ESD.33 -- Systems Engineering

Session #6
Quality Function Deployment

Dan Frey

Follow-up on Session #4

Shashi Kant -- My belief is that XP is a very interesting concept and should be covered - at least superficially. It would help to have an idea of such a process even in a highly structured development processes like in the defense or aerospace industries. So my vote would be to at least touch on the subject, I think even non-software people would find it fascinating.

Follow-up on Session #4

Stephen Friedenthal -- Intuitively it seems rational that the best decision making process is coherently logical.

However, if I take it as an axiom that I can never have perfect information this leads to the implication that a perfectly rational and logical decision making process can lead to a faulty conclusion…

But, by the same logic this implies that if your logic is flawed you may or may not get the wrong answer …

So, does this imply that it can be advantageous not to be a rational decision maker … or, is there a flaw in this train of thought?

Plan for the Session

- What is rationality?
- Quality Function Deployment
  - What is it for? What is it <u>not</u> for?
  - What is it? How do you use it?
  - Does it work?
- Next steps

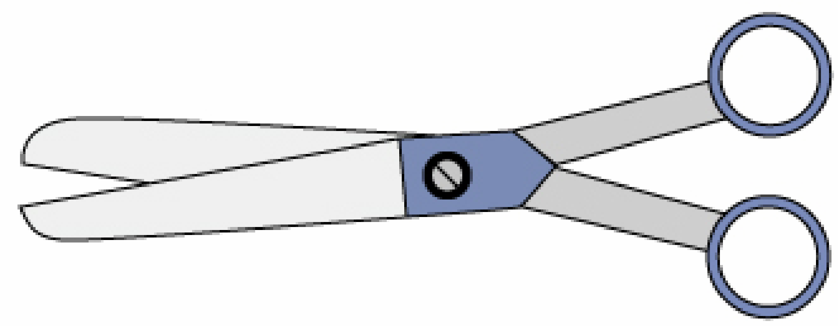
What is Rationality?

- “Theoretical rationality applies to beliefs … e.g. beliefs that are self evident or derived from self evident beliefs by a reliable procedure…”
- “Another account of rational action is ... to act rationally is to act on universalizable principles, so that what is a reason for one person must be a reason for everyone…”
- “Practical rationality applies to actions…acting rationally simply means acting in a way that is maximally efficient in achieving one’s goals”

- *Cambridge Dictionary of Philosophy*

Human rational behavior is shaped by a scissors whose two blades are the structure of task environments and the computational capabilities of the actor.

- Herbert Simon



Simon, H. A., 1990, “Invariants of human behavior,” *Annual Review of Psychology, 41,* 1-19.

"Bounded rationality is a genuinely interdisciplinary topic. Its subject matter is the mechanisms that humans, institutions, and artificial agents use to achieve their goals. The common denominator is that decisions need to be made with limited time, knowledge, and other resources, and in a world that is uncertain and changing."

Gigerenzer, G. and R. Selten, 2001, "Rethinking Rationality," in *Bounded Rationality,* MIT Press, Cambridge, MA.

"Heuristics that are matched to particular environments allow agents to be ecologically rational, making adaptive decisions that combine accuracy with speed and frugality. We call the heuristics "fast and frugal" because they process information in a relatively simple way, and they search for little information."

Todd, P. M., and G. Gigerenzer, 2003, "Bounding Rationality to the World," *Journal of Economic Psychology*, v. 24, pp. 143-165.

Concept Question

- Consumer reports suggests that a particular car model is the top rated car in its category in overall quality including frequency of repair.
- Your neighbor purchased the same car model six months ago and just experienced a major and costly breakdown.
- Should you still buy the car?

Concept Question

- Long experience suggests that a particular stretch of a river is among the safest for children to swim in.
- Yesterday your neighbor’s first born son was eaten by a crocodile in that stretch of river.
- Should you still let your child swim there?

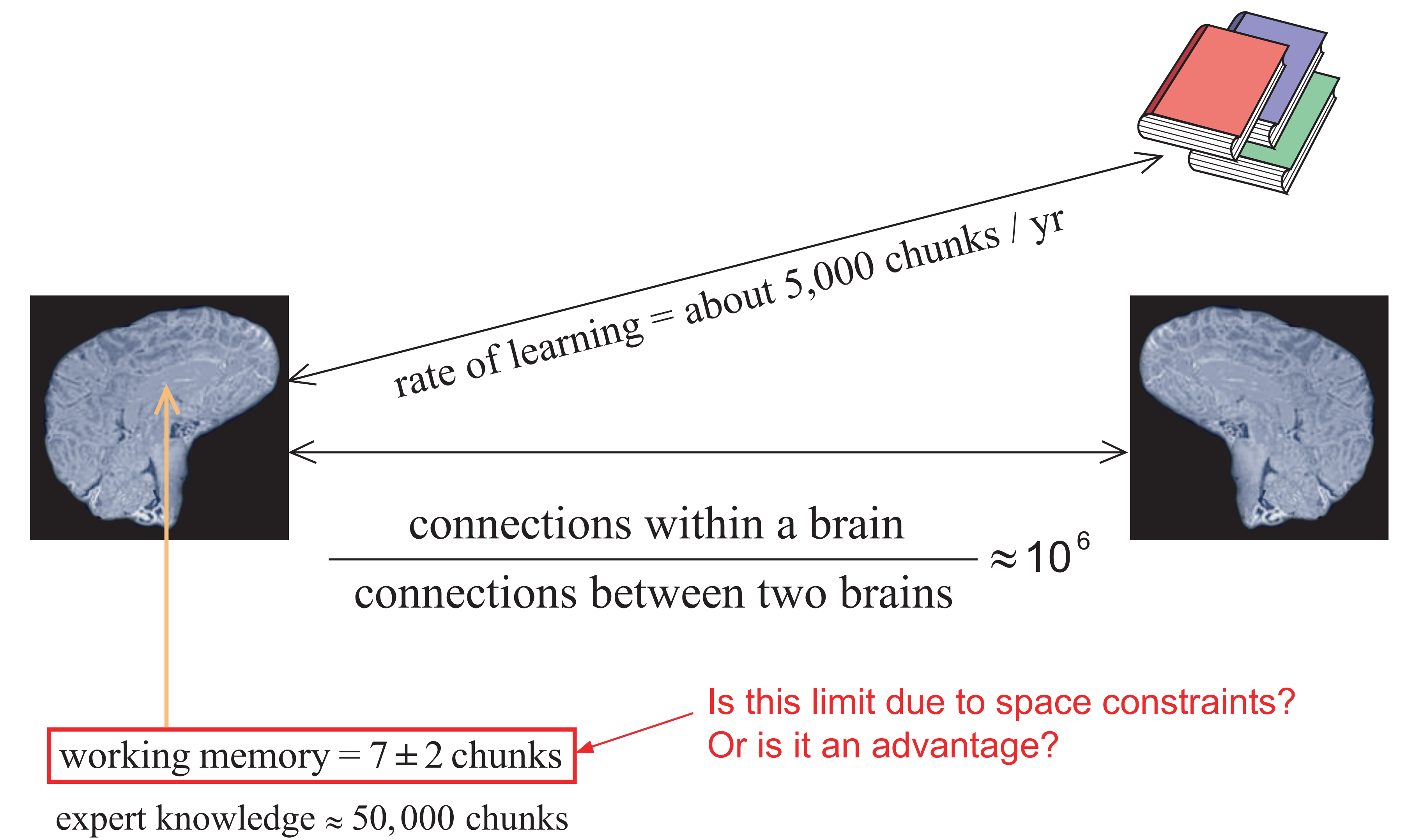
The Less is More Effect

- Goldstein and Gigerenzer (1999)
- A pair of cities is drawn from a set of the 83 largest German cities
- The task was to decide which of the two cities in each pair was larger
- American students – accuracy ~ 65%
- German students – accuracy was lower
- Why? The recognition heuristic works best when information is at an appropriate level (sometimes less information is better)

One Reason Decision Making

- The “Take The Best” heuristic equals or outperforms any linear decision strategy when information is noncompensatory, that is, when the potential contribution of each new cue falls off rapidly so that combinations of later cues cannot outweigh earlier ones (Martignon & Hoffrage,1999).
- Such environments seem fairly commonplace, at least in an approximately noncompensatory form.

Cognitive Parameters



Adapted from Simon, Herbert, 1969, *Sciences of the Artificial*, MIT Press.

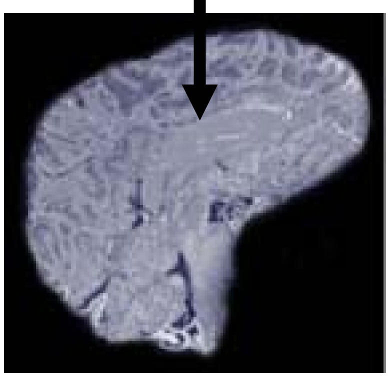
Language Learning in Children

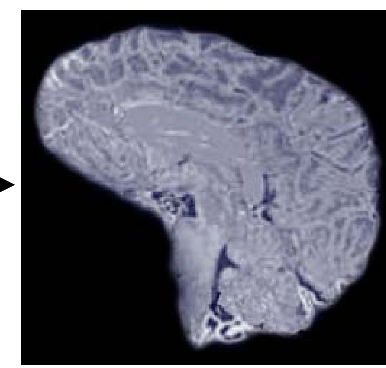
For Adults

$$\boxed{\text{working memory} = 7 \pm 2 \text{ chunks}}$$

For Children

$$\boxed{\text{working memory} \approx 4 \pm 2 \text{ chunks}}$$





You say:
It’s two hours past your bedtime.
Drink your milk.

They process:
Blah blah blah blah blah blah.
Drink your milk.

This is a good thing. They learn simple grammar first.

Follow-up on Session #4

No, sometimes they are just heuristic

Stephen Friedenthal -- Intuitively it seems rational that the best decision making process is coherently logical.

However, if I take it as an axiom that I can never have perfect information this leads to the implication that a perfectly rational and logical decision making process can lead to a faulty conclusion…

Right!!

But, by the same logic this implies that if your logic is flawed you may or may not get the wrong answer …

So, does this imply that it can be advantageous not to be a rational decision maker … or, is there a flaw in this train of thought?

Yes, there is growing, empirical evidence that it is advantageous to be irrational in a strictly formal sense and instead to be ecologically rational

Implications for “Tools” Phase

- We chose simple methods that have evidence of effectiveness in field use
- We do not assume that the latest method with added “improvements” is better
- In particular, if a new fangled method requires more information or processing it is under suspicion
- Of course, if field data prove it out, we will add it to the course

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Systems Engineering

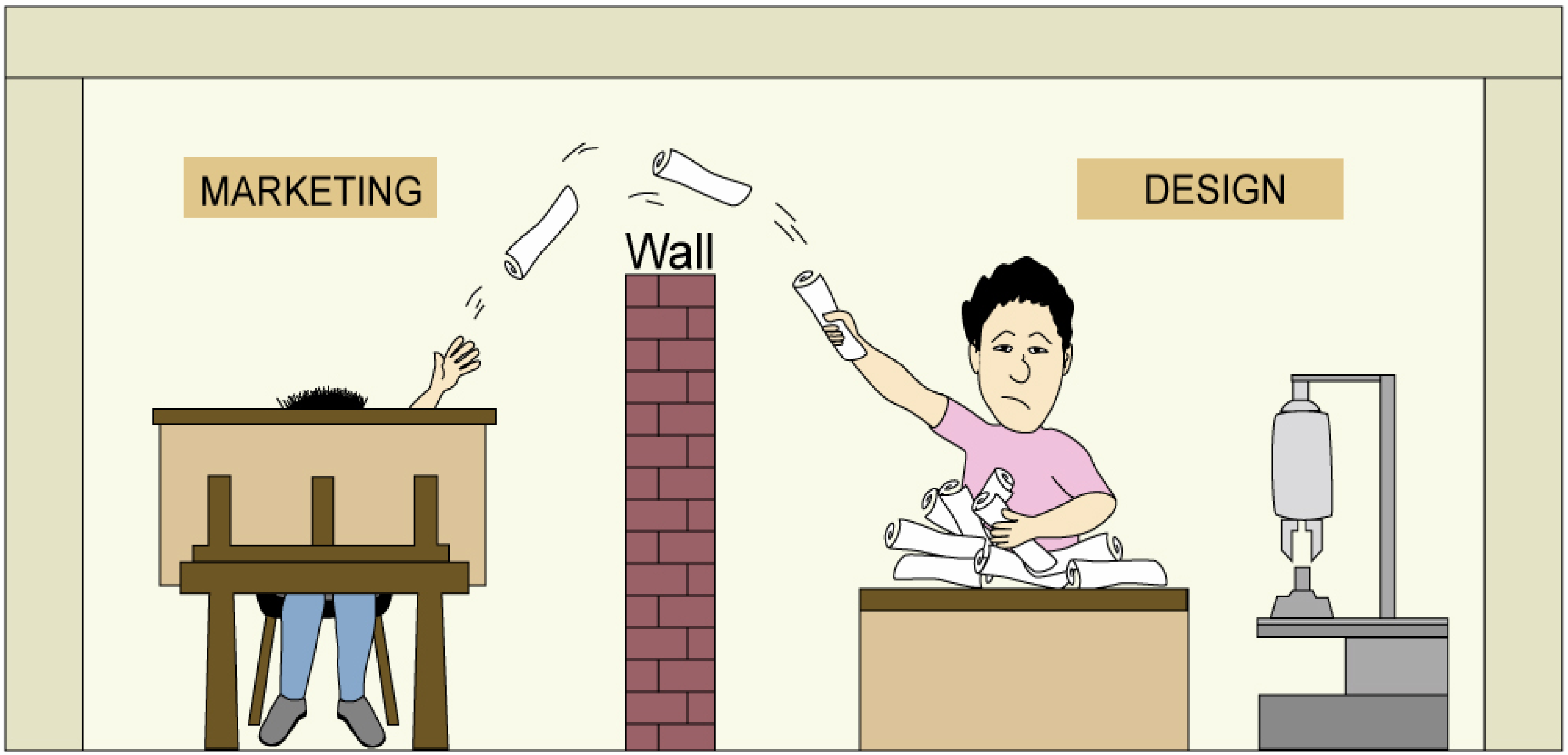
Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on <u>defining customer needs and required functionality early in the development cycle, documenting requirements,</u> then proceeding with design synthesis and system validation while considering the complete problem:

- Operations
- Performance
- Test
- Manufacturing
- Cost
- Schedule
- Training
- Support
- Disposal

Discussion of Marketing

- What training, exposure have you had to “inbound” marketing techniques?
- What are the key techniques you that can be used to:
  - Determine Customer Attributes?
  - Prioritize Customer Attributes?

Traditional "Over the Wall" Design



What is the QFD for?

QFD <u>is</u> for

- Coordinating skills within an organization
  - Serves as a lingua franca
  - Helps break down the functional silos
  - Encourages real teamwork
- Designing goods that customers want to purchase
  - Creates external focus
  - Provides immersion in the specifications
- Target setting for mature products

QFD <u>is NOT</u> for

- Automatic decision making
  - “the house absolves no one of the responsibility of making tough decisions”
- Implementing a quick fix
  - “None of this is simple…”
  - “An elegant idea ultimately decays into process…”
  - “What is also not simple is creating an organization capable of absorbing elegant ideas”
- More difficult to use for highly novel / unprecedented functions

Hauser and Clausing, 1988, “The House of Quality”, *Harvard Business Review.*

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“Rooms” in the House of Quality

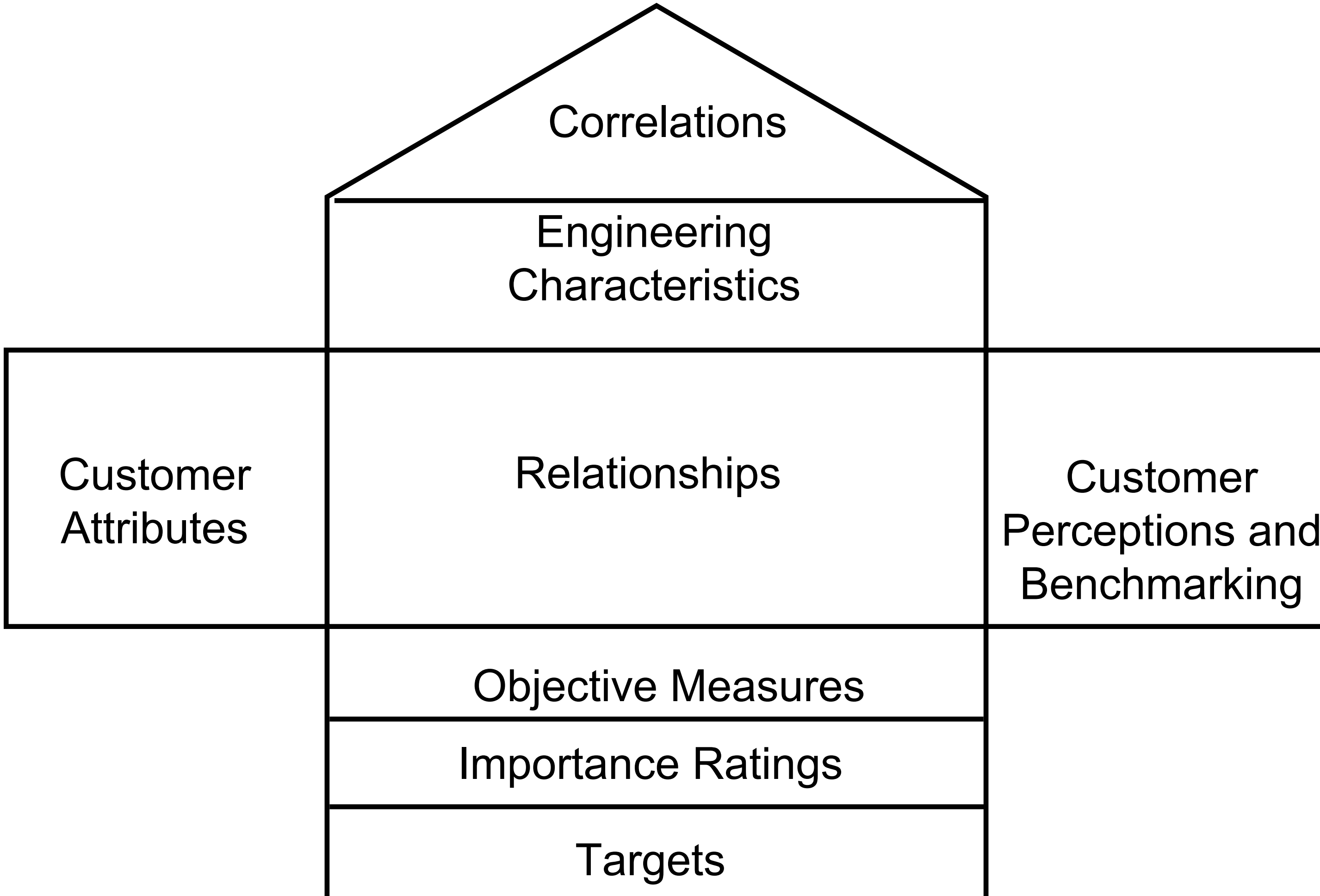
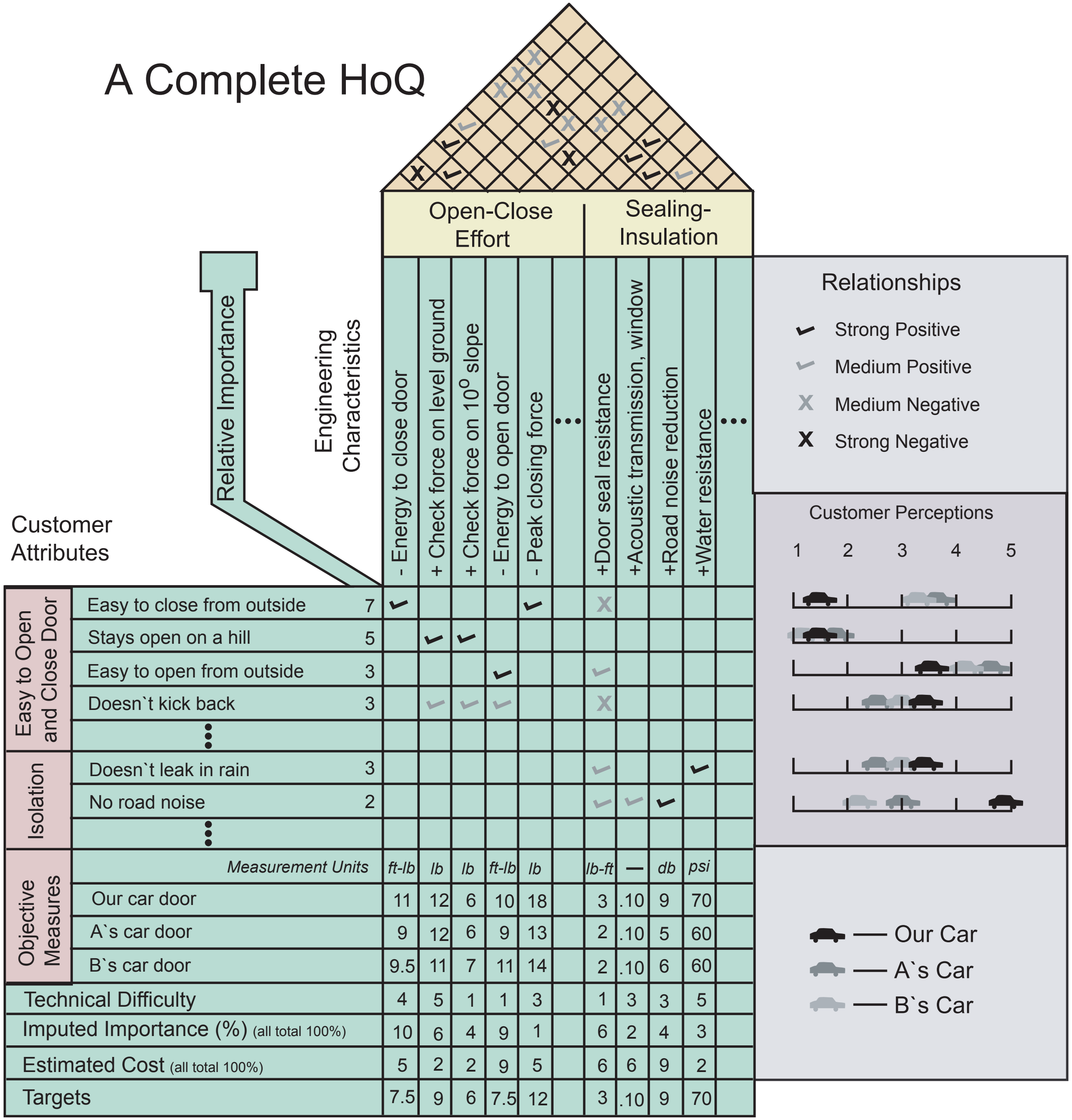


Figure adapted from Lou Cohen.

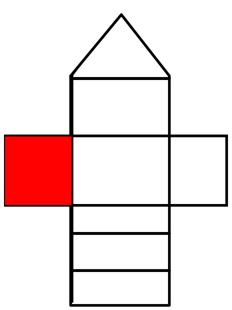
A Complete HoQ



Adapted from Hauser and Clausing.

Customer Attributes (CAs)

- CAs = phrases “customers” use to describe the desired product
  - Who are the “customers”?
- Try to preserve the “voice of the customer” by using their language
  - What are some examples?
  - How is the language of the customer different from language required for design?



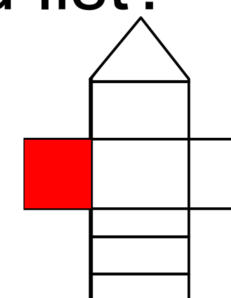
Structuring Customer Attributes

Primary	Secondary	Tertiary
Good Operation and Use	Easy to open and close door	Easy to close from outside
		Stays open on a hill
		Easy to open from outside
		Doesn`t kick back
		Easy to close from inside
		Easy to open from inside
	Isolation	Doesn`t leak in rain
		No road noise
		Doesn`t leak in car wash
		No wind noise
		Doesn`t drip water or snow when open
		Doesn`t rattle
	Arm Rest	Soft, comfortable
		In right position
Good Appearance	Interior Trim	Material won`t fade
		Attractive (nonplastic look)
	Clean	Easy to clean
		No grease from door
	Fit	Uniform gaps between matching panels

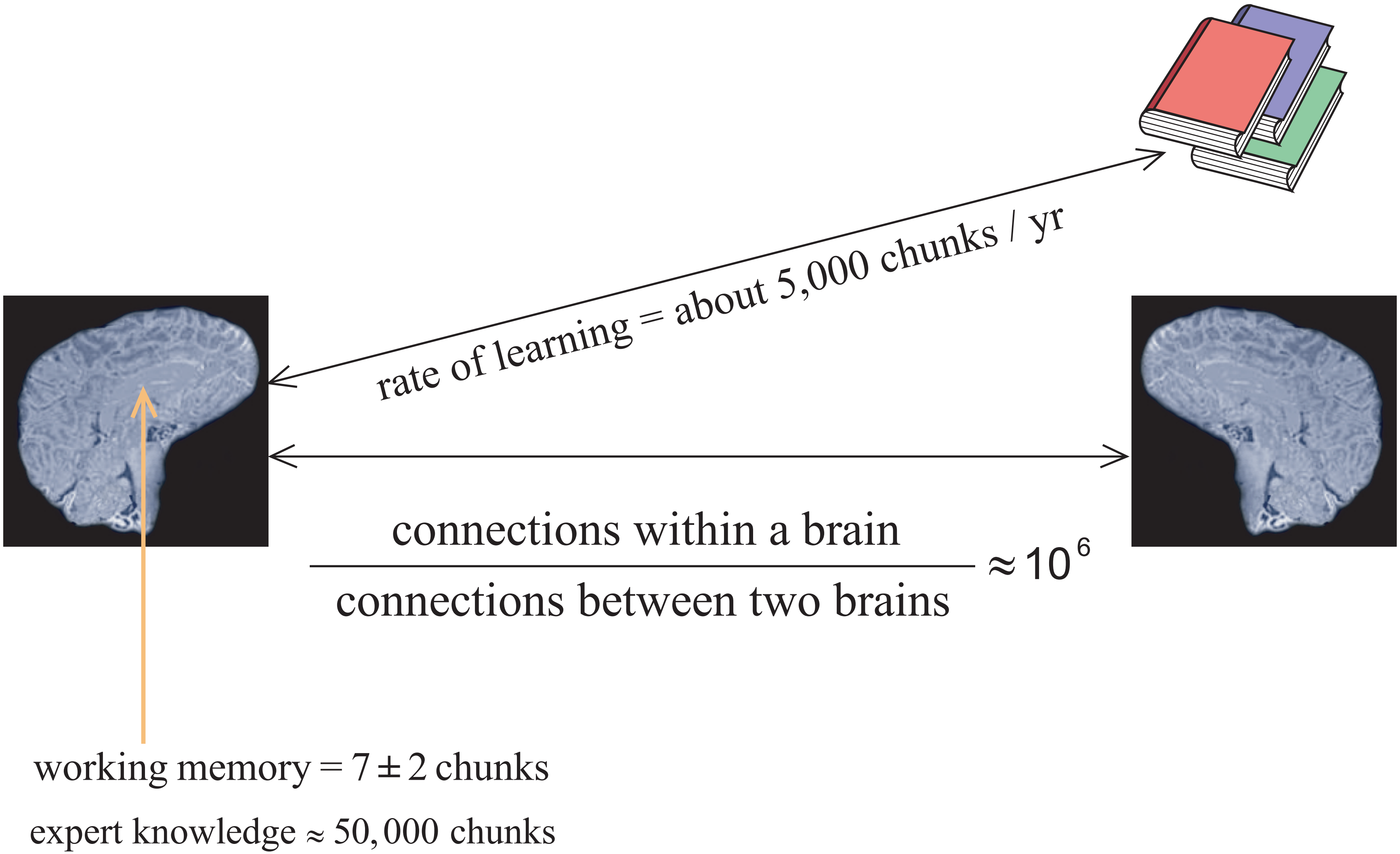
Customer Attributes and Bundles of Customer Attributes for a Car Door.

Note the tree-like structure

How would you develop a tree from a jumbled list?



Cognitive Parameters



Adapted from Simon, Herbert, 1969, *Sciences of the Artificial*, MIT Press.

Prioritizing Customer Attributes

Bundles	Customer Attributes	Relative Importance
Easy to open and close door	Easy to close from outside Stays open on a hill	7 5
Isolation	Doesn`t leak in rain No road noise	3 2
	A Complete List Totals	100%

Relative-importance Weights of Customer Attributes.

- Capture any strong consensus about relative importance
- Do not over-emphasize these ratings

“Rooms” in the House of Quality

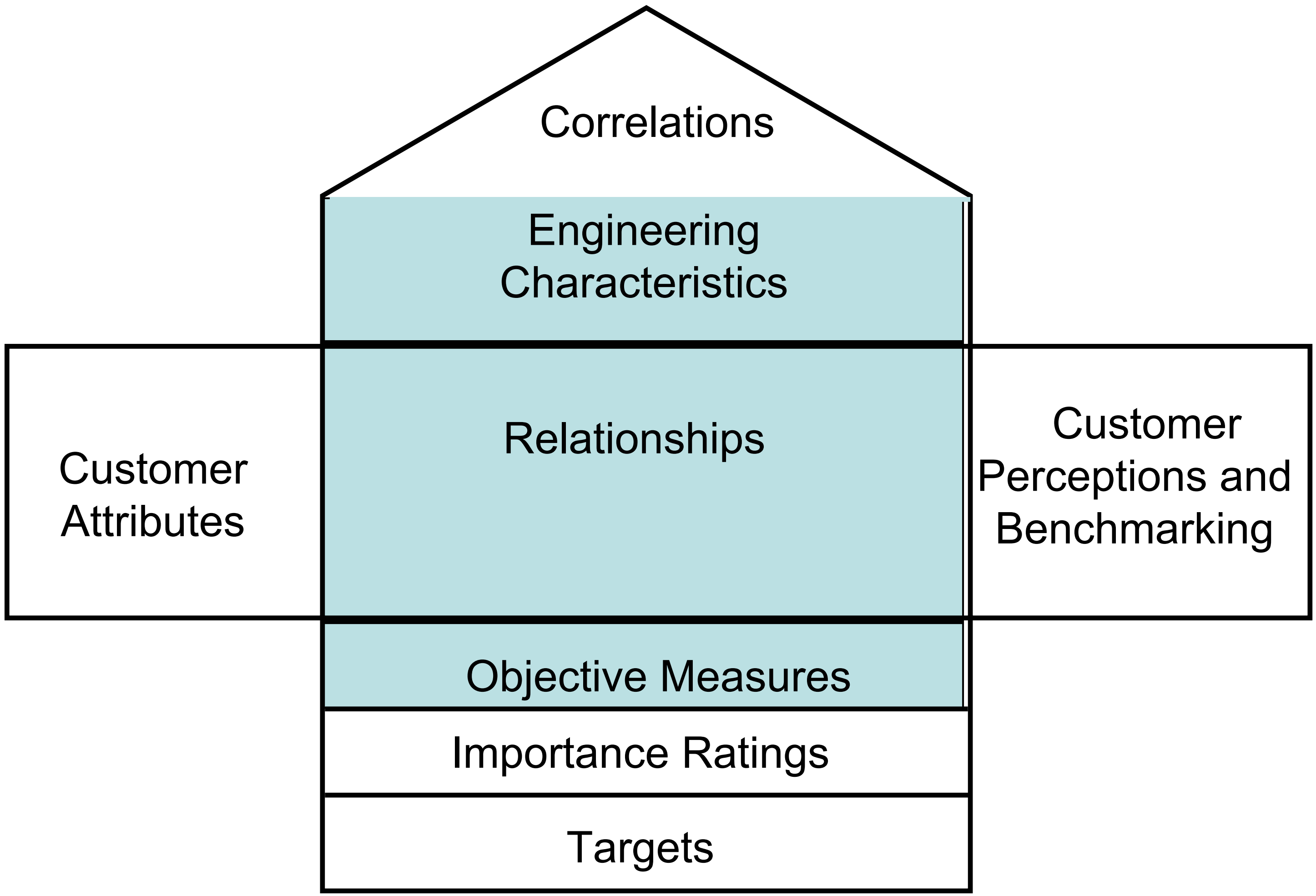
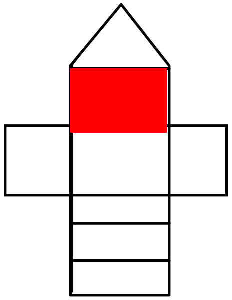


Figure adapted from Lou Cohen.

Engineering Characteristics (ECs)

- ECs should describe the product in <u>measurable</u> terms
- ECs should <u>directly</u> affect CAs
- ECs should be <u>applicable to other designs</u> (the competitor's design & new alternatives)

- Are there other attributes of good ECs?
- What are some examples of poorly written ECs?



Example Relationship Matrix

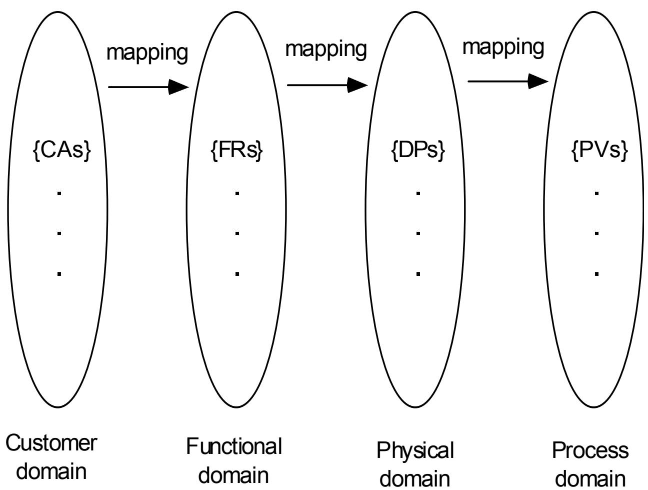
- ✓ Indicates a strong positive relationship
- ✓ Indicates a medium positive relationship
- X Indicates a strong negative relationship
- X Indicates a medium negative relationship

Note the objective measures of ECs

		Customer Attributes	Relative Importance	- Energy to close door	+ Check force on level ground	+ Check force on 10^{0} slope	- Energy to open door	- Peak closing force	...	+Door seal resistance	+Acoustic transmission, window	+Road noise reduction	+Water resistance	...
		Engineering Characteristics		Open-Close Effort						Sealing-Insulation				
Easy to Open and Close Door		Easy to close from outside	7	✓				✓		X				
		Stays open on a hill	5		✓	✓								
		Easy to open from outside	3				✓			✓				
		Doesn`t kick back	3		✓	✓	✓			X				
		⋮												
Isolation		Doesn`t leak in rain	3							✓			✓	
		No road noise	2							✓	✓	✓		
		⋮												
Objective Measures		*Measurement Units*		*ft-lb*	*lb*	*lb*	*ft-lb*	*lb*		*lb-ft*	—	*db*	*psi*	
		Our car door		11	12	6	10	18		3	.10	9	70	
		A`s car door		9	12	6	9	13		2	.10	5	60	
		B`s car door		9.5	11	7	11	14		2	.10	6	60	

Axiomatic Design

- Design viewed as mapping between the domains (customer, physical, process…)
- Theory says coupled systems are worse than uncoupled systems

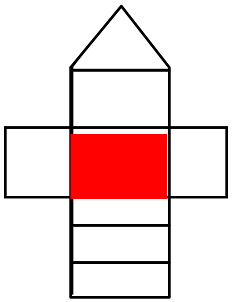


$$\{\mathbf{FR}\} = [\mathbf{A}]\{\mathbf{DP}\}$$

$\begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix}$	$\begin{bmatrix} X & X & X \\ 0 & X & X \\ 0 & 0 & X \end{bmatrix}$	$\begin{bmatrix} X & X & X \\ X & X & X \\ X & X & X \end{bmatrix}$
uncoupled design	decoupled design	coupled design
Good	OK if ordered properly	Bad

Relationship Matrix (CAs&ECs)

- What if there is an empty row?
- What if there is an empty column?
- What if there is a very full row?
- What if there is a very full column?
- What does lower diagonal block imply?
- What does a full block imply?



“Rooms” in the House of Quality

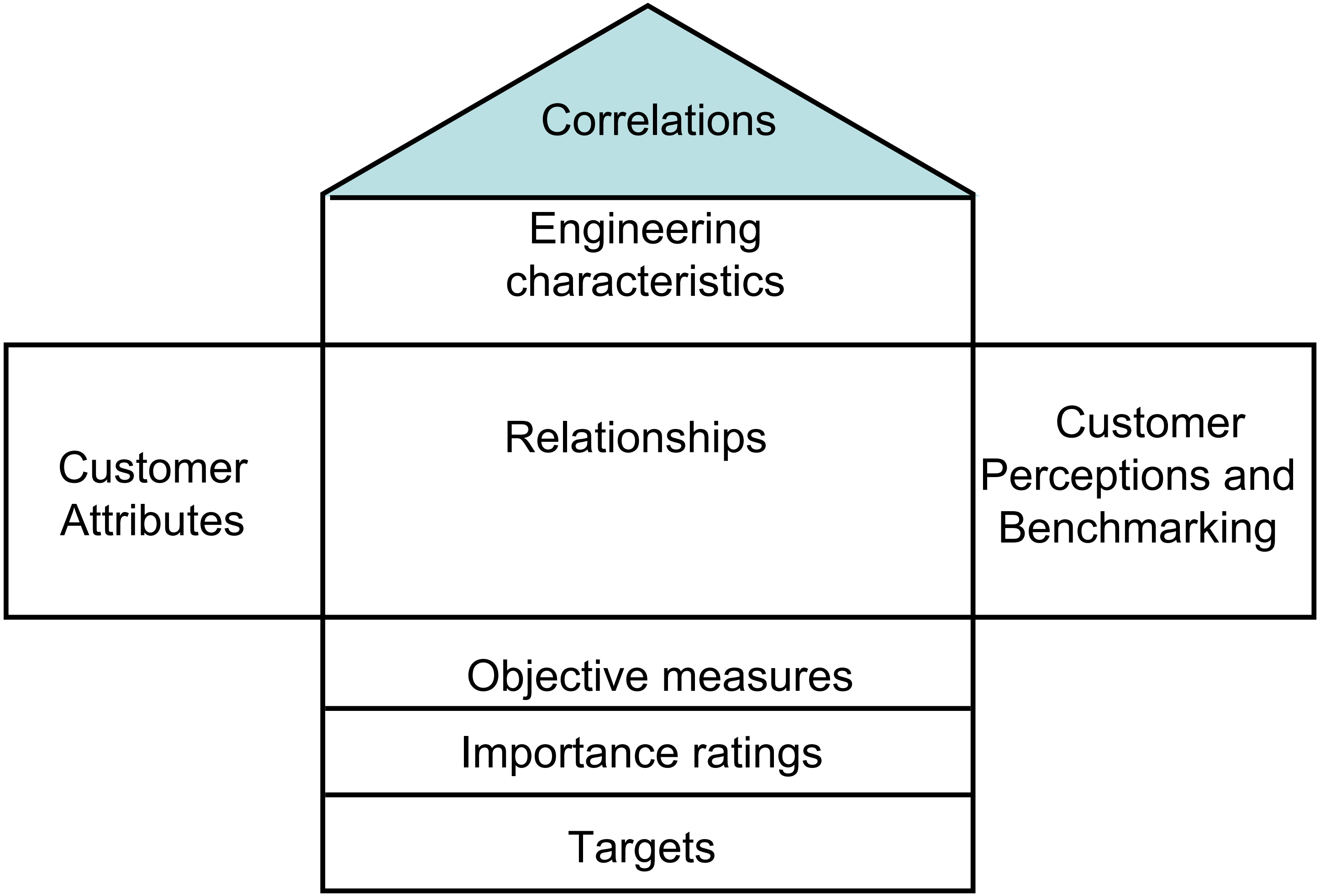
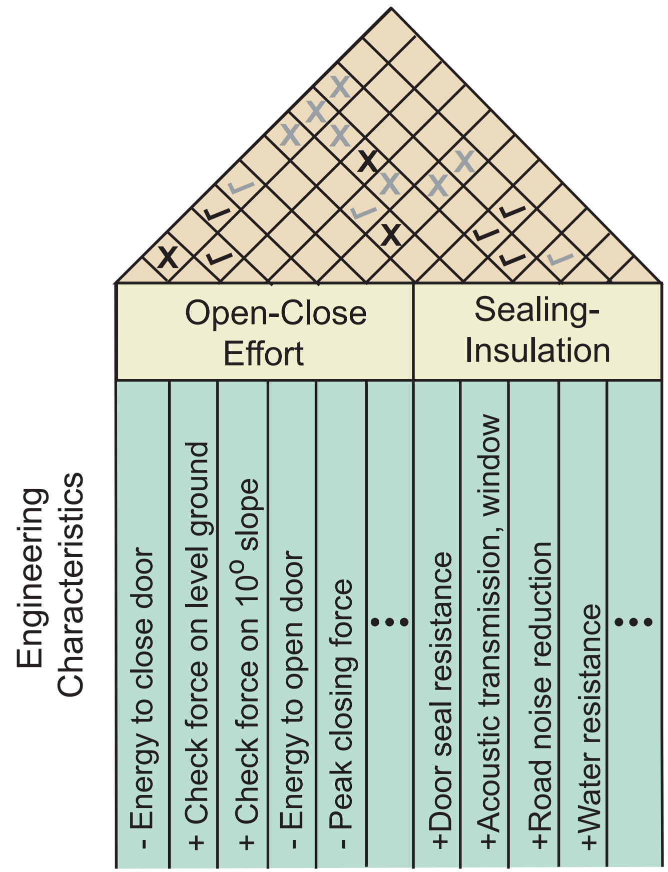
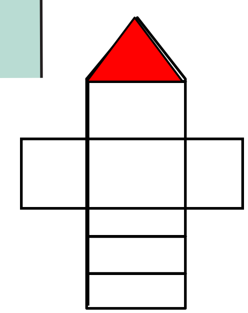


Figure adapted from Lou Cohen.

The Roof of the House

- ✓ Indicates a positive relationship
- X Indicates a negative relationship
- Is the roof matrix a function of the relationships matrix?
- Is it an Axiomatic Design matrix?
- Is it a Design Structure Matrix?





“Rooms” in the House of Quality

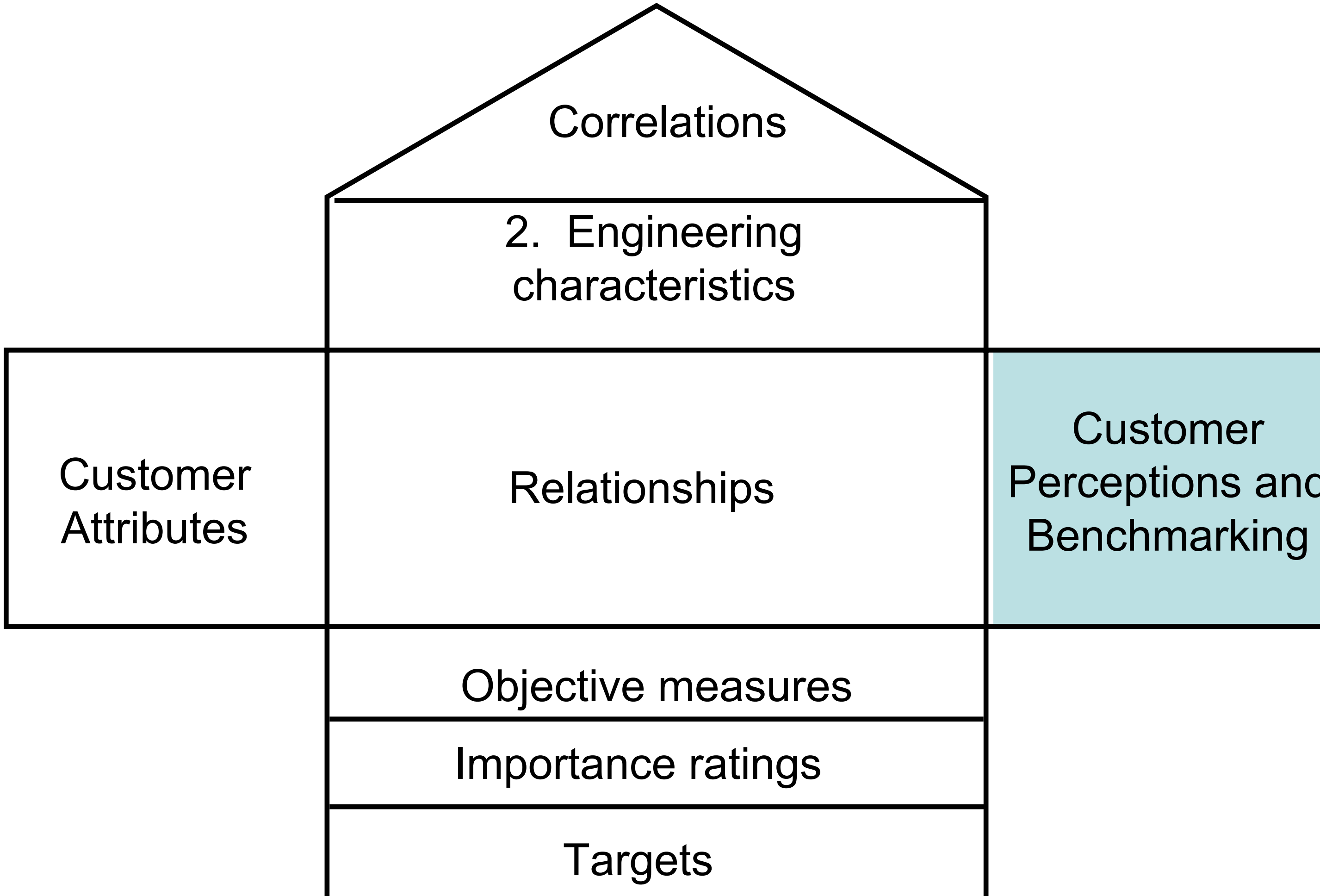
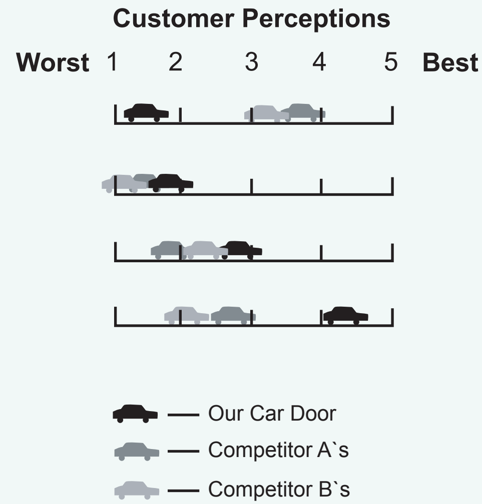


Figure adapted from Lou Cohen.

Benchmarking the Competition

Bundles	Customer Attributes	Relative Importance
Easy to open and close door	Easy to close from outside	7
	Stays open on a hill	5
Isolation	Doesn`t leak in rain	3
	No road noise	2

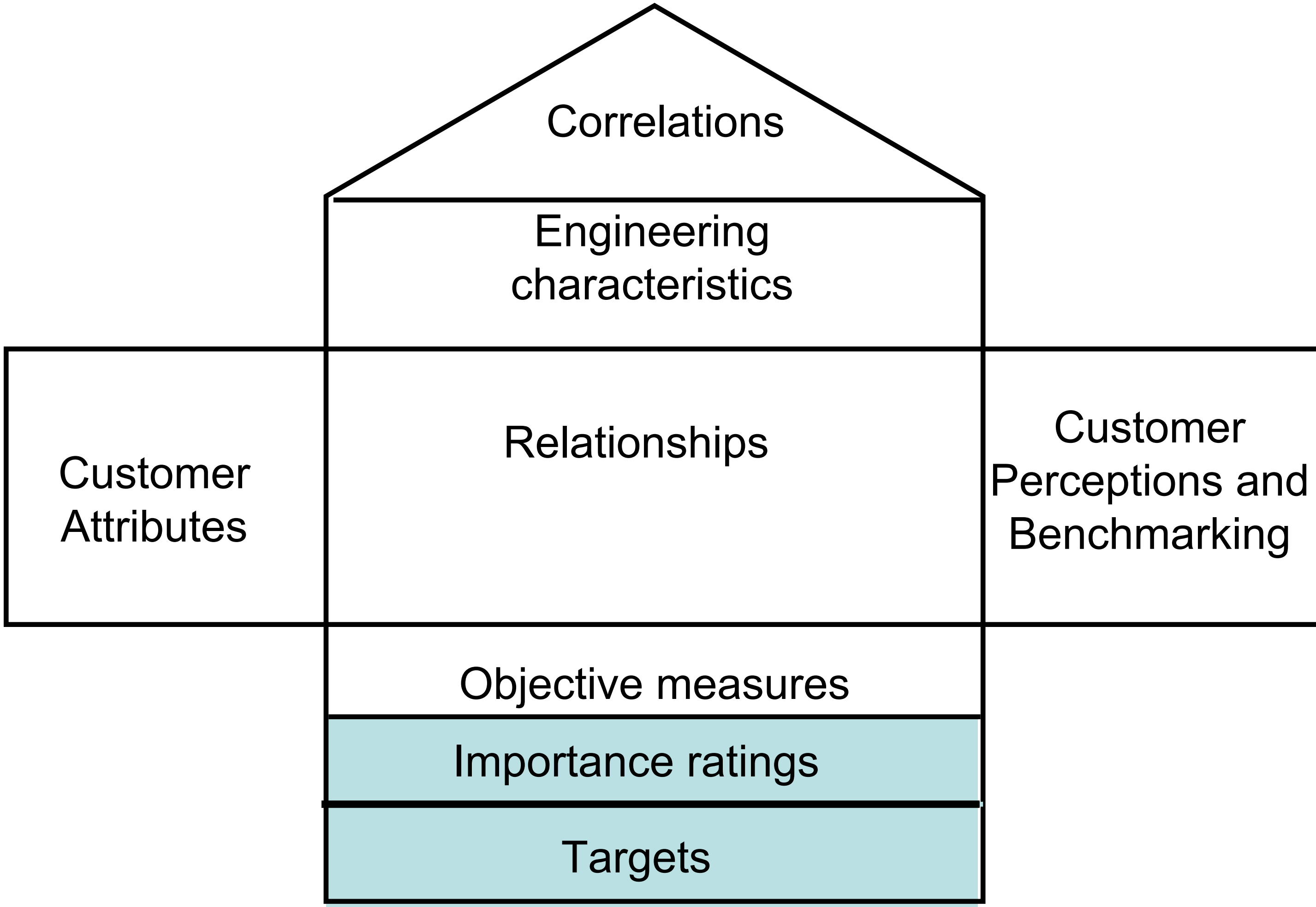


Customers' Evaluations of Competitive Products.

What opportunities reveal themselves here?

How does your industry do benchmarking?

“Rooms” in the House of Quality



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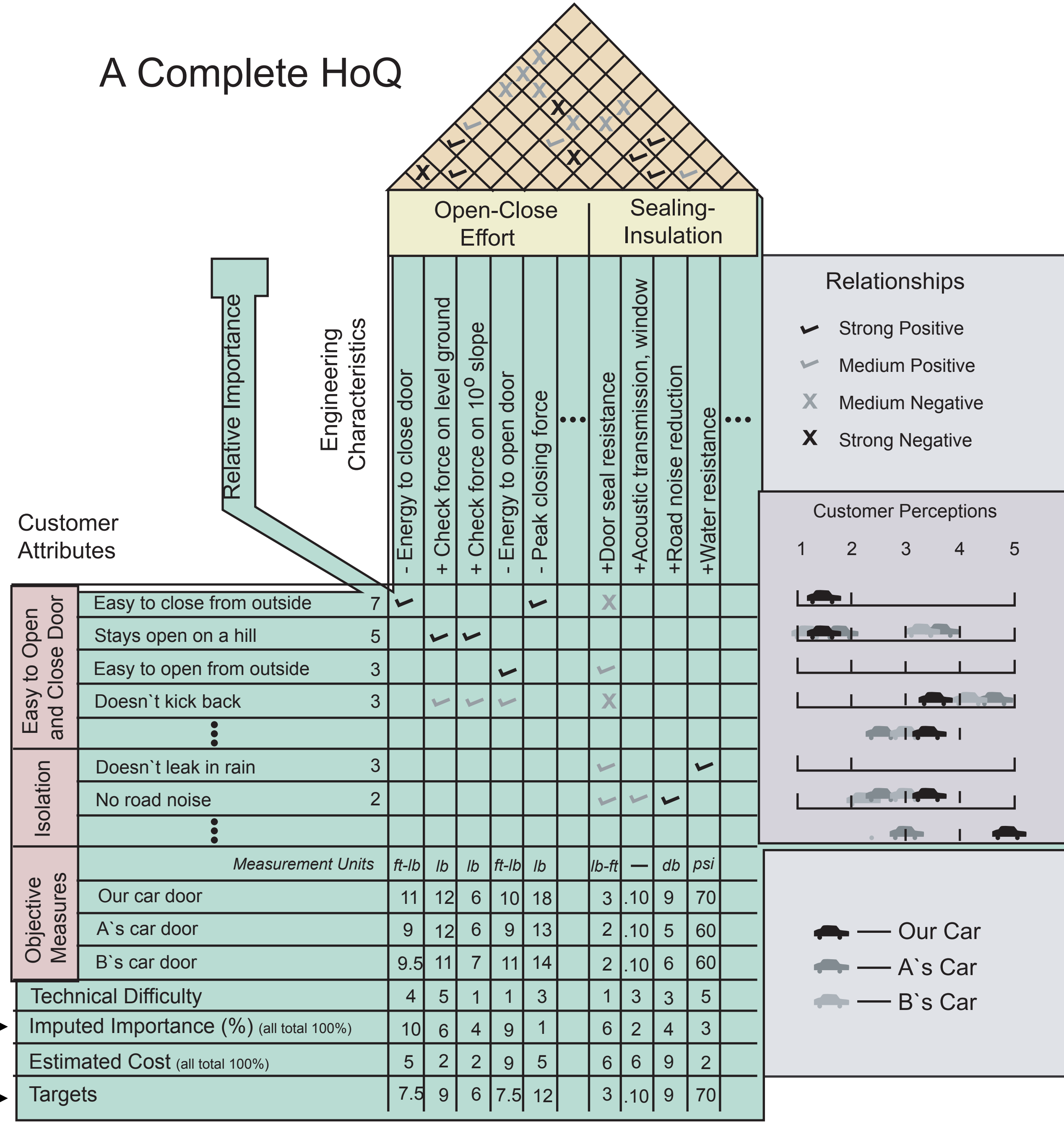
A Complete HoQ

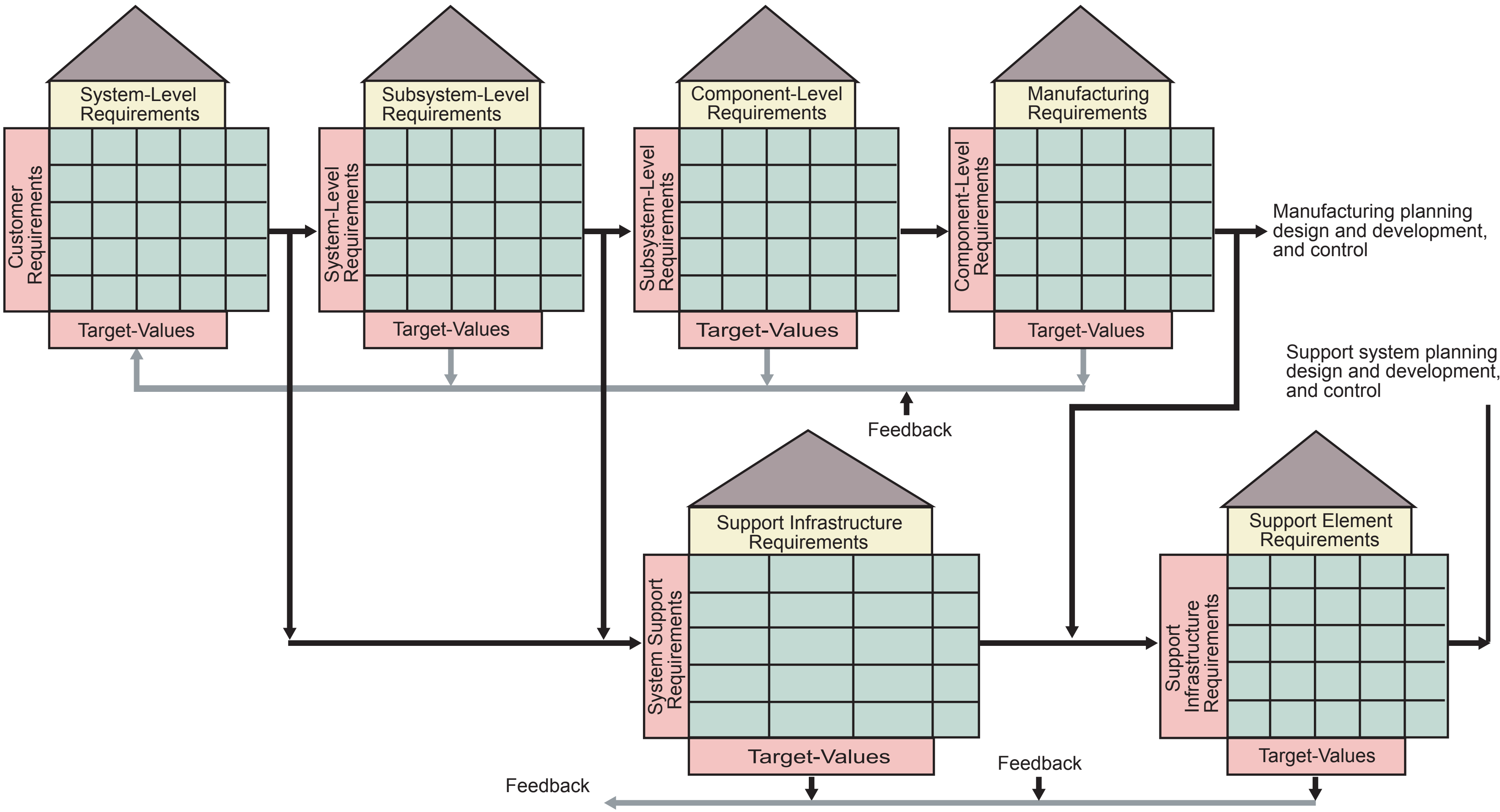


How is the “imputed importance” of ECs related to “relative importance of CAs?

Why set targets?

Adapted from Hauser and Clausing.

Families of Houses



Example of Flow-Down

- CAs
  - Engine emissions (government)
  - Engine smoothness (driver)
- ECs (engine system level)
  - Compression ratio (NOX)
  - Engine timing
- ECs (component level)
  - Crankpin throw
  - Crankpin index angle
- ECs (manufacturing requirements)
  - Lead screw precision
  - Spindle error motion

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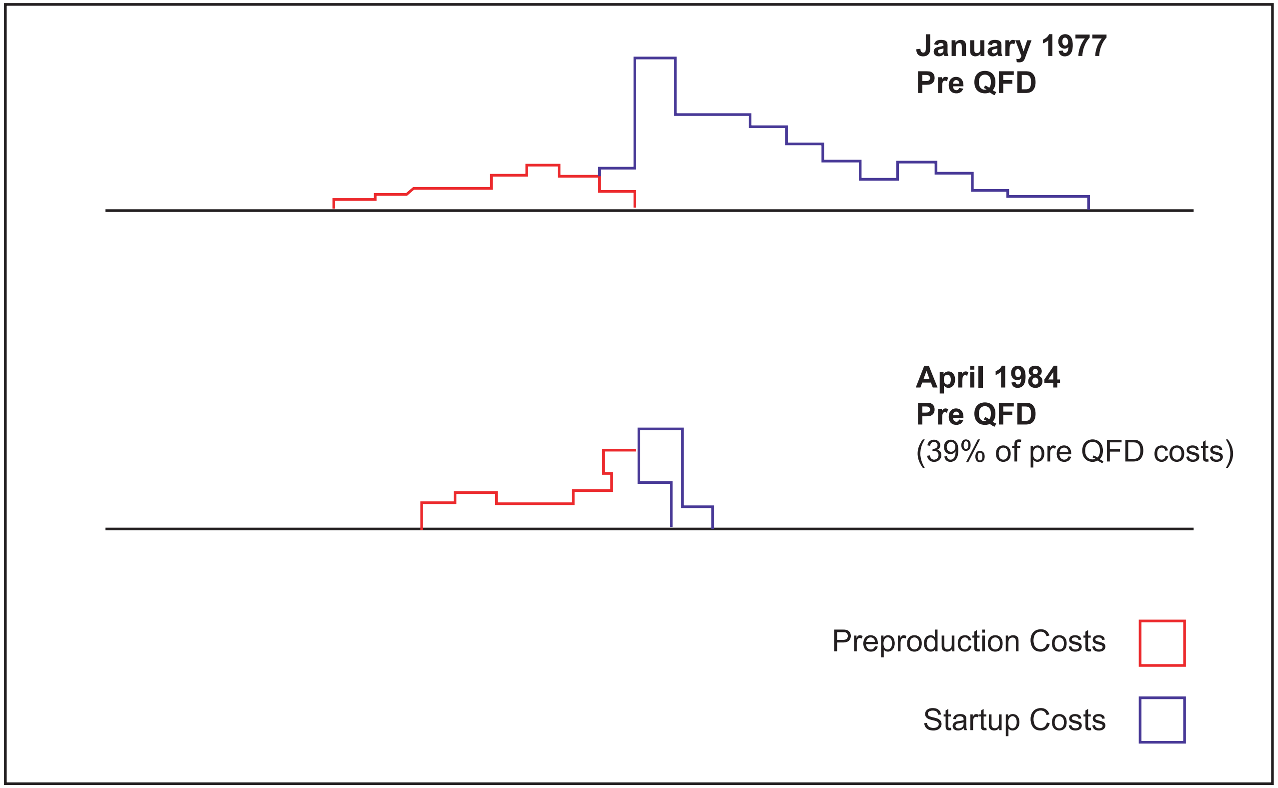
Experiences with QFD in Japan



Startup and Preproduction Costs at Toyota Auto Body Before and After QFD.

Experiences with QFD in the U. S.

- 35 projects at 9 U.S. firms (1987-1989)
- 29 had data on product quality / cost
- 7 out of 29 credit QFD with short-term material benefits (quality, time, or cost)
- Virtually all reported strategic benefits
  - Structuring decision-making across functional areas
  - Building an organized, motivated team
  - Moving information efficiently from its origin to the ultimate user

Griffin, A. "Evaluating Development Processes, QFD as an Example", Marketing Sciences Institute report 91-121.

Arrow’s Theorem and Engineering

Engineer	Preference	Votes		
		A vs B	B vs C	A vs C
I	A>B>C	A	B	A
II	B>C>A	B	B	C
III	C>A>B	A	C	C
Group preference		A>B	B>C	C>A

Hazelrigg, G. A., 1997, “On Irrationality in Engineering Design”, *ASME J of Mech Des*.

Hazelrigg’s Claims

- Arrow’s theorem implies that
  - “irrationality is practically assured”
  - “a customer-centered view of design is not possible”
- The majority of methods in common use in engineering design provide results that are “egregiously in error”
- Adopting DBD approach leads to a factor of two improvement in the bottom line

A Case Study to Test QFD

- "The major problem with HoQ is the way in which the attribute relations are established with arbitrary scales"
- "…it has been suggested that the use of such scales is no better than using a random number generator. Evidence of this is offered in the case study…"

Olenwik, A. T. and K. E. Lewis, 2003 "On Validating Design Decision Methodologies", ASME Design Engineering Technical Conference, DETC2003 DTM-48669.

A Case Study to Test QFD

• The total combination of number scales (from 1 to 9) were found. Examples include (1,3,9), (2,4,6),(1,2,3) etc. and are always in the form a>b>c.

• Next, random numbers taken from a uniform distribution from 1 to 9 were inserted where ever a relationship was found to exist.

• The relative weights were calculated for the 84 cases.

Olenwik, A. T. and K. E. Lewis, 2003 “On Validating Design Decision Methodologies”, ASME Design Engineering Technical Conference, DETC2003 DTM-48669.

A Case Study to Test QFD

Engineering attributes	Average relative weight (scales)	Average relative weight (random)
Air flow	0.17	0.16
Air temperature	0.18	0.17
Balance	0.09	0.10
Weight	0.08	0.10
Volume	0.07	0.07
Number of parts	0.02	0.03
Lifetime	0.11	0.09
Energy consumption	0.10	0.10
Noise, vibration, electromagnetic wave	0.17	0.19

Average results of all scoring combinations.

“t-tests show that the null hypothesis is not false for all the engineering attributes except balance and volume”

“Certainly, the results generated here should raise some concerns about the use of HoQ as a design tool.”

Olenwik, A. T. and K. E. Lewis, 2003 “On Validating Design Decision Methodologies”, ASME Design Engineering Technical Conference, DETC2003 DTM-48669.

Using Matlab to Check Results

- Input data (put into matrix M)

9	9	0	0	0	0	0	9	9	9
9	0	0	0	0	0	0	9	9	3
0	0	3	1	0	0	0	0	1	1
1	9	3	0	0	0	9	0	9	3
0	1	9	9	9	0	3	0	1	9
1	1	0	0	0	3	9	1	1	3
0	0	0	3	9	0	0	0	0	1
9	9	0	0	0	0	0	0	0	9

Using Matlab to Check Results "Scales"

```
function [Mp]=replace([a b c],M)
[m n]=size(M);
for i=1:m
    for j=1:n
        if M(i,j)==0 Mp(i,j)=0; end
        if M(i,j)==1 Mp(i,j)=a; end
        if M(i,j)==3 Mp(i,j)=b; end
        if M(i,j)==9 Mp(i,j)=c; end
    end
end
```

```
n=1;
for i=1:7
    for j=i+1:8
        for k=j+1:9
            scale(n,1:3)=[i j k];
            n=n+1;
        end
    end
end
```

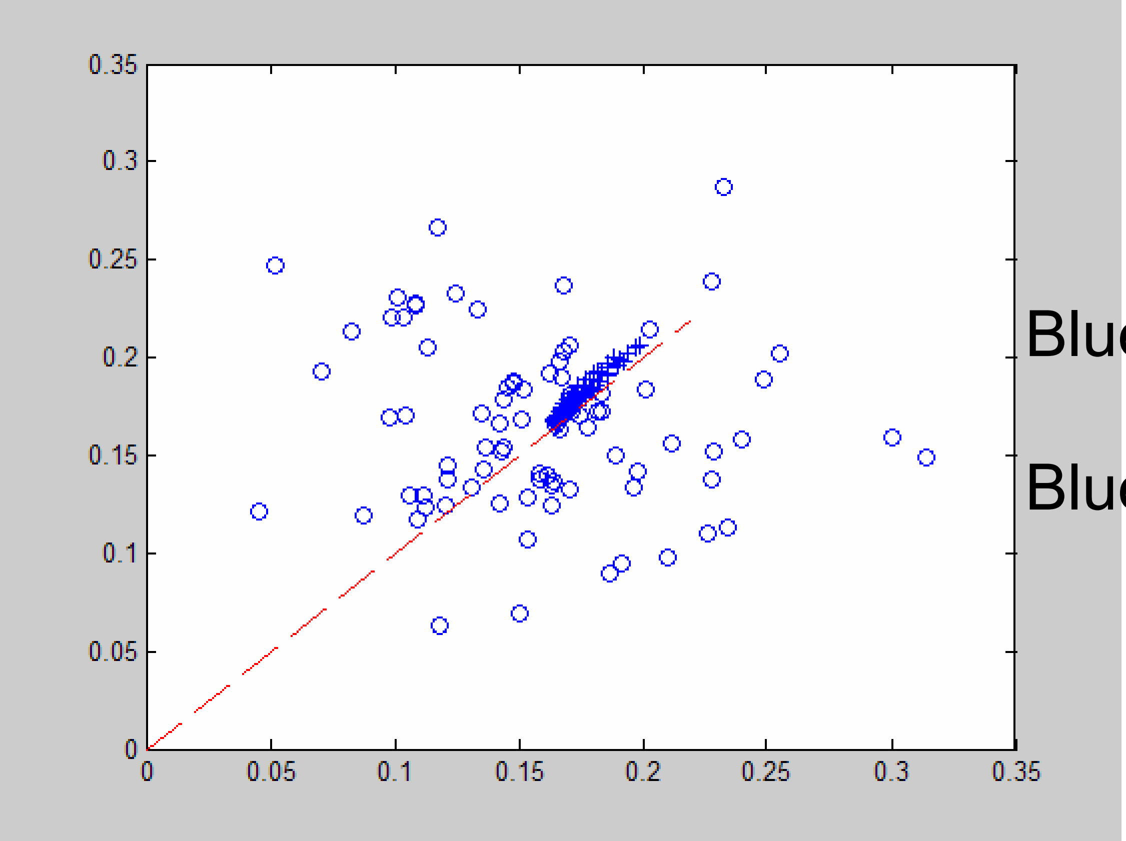
```
for i=1:84
    Mp=replace(scale(i,:),M);
    RawScore=Mp(1:8,10)'*Mp(1:8,1:9);
    RelativeWeight(i,:)=RawScore/sum(RawScore);
end
AverageRelWt(1:9)=mean(RelativeWeight(:,1:9));
plot(RelativeWeight(:,1),RelativeWeight(:,2),'+')
hold on; plot([0 0.22],[0 0.22],'--r')
```

Using Matlab to Check Results "Random"

```
function [Mp]=replacerandom(M)
[m n]=size(M);
for i=1:m
    for j=1:n
        if M(i,j)==0 Mp(i,j)=0;
        else Mp(i,j)=floor(rand(1)*9)+1; end
    end
end
```

```
for i=1:84
    Mp=replacerandom(M);
    RawScore=Mp(1:8,10)'*Mp(1:8,1:9);
    RelativeWeight(i,:)=RawScore/sum(RawScore);
end
plot(RelativeWeight(:,1),RelativeWeight(:,2),'o')
hold on; plot([0 0.22],[0 0.22],'--r')
```

Comparing Results of “Scales” and “Random”



Blue x’s are “scales” data

Blue o’s are “random” data

A Case Study to Test QFD

- "The major problem with HoQ is the way in which the attribute relations are established with arbitrary scales"

No, they are not arbitrary

- "…it has been suggested that the use of such scales is no better than using a random number generator. Evidence of this is offered in the case study…"

No, they are very different from a random number generator

Olenwik, A. T. and K. E. Lewis, 2003 "On Validating Design Decision Methodologies", ASME Design Engineering Technical Conference, DETC2003 DTM-48669.

Quality Function Deployment Summary

- "… can break down functional barriers and encourage teamwork …"
- "The house relives no one of the responsibility of making the tough decisions"
- Many of the most effective companies use QFD
- Surveys suggest that QFD provides long term competitive advantages
- The arguments against QFD so far seem weak

Plan for the Session

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- Quality Function Deployment
  - What is it for? What is it <u>not</u> for?
  - What is it? How do you use it?
  - Does it work?

➡ Next steps

Next Steps

- Optional Matlab session 11AM Fri 3-449D
- Do the reading assignment
  - Pugh_Total Design ch 4.pdf
- If you <u>have not</u> done the exam
  - Do the exam by 7:30AM Tues 29 June
  - Respect the 2 hour limit and “one sitting” rule
- If you <u>have</u> done the exam
  - Please refrain from discussing the exam
- Do assignment #3

Assignment #3 -- QFD

- Self select into teams of 3 to 5 people
- Heterogeneous teams preferred

1. Select a system of interest to you (or a subsystem) and develop a HoQ (~10X10)
2. Take a small subset (~ 2X2) and create at least three linked houses
3. Write an essay on an alternative to QFD