MODULE 7

Transdisciplinary Design Tools Integration

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Transdisciplinary modules are dedicated to Dr. Raymond T. Yeh and Mr. Bob Block, for their continued support of ATLAS, enthusiasm, dedication, and passion!

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Transdisciplinary Design Tools Integration

Integration is a basic law of life; when we resist it, disintegration is the natural result, both inside and outside of us. Thus we come to the concept of harmony through integration. **Norman Cousins**

One of the challenges in HR management in general and talent management, in particular, will be to ensure that the tools by which the ideas of talent are delivered are integrated with the tools of management of the organization as a whole with a measurable output. **Tumer & Kalman**

7.1 Introduction

Transdisciplinary tools will be covered in this module have been applied in many fields including product development, project management, many engineering disciplines, design of the organization, sustainable development, social issues, environmental issues, and others across many industries including automotive, aerospace, telecom, semiconductor, defense, transportation, energy, healthcare, agriculture, and more – the integration of well-known TD tools such as QFD, TRIZ, ISM, DSM, and AD addressing a wide range of domains will be discussed in this module.

7.2 Transdisciplinary Tools Integration for Product Design

The integrated TD tools can be used in a wide range of domains. This module shows a new framework for integrated TD tools (see Figure 7.1) which has great potential benefits to solve large-scale complex problems.

7.2.1 Integrating QFD and TRIZ

The customer requirements, in general, include contradictions, which are mainly solved by trade-offs or compromises between the two parameters. The TRIZ inventive problem solving can be used to remove compromises by resolving contradictions in the product development – the contradiction resolution is more innovative than any other trade-off solution.

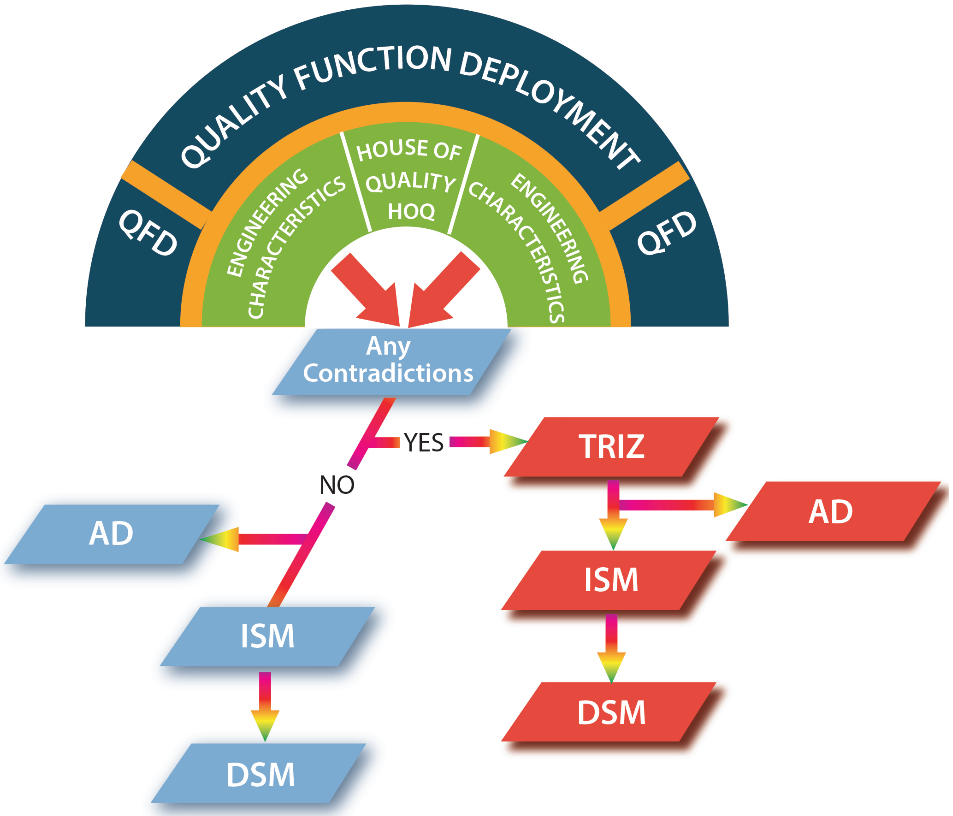

Figure 7.1: Framework of integrated TD tools.

As shown in Figure 7.2, the TRIZ method offers a wide array of applications in QFD.[1] QFD and TRIZ have complementary approaches and different viewpoints for product development and planning. Figure 7.3 illustrates the level of impact and relationships of QFD and TRIZ on certain requirements of product development.[2]

Hajime et al. developed the Innovative Product Development Process (IPDP), which systematically integrates QFD with TRIZ and enables the effective and systematic creation of technical innovation for new products.[3] The integration of TRIZ and QFD capabilities allows not only the satisfaction of the demands of customers but also the design of solutions based on technological systems that provide entirely new experiences use.[4]

[1]Philipp Tursch, Christine Goldmann, Ralf Woll, (2015). Integration of TRIZ into QFD. *Management and Production Engineering Review*, Vol. 6, No. 2, pp. 56–62.

[2]Terninko, J., Zussman, A., & Zlotin, B. (1998). Systematic innovation: an introduction to TRIZ. Boca Raton: CRC Press.

[3]H. Yamashina, T. Ito and H. Kawada,(2002). Innovative product development process by integrating QFD and TRIZ. *International Journal of Production Research*, vol. 40, no. 5, pp.1031-1050.

[4]Naveiroa, R. M., Oliveira, V. M., (2018). QFD and TRIZ integration in product development: a Model for

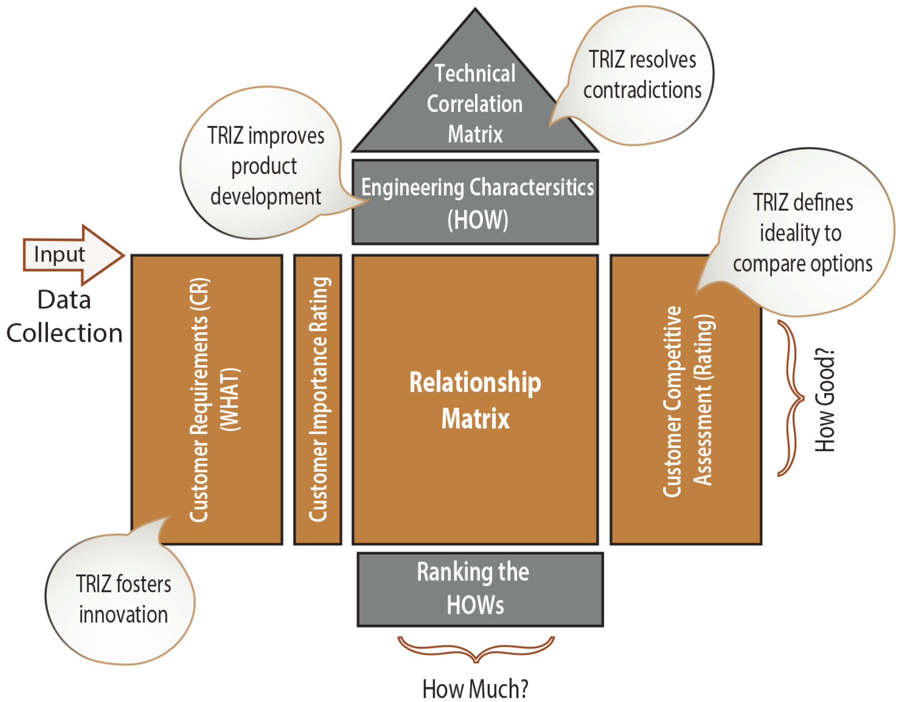

Figure 7.2: TRIZ application in QFD (adapted from reference 1).

Ranking	
Strong Relationship	XXX
Medium Relationship	XX
Weak Relationship	X

	QFD	TRIZ
Customer Satisfaction	XXX	X
Product Quality	XXX	XXX
Profits	XXX	XXX
Market Share	XXX	XXX
Innovation	XX	XXX
Failure Anticipation		XXX
Intellectual Capital Protection		XXX
Technological Prospection		XXX

Figure 7.3: QFD and TRIZ synergy (from reference 2).

The HOQ identifies relationships among requirements and interactions between the engineering characteristics of the product. The TRIZ through contradiction matrix solves the main shortcoming of the QFD method when engineering characteristics conflict with each other. The

Systematic Optimization of Engineering Requirements. Production, Vol. 28.

TRIZ inventive principles may eliminate the conflicts between engineering characteristics that occurred in the HOQ correlation matrix. The steps for finding solutions for conflicting problems that exist in the QFD with TRIZ are the following (see Figure 7.4:

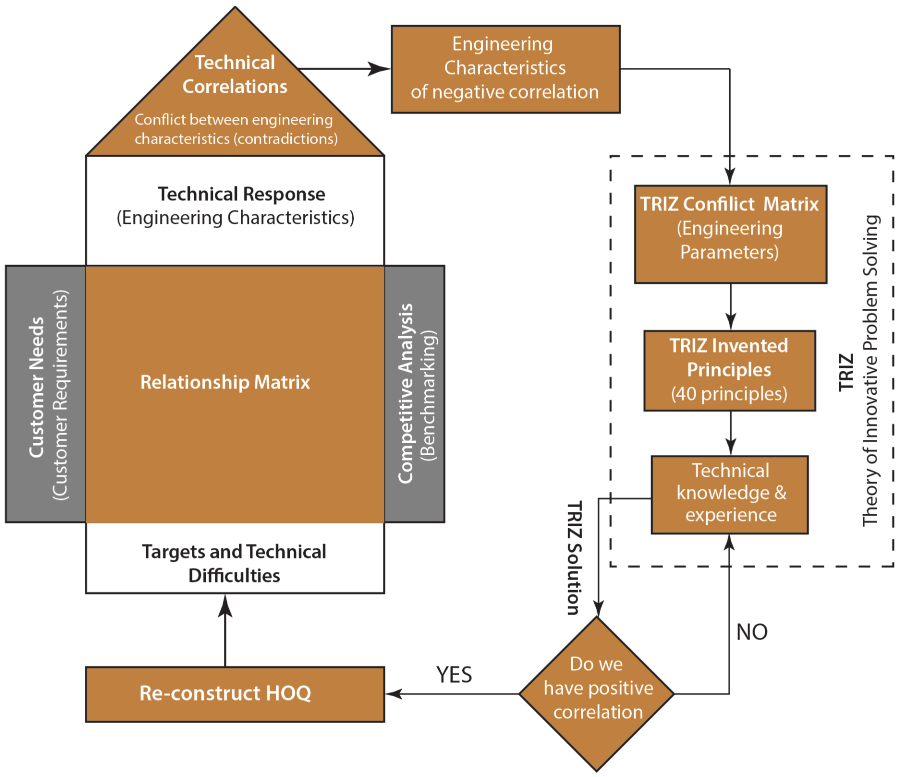

Figure 7.4: Flow chart.

1. Identify the conflicting engineering characteristics (EC) with negative correlation in the HOQ correlation matrix.
2. Identify the EC's type, which one is improving and which one is worsening characteristics.
3. Replace the ECs with corresponding parameters from TRIZ 39 contradiction matrix (Tables 3.1 through 3.6).
4. Using the contradiction matrix tables, identify which of the 40 inventive principles are applicable for your problem to resolve the contradiction (see Table 3.8 for 40 inventive principles).
5. After brainstorming, adapt the appropriate solution from 40 inventive principles to resolve the conflict among the ECs in the HOQ correlation matrix.
6. Re-construct the HOQ with the new ECs.

EXAMPLE 7.1

Using the TRIZ inventive principles resolve the conflicts among the ECs shown in Figure 7.5.

ANALYSIS

QFD of a simplified example of finger rehab device given in Figure 7.5 shows two negative correlations. In this practical example, the negative correlations between ECs are: (1)"improving support user activity" and "increase cost", (2)"improving strength" and "increasing weight". We will discuss these two cases as follows.

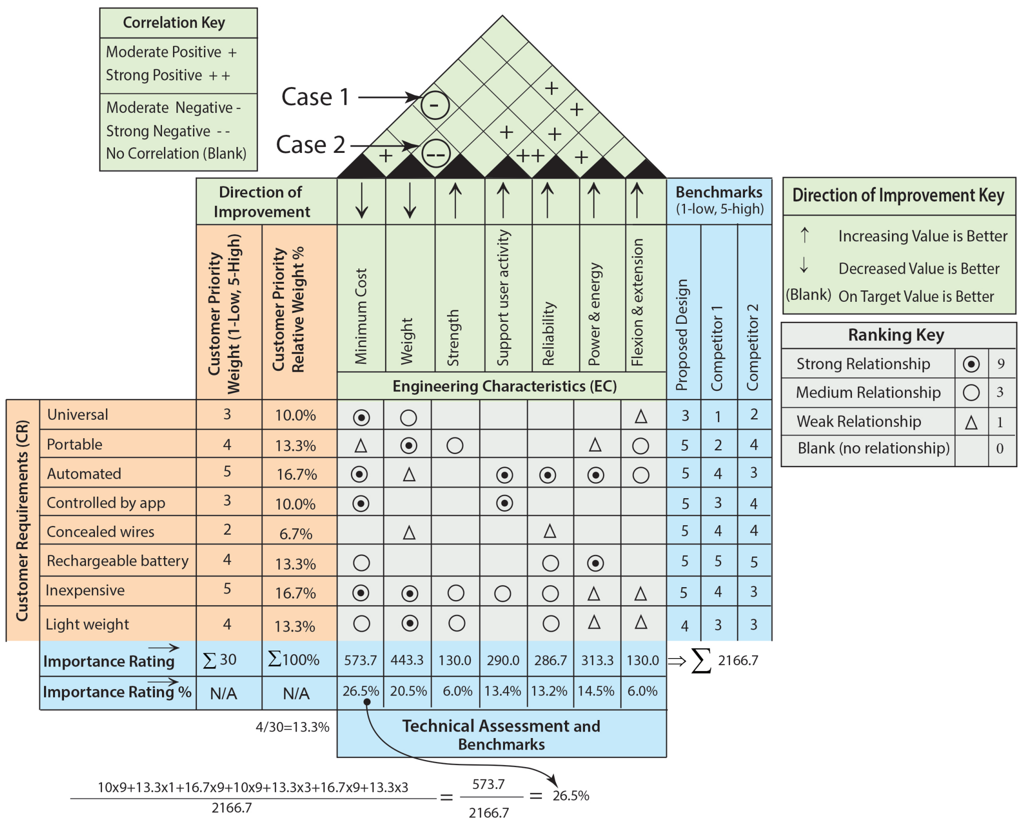

Figure 7.5: Finger rehab device of QFD.

Case 1: The improvement of the "support user activity" causes an increase in production "cost", thus resulting in a moderate negative correlation in the correlation matrix. In this case, "support user activity" is the improving characteristic, and the "cost" of production is the worsening characteristic. In other words, If we want to improve the "support user activity" it will cost more money and time.

EXAMPLE 7.1 (continued)

Many people have difficulty with the issue of cost since cost reduction is a widespread topic throughout the industry. However, many techniques of TRIZ do not deal with cost explicitly.[a]

Darrell Mann (2004) has developed a business matrix similar to the contradiction matrix. His direct cost parameters for the business matrix are as follows:[a]

- R&D Cost
- Production Cost
- Supply Cost
- Support Cost

He also included some of the same parameters used in the TRIZ matrix that cause costs to increase:[a]

- Complexity of the system
- Complexity of control
- System-generated harmful factors
- Time and risk issues for the R&D, production, supply, and support
- Speed of a process
- Duration of action
- Loss of energy, loss of material, loss of information, loss of time
- Reliability
- System-generated harmful factors
- Ease of operation
- Ease of manufacturing
- Ease of repair
- System complexity
- Extent of automation
- Productivity

Using the above information about what causes the cost to increase, we adopt "complexity of device" for "cost of production" and "ease of repair (repairability)" for "support user activity". From the matrix of contradictions, using "Repairability (34)" as the improving characteristic and "complexity of device (36)" worsening characteristic, at the intersection of the two characteristics (see Figure 7.6) the following four potential solutions principles (see Table 3-8) for the contradiction are possible:

[a] Ellen Domb, (2006). How To Deal With Cost-Related Issues In TRIZ. The TRIZ Journal. https://triz-journal.com/deal-cost-related-issues-triz/, accessed July 23, 2020.

EXAMPLE 7.1 (continued)

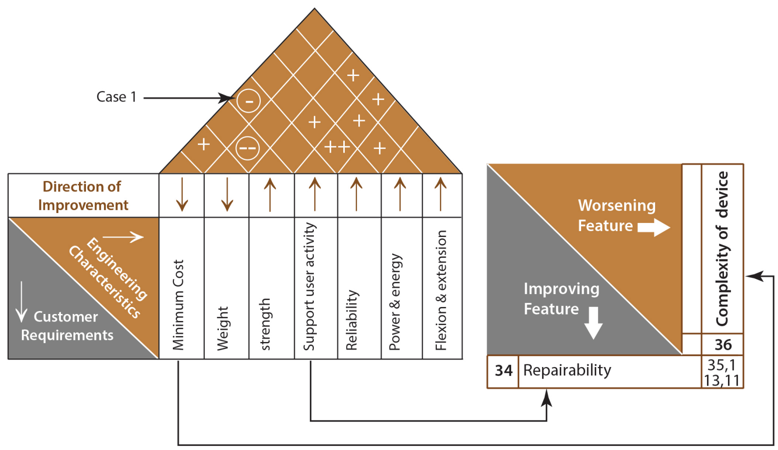

Figure 7.6: TRIZ potential principles solutions.

1. ***Segmentation (1)***
a) Divide an object into independent parts.

- Replace mainframe computer with personal computers.
- Replace a large truck with a truck and trailer.
- Use a work breakdown structure for a large project.

(b) Make an object easy to disassemble.

(c) Increase the degree of fragmentation or segmentation.

2. ***Invertion (the other way around) (13)***
(a) Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it).

- To loosen stuck parts, cool the inner part instead of heating the outer part.
- Bring the mountain to Mohammed, instead of bringing Mohammed to the mountain.

(b) Make movable parts (or the external environment) fixed, and fixed parts movable.
(c) Turn the object (or process) upside down.

3. ***Parameter change (35)***

(a) Change an object's physical state (e.g. to a gas, liquid, or solid).
(b) Change the concentration or consistency
(c) Change the degree of flexibility
(d) Change the temperature

4. ***Cushion in Advance (11)***

Prepare emergency means beforehand to compensate for the relatively low reliability of an object.

EXAMPLE 7.1 (continued)

After thorough analysis, principle 1- segmentation of "use a work breakdown structure (WBS) for a large project," will be implemented. A WBS helps to make a large project more manageable. Breaking it down into smaller pieces work can be done simultaneously by different team members, leading to better team productivity. This will save a lot of time and effort, ultimately, saves money, and reduces the production cost.

Case 2: The improvement of the" strength" causes an increase of "weight", thus resulting in a strong negative correlation in the correlation matrix. In this case, strength is the improving characteristic and weight is the worsening characteristic. From the matrix of contradictions, using "strength (14)" as the improving characteristic and "weight (1)" worsening characteristic, at the intersection of the two characteristics (see Figure 7.7) the following four potential solution principles (see Table 3-8) for the contradiction are possible:

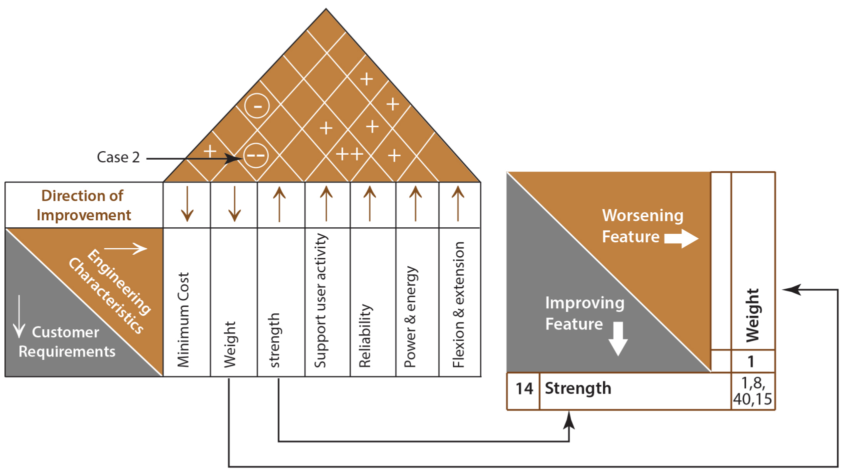

Figure 7.7: TRIZ potential principles solutions.

1. ***Segmentation (1)***

a) Divide an object into independent parts.

- Replace mainframe computer by personal computers.
- Replace a large truck by a truck and trailer.
- Use a work breakdown structure for a large project.

(b) Make an object easy to disassemble.
(c) Increase the degree of fragmentation or segmentation.

2. ***Counterweight (8)***

(a) To compensate for the weight of an object, merge it with other objects that provide lift.
(b) To compensate for the weight of an object, make it interact with the environment (e.g. use aerodynamic, hydrodynamic, buoyancy, and other forces).

3. ***Dynamicity (15)***

(a) Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.
(b) Divide an object into parts capable of movement relative to each other.

4. ***Composite material (40)*** – Change from uniform to composite (multiple) materials.

EXAMPLE 7.1 (continued)

For this case, among the other suggested solutions, composite material (40) will lead to a solution. This solution will eliminate the contradiction between weight and strength.

U.S. Department of Energy defines WBS as "A WBS is the cornerstone of effective project planning, execution, controlling, and reporting. All the work contained within the WBS is to be identified, estimated, scheduled, and budgeted. The WBS is the structure and code that integrates and relates all project work (scope, schedule, and cost)."[b]

Therefore, the relationships of the engineering characteristics with this new characteristic (WBS) should be carefully reconsidered to re-build the HOQ. A similar argument is justifiable for the replacement of "composite material" in the HOQ.

A negative correlation between ECs, mainly "cost of production" and "weight (material)", certainly affects the performance of product design. Thus, these ECs, which have negative correlations are replaced in the HOQ as shown in Figure 7.8.

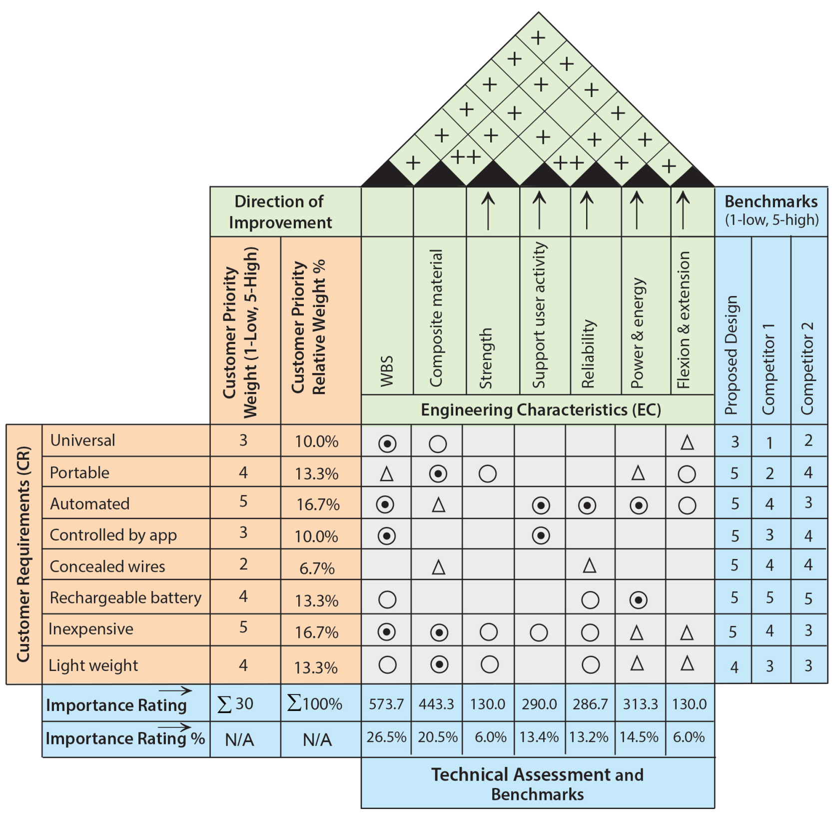

Figure 7.8: New re-build HOQ.

[b]PROJECT MANAGEMENT PRACTICES 1 Work Breakdown Structure (Rev E, June 2003, p.1), https://www4.rcf.bnl.gov/ videbaks/hft/cd1/DOE_guidance_wBS.pdf

7.2.2 Integrating ISM with QFD-TRIZ Results

EXAMPLE 7.2

Integrating ISM from the result of Example 7-1 as shown in Figure 7.9.

ANALYSIS

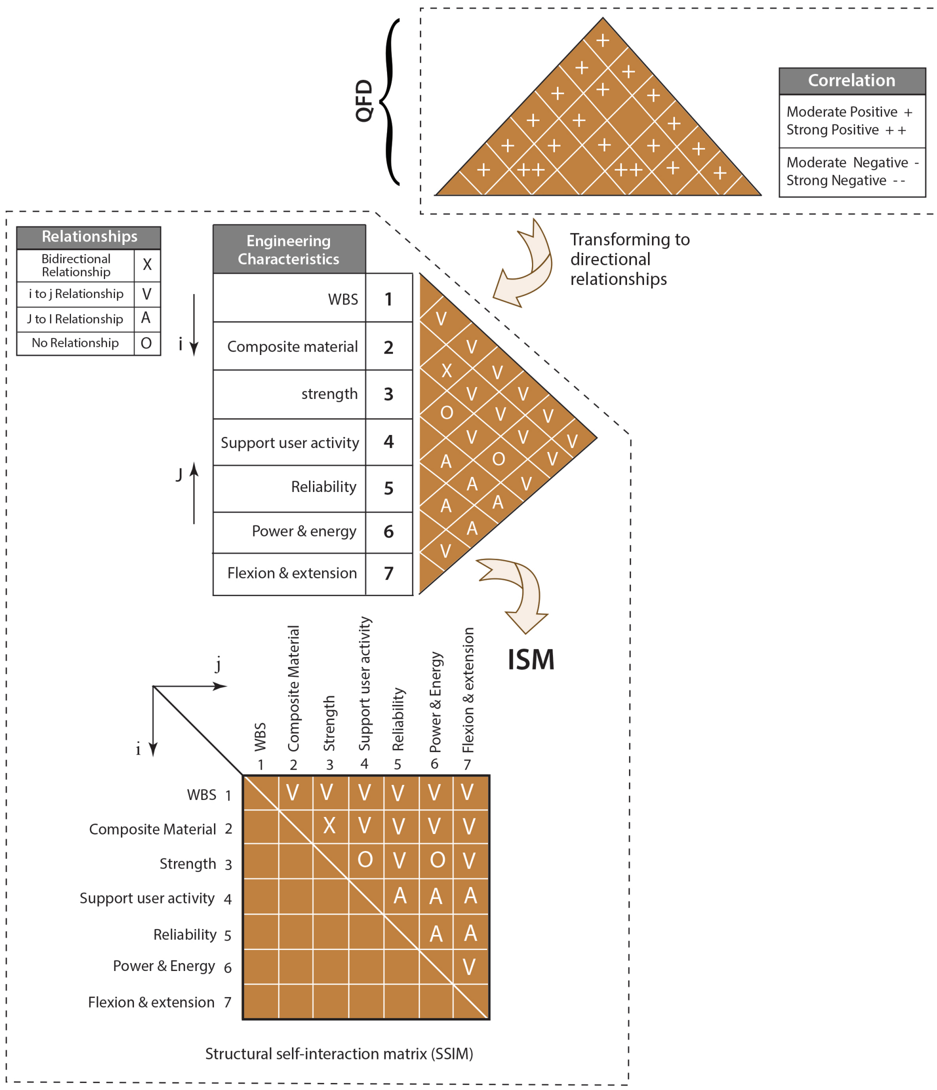

Figure 7.9: Transforming QFD to directional relationships.

EXAMPLE 7.2 (continued)

$R_a =$

		1	2	3	4	5	6	7
WBS	1	1	1	1	1	1	1	1
Composite	2	0	1	1	1	1	1	1
Strength	3	0	1	1	0	1	0	1
Support user activity	4	0	0	0	1	0	0	0
Reliability	5	0	0	0	1	1	0	0
Power & Energy	6	0	0	0	1	1	1	1
Flexion & extension	7	0	0	0	1	1	0	1

Figure 7.10: Adjacency matrix.

$R_f =$

		1	2	3	4	5	6	7	Driving Power
WBS	1	1	1	1	1	1	1	1	7
Composite	2	0	1	1	1	1	1	1	6
Strength	3	0	1	1	1	1	1	1	6
Support user activity	4	0	0	0	1	0	0	0	1
Reliability	5	0	0	0	1	1	0	0	2
Power & Energy	6	0	0	0	1	1	1	1	4
Flexion & extension	7	0	0	0	1	1	0	1	3
Dependence		1	3	3	7	6	4	5	$\sum = 29$

Figure 7.11: Final reachability matrix.

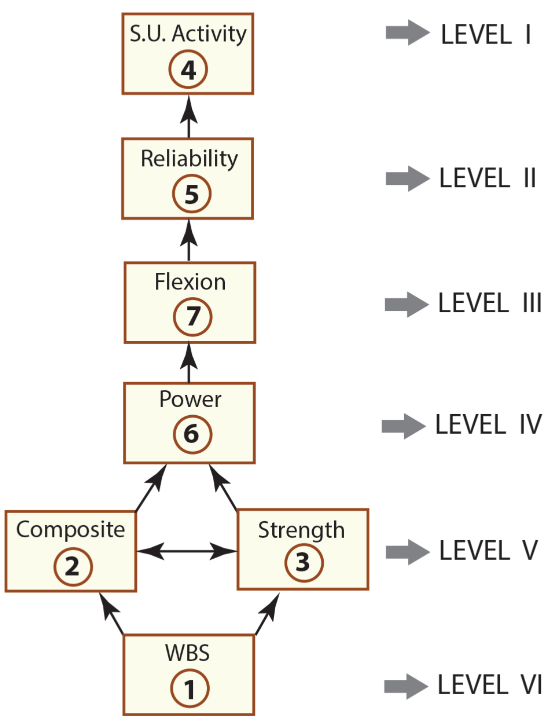

Figure 7.12: Digraph.

EXAMPLE 7.2 (continued)

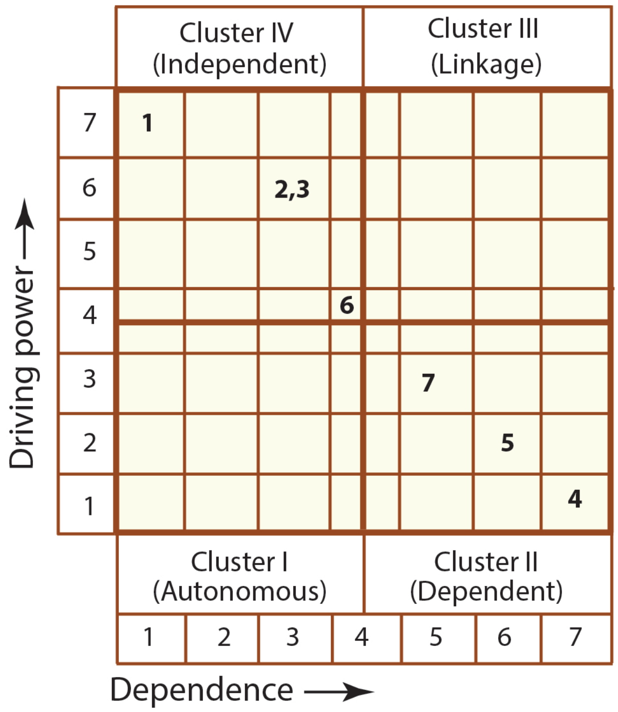

Figure 7.13: MICMAC analysis.

7.2.3 Integrating ISM Result with DSM

EXAMPLE 7.3

Integrating DSM from the results of Example 7-2 as shown in Figure 7.14 and Figure 7.15.

ANALYSIS

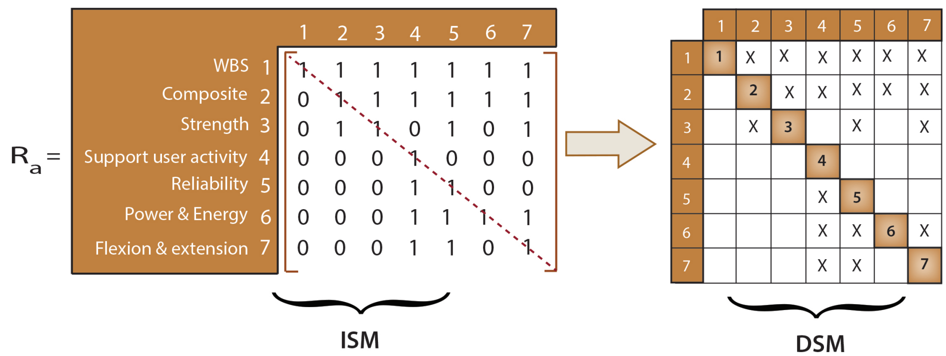

Figure 7.14: Transforming ISM to DSM.

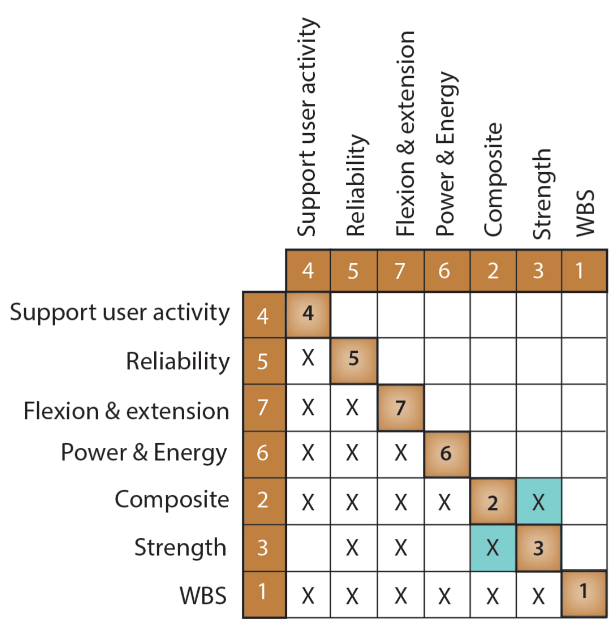

Figure 7.15: Partitioned DSM.

7.3 Integrating QFD, TRIZ, and AD for Product Design

QFD will not help us to describe details of functions and design parameters required to satisfy customer needs or to determine the functional requirements and design parameters without conflicting with each other. Therefore, QFD requires the use of other tools, such as TRIZ to resolve the conflicts in engineering characteristics or functional requirements and axiomatic design to determine the minimum set of design characteristics while satisfying the independence axiom – FRs should be independent of each other.

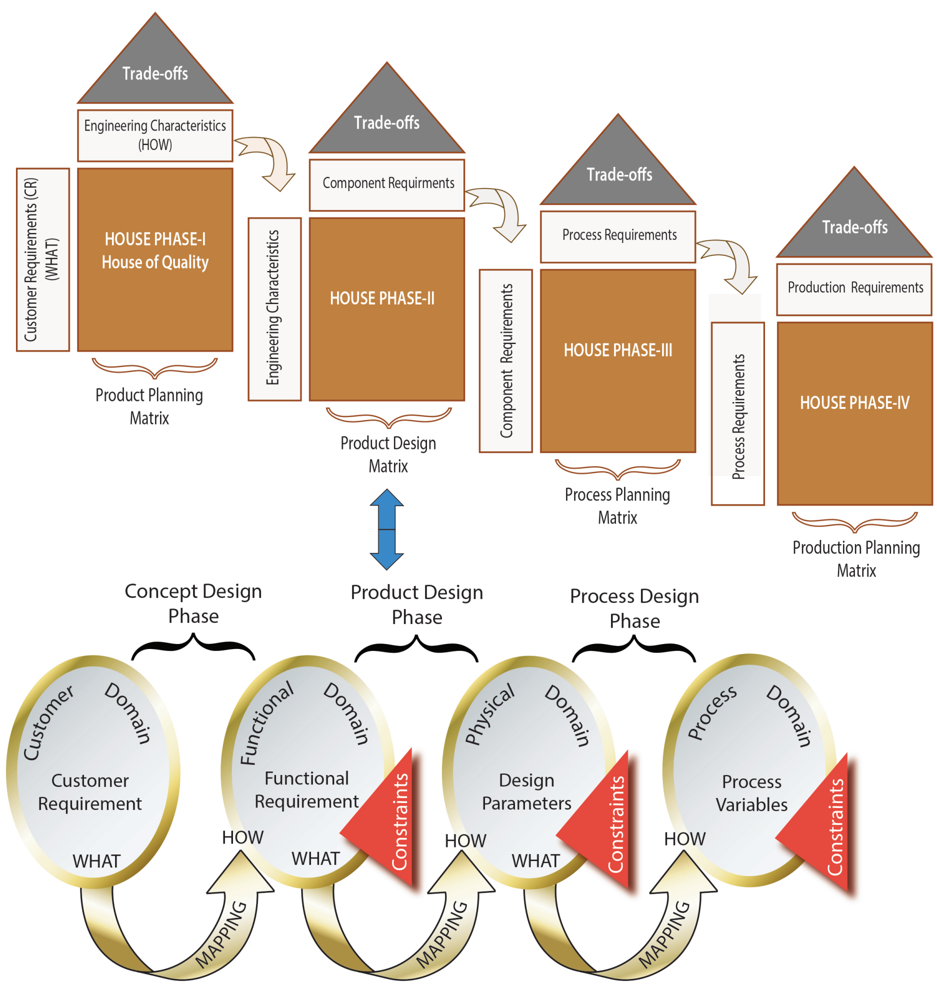

Figure 7.16: Framework of integrated TD tools.

As shown in Figure 7.16, both AD and QFD Phase II form the design process as a mapping between domains, and both the QFD's relationship matrix and the AD's design matrix serve the same purpose: mapping from WHAT to HOW. Usually, QFD focuses on customer needs but not on the product's architecture which is important for new product development (NPD). On the other hand, AD considers the customer needs as QFD does, but AD does not have a methodical process of converting the customer needs into functional requirements.[5] Figure 7.17 shows the development of conceptual architectural design steps for QFD-TRIZ-AD integration.

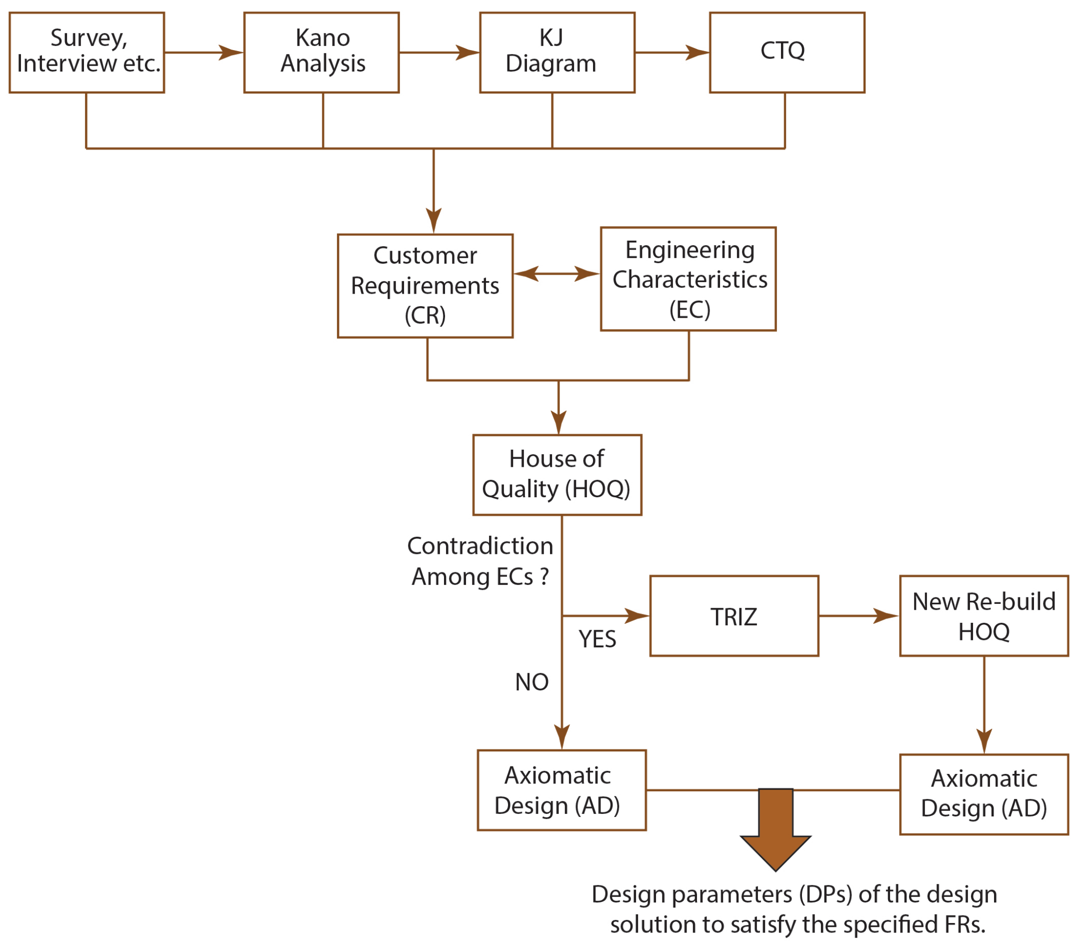

Figure 7.17: Conceptual architectural design steps for QFD-TRIZ-AD integration.

[5]Gilbert, L. R.; Omar, M. A.; Farid, A. 2016. Axiomatic design in large systems: an application of quality function deployment and axiomatic design to the conceptual design of temporary housing stakeholders. Springer, 216–240.

CASE STUDY 7.1

Develop the design parameters (DPs) of the design solution of the finger rehab device shown in Example 7.1 to satisfy the specified FRs. Use Axiomatic Design principles.

SOLUTION

As shown in Figure 7.17, the first step is to develop a list of the customers' requirements (CRs). To define the customer needs, each member of the design team performed a survey of the people that fit the chosen customer profile. Through the survey, after understanding and defining what the customer requirements are, the design team developed the HOQ. After contradictions among the engineering characteristics are resolved (TRIZ has been applied) the high-level functional requirements are identified (see Figure 7.18).

FR1: Product shall be capable of flexion & extension

FR2: Product shall be capable of supporting user activity

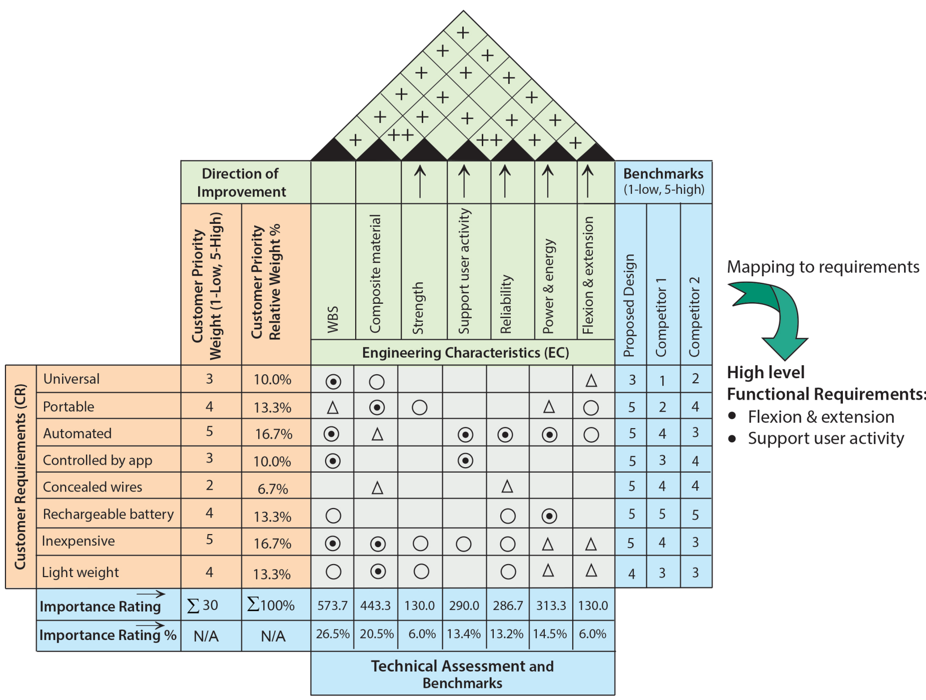

Figure 7.18: Mapping to requirements.

As seen from the above top-level FRs, they don't give us too much information, but this initial step determines the starting point for further decomposition by using the AD zigzag methodology.

CASE STUDY 7.1 (continued)

Using high-level FRs the following design parameters (DPs) are selected to fulfill each of the FRs:

DP1: Soft robotic

DP2: Activity monitoring tool

The DPs that are selected to fulfill the high-level FRs provide some insights about the finger rehab device. Formulation of the design matrix for this initial level of decomposition is shown in matrix Eq. 7.1. The design matrix shown in Eq. 7.1 should be formulated for each level to avoid violating the Independence Axiom.

$$\begin{Bmatrix} FR1 \\ FR2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \end{Bmatrix} \tag{7.1}$$

Eq. 7.1 reveals that the design is uncoupled at the top level and the independence axiom is not violated. This initial step determined the starting point for the further decomposition into additional levels of FRs. A road map for the levels of decomposition is shown in Figure 7.19.

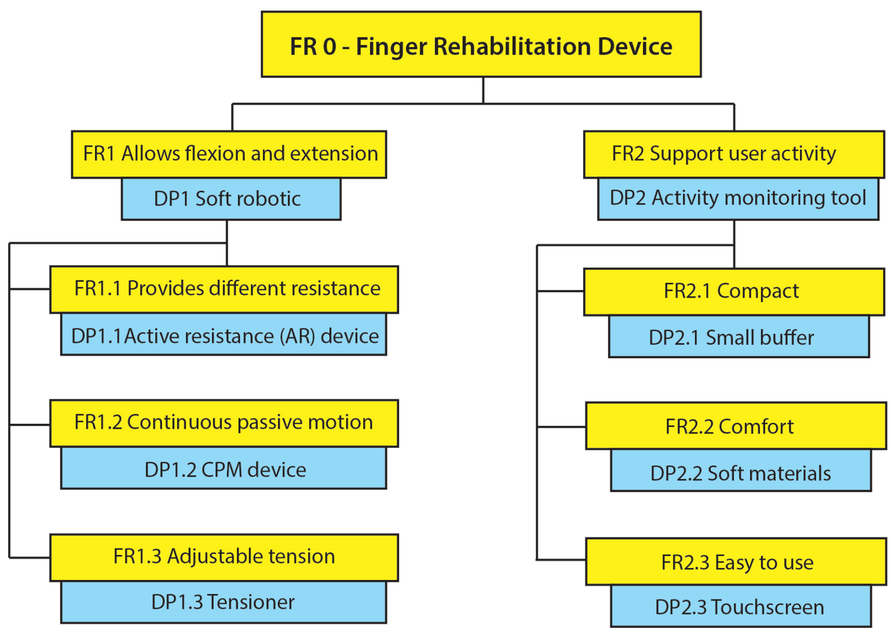

Figure 7.19: Design rod map.

CASE STUDY 7.1 (continued)

Next, using zigzagging and maintaining independence within each matrix, the additional FR levels were developed. Since all the FRs will follow a similar decomposition format, for briefness, only FR1 (Allows flexion and extension) decomposition will be shown.

FR1.1: Provides different resistance

FR1.2: Continuous passive motion (CPM)

FR1.3: Adjustable tension

The following design parameters (DPs) are selected to fulfill each of the above FRs:

DP1.1: Active resistance (AR) device

DP1.2: CPM device

DP1.3: Adjustable tensioner

The following design matrix has been develop to ensure the independent axiom is not violated.

$$\begin{Bmatrix} FR1.1 \\ FR1.2 \\ FR1.3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP1.1 \\ DP1.2 \\ DP1.3 \end{Bmatrix} \tag{7.2}$$

Eq. 7.2 shows that the design is uncoupled at the second level and the independence axiom is not violated. Figure 7.20 shows the remaining part of the decomposition of the high-level functional requirement of FR1.

FRs		DP1	DP2	DPs
Allows flexion and extension	FR1	X		Soft robotic
Support user activity	FR2		X	Activity monitoring tool

FR1 Allows flexion and extension		DP1.1	DP1.2	DP1.3	DPs	
Provides different resistance	FR1.1	X			Active resistance (AR) device	(1)
Continuous passive motion (CPM)	FR1.2		X		CPM device	(2)
Adjustable tension	FR1.3			X	Tensioner	(3)
FR1.1 Provides different resistance		DP1.1.1	DP1.1.2			
Durations of resistance	FR1.1.1	X			Timer device	(4)
Range of resistance	FR1.1.2		X		Control unit	(5)
FR1.2 Continuous passive motion		DP1.2.1	DP1.2.2			
Range of motion (ROM) in degrees	FR1.2.1	X			Goniometers	(6)
Number of cycles	FR1.2.2		X		Counter device	(7)
FR1.3 Adjustable tension		DP1.3.1	DP1.3.2			
Force measurement	FR1.3.1	X			Load cell	(8)
Range of force	FR1.3.2		X		Force sensor	(9)

Figure 7.20: Decomposition of FR1.

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CASE STUDY 7.1 (continued)

Figure 7.21 shows the decomposition of high level functional requirement of FR2.

FR2 Support user activity		DP2.1	DP2.2	DP2.3		
Compact	FR2.1	X			Small buffer	(10)
Comfort	FR2.2		X		Soft materials	(11)
Easy to use	FR2.3			X	Touchscreen	(12)
FR2.1 Compact		DP2.1.1	DP2.1.2	DP2.1.3		
Easy to carry	FR2.1.1	X			Pack with handle	(13)
Portable	FR21.2		X		Modular parts	(14)
Light weight	FR2.1.3			X	Composite material	(15)
Comfort	FR2.2	DP2.2.1	DP2.2.2			
Prevents swelling	FR2.2.1	X			Ice pad	(16)
Easy flexion of PIP or DIP joints	FR2.2.2		X		Wire-Foam and pad	(17)
Easy to use	FR2.3	DP2.3.1	DP2.3.2			
Consistent	FR2.31	X			Software	(18)
Automated	FR2.32		X		Automation Integrator	(19)

Figure 7.21: Decomposition of FR2.

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CASE STUDY 7.1 (continued)

Figure 7.22 shows the combined design matrix of all of the levels of FRs and DPs. It represents an uncoupled design. That is, each FR is satisfied by only one DP.

FRs \ DPs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
FR1.1	X																		
FR1.2		X																	
FR1.3			X																
FR1.1.1				X															
FR1.1.2					X														
FR1.2.1						X													
FR1.2.2							X												
FR1.3.1								X											
FR1.3.2									X										
FR2.1										X									
FR2.2											X								
FR2.3												X							
FR2.1.1													X						
FR2.1.2														X					
FR2.1.3															X				
FR2.2.1																X			
FR2.2.2																	X		
FR2.3.1																		X	
FR2.3.2																			X

Figure 7.22: Combined design matrix.

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