QUALITY FUNCTION DEPLOYMENT (QFD)

Listening to the Voice of the Customer

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MIT ESD.33

It is imperative for success to relate all systems-engineering decisions to the voice of the customer and to the long-term improvement of QCD. However, in the day-to-day decision making, experience has proven that it is all too easy to become overwhelmed by more local, parochial goals.[1] The original voice of the customer (VoC) has to be deployed horizontally through the phases of development: product planning, design, production-process planning, production-operations planning, and back to the customer in the form of the new system. The VoC also has to be deployed vertically down through the levels of the system. In these many steps of deployment it is easy to lose sight of the customers' imperatives unless we have a disciplined method to guide us. Quality Function Deployment (QFD) is that disciplined method.

QFD is the subject of many books and seminars; you can learn the many details leading to mastery of this tool by reading a good book[2], by attending seminars, and most important of all, by using QFD. Our purpose here is to discuss the main points of the process, and to provide an extended view of QFD that best meets the needs of the Systems Engineer.

One lens on QFD is to relate it to the RCI process. The part of Figure 1 that is enclosed in red is the core of QFD. V is the voice of the customer; more generally all stakeholders. E is the expectations of the enterprise for the new system. V and E cover the same information, but V is in the voice of the customer, while E is in the language of the enterprise. T means that we translate from the customers' relatively qualitative language into the more quantitative engineering language of the enterprise. Experience has shown that this translation can introduce serious distortions unless it is done very carefully.

Before proceeding we briefly introduce the remainder of Figure 1. F is engineering functions, as typically done in functional analysis; e.g., in value engineering. A means that the expectations E can also be viewed as amplifications of the functions F. More about this later in this note.

TSP is technology-source planning and RM is reusability matrix. This planning for new technology and reusability is usually considered part of systems architecture, and will not be discussed in this course.

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[1] See the QCD note for Session 1 of this course.

[2] We recommend "Quality Function Deployment: How to make QFD work for you", by Lou Cohen, Prentice Hall/ Addison-Wesley, 1995.

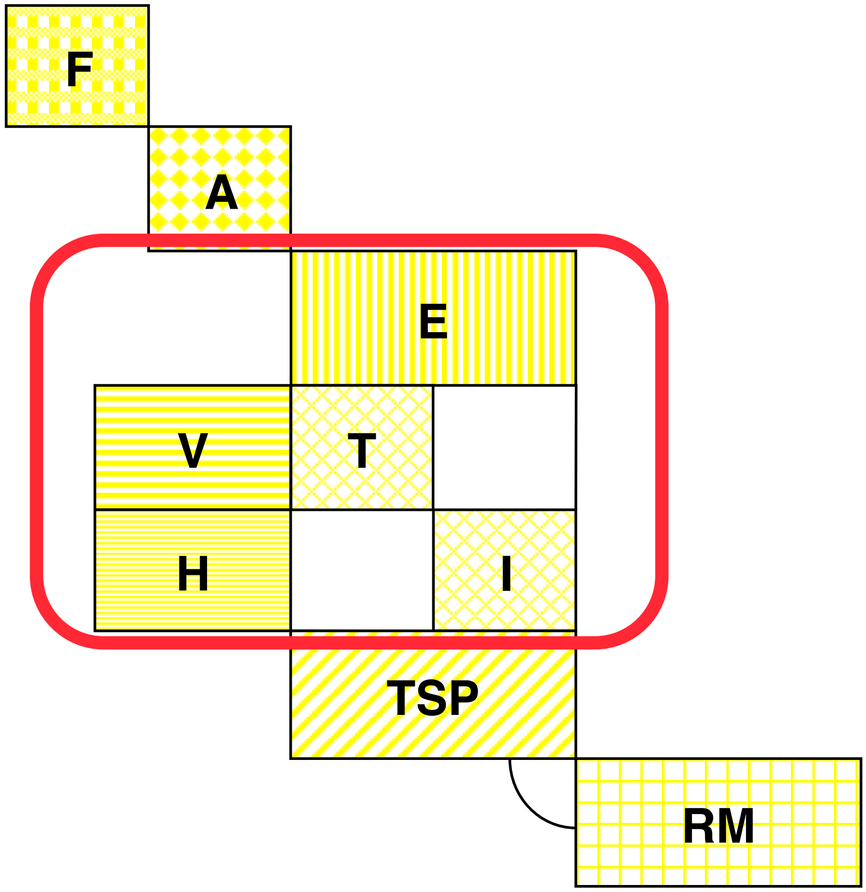

Figure 1. Context for QFD.

H refers to requirements passed down from higher levels of the system. More about that later.

The entire QFD process is conducted by the QFD team, also called the development team. This team consists of all individuals who are responsible for the development, delivery and servicing of the system. The team is often called a multifunctional team, because its members represent all the key functional groups within an organization – Marketing, Architecture and Design, Manufacturing, and Service. For large systems many of the main functions mentioned here are themselves multifunctional, so the membership of this critical QFD team must be decided on with great care.

HOUSE OF QUALITY

We now turn to a more detailed description of the elements of QFD. For this we'll refer to Figure 2. Here we see a diagram in which each rectangle (and triangle) represents a task or step in the process of reconciling customer needs with technical expectations. The triangle at the top of the diagram is actually a matrix, cut along its diagonal and rotated 45 degrees. The complete planning chart in Figure 2 evolved over several years, and when complete it was seen to look like a house; thus the name the House of Quality. Now that the diagram is seen to be a house, the elements from which it is composed become rooms. We'll now take a tour through the House of Quality.

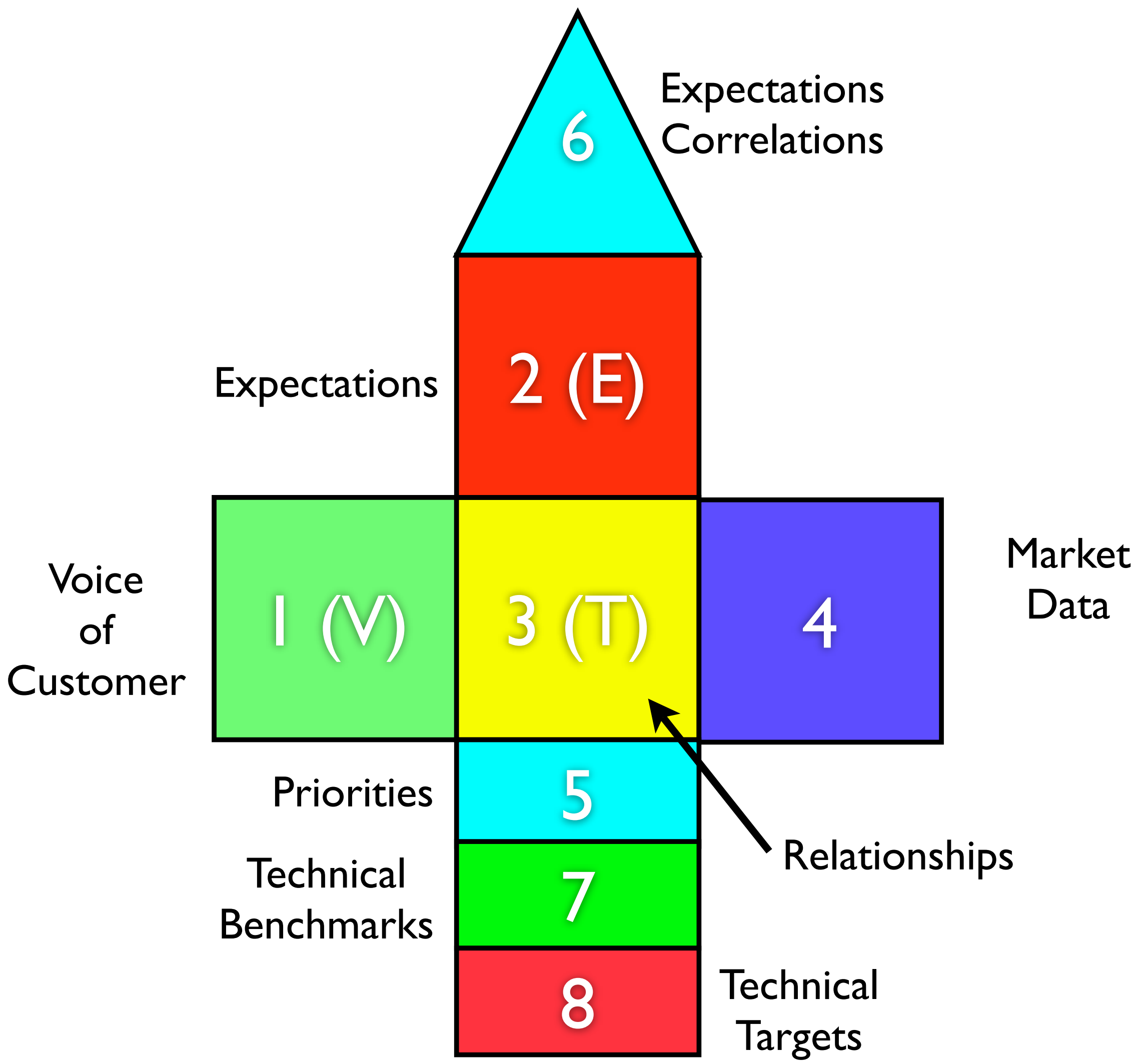

Figure 2. House of Quality

Room 1 is labeled V, the Voice of the Customer. The VoC is represented by a hierarchically arranged list of customer needs, each expressing a desire or need about the system in the customer's own language. Examples of such needs: "Fly with one engine", "A quiet ride", "Doesn't wear out."

The needs expressed in Room 1 are qualitative only.[3] It is not possible to determine the relative importance of these needs based on interviews only. The work done in Room 4, Market Data, will enable the team to rank-order these needs.

These needs are typically collected as a result of in-depth, probing customer interviews. The interviews would normally be recorded and transcribed. The transcripts are studied by the team members. The team members identify and extract the customer's phrases that represent needs.

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[3] Sometimes customers do give numbers, but usually the system-engineering team should concentrate on the customers' qualitative statements of needs. These will subsequently be quantified by competitive benchmarking and other market information.

The QFD team must sort out true customer needs from possible solutions, or designs intended to meet those needs. A good need set will be independent of the solutions for meeting those needs.

For example, if in an interview a customer asks for seats with 2 inches of padding, the astute interviewer will recognize that this is not a need at all; instead it's the customer's attempt at solving an unstated need. The intrepid interviewer will then probe: "If you had 2 inches of padding, what would be the benefit?". The customer's explanation of why the padding is desired will lead to the true need, in this case for "No muscle fatigue after a long ride." Note that this is an example of not being mislead by the customer's initial quantitative statement.

Room 2, labeled E, holds the development team's technical expectations in its columns. Good expectations are expressed in measurable terms. Ideally the measurement is along some continuum. There will be a place on the continuum which represents the ideal performance of that expectation. The best performance may be at infinity ("Larger is better"), at zero ("Smaller is better") or at some fixed value ("Nominal is best.") While the team may never be able or even willing to meet the ideal value, these categories provide a direction of goodness that will be crucial for setting meaningful system requirements.

The link between V and E is the translation matrix, labeled 3 (T). Each cell in the translation matrix corresponds to one row (need) and one column (expectation.) The QFD team must decide to what extent performing well on that expectation helps the system to meet that need. This impact is expressed as a number. One of the main tasks in QFD is to complete this process for all the cells of the translation matrix, thereby evaluating all possible relationships between expectations and needs. After doing that (and after completing Room 4) it becomes possible to prioritize the expectations, thus enabling meaningful tradeoffs during the detailed system design phase.

Room 4 provides the quantitative analysis needed to rank-order the needs in Room 1. Room 4 contains several columns, each containing the results of different types of quantitative analysis of the needs. Typically these columns display the results of surveys of many customers, measuring the relative importance of the needs to the customers, and their current levels of satisfaction with the company's current systems and with the competition's systems. Other columns contain strategic judgments made by the team. The results of all the columns are combined into a single number, called the raw weight, representing the relative importance of each need.

The remaining rooms are repositories for other key types of information that flesh out the requirements process:

Room 5 displays the priorities of the expectations, based on the raw weights from Room 4, and the impacts from Room 3, to produce weighted sums for each column (for each expectation.)

Room 6 analyses the interactions of expectations with each other.

Room 7 displays the results of technical competitive benchmarking.

Room 8 displays target values for each expectation, based on all the information in all the other rooms.

A great deal of work is required to implement QFD as described thus far. The benefits of doing this work are considerable.

First, all the work is done by the team of key developers. As the team grapples with its inevitable disagreements and conflicting interpretations of a QFD matrix, they converge on a common understanding of the customer's needs and on the system requirements. This provide great value. It results in more consistent decision making, and more efficient work at every subsequent step in system development. A critical element for success is the conviction by the system-engineering team that their system will be welcomed by its potential customers – and they know why it will be welcomed. Working through the House of Quality gives them this confidence.

Second, the QFD structure promotes systematic analysis of a myriad of inputs. Finally, the QFD process provides a roadmap to guide the team through the most far-reaching phase of system development: the requirements phase.

Next we go into more operational detail.

CORE OF THE HOUSE

The core of the House of Quality (HoQ) in Quality Function Deployment (QFD) is the combination of Customer Needs, Engineering Characteristics, and the Relationship between them. It is important to recognize that both the Customer Needs and the Engineering Characteristics are requirements or specifications that the product system must satisfy. The distinction is that the Customer Needs are in the language of the customer, while the Engineering Characteristics are in the corporate language of the system providers. A classic mistake is to use the columns (Engineering Characteristics) to show design responses. This is premature. First we have to define the needs in corporate technical language, before we can start making a design response.

The core of the HoQ is displayed in Figure 3.

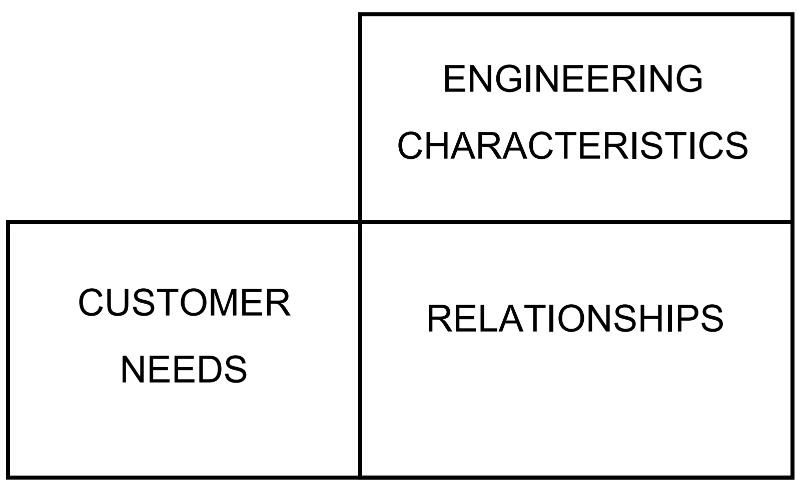

Figure 3. Core of House of Quality (HoQ).

Many different variations of words are used for Customer Needs and Engineering Characteristics. The essential distinction is that the former is in customer language and the latter is in the language of the provider. Customer Needs are measured by customer response. Engineering Characteristics are measured by technical tests. The Relationship matrix helps to match the right technical test with the related Customer Need or needs.

For a very simple product, Figure 3 is sufficient definition for the core of the HoQ. Do the market research, enter the 5 to 15 important needs in as the rows, find the related engineering characteristics that can provide technical guidance, and show the relationships between them. In its simplest form the Relationship matrix is diagonal, one Engineering Characteristic matching one Customer Need. When the product is that simple, that is all that there is to the core of the HoQ.

However, many products are far too complex for this simple approach to suffice. There can be many tens or even hundreds of Customer Needs. Also, the needs that are captured from customers can be a confusing array of apples and oranges, including obvious parents and children (some are subsets of others), crying for further clarification. Therefore, more needs to be done to provide clear guidance in the planning of the new product.

CUSTOMER NEEDS (ROOM 1)

The customer needs are developed by market research. It is usually advisable for some of the technical provider-enterprise people to be involved in this activity. Here we assume that this has been well done, and we start with the needs that are relevant to the customers.

The needs present three challenges: (1) an overwhelming number of needs, (2) children and parents are included, and (3) different types of needs. There are two methods that have long been used and are current best practice for meeting these challenges. They are the KJ Method, which addresses challenges 1 and 2, and the Kano characterization, which addresses the third challenge.

KJ Method

The KJ Method was developed by Kawakita, Jiro (KJ), a Japanese anthropologist, starting in the 1950s. Later it was imported into the business world, and had been used successfully there for many years.

The basic concept is to write each need on a notepaper or card, and then affix it to a large sheet of paper on the wall. Then the team sorts these into groups by moving the slips around.[4] When it is feasible, it is good to have customers involved.

For example, there might be 50 needs. These might be organized into 15 groups at the second level. These in turn could be organized into four groups at the third level. With numbers such as these the team would usually then decide to work primarily at the second level. Fifteen needs are feasible to work with, but 50 are typically too many. That takes care of the first challenge, too many needs.

Also, the groups should take care of parents and children that are initially mixed together. They will now be on different levels of the KJ (affinity) diagram.

Many teams do little more than has been described – shuffle slips around to form groups. This does form affinity groups, and it is acceptable to call this the affinity method. However, it does not achieve the results that can be obtained by a more developed method.

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[4] Today it would be feasible to do this electronically. However, the social dynamics would be drastically changed.

A good summary of the KJ Method is in the book by Shiba, Graham, and Walden [1993]. They show six major steps:

1. Agree on a topic
2. Write and understand the data
3. Group similar data
4. Title groups
5. Lay out groups and show relationships among groups
6. Vote on the most important low-level issues and draw conclusions

In one version of this there are a total of 19 detailed steps. This has been taught by Professor Shiba in his classes at MIT and in his work with the Center for Quality of Management. Americans tend to have the reaction that a process with 19 steps is too much detailed rigor. However, actual use of the 19 steps has brought results that are far beyond what could have been achieved by simply shuffling cards around in an undisciplined way.

Kano Diagram

Kano pointed out that not all customer needs are of the same type. Rather there are three very different types. This distinction is critical to effective use of the HoQ.

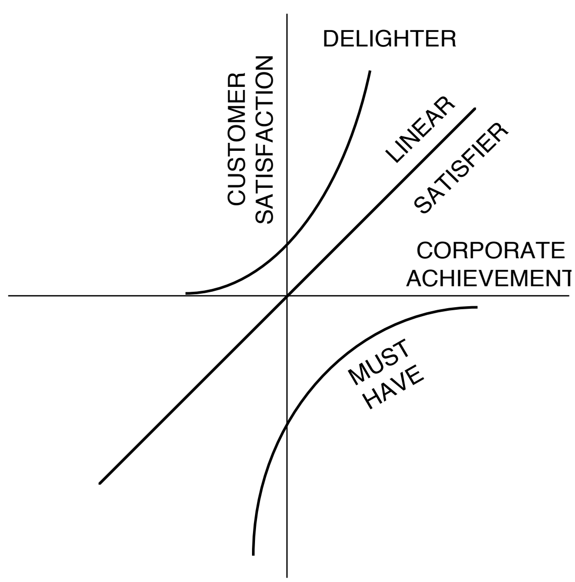

Figure 2. Kano diagram – three types of needs.

The type of need that is most frequently considered in the HoQ is the *linear satisfier*. Double the achievement doubles the satisfaction; gas mileage is an example.

An example of a *must have* is brakes. A car must have brakes. However, in the evolution of automotive technology there has been very significant advances in brakes. So even for a function that the system must have, there is still opportunity for competitive advantage.

A *delighter* is a function that the customer was not expecting and is delighted to find. Sometimes the entire product is a delighter, such as has happened recently with the Apple iPod.

Clearly the team's work to quantify the needs and the technical responses to them must take into account these different types of needs. If a *must have* is missing, it can outweigh all of the *linear satisfiers*.

Sometimes a delighter can be accomplished by combining together outstanding achievement on all of the linear satisfiers. One could assert that this is the case with the Apple iPod. Its individual features, such as a very small disk drive, are high up on a linear-satisfier scale. The combination is a delighter.

Summary of Customer Needs

The customer needs must be carefully structured before there is any attempt to use quantification to focus attention on a subset of needs that will be most productive in the enhancement of customer satisfaction. The structuring methods that are most developed are the KJ Method and the Kano diagram.

Quantification inevitably means trying to convert human feelings and language into numbers. This will always have much room for further research.

ENGINEERING CHARACTERISTICS (ROOM 2)

These are the columns in the HoQ, the technical equivalents of the customer needs. These are an alternative statement of the requirements for the system, not yet saying anything about the design of the system. This form of the requirements is technical and measurable. It has two sources: (1) responses to the customer needs, and (2) amplification of the functions of the system.

Technical Responses

This approach is straightforward. Take each customer need (at the appropriate level) and brainstorm technical means of measuring the system performance that will assure customer satisfaction on the selected need. Then work this down to the one or two that will best guide the design.

As an example consider the paper-handling subsystem for a copier/printer. Typically a customer need will be that it is *reliable*. One technical response is paper-handling *shutdown rate*. Such metrics evolve over time to best match the need that is most important to the customers. Originally this metric was shutdowns per million copies. Eventually it was recognized that the customers were really affected by shutdowns per week. This became the technical response.

The HoQ is not an end unto itself. It is a critical step to guide the selection of the system architecture, including technology selection. For a paper feeder there will be two or at most three technologies available for integration into the new copier/printer system. There will be the low-cost, low-reliability feeder, and the better feeder technology. If the shutdown rate per week for the low-manufacturing-cost feeder is less than the specified amount, about one per week, then it is selected. It the copier/printer will be used more often, so that the shutdowns per week for the cheap feeder would be excessive, then the more reliable feeder is worth the extra initial cost.

This approach of finding one or two direct responses to measure the system performance for each customer needs is always a good starting point. However, for some types of needs it is insuffi-

cient. Take the famous Toyota rust-prevention case from the 1970s. The customer needs (at the third level) were:
1. Rust prevented while driving for any purpose
2. Rust prevented in all driving modes
3. Rust prevented in all maintenance conditions
4. Rust prevented in all natural environments
5. Rust prevented in all driving environments
6. Rust prevented in all road conditions

Exactly what these meant was spelled out in the two more-detailed levels.

The technical responses were in the following columns:
1. Rust prevented at edges
2. Rust prevented at joints
3. Avoid rust that is caused by defective part
4. Provide rust-prevention paint film
5. Resist corrosion holes
6. Resist spot rusting

An excellent job was then done in applying QFD to deploy these into the design and then into production.

Note that although there are six customer needs and six engineering characteristics, there is definitely not a one-to-one matching. Reflection suggests that the detailed relationships between the rows and the columns in this case are not important. What is important is *coverage*. Do the engineering characteristics cover all of the needs?

Functional Analysis

The engineering characteristics can also be derived from the functions (F in Figure 1.) that the system must perform. This is not an alternative to deriving the technical responses from the customer needs, but a supplemental way that provides additional insight.

Functions are usually stated as a verb and a noun, *make copy*, for example. Clausing [1989, 1993] and his students [Pandey 1991, Sontow 1992], and Pahl and Beitz [1984, 1996] have pointed out that there is a generic amplification or expansion that is associated with each function. This comes in two parts.

The first part is the primary purpose of the function. All functions transform and/or transport energy, material, geometry, and/or signals.

The second part is the expanded requirements that are associated with any function. When we specify that the function is *make copy*, we mean that a copy should be made for a certain cost, with safety, satisfying all social regulations, etc. Clausing and his students generated the following starter list for the amplification (A in Figure 1.) from a function:

1. Explicit customer requirements
    - 1.1. Cost
    - 1.2. Size
    - 1.3. Mass
    - 1.4. Appearance
    - 1.5. Feel
    - 1.6. Taste
    - 1.7. Smell
    - 1.8. Sound
    - 1.9. Life expectancy
    - 1.10. Maintenance cost
    - 1.11. Operational range
2. Implicit Customer Requirements
    - 2.1. Manufacturing, distribution, Servicing
        - 2.1.1. Dimensions
        - 2.1.2. Achievable tolerances
        - 2.1.3. Packaging
    - 2.2. Safety, ergonomics, latent needs
        - 2.2.1. Operational safety
        - 2.2.2. Environmental safety
    - 2.3. Government regulations
        - 2.3.1. E.P.A. regulations
        - 2.3.2. F.D.A regulations

We see that these are the type of characteristics that go into the columns of the HoQ. Therefore, the team can review these to help generate the columns in the HoQ. However, most of these will be judged to be insufficiently important for the HoQ. They will not help in making the subsequent system architecture decisions. Instead they will be addressed by standard tests and knowledge-based engineering.

This is displayed in Figure 3.

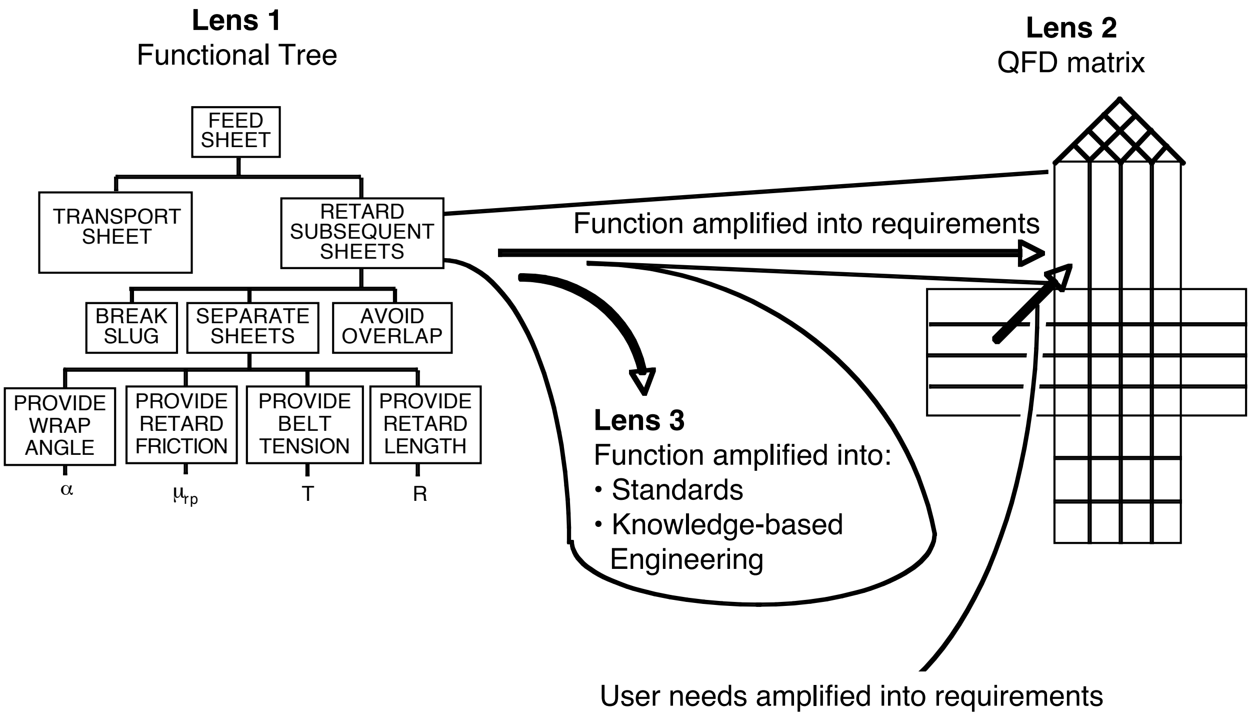

Figure 5. Expansion of functions into engineering characteristics.

Figure 5 displays that the columns in the HoQ can be thought of as coming from both the rows, and from the amplification of the system functions.

RELATIONSHIP MATRIX (ROOM 3)

The relationship matrix is a formal analysis of the relationship between the customer needs (rows) and engineering characteristics (columns) in the HoQ. However, as has been described, the relationships have already been much considered during the development of the rows and columns, especially the columns. In many cases there will be little more that needs to be done.

We have already seen in the rust-prevention case that the relative importance of the six engineering characteristics was not significant. All six were important, and all had to addressed successfully. The "importance" decision was to work on rust prevention. This was largely driven by competitive benchmarking and customer reaction.

The HoQ is not an end unto itself. It is an important step in the development of the market-attack plan (MAP). The objective is to plan a new system that will have competitive advantage. The HoQ is a major step in the identification of characteristics that will provide competitive advantage. For example, the rust-prevention project gave Toyota a tremendous improvement over their previous vehicles, and transformed rust prevention from a competitive disadvantage into a competitive advantage for Toyota.

In the relationship matrix we want to avoid excessive analysis that cannot help our team to achieve competitive advantage. When we are guided by the role of the HoQ in the development of a MAP, then we can include only those characteristics that are essential to success.

Current Practice

The best current practice is to use 9, 3, 1, and 0 in the cells of the relationship matrix to quantify the relationship between the engineering characteristic and the customer need. (Cells that are left blank are 0, or more precisely, insignificant relationship.)

The non-linear (geometric) sequence of 9, 3, and 1 tends to emphasize the relative importance of the most important characteristics.[5] This is the primary reason for using this relationship ranking.

Engineers are good at finding many relationships. A common problem is to fill the relationship matrix with symbols, such as 9, 3, and 1. A rough rule of thumb is that at most only about 1/3 of the cells should be filled. More than that suggests that there was too low a hurdle in the identification of a relationship.

Using 9, 3, and 1 while taking care to keep the matrix sparse is usually sufficient. However, many other approaches have been used. An obvious one is to use 5, 3, 1, and implicitly 0.

Many teams use graphical symbols in the cells, such as thin hollow circles, thick hollow circles and solid circles. In making calculations these have numbers, such as 9, 3, and 1, assigned to them.

The common practice is to use only positive relationships between the engineering characteristics and the customer needs. Conflicts between engineering characteristics are identified in the attic of the HoQ, where both positive (synergistic) and negative (anti synergistic) pairs of engineering characteristics are identified.

These weights are determined by the multifunctional system development team, using their best judgment. Market researchers sometimes use a quantitative method, conjoint analysis [Urban and Hauser 1993]. Multiple versions of a system are defined and described, either on paper or on a computer, which can also be displayed online. By analyzing the customers' perceptions in response to the different system-feature sets quantitative information is derived about the relationship matrix.

The relationship matrix is used to calculate the relative importance of the engineering characteristics. The importance of each need is multiplied by the relationship weight, and all cells in a column are then added to give the importance rating of that engineering characteristic. However, there are other factors that go into deciding which engineering characteristics to emphasize.

QUANTITATIVE MARKET DATA (ROOM 4)

Each customer need is characterized by more than its importance. This is displayed in Figure 6.

[5] In some literature this is called a non-compensatory scale; i.e., 1+3 cannot compensate for a 9.

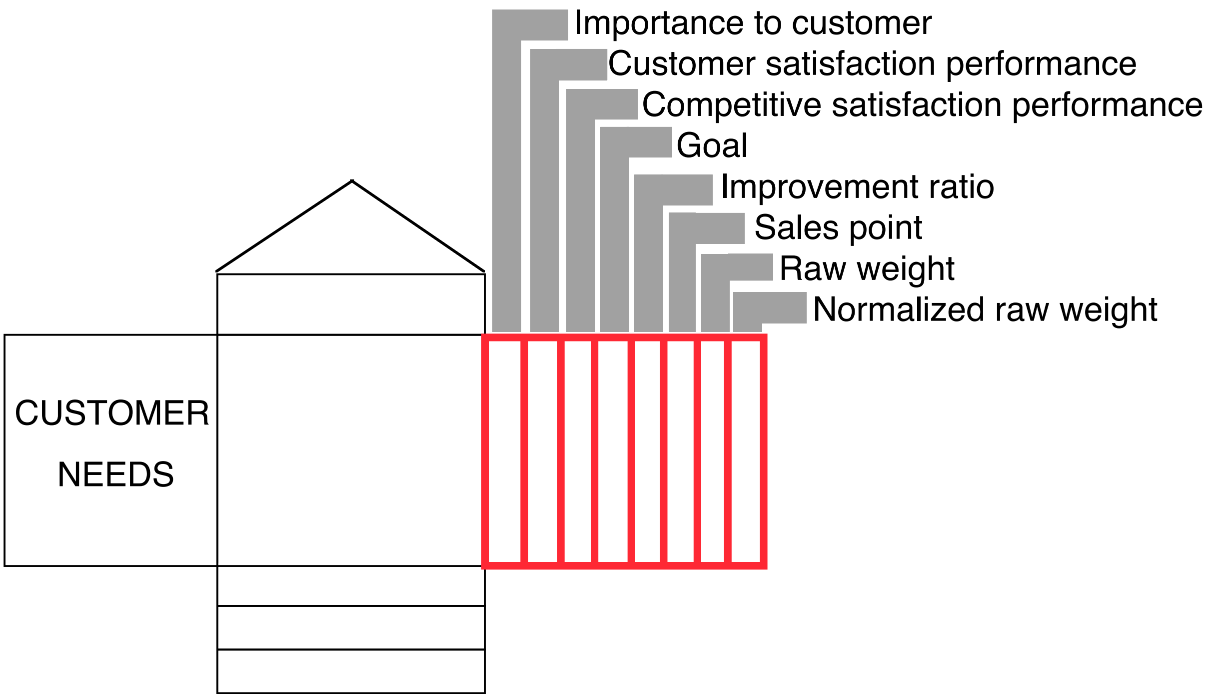

Figure 6. Room 4 of the House of Quality. After Cohen [1995].

In addition to the customers' perceptions of importance, the competitive situation is a major driver in deciding on the new product. The relationship matrix is used to convert this into the competitive rankings on the engineering characteristics based on customer perceptions. This is compared with the actual technical evaluations that are displayed in one of the lower rooms of the HoQ. Finally all of the information is used to calculate first the raw weights and then the normalized weights for each customer need. The relationship matrix is then used to translate this into guidance on the engineering characteristics.

The primary objective while working in Room 4 is to identify sales points that will make the new system attractive to the potential customers. This competitive advantage is critical to the revenue and profit of the enterprise.

PRIORITIES (ROOM 5)

In Room 5 the relative importance of each engineering characteristic (column) is calculated. This is determined from the information in Room 4 and the relationship matrix.

Systems development teams must not allow the importance scores in Room 5 to lead into mind-numbing numerology. A priority score of 100 vs a priority score of 95 is not a significant difference. What is important is to find some cluster of customer needs, translated into the supporting engineering characteristics, that will provide sales points and give competitive advantage. The priority scores are used to make a qualitative decision: this set of system features will give us a winner in the marketplace.

CORRELATIONS (ROOM 6)

This is the attic of the HoQ. Each cell in this triangular matrix is at the intersection of two columns (engineering characteristics). Here the team evaluates the conflict or synergy between pairs of engineering characteristics. Of particular interest are negative correlations (conflicts). In conflicts success in the achievement of one characteristic will have the tendency to cause difficulty with the other characteristic. Special attention will be needed to achieve customer satisfaction on both.[6]

TECHNICAL BENCHMARKS (ROOM 7)

Here are displayed scores from technical tests of our existing product and the leading competitive products. An example is horsepower.

It is important to note here whether superiority on the technical tests is matched in Room 4 by customer perception that the product is superior. If not it means that the tests are measuring what the engineers are interested in rather than what the customers respond to. Then further development is needed to make our technical tests and market evaluation consistent.

TECHNICAL TARGETS (ROOM 8)

Here is the final result. What values for each of the engineering characteristics will give us competitive advantage? “300 horsepower” “10 years without rust” “image quality above 93” These are the type of decisions that are recorded here.

The team now has to be committed to the evaluation that achievement of these targets will meet the enterprise goals for revenue and profit. The steps of the HoQ are simply aids to the team in reaching this conclusion.

CONTEXT OF QFD

There are several types of new-product developments:
1. Breakthrough product
2. Product family
3. Generic improvement

The role of QFD varies greatly for these different types of development.

Breakthrough Product

QFD has little role for a breakthrough product. Breakthrough products have a huge advantage over previous technologies in a few characteristics. An example is the xerographic copier. When Chester Carlson invented it in the 1930s he created tremendous advantages in three characteristics: (1) dry process, (2) automatic, and (3) good copy quality. These advantages greatly expanded the market for copiers to the benefit of the Xerox Corporation in the 1960s. QFD could not have helped. However, as Xerox progressed on to its second and third generation copiers in the 1960s and 1970s QFD could have been a big help. In practice Xerox started to reap the benefits of QFD in the late 1980s.

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[6] Sometimes we can find a way around the conflict. In other cases the best-balanced trade off will be successful.

In general it is true that breakthrough projects, as with xerography, succeed by making huge improvements on two or three characteristics. The team can stay focused on the two or three large improvements, and does not need to depend on QFD to help deploy and balance 15 or 20 smaller improvements.

Breakthrough products usually result from a major invention; e.g., xerography. Later in this course we will consider TRIZ, a powerful aid for invention.

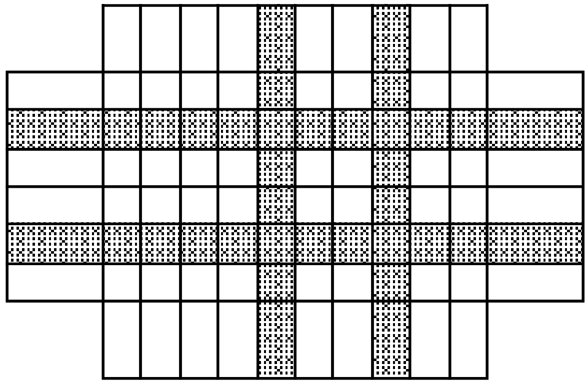
Product Family

The most important use of the House of Quality is to help in the planning of a product family.[7] Here the great innovation in QFD has been the Master House of Quality [Clausing and Cohen 1994, Cohen 1995]. The several products in a product family will obviously have Houses of Quality that are closely related. Cohen took this a step farther by developing the Master HoQ. The key insight is that the customer needs and the responsive engineering characteristics are the same for all market segments that are addressed by a product family. The difference among market segments is the relative importance given to each characteristic, and the performance that will be competitive. The Master HoQ can be tailored to develop the specific HoQs for each product. This is illustrated in Figure 7. Quoting from Clausing and Cohen [1994]

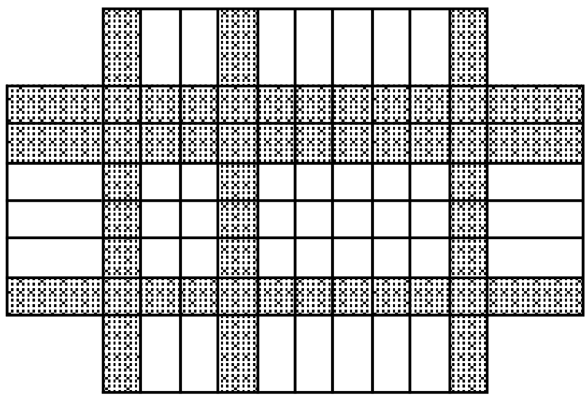
> "the team created a handbook which explained to future product developers in the company how to customize the master HOQ for their specific market segments. Each future product team is expected to determine the relative importance of the four customer types and the secondary customer attributes for *their* market, plug those numbers into the master HOQ, and thereby prioritize the performance measures for their market segment.
>
> By experimenting with some hypothetical importance values, the team determined that it would be possible for most future development teams to identify a small handful of performance measures out of the master list of 150 that would be critical for success in a particular market segment. Thus the master House of Quality will be the source for many market-specific Houses of Quality that will be created by future market segment teams."

This is with reference to a particular case study for which Cohen provided the QFD leadership.

[7] A product family is several products based on a significant set of common parts. Each product addresses a different market segment. Sometimes the products are said to be based on a common platform.



House of Quality for market segment A



House of Quality for market segment B

Figure 7. The Master House of Quality, tailored to two different market segments.

Clayton Christensen wrote a book, *The Innovator's Dilemma* [1997], which became very popular. It is about the creation of new market segments. When technical capabilities are rapidly improving, as they were in the disk-drive industry that Christensen studied, new market segments can make or kill a company. The Master HoQ is a good analysis to guide market segmentation.

The HoQ is a key element in the development of a Market-Attack Plan (MAP) [Holmes and Campbell 2004]. To be perceived in context the HoQ, Master and individual, must be considered in its larger role as an element of the MAP. To quote from Holmes and Campbell:

> "The strategic plan should constitute a complete map for achieving success in the targeted market; accordingly, it can be referred to as a Market Attack Plan (MAP). The plan is resourced for all elements, e.g., technology sets, products, services, and value chain enablers, that are strategically aligned with market segments, key business goals, and corporate priorities. The business goals, expected outcomes, and funding plans are documented in a corporate Plan of Record.

> With the end-to-end business perspective pervading the strategic front end, companies achieve a more effective balance among new products and services, products currently under development, and products and services already in the field. By funding the product team and the total value chain as a whole, companies assure better alignment of resources and priorities of the entire company with the portfolio decisions made in the strategic front end."

This is the role of the HoQ for new products and product families. All evaluations, speculations, and proposals for improvement to the HoQ must past the test that they will improve the MAP. Focusing on the Relationship Matrix in isolation is a classical example of minutely examining the twigs while being lost in the forest. Changes in the HoQ methodology will be significant only if they lead to different Market-Attack Plans.

The ultimate role of the HoQ is to be a step in the development of the Market-Attack Plan. Here we start with the Market-Attack Plan, and work backwards to identify changes in the HoQ that would make a difference.

The MAP addresses the following questions [Holmes and Campbell 2004]:
- What business are we in?
- What markets do we/ can we serve?
- In what segments can we effectively participate?
- How large is the business opportunity?
- What are our expectations for the competitive environment?
- What are our key value propositions?
- What will we establish as major vectors of differentiation?
- What are the platforms to address the targeted customer and markets?
- What architectures and technology sets will enable these platforms?
- What will we offer as product families and services?
- How will we organize the value chain strategies and enablers?
- What are the resources required to deliver against the product and strategic plans?
- What is our expected integrated business outcome?

The MAP is a complete, integrated plan for success in the targeted market. How can the HoQ contribute to the development of the MAP?

Consider the first four questions.
- What business are we in?
- What markets do we/ can we serve?
- In what segments can we effectively participate?
- How large is the business opportunity?

These questions are addressed by a Master HoQ. A single-product HoQ in the absence of a Master HoQ will likely leave these questions not effectively addressed. To be an effective part of a MAP the HoQ must be related to a Master HoQ.

The next three questions are:

- What are our expectations for the competitive environment?
- What are our key value propositions?
- What will we establish as major vectors of differentiation?

These are addressed in Room 4 of the HoQ, see Figure 4. Quantification must help to translate these customer perceptions into technical objectives for design and production.

The next three questions address the system architecture:

- What are the platforms to address the targeted customer and markets?
- What architectures and technology sets will enable these platforms?
- What will we offer as product families and services?

This emphasizes the point that the HoQ can only guide decisions among available options. For any function of the system there are usually only two or three options to choose from. These decisions are dominated by a few characteristics. The only changes in the HoQ that we need to consider are those that would change a system decision.

Generic Improvement

The rust-prevention case study is a perfect example of this. The HoQ was not the most important element of this case. It was used to help in the decision to make a major effort on rust prevention. Most of the help from QFD in this case came from the subsequent QFD matrixes, design, production planning, and production operations.

The rust-prevention case provided Toyota with great competitive advantage, but it was not a breakthrough. As noted earlier, QFD is superfluous for a breakthrough development, such as xerography.

COMPLETE QFD

Complete QFD includes horizontal deployment from the HoQ to production processes, process planning, and production operations. It also includes vertical deployment downward from the total system, to subsystems, and on down to piece-part features. The role of the HoQ in the total development is revealed by the complete QFD, and will vary by project. For generic improvements, such as rust prevention, the additional QFD steps are often more important than the HoQ itself.

Horizontal Deployment – To The Factory Floor

The nature of the horizontal deployment to the factory floor is displayed by the examples in Figures 8 – 11. These are taken from the rust-prevention QFD that was done at Toyota Auto Body in the 1970s. These go from the voice of the customer in Figure 8 to the design of the die in Figure 11 that is used to stamp the sheet steel. Careful study of these four figures will reveal the general nature of horizontal deployment.

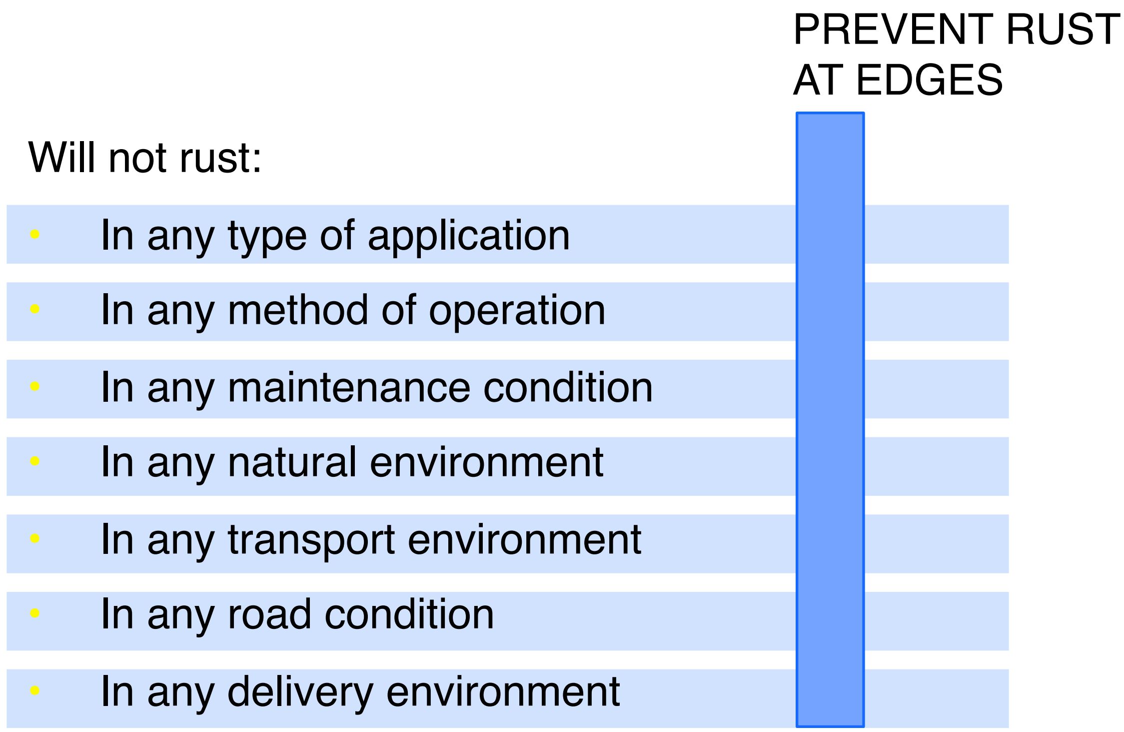


Figure 8. Example from House of Quality.

Figure 8 shows one column in the House of Quality. In order to have good rust prevention for the vehicle it is necessary to prevent rust at the edge of the sheet steel that is used to manufacture the body.

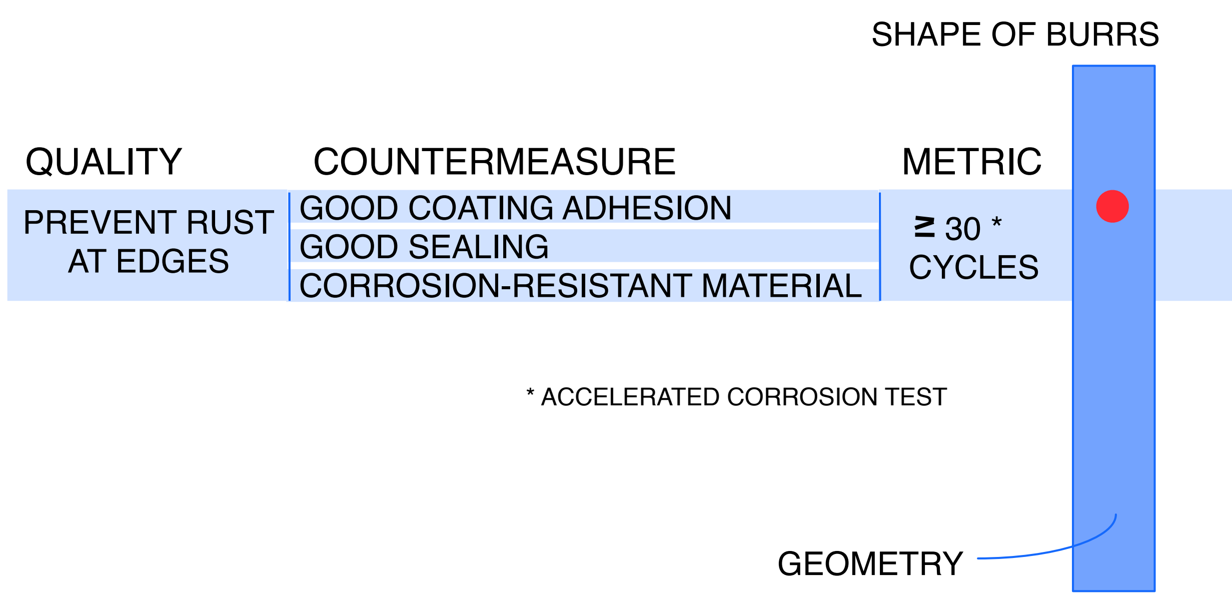


Figure 9. Example from Parts Deployment.

The prevention of rust at the edges is decomposed down to three requirements to overcome the three common failure modes. It is further noted that more than 30 cycles in an appropriate accelerated corrosion test is believed to be sufficient to make the vehicle a winner for rust prevention.

It is further noted that the shape of the burr that is left when the sheet-metal part is stamped from the raw sheet will have a major influence on the rust prevention.

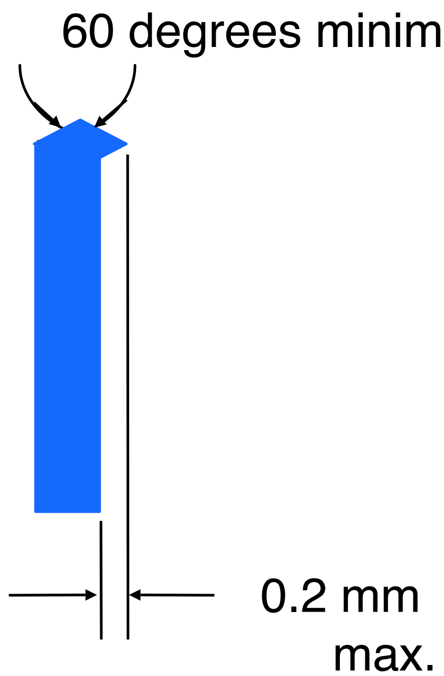


Figure 10. Burr geometry on the edge of the sheet steel, good enough to prevent rust.

Figure 10 shows the burr geometry that is good enough to avoid the burr being a site for rust to start. Qualitatively the burr must be blunt. It should not be a "feather" sticking out, which is easily bent and/or broken.

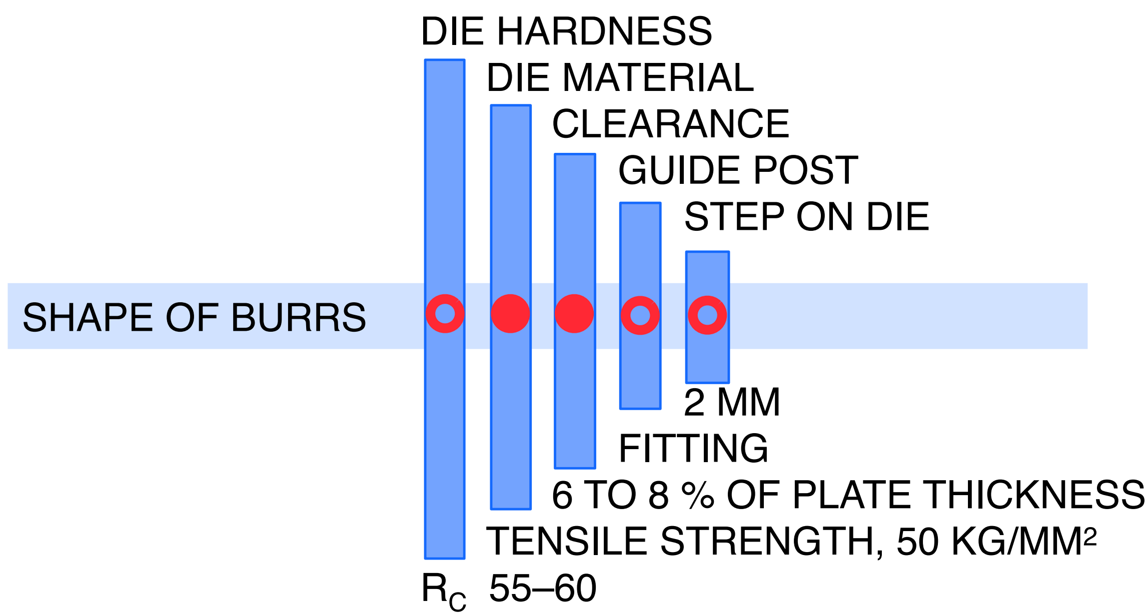


Figure 11. Example from Production Process deployment.

Finally Figure 11 gives the characteristics of the die that is used to stamp out the sheet-metal parts. When the die has the values that are shown, then the burr will be at least as good as shown in Figure 10.

Now working backwards, if care is taken with the die as shown in Figure 11, then the burr on the edge of the sheet steel will not be worse than shown in Figure 10, with the result that the rust avoidance will be at least as good as shown in Figure 9, with the result that all of the customer needs in Figure 8 will be satisfied. The strategic advantage will be that customers will prefer our cars because they have superior rust prevention. This QFD was a major enabler for the Toyota thrust into the American market.

Horizontal and Vertical Deployment

The table on the next page shows both horizontal and vertical deployment.

Symbols in top row relate to Figure 5 *These are examples of item(s) described above in each cell*	V O I	QFD Product Matrix $E_{F-} - E_F$	Product Functions F	Pugh Concept Selection C_H (C_P)	Production Process Functions P	QFD Process Planning Matrix $E_F - E_P$	QFD Production Operations Planning Matrix $E_P - E_O$
Total System TS	C E	House of Quality VoC – E_{TS} *Always get a copy* *Misfeed rate*	Total System Functions F_{TS} *Make copy*	Total System Architecture C_{TS} *Copier*	Total System Process Functions P_{TS} *Assemble modules*	Final Assembly Planning Matrix $E_{TS} - E_{TSA}$ *Misfeed rate* *Subsystem alignment*	Final Assembly Operations Matrix $E_{TSA} - E_{TSO}$ *Subsystem alignment* *Alignment procedure*
Subsystem SS	O F	TS/SS Design Matrices $E_{TS} - E_{SS}$ *Misfeed rate* *Misfeed rate (SS)*	Subsystem Functions F_{SS} *Feed sheet*	Subsystem Concepts C_{SS} *Paper feeder*	Subsystem Process Functions P_{SS} *Assemble feeder*	Subsystem Assembly Matrices $E_{TSA}/E_{SS}–E_{SSA}$ *Misfeed rate (SS)* *Align feedhead*	Subsystem Assembly Operations Matrices $E_{SSA} - E_{SSO}$ *Align feedhead* *Alignment steps*
Subassembly SA		SS/SA Design Matrices $E_{SS} - E_{SA}$ *Misfeed rate (SS)* *Wrap angle*	Subassem. Function F_{SA} *Provide wrap*	Subassembly Concepts C_{SA} *Belt wrapped around roll*	Subassem. Process Functions P_{SA} *Assemble belt and roll*	Subassembly Assembly Matrices $E_{SA} - E_{SAA}$ *Wrap angle* *Adjust angle*	Subassembly Assembly Operations Matrices $E_{SAA} - E_{SAO}$ *Adjust angle* *Adjustment steps*
Piece-part concept PPC	C U S T	SA/PPC Design Matrices $E_{SA} - E_{PPC}$ *Wrap angle* *Beam straightness*	Piece-part Concept Functions F_{PPC} *Position roll and belt*	Piece-part Concepts C_{PPC} *Al die-casting beams*	Part Formation Process Functions P_{PPC} *Make castings*	Part Formation Matrices $E_{PPC} - E_{PF}$ *Straight beams* *Casting temperature*	Part Formation Operations Matrices $E_{PF} - E_{PFO}$ *Casting temperature* *Controller operation*
Piece-part features PPF	O M E R	Part Feature Design Matrices $E_{PPC} - E_{PPF}$ *Beam straightness* *Machining precision*	Piece-part Feature Functions F_{PPF} *Position roll*	Piece-part Feature Concepts C_{PPF} *Low distortion*	Final Processing Functions P_{PPF} *Machine land on beam*	Final Processing Matrices $E_{PPF} - E_{FP}$ *Machining precision* *Clamping fixture*	Final Operations Matrices $E_{FP} - E_{FO}$ *Clamping fixture* *Clamp to datum D*

This table is taken from Clausing [1995], and is in turn a further development from an earlier paper by Clausing and Pugh [1991]. The example is for a copier/printer paper feeder.

In this table deployment is done horizontally through the stages defined by the column headings, and vertically through the system levels defined by the row headings.

One feature that is revealed is that complete deployment requires that concepts be selected, which is done by the Pugh Concept Selection (convergence) process.

Also, the functions F are shown here for completeness. As discussed earlier, these can be amplified into the expectations E. For example, the function *make copy* has as one amplification the *misfeed rate*. In other words, when the function is identified to be *make copy*, there are a set of implied expectations, including that the misfeed rate from the paper feeder will be less than one per week.

It is not to be expected that any one project will use all of the QFD that is implied by the table. For example, only a tiny fraction of all piece-part features would be deployed by QFD. Careful consideration will reveal which cells will give competitive advantage for each specific project.

SUMMARY

Quality Function Deployment (QFD) provides the systems-engineering team with methods that help to carefully deploy the voice of the customer throughout the system-development activity. This gives the team meaningful goals for all of their myriad of activities. These clear goals help the team to achieve a system that is attractive to the potential customers.

Of course, it is easy for QFD, or any other method, to become bureaucratic. If it is allowed to deteriorate into a mind-numbing exercise to “fill in the forms,” the result will be worse than useless.

If the team works in a style of constantly asking how they can leverage the many aspects of QFD to develop a better system, then they will be able to ascertain the specific applications of QFD that will best improve their system to make it attractive to potential customers.

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