Instructor’s
Title & Name

Course Title….

Requirements Development Process

The **requirement** is specific documented physical and functional capabilities and attributes that a particular design, product, or process must be able to perform.

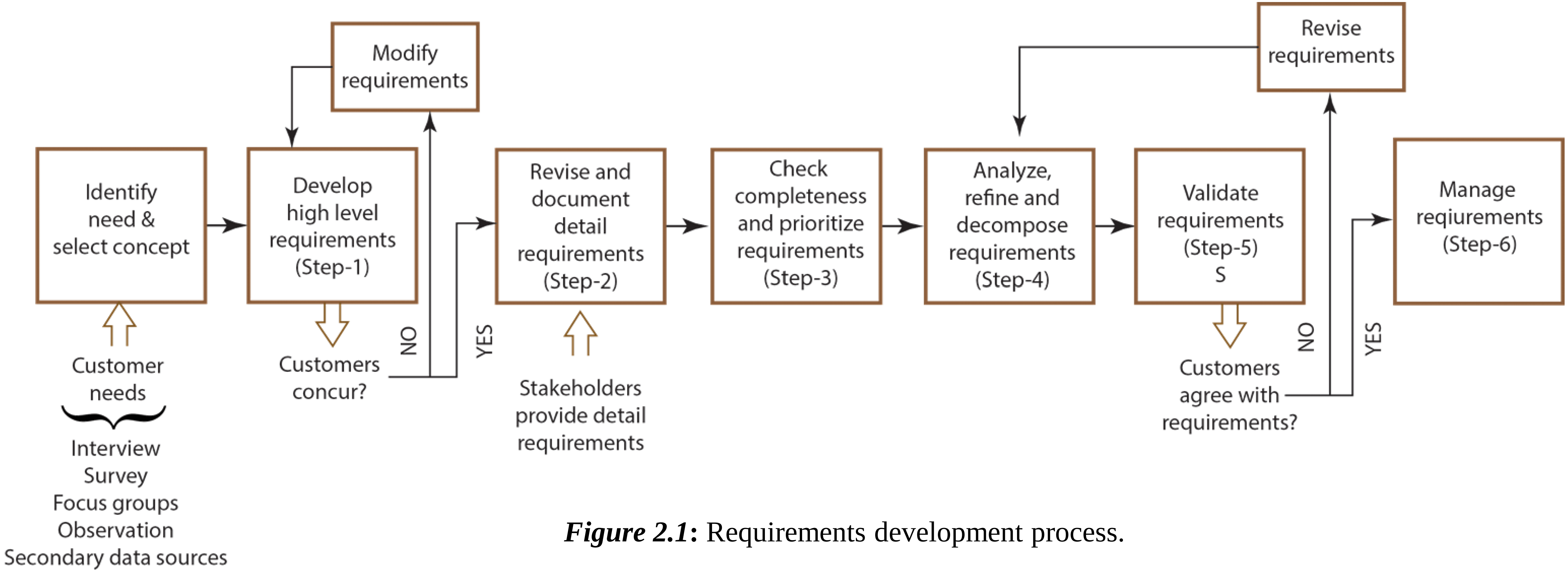

Figure 2.1**:** Requirements development process.

Process of Defining Requirements and Customer Needs

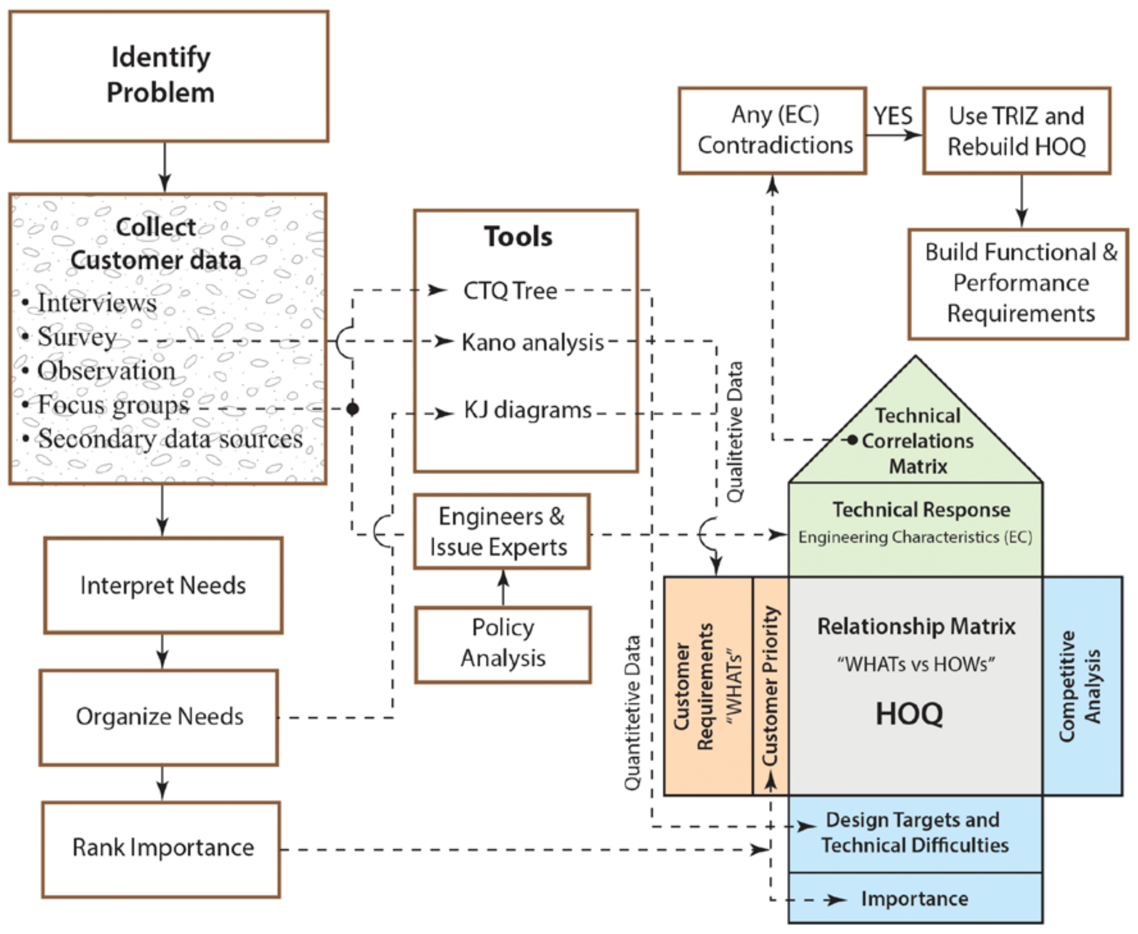

Figure 2.2: Process of defining requirements and customer needs

Survey Development

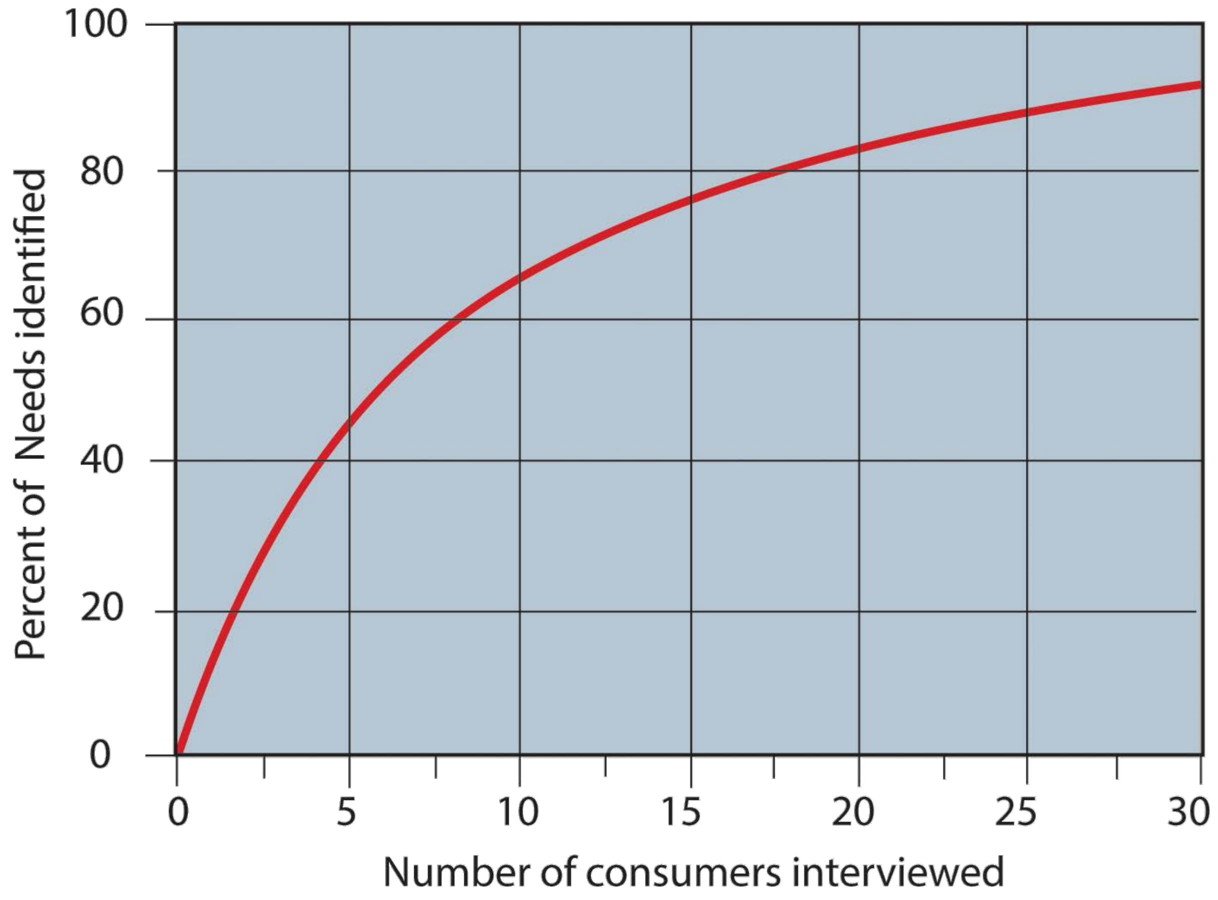

Figure 2.3**:** Survey result for customer need (Griffin, Abbie and John R. Hauser, 1993).

Kano Model: Understanding Customer Needs

The main objective of the Kano method is to help research teams uncover and classify customer needs and attributes into five categories.

- Threshold Attributes (Must be Requirements)
- Performance Attributes (Linear Requirements)
- Excitement Attributes (Attractive Requirements)

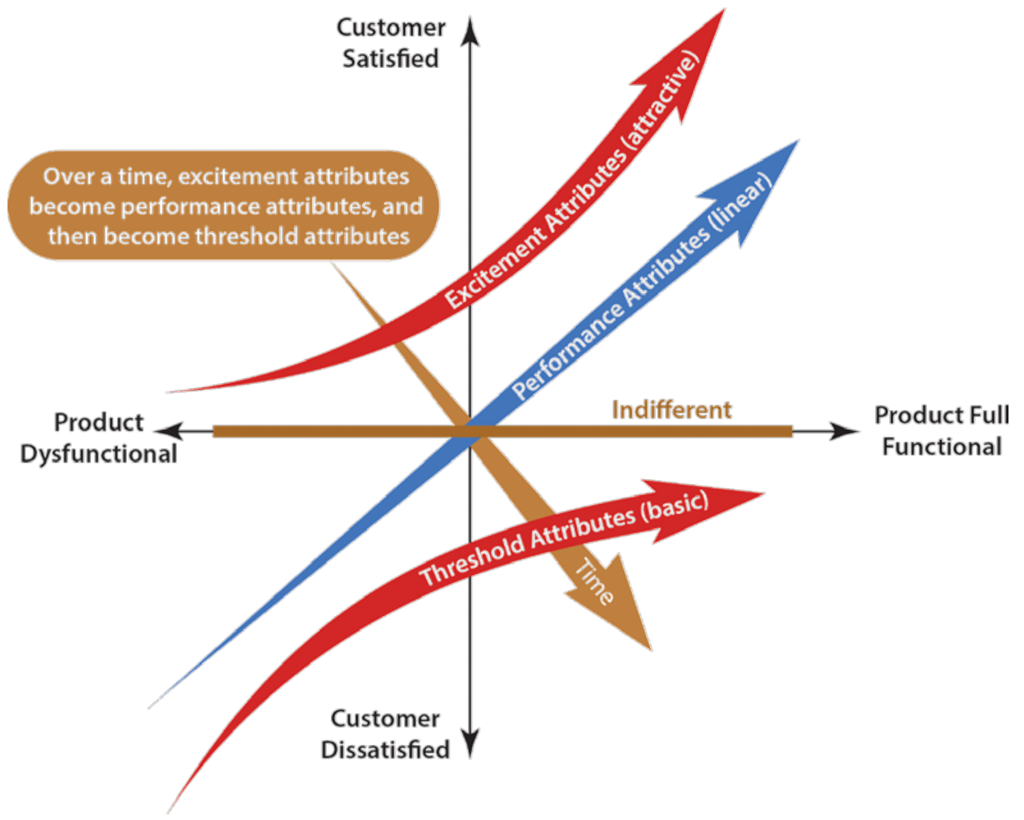

Figure 2.4: Kano model.

Table 2.1: Classification of customer needs and attributes.

Requirement Type	Definition
Must be (Threshold Attributes)	These are the basic (must be) features of a product or service– customers expect these requirements that are fulfilled.
One-Dimensional/Linear (performance quality)	These qualities are not absolutely necessary, but they increase a customer's satisfaction.
Excited attractive quality	These are the surprise qualities of a product or service. If these qualities are absent, it does not cause customer dissatisfaction.
Indifferent quality	Customers don't care if these features are provided or not provided.
Reverse quality	Providing more features may cause dissatisfaction.

Table 2.2: Example of Kano questionnaire.

If gym memberships & fitness programs is free, how do you feel? (Positive question)	(a) I like it (b) It must be that way (c) I am neutral (d) I can live with it (e) I dislike it
If gym memberships & fitness programs is not free, how do you feel? (Negative question)	(a) I like it (b) It must be that way (c) I am neutral (d) I can live with it (e) I dislike it

Customer Response (Requirement)		Negative Question (dysfunctional)				
		(a) I like it	(b) must be	(c) neutral	(d) live with	(e) dislike it
Positive Question (functional)	(a) I like it	Q	E	E	E	L
	(b) It must be that way	R	I	I	I	M
	(c) I am neutral	R	I	I	I	M
	(d) I can live with it	R	I	I	I	M
	(e) I dislike it	R	R	R	R	Q

M = Must be; R = Reverse (can be either way); L= Linear (one-dimensional); Q = Questionable (incorrect answer); E= Exciter (attractive); I = Indifference (no preference)

Figure 2.5: Kano model questionnaire evaluation.

Table 2.3: Results of Kano Analysis for 45 responses.

Gym Features	Exciter	Linear	Must be	Indifferent	Reserve	Questionable
Acceptable price range	1	29	11	3	1	0
Variety of exercise equipment	4	17	21	1	1	1
Pleasant Personal Trainers	5	15	21	2	1	1
Pleasant atmosphere	22	8	7	6	1	1

Critical to Quality (CTQ) Trees

- When developing new products, quality is important.
- CTQ is a measurable characteristic of a product or service that is provided to customers.
- Critical to Quality (CTQ) trees help the customer of any company or business to translate the most important needs on products or processes into requirements to ensure their quality.

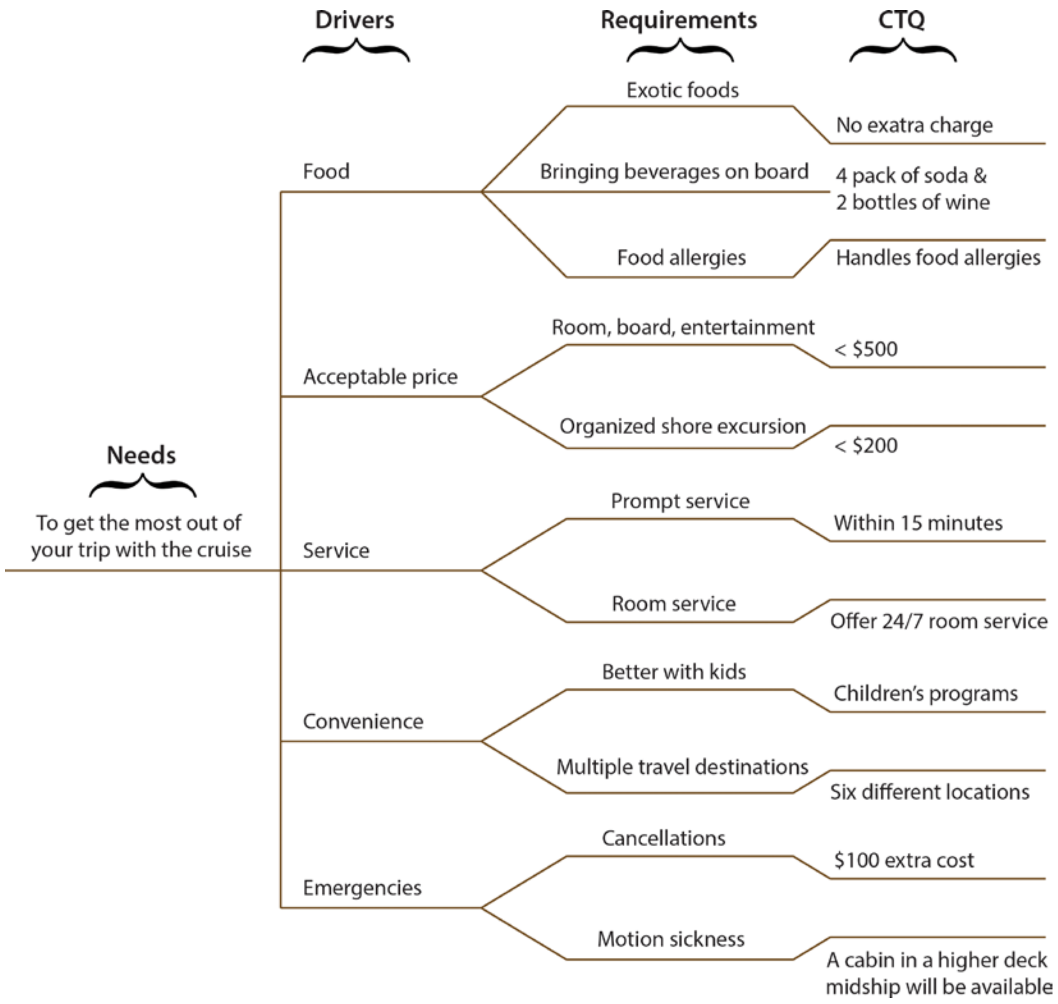

Figure 2.6: CTQ tree.

KJ Diagram: Organize Needs

The KJ concept is a simple but effective method for gathering and organizing ideas, opinions, and issues regarding a given specific problem. The tool is especially helpful when working in a team. The goal of the KJ method in concept engineering is to group the qualitative data (in the form of hundreds of voices and images) and extract a useful set of customer requirements. The following simple steps can be used for the KJ analysis:

- Collect all ideas without considering their rationality
- Group the ideas in a manner appropriate to the topic
- Form hierarchies of groups and subgroups
- Evaluate the ideas by ranking, sequencing -- find the best solutions chosen from the groups

Example

To design a new finger rehab device as shown in the figure, following positive and negative survey questions were sent to a group of customers to define their needs. The survey questions were as follows:

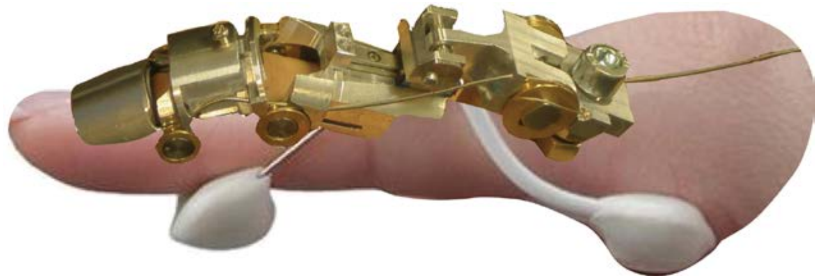

Figure 2.7: Finger rehab device.

Example (continued)

Positive Questions (functional):

1. How would you feel if the rehabilitation device function (flexion & extension) is automated?
2. How would you feel if the rehabilitation device is designed for patient comfort?
3. How would you feel if the rehabilitation device is lightweight?
4. How would you feel about the rehabilitation device low cost?
5. How do you feel about the rehabilitation device being controlled by an app?
6. How do you feel about the battery being rechargeable?
7. How do you feel about the rehabilitation device with concealed wires?
8. How do you feel about the rehabilitation device is portable?

9 How do you feel about if the product prevents swelling?

10. How do you feel about if the device has continuous passive motion.
11. How do you feel about if the device meets the medical device regulations.
12. How do you feel about if the device supports user activity.

Example (continued)

Negative Questions (dysfunctional):

1. How would you feel if the rehabilitation device function (flexion & extension) is not automated?
2. How would you feel if the rehabilitation device is not designed for patient comfort?
3. How would you feel if the rehabilitation device is not light weight?
4. How would you feel about the rehabilitation device is not low cost?
5. How do you feel about the rehabilitation device is not controlled by an app?
6. How do you feel about the battery not being rechargeable?
7. How do you feel if the rehabilitation device has exposed wires?
8. How do you feel about the rehabilitation device is not portable?
9. How do you feel about if the rehabilitation device doesn't prevent swelling?
10. How do you feel about if the device doesn't have continuous passive motion. 11. 11. How do you feel
11. How about if the device doesn't meet the medical device regulations.
12. How do you feel about if the device doesn't support user activity.

Example (continued)

KANO ANALYSIS

The survey was sent to approximately 40 people and 30 responses were received. Raw data from customer responses were analyzed and customers' need statements were extracted from each response. Using survey results and Figure 2.5, each positive question was compared against each negative question for every respondent to determine appropriate letters shown in Table 2.4.

Customer Response (Requirement)		Negative Question (dysfunctional)				
		(a) I like it	(b) must be	(c) neutral	(d) live with	(e) dislike it
Positive Question (functional)	(a) I like it	Q	E	E	E	L
	(b) It must be that way	R	I	I	I	M
	(c) I am neutral	R	I	I	I	M
	(d) I can live with it	R	I	I	I	M
	(e) I dislike it	R	R	R	R	Q

M = Must be; R = Reverse (can be either way); L= Linear (one-dimensional); Q = Questionable (incorrect answer); E= Exciter (attractive); I = Indifference (no preference)

Figure 2.5: Kano model questionnaire evaluation.

Table 2.4: Kano analysis results for 30 responses.

Features ↓	**E**	**L**	**M**	**I**	**R**	**Q**
Automated	10	6	7	3	0	4
Comfort	14	8	4	3	0	1
Light weight	9	9	9	0	0	0
Low cost	4	10	8	4	0	4
Device controlled by an app	13	5	5	4	0	3
Device with rechargeable battery	5	10	9	4	0	2
Device with concealed wires	6	6	14	2	1	1
Portable/robust	5	12	6	4	0	3
Device prevents swelling	6	6	14	2	0	2
Device has continuous passive motion	4	9	10	4	0	3
Meets regulations	2	9	12	4	0	3
Support user activity	4	8	11	4	0	3

Example (continued)

Critical to Quality (CTQ) Tree

From the Kano analysis results, we can define the most important design categories to include in the final customer needs and engineering requirements. In Figure 2.8, the driving design categories are expanded more in a rehab device CTQ tree to allow a more specific idea of what is needed for the design requirements to be developed.

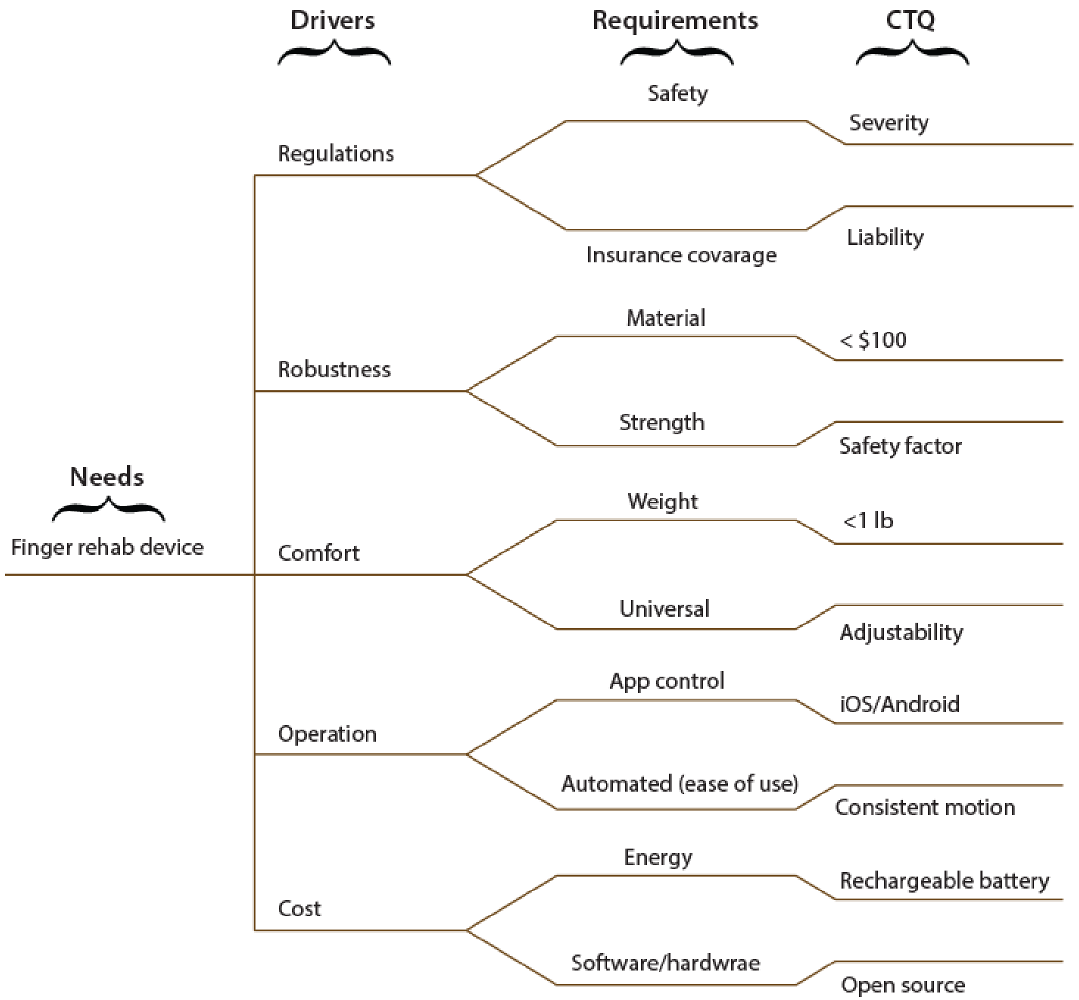

Figure 2.8: CTQ of finger rehabilitation device.

Example (continued)

KJ Diagram

This process allows us to easily transition into forming a KJ diagram shown in Figure 2.9.

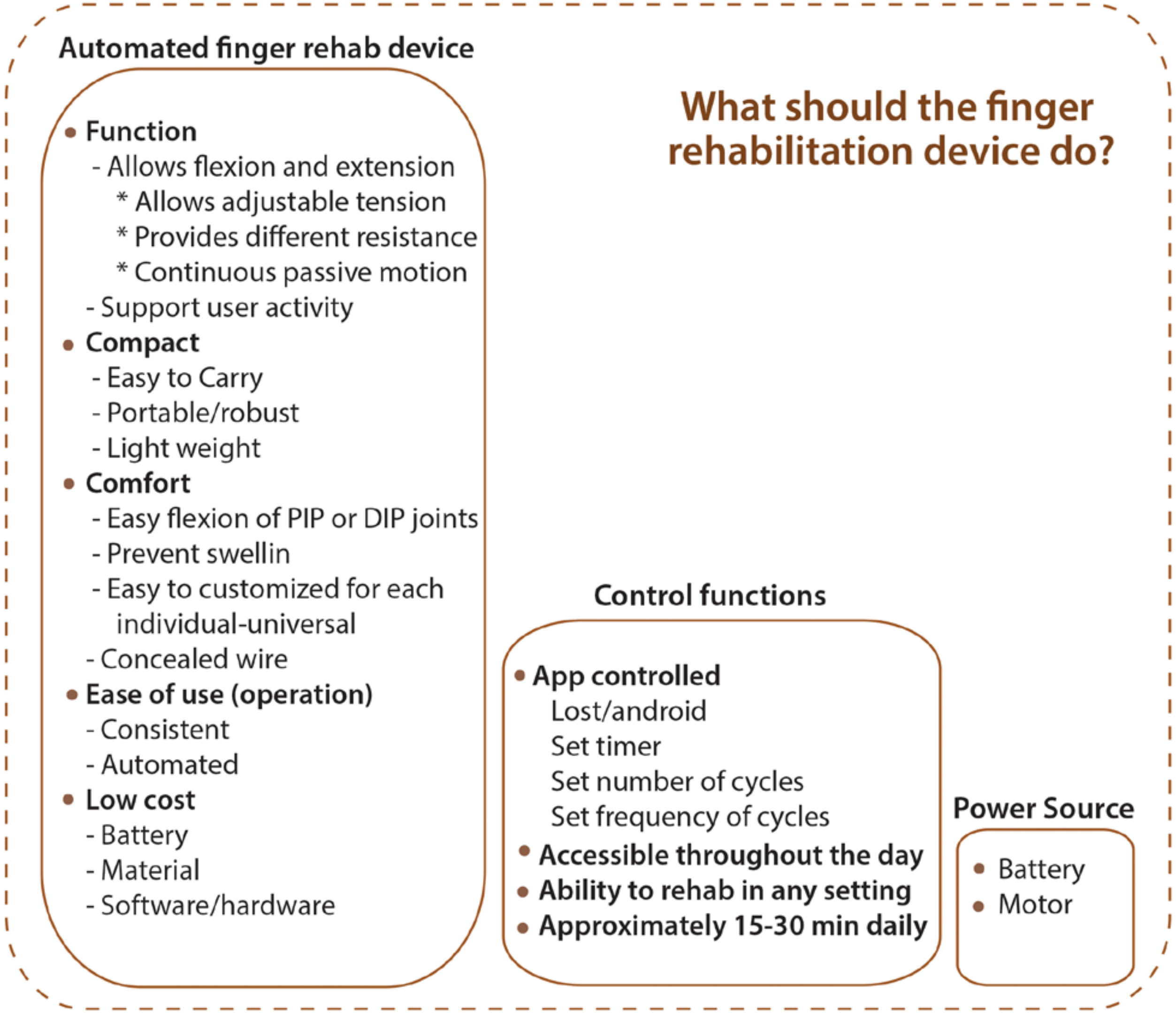

Figure 2.9: KJ diagram of finger rehabilitation device.

Quality Function Deployment (QFD)

Quality Function Deployment (QFD) was developed in Japan in the early 1970s and has been effectively used in the United States since the 1980s.

QFD is a method for identifying customer needs and making sure that the voice of the customer is included in the design process for product development.

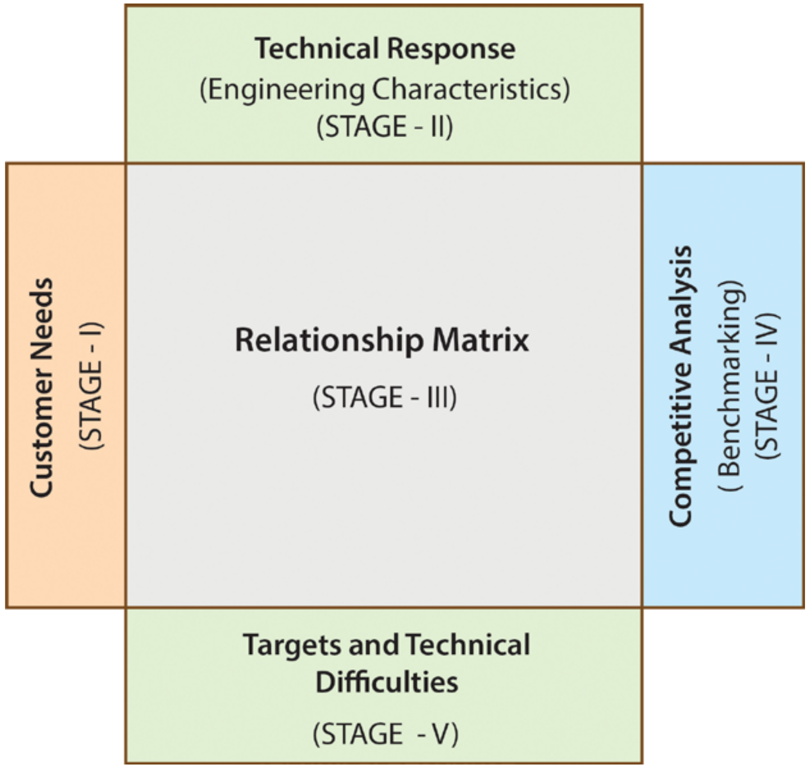

Figure 2.10: QFD matrix.

Example

Using Kano analysis results, CTQ (given in Figure 2.8), and KJ diagram (given in Figure 2.9) develop Quality Function Deployment for the finger rehab device.

SOLUTION

Using the results of Kano, KJ, and QTC, the student research team developed the following customer needs.

Universal: The design of the finger rehab device will be usable by all people, to the greatest extent possible.

Portable: The next customer need is " the device must be portable" - lightweight, compact, and small enough to fit on a finger.

Automated: Automation is an important aspect of this design. The purpose of designing an automated device is to mobilize the finger in a safe and repetitive way, so that users achieve their highest level of recovery.

Controlled by app…
Concealed Wires…
Rechargeable Battery…
Cost…
Light Weight…

Example (continued)

Engineering characteristics are what you control, performance criteria are what your customer cares about. A `target value'' refers to the planned value for an ``engineering characteristic'' in the final design that you have certain control over. For example, weight, size, shape, speed, cost, etc.

Ranking Key		
Strong Relationship	◉	9
Medium Relationship	○	3
Weak Relationship	△	1

Customer Requirements (What?)	Minimum cost	Weight	Strength	Support user activity	Reliability	Power & energy	Flexion & extension	Customer Score	Proposed Product	Competitor 1	Competitor 2
	Engineering Characteristics (EC) (How?)								Benchmarks (1-low, 5 high)		
Universal	◉	○					△	13	3	1	2
Portable	△	◉	○			△	○	17	5	2	4
Automated	◉	△		◉	◉	◉	○	40	5	4	3
Controlled by app	◉			◉				18	5	3	4
Concealed wires		△			△			2	5	4	4
Rechargeable battery	○				○	◉		15	5	5	5
Inexpensive	◉	◉	○	○	○	△	△	29	5	4	3
Light weight	○	◉	○		○	△	△	20	4	3	3
(EC) Score	43	32	9	21	19	21	9				
Unit	$	lb	psi		%						
Target Value	<90	<1	400		99%						
Technical Difficulty (1-Easy, 5-Most Difficult)	3	3	4	4	4	2	3				
	Product Targets and Benchmarks										

Figure 2.11: Quality Function Deployment (QFD).

Example (continued)

Customer Requirements (What?)	Minimum cost	Weight	Strength	Support user activity	Reliability	Power & energy	Flexion & extension
Universal	⊙	○					△
Portable	△	⊙	○			△	○
Automated	⊙	△		⊙	⊙	⊙	○
Controlled by app	⊙			⊙			
Concealed wires		△			△		
Rechargeable battery	○				○	⊙	
Inexpensive	⊙	⊙	○	○	○	△	△
Light weight	○	⊙	○		○	△	△

Engineering Characteristics (EC) (How?)

Mapping to requirements

Functional Requirements:

Support user activity
Flexion & extension

Non-functional Requirements:

Reliability
Minimum cost
Weight
Strength
Power/energy

Figure 2.12: Mapping to requirements.

Requirement Categories

There are three main requirement categories.

a) **Functional/Non-functional Requirements**

A functional requirement (FR) describes ***"what"*** the system/product must do without describing them in quantitative terms. For example, "the finger rehab device shall be capable of flexing and extending the hand fingers, repetitively."

Non-functional requirements (NFR) serve as constraints or restrictions on the design of a system. For example, security, reliability, maintainability, lightweight, strength, etc.

Requirement Categories

b) Performance Requirements

Performance requirements describe "***how well***" the system/product must perform certain functions under specific conditions. They are quantitative requirements and are verifiable. For example, "the finger rehab device shall be capable of exerting 3-axis forces at each fingertip with output force ranges up to 3.5 N, having 0.5 second response time during each cycle, in order to open the fingers." As seen from this example, there is more than one performance requirement associated with a single functional requirement.

Requirement Categories

c) Design Constraints

Constraints determine the performance limits of the system/product such as acceptable range of frequency, temperature range, operation range, weight, size, etc. – what is expected of the product. For example, “The finger rehab device weight shall not exceed 0.5 lb”. Categories of some examples of constraints are shown in Table 2.5.

Table 2.5: Categories of some examples of constraints.

Technical	**Social**	**Environmental**	**Economical**
Physical	Legal/Ethical	Ecological	Ergonomic design
Functional/performance	Political	Operational	Cybernetic design
Laws and regulations	Health	Regulations	Microeconomic factors
Standards and guidelines	Security	Storage	Affordability constraints
Policies and procedures	Public and & international laws	Reuse and reusability	Budget
Codes	Safety		

How to Write Good Requirement

Writing good requirements is not an easy task.
As mentioned by Albert Einstein, *“When you are out to describe the truth, leave elegance to the tailor.”*

This quote tells us that elegant and entertaining requirement writing style is not necessary – don’t use buzzwords.

How to Write Good Requirement

Followings are the summary of essential points to write a good requirements:

- Define requirements as clear as possible – uncertainty leads to confusion and unhappiness.
- Define one requirement one at a time - each requirement should be short. To avoid confusion try not to use conjunctions like and, or, also, with and the like.
- If extensive conjunctions are necessary for clarity, the sentence should be decomposed into shorter sentences.

How to Write Good Requirement

- Each requirement should have a complete sentence with no buzzwords or acronyms.
- Don’t use vague and unverifiable terms. For example: user-friendly, versatile, robust, approximately, minimal impact, easy, sufficient, flexible, adequate, fast, large, small, etc. This will cause difficulties to define their test cases.
- Each statement that defines a requirement must contain the word “**SHALL**”. Use positive statements such as “the system shall…”, instead of “the system shall not…”

How to Write Good Requirement

Examples Using Correct Terms

- The finger rehab device **shall** be capable of exerting 3-axis forces at each fingertip with output force ranges up to 3.5 N.
- The buildings **shall** withstand wind loads of 150 mph.
- The scooter **shall** have a maximum speed of 10 mph.

Examples Using Incorrect Terms

- The finger rehab device **shall not** be capable of exerting 3-axis forces at each fingertip with output force ranges up to 3.5 N.
- The buildings **will** withstand wind loads of 150 mph.
- The scooter **should** have a maximum speed of 10 mph.

How to Write Good Requirement

- “**Will**” should be used only for statements that provide information; and “**Should**” be used to represent a goal to be achieved.

- Requirements must be realistic and allow acceptable solutions (what not how). Requirements should state **WHAT** is needed, not **HOW** to provide it.

- Requirements must be quantifiable, testable, and verifiable.

- Do not use “To Be Determined” **(TBD)** and “To Be Resolved” **(TBR).** Use the current best estimate within brackets [value] in the requirement and state your basis for why the value is still an estimate.

- State tolerances for qualitative values. For example, less than; greater than or equal to; plus or minus; root mean squares.

How to Write Good Requirement

Check Requirements Reliability & Correctness

- Is each requirement correct and as clear as possible?
- Are the requirements technically feasible and realistic?
- Are the requirements measurable, testable, and verifiable?
- Are the reliability requirements specified?

Requirement Decomposition

Requirement decomposition is a complex system engineering task. When developing large systems it is important that the requirement decomposition process is performed.

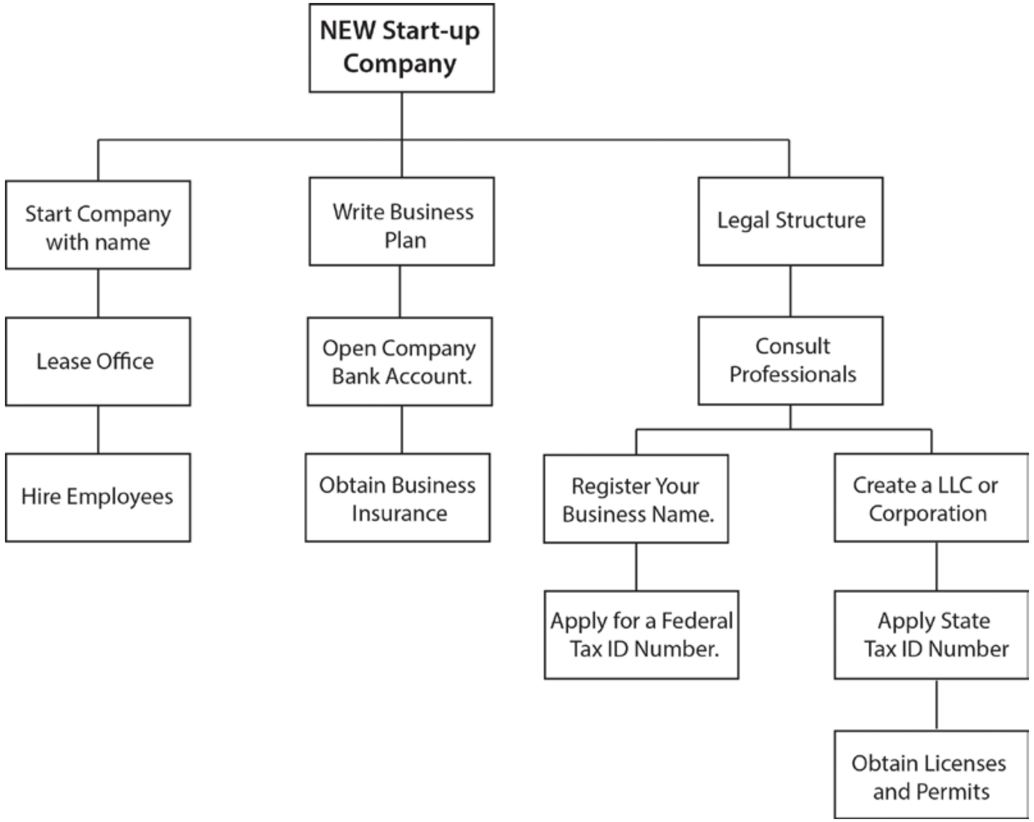

Figure 2.13: Requirement decomposition of a new start-up company.

House of Quality (HOQ)

Afterward, Toyota improved the QFD and introduced the House of Quality (HOQ).

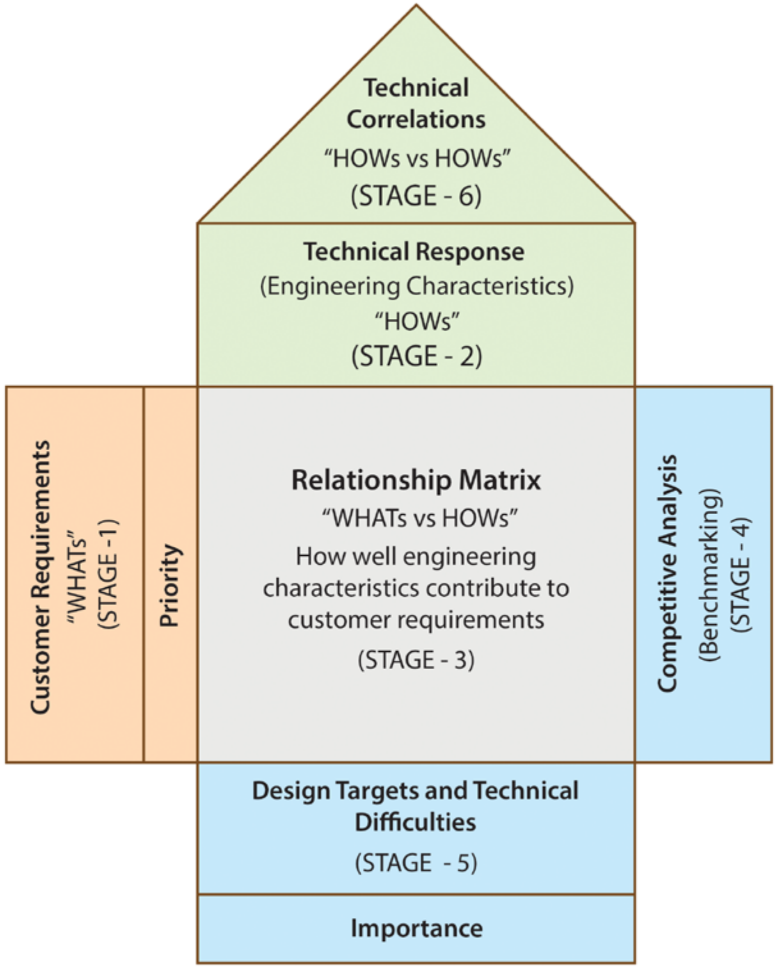

Figure 2.14: House of Quality (HOQ).

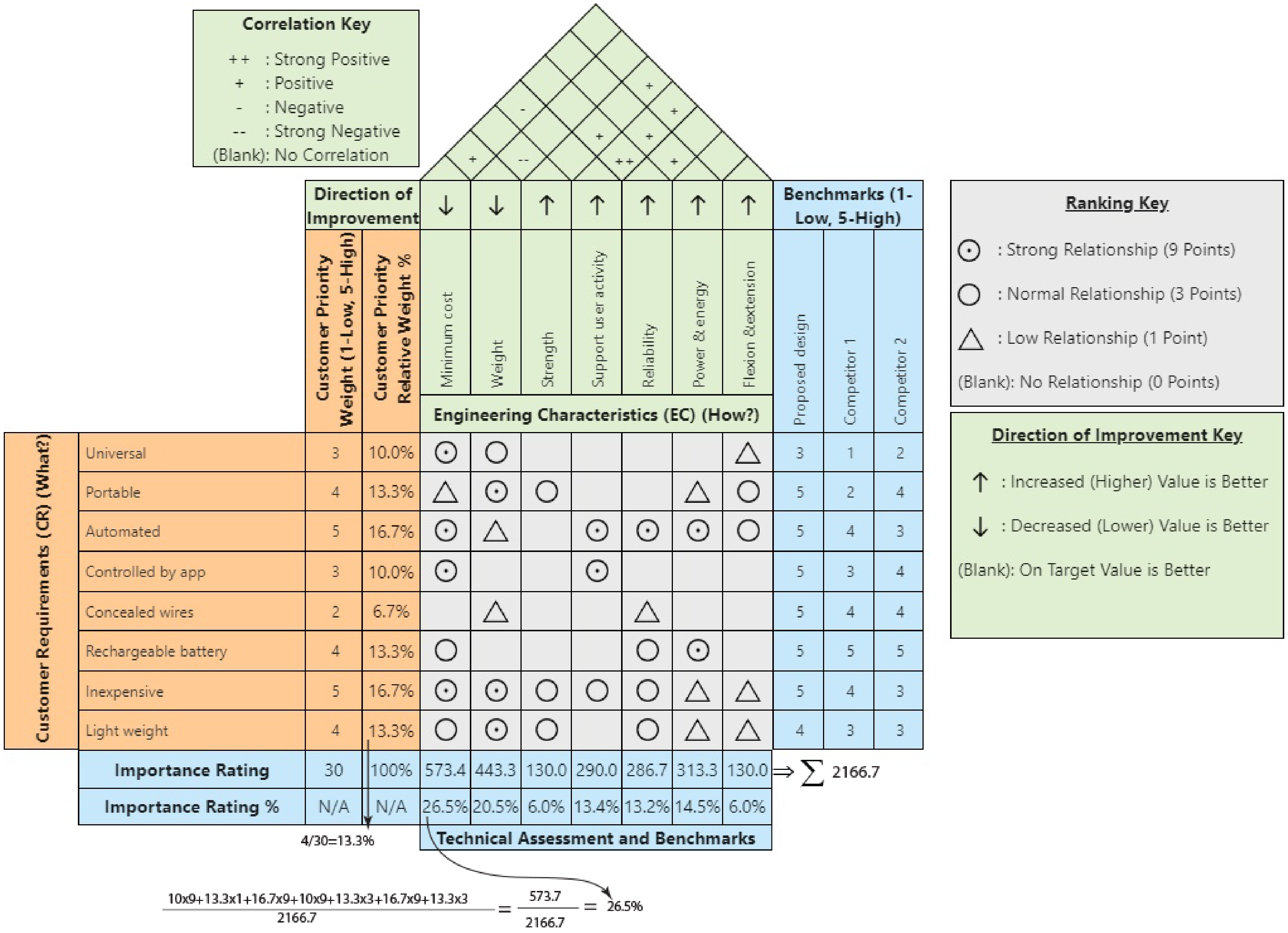

Figure 2.15: HOQ for the finger rehab device.

Concept Development

The importance rating of engineering characteristics from HOQ analysis can be used for concept development.

Criteria (Engineering Characteristics)	Importance Rating, % (IR)	Concept A (IR)x(R)	Concept B (IR)x(R)
Minimum cost	26.5	⊙ = 132.5	○ = 79.5
Weight	20.5	○ = 61.5	⊙ = 102.5
Streght	6.00	⊙ = 30.0	○ = 18.0
Support User Activity	13.4	○ = 40.2	▲ = 13.4
Reliability	13.2	▲ = 13.2	○ = 39.6
Power & Energy	14.5	○ = 43.5	○ = 43.5
Flexion & extension	6.0	○ = 18.0	○ = 18.0
		338.9	**314.5**

Ranking (R)		
Strong Relationship	⊙	5
Medium Relationship	○	3
Weak Relationship	▲	1

Figure 2.16: Concept selection matrix.

Cascading QFD Analysis

Usually, one QFD may not be sufficient to explain the customer requirements down to actual production. As shown in Figure 2.17, there are four phase processes to develop a product which includes four cascaded House of Qualities (HOQ). This figure shows that QFD is an integrative process for connecting customer requirements to production -- HOWs are refined until the detailed level of production requirements is reached. As seen from this figure, HOWs of phase-I become the WHATs of phase-II.

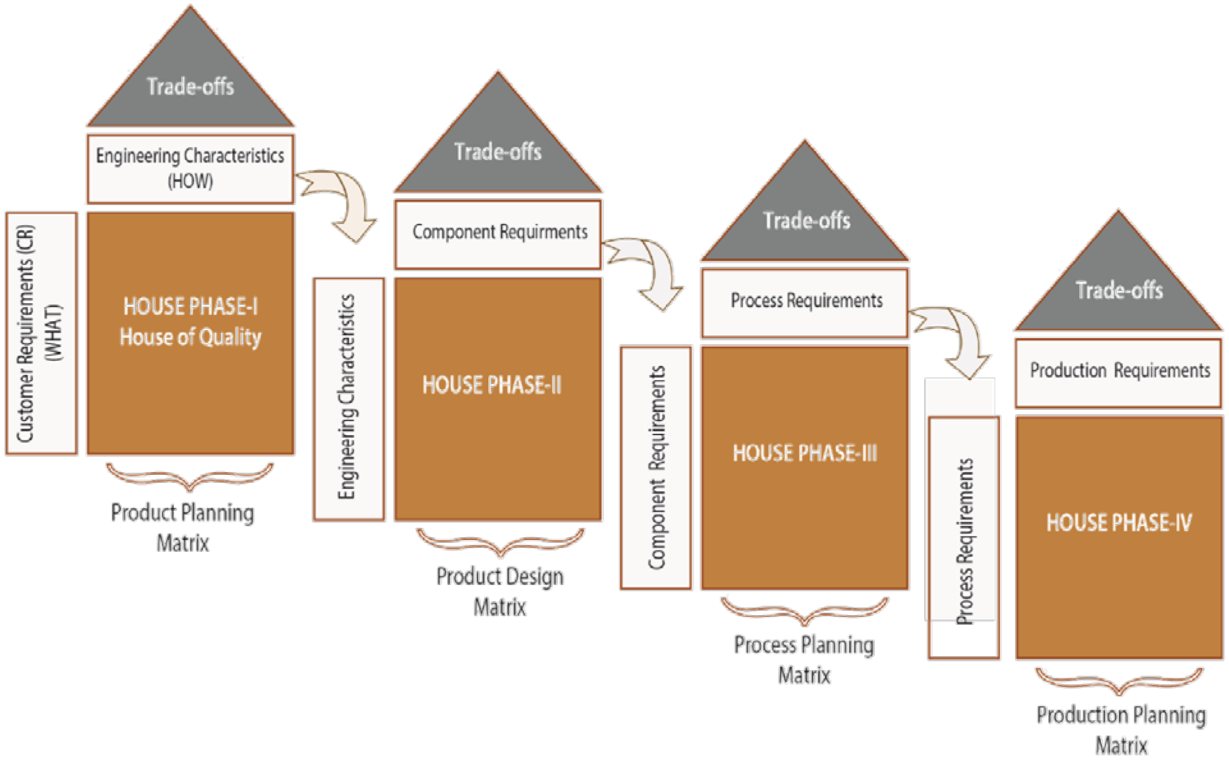

Figure 2.17: Connecting customer requirements to production