# TRANSACTIONS FROM

## THE EIGHTEENTH SYMPOSIUM ON QUALITY FUNCTION DEPLOYMENT

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# Using a Spec Document, the Customer Voice Table, and a QFD Matrix to Generate a CTQ (Critical to Quality) List

*Author*
Bruce White
QFD Black Belt®
R&D Lean Champion
Staff Statistician
Imation, Corp.

*Abstract*
When all you have to work with is a large specification document and you need to identify what specs are truly important to the customer, the techniques outlined in this paper will help you. The tools used in this paper were adapted from the QFD Black Belt® curriculum in consultation with Glenn Mazur of the QFD Institute.

*Keywords*
Customer Voice Table, Affinity Diagramming, Hierarchical Analysis, Analytic Hierarchy Process, QFD Matrix, Pareto Chart

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*Background*

Suppose you find yourself in a situation where you have a large specification document from an OEM (referred to as "customer" in this paper) describing a product they want you to make. You would like to pare down the large list of specs to a "critical" few. How do you do this? This paper will give you one way to accomplish this task.

The process outlined in this paper is being used at Imation. Imation is the world leader in removable data storage products. The products referred to in this paper are backup tape products consisting of a reel of magnetic tape enclosed in a plastic cartridge.

*CTQ Definition*

The definition we use at Imation for CTQ (critical-to-quality) is as follows:

> CTQs are the most important, measurable characteristics of the finished product that are strongly linked to customer requirements.

*Expanded Definition*

"**CTQs are the most important**"—the "most important" CTQs are determined using QFD tools including the Customer Voice Table, Affinity Diagramming with Hierarchical Analysis, Analytic Hierarchy Process, and a basic QFD Matrix.

"**measurable characteristics of the finished product**"—a CTQ will be a characteristic of the finished product. The measurement may not always take place on the finished product—though it should be possible. Examples of characteristics measured on the finished cartridge would be cartridge dimensions like length, width, and height, and product performance measurements like capacity, write time, or error performance. Examples of characteristics measurable on the finished product, whose values are actually captured further upstream in the manufacturing process would be caliper, coercivity, and tape width.

"**that are strongly linked to customer requirements**"—the strong link will be indicated via a basic QFD matrix. If there is little or no relationship between a product characteristic and important customer requirements, then that characteristic will not make the CTQ list.

*Process outline*

The basic process steps are outlined below. Figure 1 illustrates this in a flow chart.

1. Use the Customer Voice Table to turn specs into customer need statements.
2. Use Affinity Diagramming and Hierarchical Analysis to structure the customer need statements.


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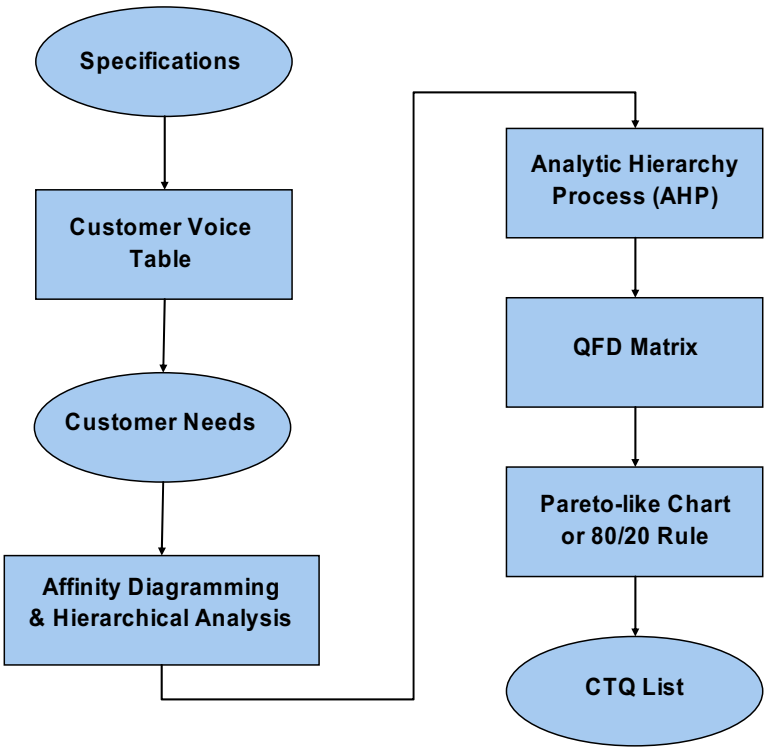
3. Generate importance weights for the customer need statements using the Analytic Hierarchy Process.
4. Place customer needs and importance weightings on the left side of a QFD matrix.
5. Place the specs across the top of the QFD matrix.
6. Assess the strength of the relationships between the customer need statements and the specs.
7. Carry out the normal QFD matrix math.
8. Use a Pareto-like chart of the normalized weights or use the 80/20 rule to identify your CTQ candidates.

**Figure 1**




*Step 1—Process the specs through the Customer Voice Table to generate need statements*

The way we are taught to use the Customer Voice Table (CVT) in the QFD training done by the QFD Institute is to have a column of customer needs statements that are generated from information about the customer and statements gathered from customers. The customer information is aligned in columns to the left of the needs column and statements are placed in columns to the right of the customer needs column. See the illustrations in Figures 2 (overview—not meant to be read) and 3 (zoom in on detail).

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**Figure 2**

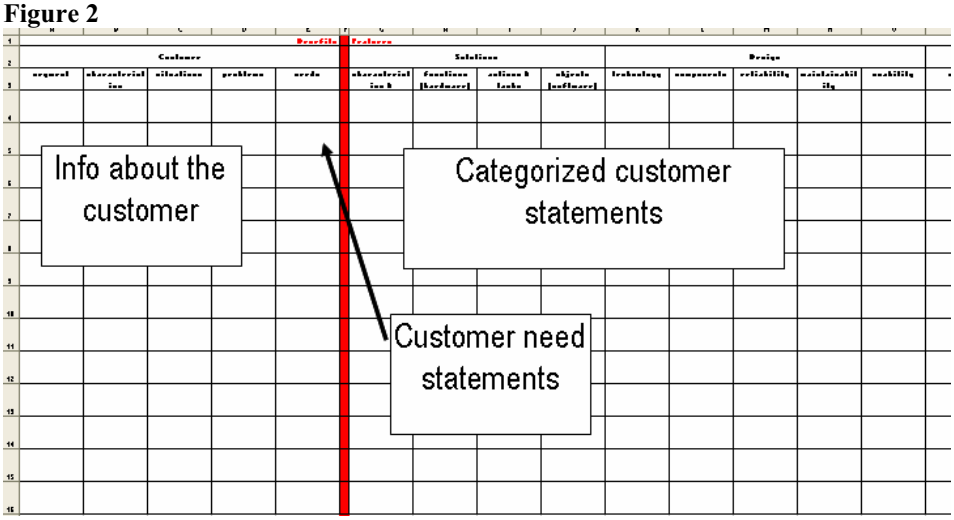


**Figure 3**

| | | | | | Benefits | Features | | |
|---|---|---|---|---|---|---|---|---|
| | Customer | | | | Solutions | | | |
| | characteristics | situations | problems | needs | characteristics & capabilities | functions (hardware) | actions & tasks (service) | objects (software) |
| | | | | | | | | |
| | | | | | | | | |

A thoroughly written specification document will be logically divided into sections addressing various aspects of the product (or service). The section titles can be used as headings on the right side of the Customer Voice Table. Information about the customer can still be recorded in the left columns of the spreadsheet. We then usually record one specification per line under the appropriate heading.

We also create a column between the various spec heading columns and the customer need statement column titled “Function”. Considering the specs one-at-a-time, we ask the question, “What function of the product does the specified characteristic serve to fulfill?” Once we have generated function statements, we then ask “What benefit to the customer does that function bring?” Answers to this question become our customer need statements. Usually these statements take a form like “cartridge must …” or “tape must …”. See Figures 4 (overview) and 5 (detail) for an example of what our completed CVT looks like.


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**Figure 4**

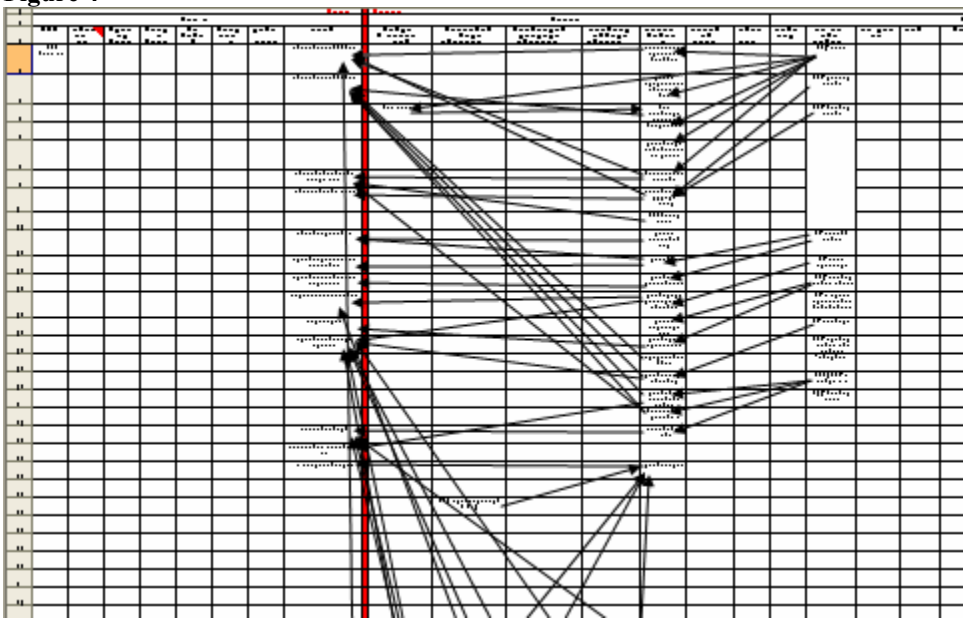
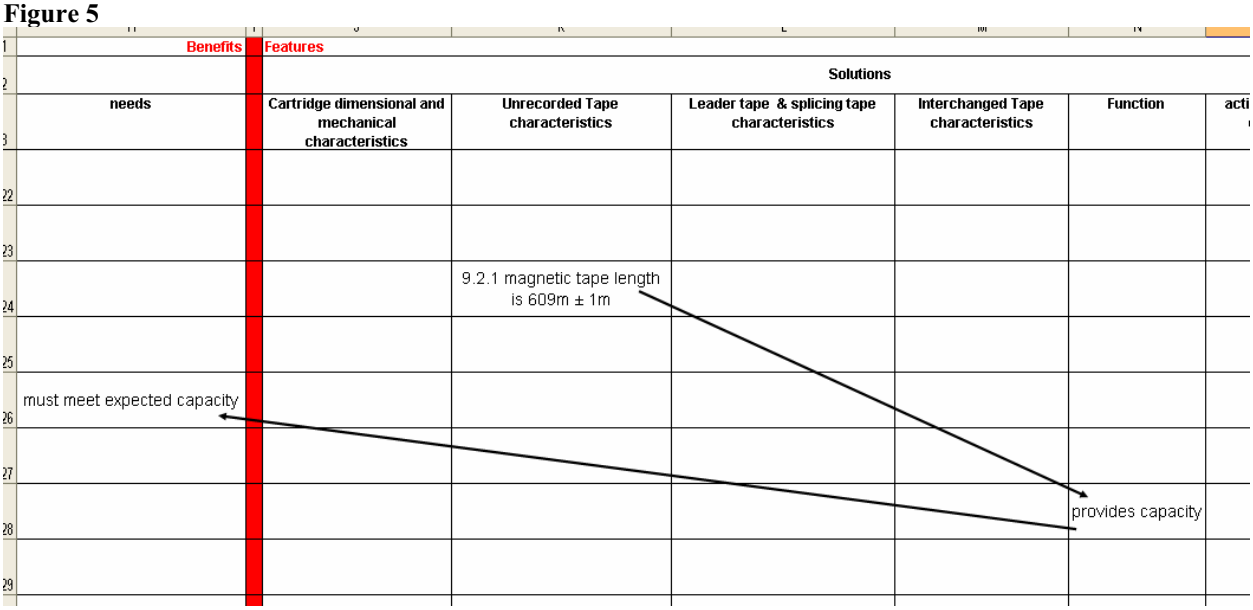


**Figure 5**




*Step 2—Structure the customer need statements*

In this step, we use Affinity Diagramming and Hierarchical Analysis to put structure to the customer need statements. The reason for this step will become clearer in step 3. All the customer need statements are recorded on sticky notes which are then placed on a wall. The Affinity Diagramming exercise is done with a group of about 6-10 people. In the exercise, participants rearrange the sticky notes into groups of logically related clusters. No talking is allowed during the exercise. Clusters should all be reasonably equally sized—preferably about

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6-8 items each. If one cluster is too large, it may need to be broken into two separate clusters. When all note arrangement stops, or slows appreciably, this portion of the Affinity Diagramming ends.

Once the clusters are assembled, discussion is allowed to create category headings for each cluster. Sometimes, one of the sticky notes in the group may be used as the group heading, or a new title can be used. If there are many categories, the group may decide to add another level of hierarchy be grouping categories into logical arrangements with titled headings.

Once all headings have been created, we sweep back through each category and examine all the elements of that category. Using the category heading as a guide, we ask if the items listed fill out that category adequately or if we need to generate more items for that category. This is the Hierarchical Analysis step. Also during this step we assess whether all the customer need statements are on the same level of abstraction or detail.

Once we are comfortable with the results of this step, we move on to the third step in our process.

*Step 3—Use the Analytic Hierarchy Process to prioritize customer need statements*

The Analytic Hierarchy Process (AHP) is based on a series of pair-wise comparisons. This highlights the need for step 2 in our process. Without the hierarchical structure given to the customer need statements in step 2, we would be overwhelmed with a large number of pair-wise comparisons to consider.[1] If, after step 2, we have 40 customer need statements arranged into 5 groups of 8 each, we would greatly reduce the number of pair-wise comparisons necessary.[2] The AHP process is then carried out on the 5 category titles and then within each of the 5 groups.

To gather the AHP input, I prefer to have each participant fill out the matrix of comparisons individually. This allows all relevant participants to have an equal voice in the prioritization process. Collecting the input individually rather than in a group, prevents any single person or group of people from dominating the discussion. Once the results are collated, the group can then discuss the results.

The pair-wise comparisons are set up in matrix format as shown in Tables 1 and 2. Table 1 shows how to set up the categories and Table 2 shows the comparisons within one of the categories. The body of the matrix is filled out row-by-row. The comparison criteria for each cell is "what is more important, the column element or row element?" If the row is more important, place a whole number in the cell according to the scale below, and if the column is more important, use the reciprocal of the number:

[1] If we have N customer need statements, there are N*(N-1)/2 total pair-wise comparisons to compare every statement with every other statement. Thus, if we have 40 statements, we would have a total of 40*39/2 = 780 pair-wise comparisons.

[2] Each group of 8 has 8*7/2 = 28. With 5 groups of 8, we have 5*28 = 140 pair-wise comparisons. With 5 categories, there are 5*4/2 = 10 comparisons, bringing the total to 150. This is a reduction of over 80% from the 780 calculated in Footnote 1.

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1—Equal Importance
3—Moderately More Important
5—Strongly More Important
7—Very Strongly More Important
9—Extremely More Important

This scale was developed by Thomas L. Saaty, the innovator of AHP. To learn more about this technique, see *Decision Making for Leaders* by Thomas L. Saaty.

**Table 1**

| First Level Categories | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| 1 Category A | 1 | 3 | 1/3 | 3 | 1/5 |
| 2 Category B | 3 | 1 | 1/5 | 5 | 7 |
| 3 Primary Performance Expectations | 1/3 | 5 | 1 | 7 | 9 |
| 4 Category D | 1/3 | 1/5 | 1/7 | 1 | 1/7 |
| 4 Category E | 5 | 1/7 | 1/9 | 7 | 1 |

**Table 2**

| Second Level Needs | **3.1** | **3.2** | **3.3** | **3.4** | **3.5** | **3.6** | **3.7** |
|---|---|---|---|---|---|---|---|
| 3.1 must meet expected capacity | 1 | 5 | 3 | 7 | 1 | 3 | 3 |
| 3.2 must write rapidly | 1/5 | 1 | 3 | 3 | 1/3 | 3 | 5 |
| 3.3 must read rapidly | 1/3 | 1/3 | 1 | 7 | 1 | 1/5 | 1/5 |
| 3.4 must … | 1/7 | 1/3 | 1/7 | 1 | 1/7 | 1/5 | 1/5 |
| 3.5 must … | 1 | 3 | 1 | 7 | 1 | 1/7 | 1/7 |
| 3.6 must … | 1/3 | 1/3 | 5 | 5 | 7 | 1 | 1/5 |
| 3.7 must … | 1/3 | 1/5 | 5 | 5 | 7 | 5 | 1 |

The table diagonals are always 1, as any element is always equal to itself. In reality, only the portion of the table above the diagonal needs to be filled out, as the lower portion consists of the reciprocals of the corresponding elements of the upper portion. This paper is not meant to explain the math behind AHP (for details see the book referenced above), but a useful approximation to use for calculating the relative weights is to normalize the columns, sum across the rows and then normalize those sums.

For the data in Tables 1 and 2, we get the weights shown in table 3.

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Table 3

| Category | Weights |
|---|---|
| 1 | 0.151 |
| 2 | 0.230 |
| 3 | 0.390 |
| 4 | 0.038 |
| 5 | 0.191 |

| Category 3 | Weights |
|---|---|
| 3.1 | 0.251 |
| 3.2 | 0.169 |
| 3.3 | 0.069 |
| 3.4 | 0.022 |
| 3.5 | 0.133 |
| 3.6 | 0.150 |
| 3.7 | 0.206 |

The weights within each table will always sum to unity. These weights can be relatively compared within each table. E.g., for the Categories, the importance of Category 3 is about twice that of Category 5. Within Category 3, the importance of item 3.1 is almost twice that of item 3.5. Alternatively, the word comparisons can be used—3.1 is moderately more important than 3.7 and extremely more important than 3.4. To compare the global importance of all items in all categories, each item needs to be "adjusted" by the importance weighting of its corresponding category. Thus, all the weights of Category 3 would be adjusted by multiplying the weight of each element by the importance weighting of category 3 (0.39). Thus, the global weight of element 3.1 would be 0.251*0.39 = 0.098. After obtaining all the global weights we proceed to the next step in our CTQ process.

*Steps 4 & 5—Place the customer needs, their weights, and the specs in a QFD matrix*

These steps are more mechanical than conceptual. See Figure 6 for the entries across the top and down the side.

**Figure 6**

| | | | | Quality Characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Importance Rating | Spec Attribute 1 | Spec Attribute 2 | Spec Attribute 3 | tape length | Spec Attribute 6 | Spec Attribute 6 | Spec Attribute 7 | Spec Attribute 8 | Spec Attribute 9 |
| Cust. Needs | Category 3 | 3.1 must meet expected capacity | 0.098 | | | | | | | | | |
| | | 3.2 must write rapidly | 0.065 | | | | | | | | | |
| | | 3.3 must read rapidly | 0.009 | | | | | | | | | |
| | | … | 0.023 | | | | | | | | | |
| | Cate | 4.1 must … | 0.078 | | | | | | | | | |
| | | 4.2 must | 0.016 | | | | | | | | | |


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*Step 6—Assess the strength of the relationships in the body of the matrix*

This is the typical QFD matrix relationship exercise. Work either by row or by column. In my experience, column-wise seems to work best. E.g., while considering the column labelled "Spec Attribute 1", proceed row-by-row to ask how strongly does this spec attribute relate to each of the customer need statements. Use a three or five level weighting of the relationship. A three level weighting would use words like "strong", "moderate", and "weak". A five level weighting might use words like "extremely strong", "very strong", "strong", "moderate", and "weak". I generally fill in the body of the matrix with letters (for three levels—S, M, W) or symbols (for five levels—cloud cover symbols) until the exercise is complete and then replace the letters/symbols with numbers. If a relationship is not strong enough to earn a "weak" designation, leave the cell blank.

AHP can be used to generate weights for the verbal descriptions of relationships given above. "Classical" QFD uses 9, 3, and 1 for a three level approach. I used AHP to gather the three-level weights with input from 20+ people and then transformed the results to whole numbers. This gave me 10, 3, and 1—not much different than "classical" QFD.

Figure 7 shows the matrix with the body filled in.

Figure 7

| | | | | Quality Characteristics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Importance Rating | Spec Attribute 1 | Spec Attribute 2 | Spec Attribute 3 | tape length | Spec Attribute 6 | Spec Attribute 6 | Spec Attribute 7 | Spec Attribute 8 | Spec Attribute 9 |
| Cust. Needs | Category 3 | 3.1 must meet expected capacity | 0.098 | 1 | 1 | 3 | 10 | | 3 | | | 3 |
| | | 3.2 must write rapidly | 0.065 | | | | | 10 | 10 | 10 | 10 | |
| | | 3.3 must read rapidly | 0.009 | | | | | 10 | 10 | 10 | 10 | |
| | | ... | 0.023 | | | | 10 | | | | 3 | |
| | Category 4 | 4.1 must ... | 0.078 | | | | 3 | | 1 | | | |
| | | 4.2 must | 0.016 | | | 10 | 1 | | | | 10 | |

*Step 7—Carry out the normal QFD math.*

Once the body of the matrix is filled in, multiply the values in each column of the body of the matrix by the corresponding values in the importance column and sum down the column. All the raw column weights thus calculated are then normalized, as shown in Figure 8.

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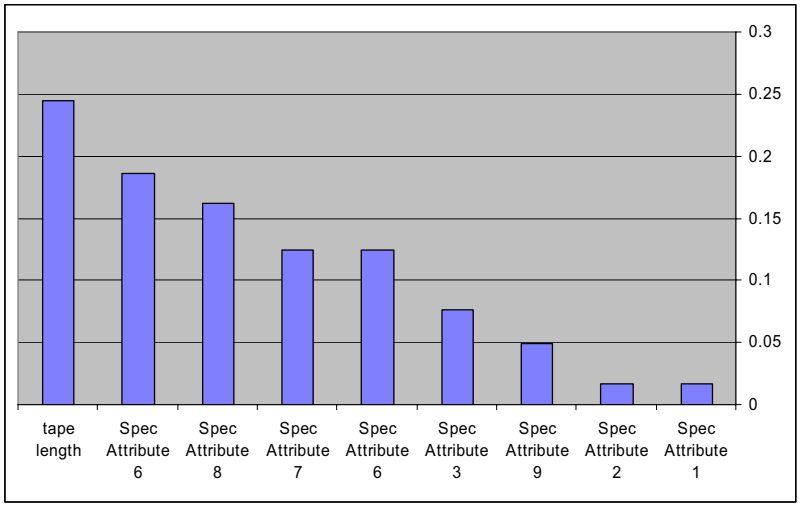
**Figure 8**

| | | | | Quality Characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Importance Rating | Spec Attribute 1 | Spec Attribute 2 | Spec Attribute 3 | tape length | Spec Attribute 6 | Spec Attribute 6 | Spec Attribute 7 | Spec Attribute 8 | Spec Attribute 9 |
| Cust. Needs | Category 3 | 3.1 must meet expected capacity | 0.098 | 1 | 1 | 3 | 10 | | 3 | | | 3 |
| | | 3.2 must write rapidly | 0.065 | | | | | 10 | 10 | 10 | 10 | |
| | | 3.3 must read rapidly | 0.009 | | | | | 10 | 10 | 10 | 10 | |
| | | ... | 0.023 | | | | 10 | | | | 3 | |
| | Category 4 | 4.1 must ... | 0.078 | | | | 3 | | 1 | | | |
| | | 4.2 must | 0.016 | | | 10 | 1 | | | | 10 | |
| | | Absolute Weight | | 0.098 | 0.098 | 0.454 | 1.460 | 0.740 | 1.112 | 0.740 | 0.969 | 0.294 |
| | | Relative Weight | | 0.016 | 0.016 | 0.076 | 0.245 | 0.124 | 0.186 | 0.124 | 0.162 | 0.049 |

*Step 8—Find the largest relative weights*

For this step, some judgement is needed. We can use the 80/20 rule and choose the top 80% of the weights. Graphically, we can create a Pareto-like chart of the weights ranked from largest to smallest and look for a "break" in the height of the bars. We may decide ahead of time to consider only the top 25% or 33% of the list. What decision criteria you use will depend on your ultimate use you will make of your CTQ list. Figure 9 shows a Pareto-like chart of the weights, created in Excel.

**Figure 9**





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Working from left to right, the first three "steps" or "breaks" in the chart seem to occur between the first and second bars, between the 3rd and 4th and between the 5th and 6th. If we choose to consider the five largest bars, our relative weights for those bars add up to 0.842, which also agrees with the 80/20 guideline.

Looking at the matrix in Figure 10, we have identified the highlighted relative weights as being most strongly related to customer requirements.

**Figure 10**

| | | | | Quality Characteristics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Importance Rating | Spec Attribute 1 | Spec Attribute 2 | Spec Attribute 3 | tape length | Spec Attribute 6 | Spec Attribute 6 | Spec Attribute 7 | Spec Attribute 8 | Spec Attribute 9 |
| Cust. Needs | Category 3 | 3.1 must meet expected capacity | 0.098 | 1 | 1 | 3 | 10 | | 3 | | | 3 |
| | | 3.2 must write rapidly | 0.065 | | | | | 10 | 10 | 10 | 10 | |
| | | 3.3 must read rapidly | 0.009 | | | | | 10 | 10 | 10 | 10 | |
| | | ... | 0.023 | | | | 10 | | | | 3 | |
| | Cate | 4.1 must ... | 0.078 | | | | 3 | | 1 | | | |
| | | 4.2 must | 0.016 | | | 10 | 1 | | | | 10 | |
| | | Absolute Weight | | 0.098 | 0.098 | 0.454 | 1.460 | 0.740 | 1.112 | 0.740 | 0.969 | 0.294 |
| | | Relative Weight | | 0.016 | 0.016 | 0.076 | 0.245 | 0.124 | 0.186 | 0.124 | 0.162 | 0.049 |

These five attributes are then our CTQ candidates.

*Summary*

Identifying what aspects of your product are critical-to-quality is as much an art as a science. The procedures presented in this paper provide some objective basis for making that determination. The procedure is captured generically in Figure 11.

The process outlined in this paper has helped add greater objectivity to generating a list of CTQs within Imation. What had been a rather nebulous procedure now has methodical and logical steps. This method is not perfect (what method is?), so we use the resulting list as a guideline. Nevertheless, we have found this process to be both useful and practical.

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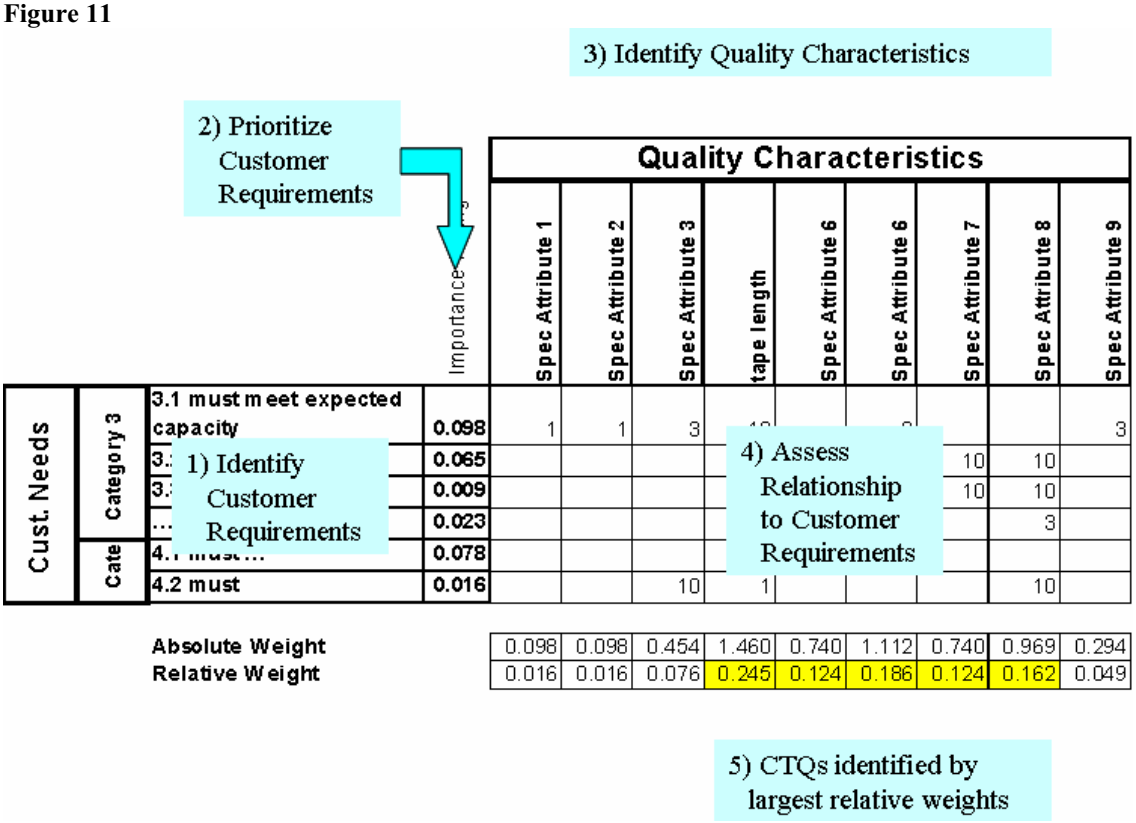
**Figure 11**




| Cust. Needs | | | Importance | Quality Characteristics | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Spec Attribute 1 | Spec Attribute 2 | Spec Attribute 3 | tape length | Spec Attribute 6 | Spec Attribute 6 | Spec Attribute 7 | Spec Attribute 8 | Spec Attribute 9 |
| | Category 3 | 3.1 must meet expected capacity | 0.098 | 1 | 1 | 3 | | | | | | 3 |
| | | 3.… | 0.065 | | | | | | | | 10 | 10 | |
| | | 3.… | 0.009 | | | | | | | | 10 | 10 | |
| | | … | 0.023 | | | | | | | | | 3 | |
| | Cate | 4.… must … | 0.078 | | | | | | | | | | |
| | | 4.2 must | 0.016 | | | 10 | 1 | | | | | 10 | |
| | | Absolute Weight | | 0.098 | 0.098 | 0.454 | 1.460 | 0.740 | 1.112 | 0.740 | 0.969 | 0.294 |
| | | Relative Weight | | 0.016 | 0.016 | 0.076 | 0.245 | 0.124 | 0.186 | 0.124 | 0.162 | 0.049 |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*Biography*

Bruce White received his BA in Mathematics in 1976 from St. Cloud State University in St. Cloud, MN and his MS in Statistics from the University of Minnesota in 1983. He has worked for 3M and then Imation, Corp. for 29 years. He is currently the resident statistician at Imation, Corp. As such, he provides expertise in DOE, SPC, EMP, QFD, AHP, JMP, FMEA, TRIZ, HALT and a whole bunch of other letters. He has been through black belt training in DFSS, DMAIC, and QFD. He hates acronyms.

Bruce lives in Hugo, MN with his wife, five children, one dog, seven chickens, two parakeets, and about a dozen fish. He loves to laugh.

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