QUALITY FUNCTION DEPLOYMENT
AND
PROCESS MODELS

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What is Quality?

Quality is an abstract term, often defined as
the extent to which the customers (users)
believe the product meets
their requirements and expectations
Examples of Quality Measures

- General
  Degree of customer satisfaction

- Specific
  Reliability

Quality Function Deployment (QFD) Matrix

QFD - Basic Idea

Basic idea of QFD is to transform customer requirements into design requirements:

- QFD begins by obtaining the customer requirements (CRi) with respect to the product being designed
- Technical descriptions (DRj) are listed and evaluated from the point of view of the requirements

Known also as the House of Quality
**QFD Cascade**

- **Customer requirement**
- **Technical description**
- **Functional description**
- **Design activity**

**THE HOUSE OF QUALITY:**

**EXAMPLES**

**Six step procedure for forming a QFD matrix**

1. The primary customer requirements are normally expanded into secondary and tertiary requirements using AND/OR tree.
2. The design requirements must be related to the customer requirements and should be selectively deployed throughout the manufacturing, assembly, and service process to manifest themselves in the final product performance and customer acceptance.
3. Developing a matrix describing the customer requirements and the design requirements is accomplished.
4. Market evaluation which covers the customer-expressed importance ratings, requirements, and competitive products is performed.
5. The target for each of the design requirement is defined.
6. Selection of the best solution should be deployed.

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**Six steps for building a house of quality**

- **Voice of Customer**
- **Competitive Analysis**
- **Technical Specification**
- **Trade-offs**
- **Voice of Engineer**
- **Requirements**
Example 1

House of quality for the design of a sample product

Example 2

House of quality: BP team

Examples of Rows

Very Compact
Weighs little
Lights easily
Very stable
Opens quietly
Heats quickly

Examples of columns

Force
Speed
Manufacturing cost
Maintenance cost
Example 3

QFD Benefits

- Product objectives based on customer requirements are not misinterpreted at the subsequent stages
- Particular marketing strategies or sales points do not become lost or blurred during the translation process from marketing through planning to execution
- Important production control points are not overlooked - everything necessary to achieve the desired outcome is understood
- Efficiency is improved as the misinterpretation of design objectives, marketing perception, and critical control points, and the need for changes is minimized

DESIGN PROCESS

IDEF3 design process model of an electro-mechanical product

Activities

1. Prepare system specifications
2. Generate preliminary design
3. Evaluate cost of different alternatives
4. Build prototype
5. Perform tests on prototype
6. Analyze test data
7. Finalize design details
Modeling

RELATIONSHIP BETWEEN DESIGN PROCESS ATTRIBUTES AND VARIABLES OF CRITICAL ACTIVITIES

• An attribute is an element of a design process performance measure or the measure itself

• An attribute is a function of design process variables

List of activities of the design process

<table>
<thead>
<tr>
<th>No.</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Perform project planning</td>
</tr>
<tr>
<td>2</td>
<td>Review and analyze customer requirements</td>
</tr>
<tr>
<td>3</td>
<td>Develop project coordination document</td>
</tr>
<tr>
<td>4</td>
<td>Define design requirements</td>
</tr>
<tr>
<td>5</td>
<td>Establish system design goals</td>
</tr>
<tr>
<td>6</td>
<td>Perform system tradeoffs</td>
</tr>
<tr>
<td>7</td>
<td>Finalize product requirements</td>
</tr>
<tr>
<td>8</td>
<td>Develop system requirements</td>
</tr>
<tr>
<td>9</td>
<td>Conduct internal requirements review</td>
</tr>
<tr>
<td>10</td>
<td>Review requirements with customer</td>
</tr>
<tr>
<td>11</td>
<td>Analyze modifications of system specifications</td>
</tr>
<tr>
<td>12</td>
<td>Finalize the system specifications</td>
</tr>
</tbody>
</table>

QFD in Design

Relationships

(a) Process attribute - process variable
(b) Activity - attribute
(c) Other relationships
### Relationship Matrix
- **Strong positive**
- **Medium positive**
- **Weak positive**
- **Negative**

### Interaction Matrix
- **Positive**
- **Negative**

### Symbols used in the house of quality for design process attributes and variables

### Conversion of symbols
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Coefficient Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>●</td>
<td>+9</td>
</tr>
<tr>
<td>○</td>
<td>+3</td>
</tr>
<tr>
<td>▼</td>
<td>-1</td>
</tr>
<tr>
<td>×</td>
<td>-3</td>
</tr>
</tbody>
</table>

### House of quality for a design process

### Conversion of QFD into a mathematical programming model

### Relationships Quantification
The Design Process Example

Relationships

Attribute - variable

or

Activity - attribute (characteristic)

Design process attributes

\[ y = (y_1, ..., y_i, ..., y_n) \]

Feasible range for \( y_i \) is:

\[ y_{iL} \leq y_i \leq y_{iU} \]

Values of the design process variables:

\[ x = (x_1, ..., x_i, ..., x_m) \]

Feasible range for \( x_i \) is:

\[ x_{iL} \leq x_i \leq x_{iU} \]

Attribute \( y_i \) is a function of the design process variables

\[ y_i = f(x) \]

The design process variables are scaled in the range of 0 to 1 to obtain the vector of relative design process variable values:

\[ x' = (x'_1, x'_2, ..., x'_m) \]

\[ y'_i = f(x') \]
Why scaling variables?

Same ‘weight’ assigned to each variable

Scaling equations

Consider equation y2':

\[ y2' = 3x1' + 9x2' + 3x3' + 3x1'x2' + 3x2'x3' \]

\[ \min y2' = 0 \text{ and } \max y2' = 21 \]

Note: (21 - 0) is the range for y2' obtained by maximizing and minimizing \[ y2' = 3x1' + 9x2' + 3x3' + 3x1'x2' + 3x2'x3' \]

and (1 - 0) the range for y2 from the table

Expression for y2 as a function of x’s scaled in [0, 1]:

\[ y2 = 0 + (1 - 0) \frac{(3x1' + 9x2' + 3x3' + 3x1'x2' + 3x2'x3')}{(21 - 0)} \]

Equation Balancing

\[ y - y1 = \frac{y2 - y1}{y2' - y1'} (y' - y1') \]
Balancing equation

\[ y = \text{Lower limit of } y + (y \text{ range})(y'/y' \text{ range}) \]

Scaling to \( y \) range  Scaling of \( y' \) to \([0, 1]\)

**Example**

\[ y_2 = 0 + (1 - 0) \frac{y_2'}{(21 - 0)} \]

**Example 1**

\[ y = a + (b - a)x \]

\[ y = 0 + (10 - 0)x = 1 \times 3 = 3 \]

**Example 2**

\[ y = a + (b - a)x \]

\[ y = 2 + (10 - 2)x = 2 + 8 \times 3 = 4.4 \]
Expression for $y_s$ as a function of $x$'s scaled in $[0, 1]$:

$ranges$ determined using Lingo Optimization Software

$y_1 = 0 + (8 - 0)(9x_1' + 3x_2' + 9x_4' + 3x_1'x_2' - 3x_1'x_4' + 3x_2'x_4') / (24 - 0)$

$y_2 = 0 + (1 - 0)(3x_1' + 9x_2' + 3x_3' + 3x_1'x_2' + 3x_2'x_3') / (21 - 0)$

$y_3 = 2.5 + (9.4 - 2.5)(3x_1' + 9x_2' + x_4' + 3x_1'x_2' - 3x_1'x_4') / (15 - 0)$

$y_4 = 18 + (35 - 18)(3x_1' + 3x_2' + 9x_3' + x_4' + 3x_1'x_2' + 3x_2'x_3' - 3x_1'x_4' - 3x_3'x_4') / (21 - 0)$

**EXAMPLE 4:** Critical design activities used as design process attributes and their feasible ranges

<table>
<thead>
<tr>
<th>Activity No.</th>
<th>Critical Activity Name</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>y1</td>
<td>Define design requirements</td>
<td>$0 \leq y_1 \leq 1$</td>
</tr>
<tr>
<td>y2</td>
<td>Finalize product requirements</td>
<td>$0 \leq y_2 \leq 1$</td>
</tr>
<tr>
<td>y3</td>
<td>Develop system requirements</td>
<td>$0 \leq y_3 \leq 1$</td>
</tr>
<tr>
<td>y4</td>
<td>Analyze modifications of system specifications</td>
<td>$0 \leq y_4 \leq 1$</td>
</tr>
</tbody>
</table>

Variables affecting the quality of design activities and their limits

<table>
<thead>
<tr>
<th>Variable</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>x1</td>
<td>$0 \leq x_1 \leq 8$</td>
</tr>
<tr>
<td>x2</td>
<td>$4.6 \leq x_2 \leq 12.34$</td>
</tr>
<tr>
<td>x3</td>
<td>$1 \leq x_3 \leq 5$</td>
</tr>
<tr>
<td>x4</td>
<td>$8 \leq x_4 \leq 25$</td>
</tr>
<tr>
<td>x5</td>
<td>$3 \leq x_5 \leq 11$</td>
</tr>
</tbody>
</table>

House of quality for relationships between critical activities and process variables
\[ y_1 = 0 + (1 - 0)(3x_1' + x_2' - x_4' + 9x_5' - x_1'x_2' - x_1'x_5' + 3x_2'x_4') / (13 - (-1)) \]
\[ y_2 = 0 + (1 - 0)(9x_1' + 3x_3' + x_5' - x_1'x_5' + 3x_3'x_5') / (15 - 0) \]
\[ y_3 = 0 + (1 - 0)(9x_1' + x_2' + 9x_3' + 3x_5' - x_1'x_2' - x_1'x_5' + 3x_3'x_5') / (23 - 0) \]
\[ y_4 = 0 + (1 - 0)(3x_1' + 9x_2' + 3x_3' - x_4' - x_1'x_2' + 3x_2'x_4') / (16 - (-1)) \]

Maximize \[ w_1 y_1 + w_2 y_2 + w_3 y_3 + w_4 y_4 \]
s.t.
\[ y_1 = 0 + (1 - 0)(3x_1' + x_2' - x_4' + 9x_5' - x_1'x_2' - x_1'x_5' + 3x_2'x_4') / 14 \]
\[ y_2 = 0 + (1 - 0)(9x_1' + 3x_3' + x_5' - x_1'x_5' + 3x_3'x_5') / 15 \]
\[ y_3 = 0 + (1 - 0)(9x_1' + x_2' + 9x_3' + 3x_5' - x_1'x_2' - x_1'x_5' + 3x_3'x_5') / 23 \]
\[ y_4 = 0 + (1 - 0)(3x_1' + 9x_2' + 3x_3' - x_4' - x_1'x_2' + 3x_2'x_4') / 17 \]
\[ 0 \leq x_i' \leq 1 \quad \text{for} \quad i = 1, 2, 3, 4, 5 \]

Example

Maximize \[ 10y_1 + 35y_2 + 20y_3 + 15y_4 \]
s.t.
\[ y_1 = 0 + (1 - 0)(3x_1' + x_2' - x_4' + 9x_5' - x_1'x_2' - x_1'x_5' + 3x_2'x_4') / 14 \]
\[ y_2 = 0 + (1 - 0)(9x_1' + 3x_3' + x_5' - x_1'x_5' + 3x_3'x_5') / 15 \]
\[ y_3 = 0 + (1 - 0)(9x_1' + x_2' + 9x_3' + 3x_5' - x_1'x_2' - x_1'x_5' + 3x_3'x_5') / 23 \]
\[ y_4 = 0 + (1 - 0)(3x_1' + 9x_2' + 3x_3' - x_4' - x_1'x_2' + 3x_2'x_4') / 17 \]
\[ 0 \leq x_i' \leq 1 \quad \text{for} \quad i = 1, 2, 3, 4 \]

Maximize \[ 33.62x_1' + 10.58x_2' + 17.47x_3' - 1.60x_4' + 11.37x_5' - 2.47x_1'x_2' - 3.92x_1'x_5' + 4.79x_2'x_4' + 9.61x_2'x_5' \]
s.t.
\[ 0 \leq x_i' \leq 1 \quad \text{for} \quad i = 1, 2, 3 \]

The optimal solution (scaled in \([0, 1]\)) is:
\[ x_1' = 1.00, \quad x_2' = 1.00, \quad x_3' = 1.00, \quad x_4' = 1.00, \quad x_5' = 1.00 \]
### Values of variables affecting the quality of critical design activities

<table>
<thead>
<tr>
<th>Variable</th>
<th>Best Value</th>
<th>Alternative Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_1$ Average level of expertise</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>$x_2$ Average resource level</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>$x_3$ Frequency of interaction between different functional design groups</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>$x_4$ Number of resource preemptions</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>$x_5$ Number of information sources</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

Value of the Objective Function: 68.1

### Variable Limits

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<td>$x_1$ Average level of expertise</td>
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<td>$x_5$ Number of information sources</td>
<td>$3 \leq x_5 \leq 11$</td>
</tr>
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</table>

$x_{1}’ = 1.00$, $x_{2}’ = 1.00$, $x_{3}’ = 1.00$, $x_{4}’ = 1.00$, $x_{5}’ = 1.00$

E.g., $x_1 = 0 + (8 - 0)x_{1}’ = 8$

$x_2 = 4.6 + (12.34 - 4.6)x_{2}’ = 12.34$