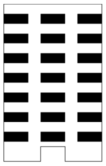
QUALITY FUNCTION DEPLOYMENT AND PROCESS MODELS



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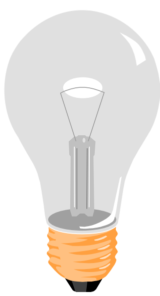
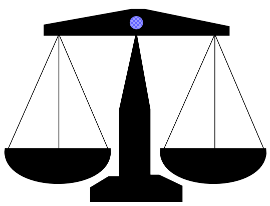
What is Quality?



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

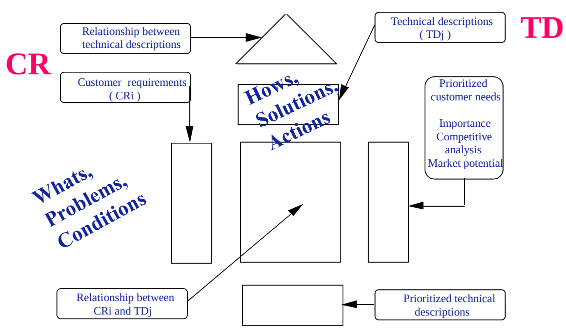
QFD - Basic Idea

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

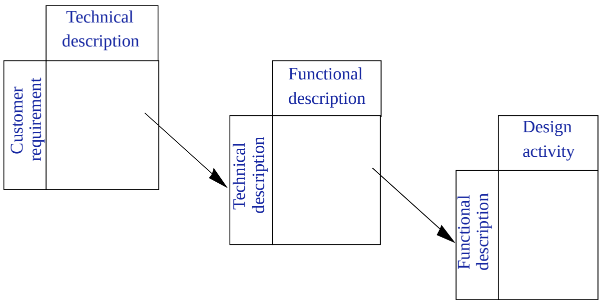
Quality Function Deployment (QFD) Matrix



QFD

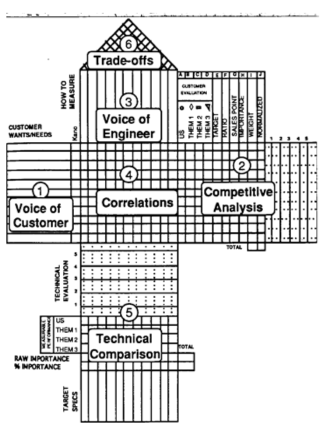
Known also as the House of Quality

QFD Cascade



THE HOUSE OF QUALITY:

EXAMPLES



Six steps
for building
a house
of quality

Six step procedure for forming a QFD matrix

Step 1. The primary customer requirements are normally expanded into secondary and tertiary requirements using AND/OR tree.

Step 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.

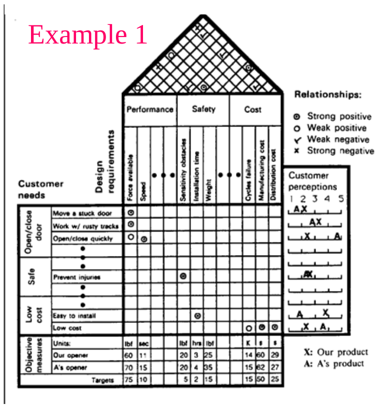
Step 3. Developing a matrix describing the customer requirements and the design requirements is accomplished

Step 4. Market evaluation which covers the customer-expressed importance ratings, requirements, and competitive products is performed.

Step 5. The target for each of the design requirement is defined.

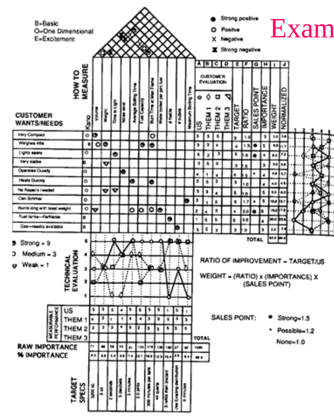
Step 6. Selection of the best solution should be deployed.

Example 1



House of quality for the design of a sample product

Example 2



House of quality: BP team

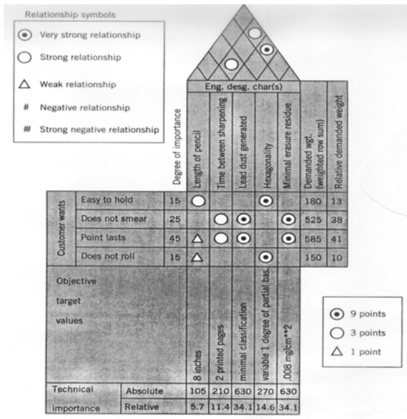
Examples of Rows

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

Examples of columns

Force
Speed
Manufacturing cost
Maintenance cost

Example 3

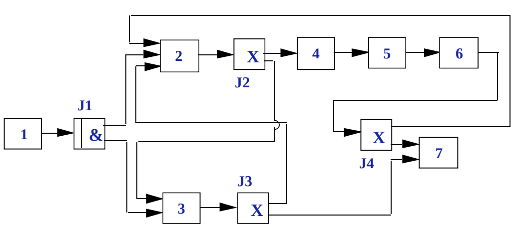


QFD Benefits

- 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

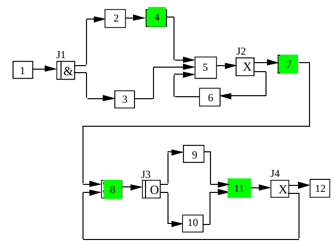
1. Prepare system specifications
2. Generate preliminary design
3. Evaluate cost of different alternatives
4. Build prototype
5. Perform tests on prototype
6. Analyze test data
7. Finalize design details

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

Process model with critical activities



Modeling attribute-variable relationship

Critical activity

List of activities of the design process

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

QFD in Design

Relationships

(a) Process attribute - process variable

(b) Activity - attribute

(c) Other relationships

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

Relationship Matrix	
●	Strong positive
○	Medium positive
▽	Weak positive
×	Negative

Interaction Matrix	
○	Positive
×	Negative

House of quality for a design process

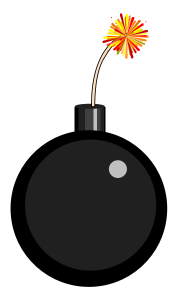
Design Process Attributes \ Design Process Variables	Average resource level savings	No. of design projects undertaken	Frequency of interaction among different design functional groups	No. of supporting functional groups involved
No. of design activities delayed due to the resources being not available	●	○		●
Risk of violating the due date	○	●	○	
Average lateness of design activities	○	●		▽
Completion time of the last design activity in the network	○	○	●	▽

Conversion of symbols

Symbol	Coefficient Value
●	+9
○	+3
▽	+1
×	-3

Design Process Attributes \ Design Process Variables	Average resource level savings	No. of design projects undertaken	Frequency of interaction among different design functional groups	No. of supporting functional groups involved
No. of design activities delayed due to the resources being not available	●	○		●
Risk of violating the due date	○	●	○	
Average lateness of design activities	○	●		▽
Completion time of the last design activity in the network	○	○	●	▽

Relationships Quantification



Converting QFD into into a mathematical programming model

The Design Process Example

Relationships

Attribute - variable

or

Activity - attribute (characteristic)

Design process attributes
$y = (y1, \ldots, yi, \ldots, yn)$
Feasible range for yi is:
$y_{iL} \le y_i \le y_{iU}$

Design process attributes and their feasible ranges

	Attribute	Range
y1	No. of design activities delayed due to the resources not being available	$0 \le y_1 \le 8$
y2	Risk of violating the due date	$0 \le y_2 \le 1$
y3	Average lateness of design activities	$2.5 \le y_3 \le 9.4$
y4	Completion time of the last design activity in the network	$18 \le y_4 \le 35$

Values of the design process variables:
$x = (x1, \ldots, xi, \ldots, xm)$
Feasible range for xi is:
$x_{iL} \le x_i \le x_{iU}$

Design Process Variables and their Feasible Ranges

Variable	Range
Average resource level savings	$3.2 \le x_1 \le 8.4$
Number of design projects undertaken	$4 \le x_2 \le 10$
Frequency of interaction among different design functional groups	$2 \le x_3 \le 6$
Number of supporting functional groups involved	$5 \le x_4 \le 10$

Attribute yi is a function of the design process variables

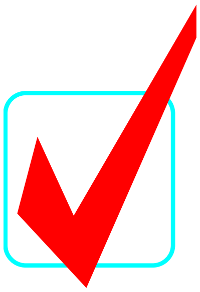
$$yi = f(x)$$

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

$x' = (x1', x2', \ldots, xm')$

$yi' = f(x')$

Why scaling variables?



Same 'weight' assigned to each variable

For x's scaled in [0, 1]

y1' = 9x1' + 3x2' + 9x4' + 3x1'x2' - 3x1'x4'

y2' = 3x1' + 9x2' + 3x3' + 3x1'x2' + 3x2'x3'

y3' = 3x1' + 9x2' + x4' + 3x1'x2' - 3x1'x4'

y4' = 3x1' + 3x2' + 9x3' + x4'+ 3x1'x2' + 3x2'x3' - 3x1'x4' - 3x3'x4'

Symbol	Coefficient Value
●	+9
○	+3
▽	+1
×	-3

	Design Process Attributes	Average resource level savings (x1')	No. of design projects undertaken	Frequency of interaction among different design functional groups	No. of supporting functional groups involved (x4')
y1'	No. of design activities delayed due to the resources being not available	●	○		●
	Risk of violating the due date	○	●	○	
	Average lateness of design activities	○	●		▽
y4'	Completion time of the last design activity in the network	○	○	●	▽

Design Process Variables

Scaling equations

Consider equation y2':

y2' = 3x1' + 9x2' + 3x3' + 3x1'x2' + 3x2'x3'

min y2' = 0 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'

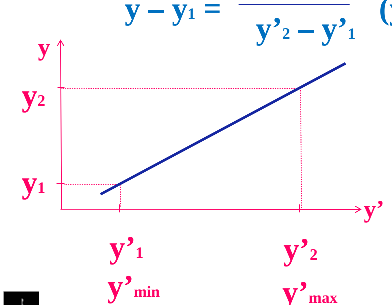
and (1 - 0) the range for y2 from the table

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

y2 = 0 + (1 - 0) (3x1' + 9x2' + 3x3' + 3x1'x2' + 3x2'x3') / (21 - 0)

Equation Balancing

$$y - y_1 = \frac{y_2 - y_1}{y'_2 - y'_1}(y' - y'_1)$$



Balancing equation

y = Lower limit of y +

(y range)[y'/(y' range)]

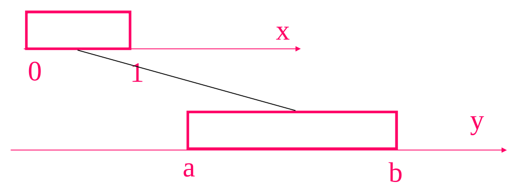
Shifting by lower y limit

Scaling to y range

Scaling of y' to [0, 1]

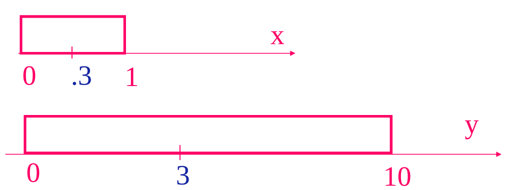
Example y2 = 0 + (1 - 0) y2' /(21 - 0)

Scaling



y = a + (b - a)x

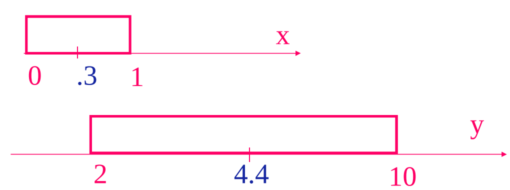
Example 1



y = a + (b - a)x

y = 0 + (10 - 0)x = 1x.3 = 3

Example 2



y = a + (b - a)x

y = 2 + (10 - 2)x = 2 + 8x.3 = 4.4

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

(ranges determined using Lingo Optimization Software)

y1 = 0 + (8 - 0)(9x1' + 3x2' + 9x4' + 3x1'x2' - 3x1'x4' + 3x2'x4') / (24 - 0)

y2 = 0 + (1 - 0)(3x1' + 9x2' + 3x3' + 3x1'x2' + 3x2'x3') / (21 – 0)

y3 = 2.5 + (9.4 – 2.5)(3x1' + 9x2' + x4' + 3x1'x2' - 3x1'x4') / (15 - 0)

y4 = 18 + (35 - 18)(3x1' + 3x2' + 9x3' + x4' + 3x1'x2' + 3x2'x3' – 3x1'x4' – 3x3'x4') / (21 – 0)

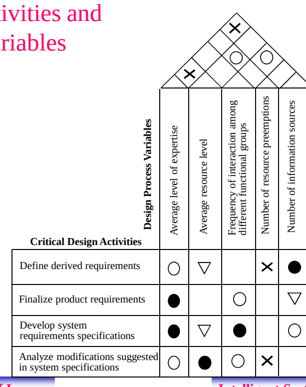
EXAMPLE 4: Critical design activities used as design process attributes and their feasible ranges

	Activity No.	Critical Activity Name	Limits
y1	4	Define design requirements	$0 \le y_1 \le 1$
y2	7	Finalize product requirements	$0 \le y_2 \le 1$
y3	8	Develop system requirements	$0 \le y_3 \le 1$
y4	11	Analyze modifications of system specifications	$0 \le y_4 \le 1$

Variables affecting the quality of design activities and their limits

	Variable	Limits
x1	Average level of expertise	$0 \le x_1 \le 8$
x2	Average resource level	$4.6 \le x_2 \le 12.34$
x3	Frequency of interaction between different functional design groups	$1 \le x_3 \le 5$
x4	Number of resource preemptions	$8 \le x_4 \le 25$
x5	Number of information sources	$3 \le x_5 \le 11$

House of quality for relationships between critical activities and process variables



$y1 = 0 + (1 - 0)(3x1' + x2' - x4' + 9x5' - x1'x2' - x1'x5' + 3x2'x4') / (13 – (-1))$

$y2 = 0 + (1 - 0)(9x1' + 3x3' + x5' - x1'x5' + 3x3'x5') / (15 - 0)$

$y3 = 0 + (1 - 0)(9x1' + x2' + 9x3' + 3x5' - x1'x2' - x1'x5' + 3x3'x5') / (23 – 0)$

$y4 = 0 + (1 - 0)(3x1' + 9x2' + 3x3' - x4' - x1'x2' + 3x2'x4') / (16 – (-1))$

Maximize $w1y1 + w2y2 + w3y3 + w4y4$

s.t.

$y1 = 0 + (1 - 0)(3x1' + x2' - x4' + 9x5' - x1'x2' - x1'x5' + 3x2'x4') / 14$

$y2 = 0 + (1 - 0)(9x1' + 3x3' + x5' - x1'x5' + 3x3'x5') / 15$

$y3 = 0 + (1 - 0)(9x1' + x2' + 9x3' + 3x5' - x1'x2' - x1'x5' + 3x3'x5') / 23$

$y4 = 0 + (1 - 0)(3x1' + 9x2' + 3x3' - x4' - x1'x2' + 3x2'x4') / 17$

$0 \leq x'_i \leq 1$ for $i = 1, 2, 3, 4, 5$

Example

$w1 = 10$, $w2 = 35$, $w3 = 20$, $w4 = 15$

Maximize $10y1 + 35y2 + 20y3 + 15y4$

s.t.

$y1 = 0 + (1 - 0)(3x1' + x2' - x4' + 9x5' - x1'x2' - x1'x5' + 3x2'x4') / 14$

$y2 = 0 + (1 - 0)(9x1' + 3x3' + x5' - x1'x5' + 3x3'x5') / 15$

$y3 = 0 + (1 - 0)(9x1' + x2' + 9x3' + 3x5' - x1'x2' - x1'x5' + 3x3'x5') / 23$

$y4 = 0 + (1 - 0)(3x1' + 9x2' + 3x3' - x4' - x1'x2' + 3x2'x4') / 17$

$0 \leq x'_i \leq 1$ for $i = 1, 2, 3, 4, 5$

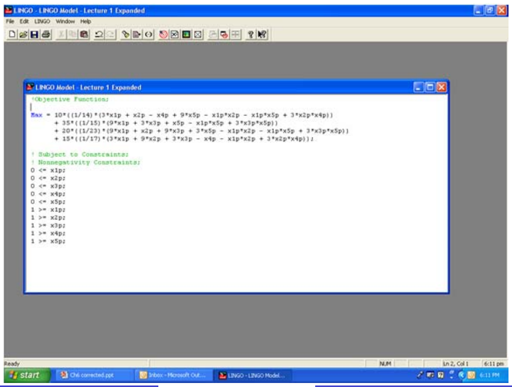
Max $33.62x1' + 10.58x2' + 17.47x3' - 1.60x4' + 11.37x5' -2.47x1'x2' – 3.92x1'x5' + 4.79x2'x4' + 9.61x2'x5'$

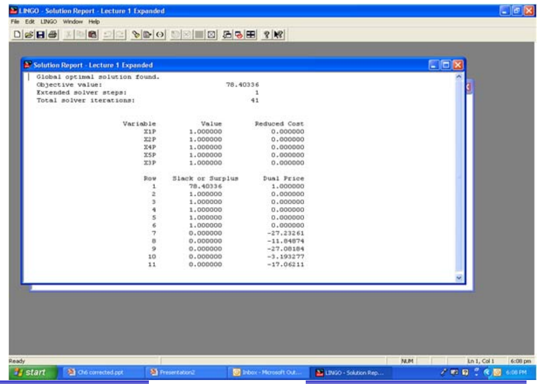
s.t.

$0 \leq x'_i \leq 1$ for $i = 1, 2, 3, 4$

The optimal solution (scaled in [0, 1]) is:

$x1' = 1.00$, $x2' = 1.00$, $x3' = 1.00$,
$x4' = 1.00$, $x5' = 1.00$





	Variable	Limits
x1	Average level of expertise	0 ≤ x1 ≤ 8
x2	Average resource level	4.6 ≤ x2 ≤ 12.34
x3	Frequency of interaction between different functional design groups	1 ≤ x3 ≤ 5
x4	Number of resource preemptions	8 ≤ x4 ≤ 25
x5	Number of information sources	3 ≤ x5 ≤ 11

$x1' = 1.00$, $x2' = 1.00$, $x3' = 1.00$,
$x4' = 1.00$, $x5' = 1.00$

E.g., $x1 = 0 + (8 - 0)x1' = 8$
$x2 = 4.6 + (12.34 - 4.6)x2' = 12.34$

Values of variables affecting the quality of critical design activities

	Variable	Best Value	Alternative Value
x1	Average level of expertise	6	6
x2	Average resource level	11	9
x3	Frequency of interaction between functional design groups	4	4
x4	Number of resource preemptions	10	10
x5	Number of information sources	9	7
	Value of the Objective Function	68.1	59.33