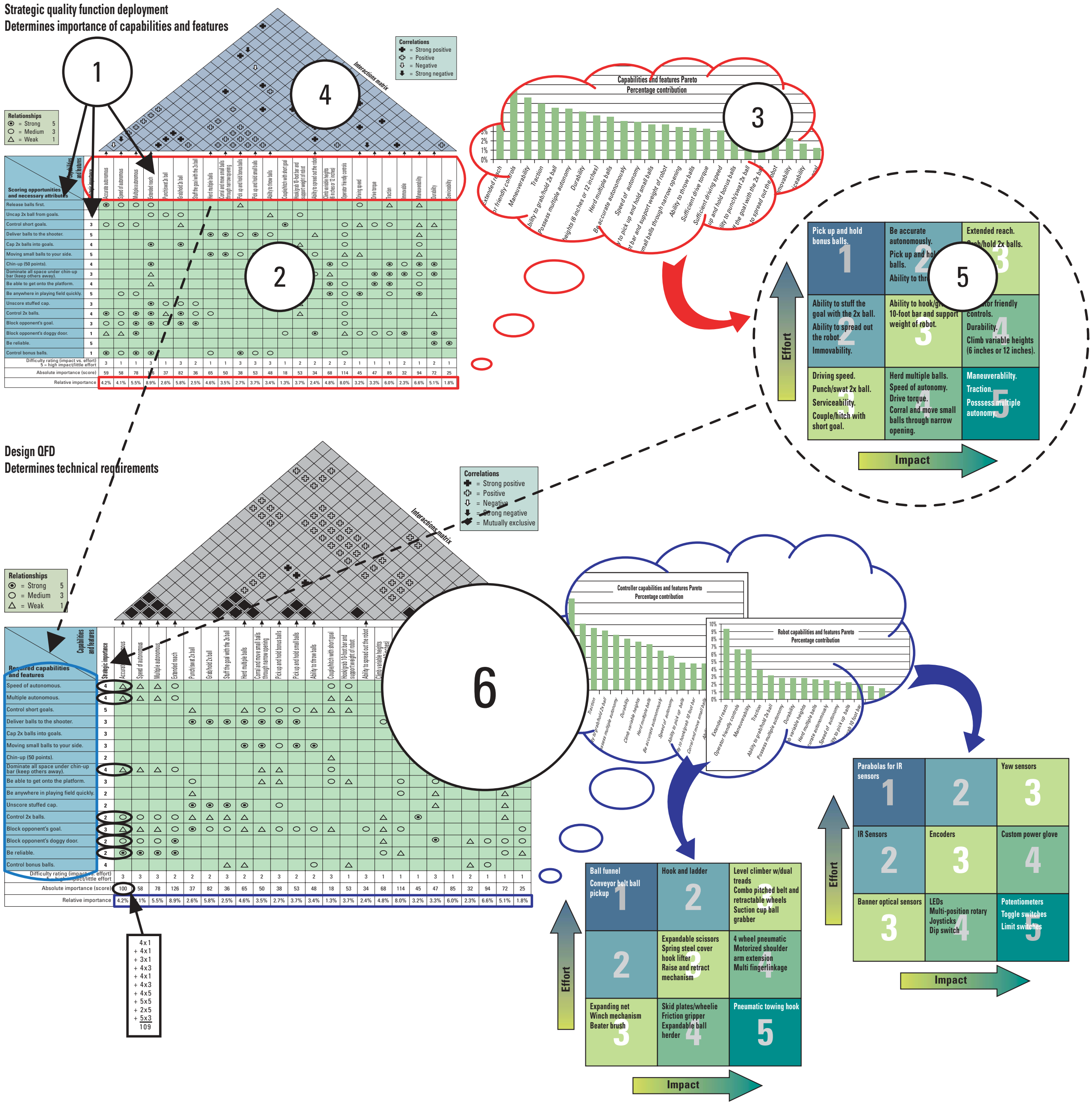


FIGURE 6 Strategic and Design Quality Function Deployment



The wonderful thing was we did not have to start all over at the beginning. We had a great head start on the second level QFD. The technical response (capabilities and features) part of the first QFD was flipped to the vertical column of the design QFD. Then the importance of each of those features was determined by the scores in the impact vs. effort diagram. This way, the results of the strategic QFD and our available resources weighed into the results of our design QFD.

To finish things off, we completed the design QFD in the same manner as the strategic one. There were a couple of minor differences, however. In our design QFD, we had both mechanical and control design features. We wrestled with splitting the design QFD in two but decided this was not wise due to the necessary correlations in the roof matrix.

Instead, we simply split the mechanical and control items into two separate Pareto charts from the results on a single design QFD. From each Pareto chart, we developed an impact vs. effort matrix that served as the final guide to building our robot (see Figure 6).

Key Points

Key steps for the design QFD were as follows:

1. Brainstorm to fill out the vertical column, importance column and top row responses. Include everyone on the team.
2. Fill in the relationship matrix. Form an executive committee (you will never get a large group to reach consensus in a timely manner). It is important each team member feel some ownership of the QFD. Post the results for everyone in the group to review. If the results do not pass the litmus test, give each team member the opportunity to post suggested changes and lobby for the group's approval of the suggested change. Have all change proposals reviewed in a single session by the entire team.
3. Use Pareto diagrams to identify the most important features.
4. Fill in the roof matrix to determine which features can be packaged together.
5. Impact vs. effort diagrams act as a reality check to make sure resources are allocated on the achievable items that have the greatest impact.
6. Repeat the process for each level if more than a single QFD is required.

MENTORING: The author, John Sanford, explains an aspect of quality function deployment to students in the FIRST Robotics Competition.

How Did We Do?

From March 25-27, 2004, the Lakota Thunderhawks Team #1038 competed against 60 teams at the Buckeye Regional event in Cleveland. The team won second place and a berth at the April 15-17 national competition at the Georgia Dome in Atlanta.

The national competition is divided into four divisions: Curie, Galileo, Newton and Archimedes. The division champions advance to the national semifinal and final rounds. At the national competition, the Thunderhawks went on to win the Curie Division championship and earned a final ranking of third-place among alliances.

Did QFD make a difference? We struggled at times trying to implement this tool with a large group in such a short time, but we managed to reach design consensus in slightly less time than we did the first year.

Now that we have the process nailed down, we expect to spend a great deal less time on the design phase for 2005, which starts this month. In 2004, the QFD process did influence and validate the choice of design, and the competition results seem to indicate we hit the mark.

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