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APPLICATION OF QUALITY FUNCTION DEPLOYMENT FOR NEW BUSINESS R&D STRATEGY DEVELOPMENT

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ABSTRACT

This paper describes a decision-making framework for Research and Development (R&D) strategy development using an adaptation of quality function deployment (QFD). Many manufacturing companies are facing challenges in strengthening their competitiveness to survive in an uncertain and fierce competitive businesses environment. Decision-making on R&D strategy, not only for incremental innovation, but also for radical innovation, is essential for the sustainable future of the company. There are well-structured methodologies for routine product development tasks that help planning and decision-making. QFD is one of the most well known tools for product development that uses matrices to identify relative worth of product requirements from market information and flow the requirements down to more detailed decisions. However, in the R&D strategic planning process that occurs prior to product development, there is little work utilizing structured methodologies such as QFD. This paper presents a new usage of QFD in the R&D strategy development process to cover both incremental and radical innovation. Market-pull R&D leads to incremental innovation of the company, and QFD helps identify new technology requirements using future market predictions. On the other hand, technology-push R&D seeks radical innovation; an inverse usage of QFD that defines new customer needs from new technology development can support a step-by-step approach for future business creation in this context. The paper includes a detailed example from the medical device industry that demonstrates the utility of the method in R&D strategy decision process.

KEYWORDS: *Quality Function Deployment, New Business, Innovation, Market-pull R&D, Technology-push R&D*

1. INTRODUCTION

1.1. Motivation

For many companies, long-term sustainable success is their ultimate goal. Recently, not only has product lifecycle accelerated, but the average company's life has shortened. The average life span of a Fortune 500 company is less than half a century and many companies have only few years of life (Geus & Senge, 1997). Among the best 50 Japanese manufacturing companies in 1950, 33 companies still exist today; others are either bankrupt or have merged with other companies (Narushima, 2002). Increasing uncertainties and competitiveness of businesses make survival of companies more serious and challenging.

Companies that sustain long-term success exhibit some common capabilities. Particularly for a manufacturing company, innovation and product development capability are the most essential elements of long-term success. In product development, there exist well-structured methodologies for routine product development tasks that help planning and decision-making. In the innovation process, new idea creation and R&D strategy process take an essential role. However there is little prior work utilizing structured methodologies for decision-making within the R&D strategy process.

For many existing companies, new business concepts and associated R&D strategies are essential if they want to enter a new market. This R&D strategy planning process occurs prior to the product development process. Figure 1 shows a schematic view of the phases from new business concept to product development.

Generally, companies conduct the R&D phase prior to product development in order to develop new market knowledge and technologies for reducing uncertainties. One should make decisions on this R&D phase based on new business concepts. After this R&D phase, well-structured methodologies of product development work effectively. Since there is little work utilizing structured methodologies for decision-making for R&D strategies, a study on applying product development structured methodologies to R&D strategy decision-making is a reasonable approach. This paper presents a new application of product development methodologies in the R&D strategy development process.

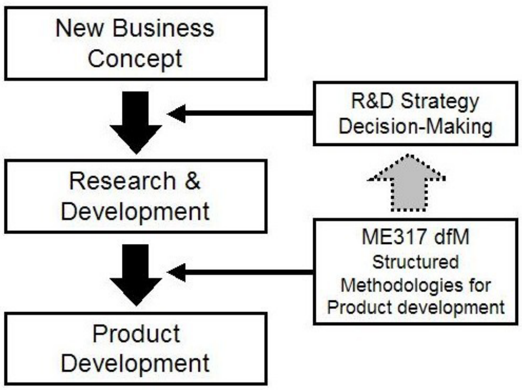

Figure 1. Overall Business Process

1.2. Structure Methodology on Product Development Process

Recently, many manufacturing companies and researchers have adopted product development methodologies, generally referred to as Design for X (DFX) methodologies (Hermann et al, 2004). The 'X' in DFX represents any one of a products design factor, such as assembly, variety, or manufacturing. Recently, an academic course has been providing an effective structured product development process called Design for Manufacturability (dfM) (Ishii, 2004). The dfM process is a combination of DFX methodologies and instructs engineers to use different tools in appropriate manner.

The dfM process focuses on value creation for the customer in the planning phase of the product development process. This approach enables improvement in the total quality of the product and reduction of development time. The dfM process requires cross-functional teams to exchange opinions and conduct evaluation, and thus extract or activate the company's internal knowledge. One of the key tools is quality function deployment (QFD), which logically represents relationships between market information and product features. QFD enables externalization of the implicit market and technical knowledge of engineering and personnel. For many manufacturing companies, a structured product development methodology such as QFD has effectively improved their product competitiveness.

1.3. Innovation types and R&D strategy

Innovation is the use of new knowledge to offer a new product or service that customer's value (Afuah, 2003). Generally, one can divide types of innovation into two categories: Incremental innovation and Radical innovation (Luecke, 2003). Incremental innovation is the use of existing forms or technologies. It either improves upon something that already exists or reconfigures an existing form or technology to serve some other purpose. A radical innovation is something new to the world and a departure from existing technology or methods. When compared with radical innovation, incremental innovation takes less time and involves less risk. However, incremental innovation alone cannot ensure a company's future competitiveness.

One implication of this innovation classification is that the newly entrant companies are more likely to do well in radical innovation, whereas incumbent companies are more likely to do better in incremental innovation. However, in many industries, incumbent companies have been the first to introduce or exploit radical innovations and yet have often failed to exploit incremental innovations. Abernathy and Clark (1985) explained why some incumbent companies may do well in radical innovation using two kinds of knowledge that underpin innovation: technological knowledge and market knowledge. Henderson and Clark (1990) explained why some incumbent companies fail in executing incremental innovation using two kinds of knowledge: architectural knowledge and component knowledge. This research implies that well-structured strategies for both incremental and radical innovation are essential for any company, and a hand-in-hand process of radical and incremental innovation is ideal for continuous improvement. Many company experience a dynamic model of innovation in which introduction of a successful radical innovation is often followed by a period of incremental innovations, which improves product performance or extends its application (Utterback, 1994).

This study focuses on developing a structured methodology for R&D strategy by applying QFD to both radical and incremental innovation and their related dynamic processes. Market-pull R&D leads to incremental innovation within the company, and QFD provides new technology requirements using the prediction of future market needs. On the other hand, technology-push R&D leads to radical innovation; in this case, the inverse use of QFD, which cultivates new customer needs from new technology development, can support a step-by-step approach to future business creation. The combined use of market-pull R&D and technology-push R&D supports the dynamic process of incremental and radical innovation. This paper describes the R&D strategy decision process methodology. This paper illustrates this methodology with a case study from the medical device industry, and demonstrates the utility of the method in both market-pull R&D and technology-push R&D.

2. DESCRIPTION OF THE R&D STRATEGY METHOD

2.1. Quality Function Deployment Application

QFD is a key tool in product development methodology. It is a common matrix method that transforms customer requirements (CR) and their importance to product part characteristics (Akao, 1990). QFD helps engineers to understand the logical connection between market side information and technology side information. The authors use a simplified version of QFD. Figure 2 shows a schematic view of the simplified version of QFD.

QFD I consists of customer requirements (CR), corresponding weights of the CR, engineering metrics (EM), and a correlation matrix. Engineers assess correlations between customer requirements (CR) and engineering metrics (EM) using an exponential (e.g., 1-3-9) rating scale. QFD I calculates relative worth of the EM from these factors. QFD II consists of the relative worth of the EM, parts attributes of the product, and a correlation matrix. QFD II calculates the relative worth of product part characteristics (PC). QFD helps engineers identify the key design points in product development.

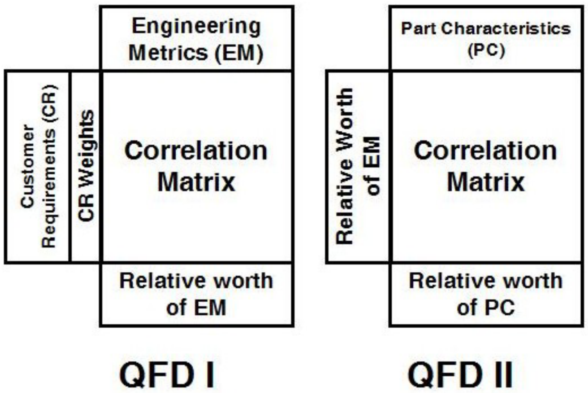

Figure 2. Quality Function Deployment

QFD is a very flexible tool and supports various purposes. Chao and Ishii (2003) developed Project QFD. Project QFD expands project requirements to project resource worth. Project resource includes organizational tools, such as the dfM tools or specific resources such as consultants or information databases. Project managers can use Project QFD as a decision-making tool for project resource allocation.

This study yielded what we call "Technology QFD", which is an adaptation of Project QFD application. Technology QFD focused on technology development tasks instead of project resources.

2.2. Market-pull R&D Strategy Development

Market-pull R&D leads to incremental innovation within the company. Figure 3 shows a schematic of market-pull R&D.

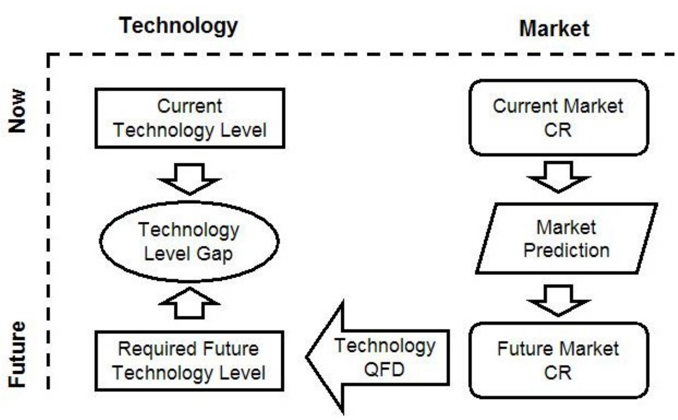

Figure 3. Schematic of Market-pull R&D

In incremental innovation, usually the object product already exists and it is possible to get future customer requirements and their importance by using market trends or industry roadmap information. Technology QFD can extract technological worth from future market CR.

The R&D strategy planning process needs an estimation of required future technology levels. The comparison of required future technology levels and the current technology level of the company enables estimation of the technology level gap. Estimation of technology development cost or development time becomes a reasonable technology level metric.

A technology map, which consists of technology worth and technology level gap, provides a decision-making guideline for the Market-pull R&D strategy. Figure 4 shows the Market-pull R&D technology map. In the map, the x-axis is technology worth and the y-axis is technology level gap. The four regions can provide decision-making guidelines.

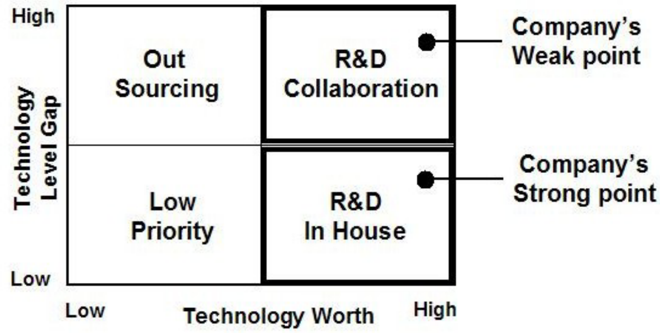

Figure 4. Market-pull R&D Technology map

Region-1: High worth & high gap technologies. These technologies have high worth, however, the company needs a large effort to reach the target. Usually, these technologies are the company's weak point. A possible strategy for acquiring these technologies is R&D collaboration with other companies, universities, or research institutes.

Region-2: High worth & low gap technologies. These technologies have high worth, but the company nearly has the ability to reach the target. In this case, these technologies are the company's strong point. Conducting in-house R&D is the best strategy for these technologies.

Region-3: Low worth & high gap technologies. These technologies have low worth, so R&D priority for these technologies is low. However, the company needs a large effort to reach the target. Usually, out-sourcing is the best strategy for these technologies.

Region-4: Low worth & low gap technologies. These are low priority technologies. The company does not need a particular R&D strategy for these technologies.

The decision-making process of the Market-pull R&D strategy using the technology map includes both market information and current company technology position.

2.3. Technology-push R&D Strategy Development

Technology-push R&D seeks radical innovation in the company. The fact that the product does not exist makes radical innovation very difficult. Potential customers cannot say anything about the product if does not exist. Therefore, there is big discontinuity between the current market and the future market. Business experts may overcome this discontinuity with innovative business ideas, but this approach is difficult to organize as a structured methodology. So, this study suggests a step-by-step approach from the technology side. Figure 5 shows a schematic of technology-push R&D.

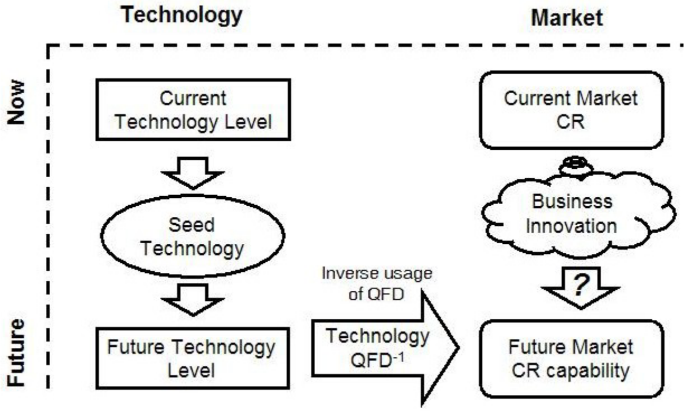

Figure 5. Schematic of Technology-push R&D

R&D decisions determine the company's future technology level. An inverse usage of Technology QFD can extract the effects on future market CR importance from R&D decision and technology improvement. This study yields a conjoint matrix and a technology sensitivity chart as an inverse function of Technology QFD. Figure 6 shows an overall process of Technology R&D decision-making using these new ideas.

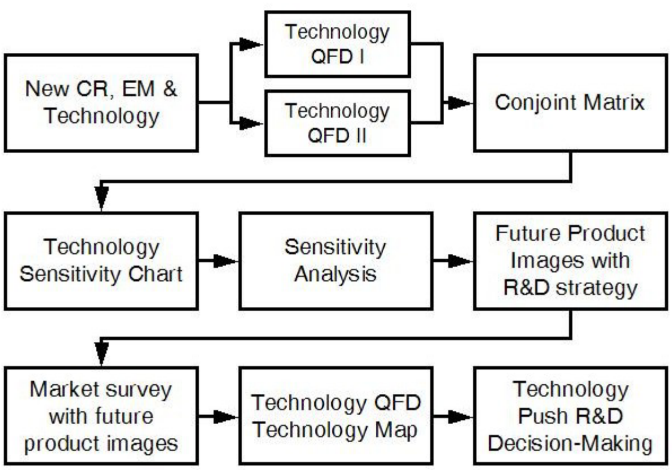

Figure 6. Technology-push R&D processes

The baseline is a Technology QFD of an existing product. Current CR, EM, and technologies serve as a starting point for a new product. Then, engineers have to list new CR, EM, and technologies to make the new Technology QFD for future markets. This process strongly depends on an engineer's individual skill. This step does not require a clear image of the future product, but some level of information of the future market and product are essential to list the new CR, EM and technologies.

The next step is developing a new Technology QFD including new CR, EM and technologies. At this stage CR weights are unknown, so all weights are temporally unit weight.

A conjoint matrix is a combination of matrices of QFD I and QFD II. Equations (1) and (2) represent functions of QFD I and QFD II.

$$\vec{m} = QFDI(\vec{v}) = \frac{\partial \vec{m}}{\partial \vec{v}} \vec{v} \quad (1)$$

$$\vec{x} = QFDII(\vec{m}) = \frac{\partial \vec{x}}{\partial \vec{m}} \vec{m} \quad (2)$$

Where, $\vec{v}$ is CR weight vector, $\vec{m}$ is EM worth vector, $\vec{x}$ is technology worth vector, $\partial\vec{m}/\partial\vec{v}$ is correlation matrix of QFD I, and $\partial\vec{x}/\partial\vec{m}$ is correlation matrix of QFD II. Equation (3) calculate combination of QFD I and QFD II using equations (1) and (2).

$$\vec{x} = QFDII\{QFDI(\vec{v})\} = \left(\frac{\partial \vec{x}}{\partial \vec{m}} \times \frac{\partial \vec{m}}{\partial \vec{v}}\right)\vec{v} \quad (3)$$

Where, $\left(\frac{\partial \vec{x}}{\partial \vec{m}} \times \frac{\partial \vec{m}}{\partial \vec{v}}\right)$ is the conjoint matrix. Equation (3) shows that the conjoint matrix represents the sensitivity of technology against CR. The technology sensitivity chart is a visualized chart of the conjoint matrix factors. The technology sensitivity chart easily shows the high sensitive combinations of technology and CR.

The purpose of sensitivity analysis is to examine the controllability of CR. Technology sensitivity indicates required technology improvement for unit scale improvement of the CR. So, high technology sensitivity implies that the CR are effectively improved by improvement of the technology. The sensitivity analysis helps development of future product image that include several high CR. These future product images logically relate to the company's technology improvement scenarios.

Future product images have an essential role in future market research. Customers cannot easily indicate preferences for not-existent products. But if customers saw the product images that have noticeable attractive features, they can provide preferences for the features. This market research enables establishes the CR weight of the future product. Technology QFD with CR weight calculates the technology worth for the future product. Now engineers can create a technology map for the future product using technology worth and technology level gap. The technology map provides a decision-making guideline for a Technology-push R&D strategy using the same logic as Market-pull R&D.

3. CASE STUDY I: MARKET-PULL R&D FRAMEWORK IN AN EXISTING MARKET

3.1. Case Study Background

A startup company in California serves as a case study. This company has developed a reheating device to warm a person from a hypothermic state at an unprecedented rate. An external organization has developed the key technology of body core warming, and the company is the exclusive licensee of this key technology. This technology takes advantage of the body's natural thermoregulatory system to channel thermal energy non-invasively to the body's core six times more quickly than other non-invasive methods. The company is commercializing this technology for a medical device that is configured for recovery from and prevention of hypothermia in medical procedures.

In 2004, this company applied structured dfM methodologies to identify the new market for the company and redesign the conventional product to match the new market requirements. In this dfM project, the team focused on product development decisions (Melamud, Milne, Ashihara, 2004), so this project provides an ideal example for this study. Because the company intended to expand their business using their core technology, R&D strategy planning was essential in this phase.

This case study will illustrate the medical product development challenge from an R&D strategy viewpoint using structured methodologies described before. This section focuses on the application of the market-pull R&D strategy decision-making tool to foster incremental innovation. The next section applies the technology-push R&D strategy decision-making tool to explore radical innovation.

3.2. Technology QFD development for medical market

In this case study, incremental innovation is taken to mean improving existing product features or reducing product cost in order to obtain more customers. Technology QFD plays a key role in deriving important technologies from customer needs. The 2004 dfM project result helped to develop Technology QFD. Analysis of product configuration and part design enabled listing the required technologies of existing product.

Figure 7 shows the Technology QFD I for this medical market. It consists of CR, CR weight, EM and correlation matrix. The output of QFD I is relative worth of EM. In this case, the top three EM in order of importance are:

1	Heat Output	20%
2	Vacuum Pressure	16%
3	Time to Reheat	16%

Customer Requirements	Customer Weights	Engineering Metrics: Volume	Weight	Vacuum Pressure	Heat Output	Water Resistance	Drop Test	Power Consumption	Time to Reheat	Time to Initiate
Cleanable	9	3	3			3	1			
Small size	1	9	3	1	1				1	3
Light weight	1	3	9	9	3		1	3		3
Fast-Reheating	9			9	9			9	9	3
Adaptable	3	3	3	1	1	9	3		3	3
Safe	9			3	9	3	1	9		
Easy to use	3	3	3	1	1	3	1		9	9
Reliable	9			9	9	1	3	3	9	9
	Raw score	57	57	205	253	99	58	192	199	150
	Relative Weight	4%	4%	16%	20%	8%	5%	15%	16%	12%

Figure 7. Technology QFD I for Medical Market

Figure 8 shows the Technology QFD II for this medical market. It consists of EM, technologies and correlation matrix. The relative worth of EM, which is the output of QFD I, goes into QFD II. The output of QFD is the relative worth of technologies. In this case, the top three technologies are:

1	Body Core Warming Technology	21%
2	Vacuum Technology	14%
3	Power Management Technology	13%
3	Heat Control Technology	13%

Body core warming is a key technology of this product, and the company licensed this technology from an external organization. The QFD II output also indicates that this technology is the most important technology.

Engineering Metrics	Phase I Relative Weights	Technology: Body Core Warming	Seal	Vacuum	Sensing	Heat Control	Electrical	Power management	Information	Molding Design
Volume	4%			1			3			3
Weight	4%			3			1			3
Vacuum Pressure	16%	9	9	9	3		1	3	3	1
Heat Output	20%	9			3	9	3	3	3	
Water Resistance	8%		1				1			3
Drop Test	5%		3				1			3
Power Consumption	15%				1	3	1	9	3	
Time to Reheat	16%	9	1	1	3	3	3	3	3	
Time to Initiate	12%			9		3	3			
	Raw score	4.7	1.8	2.9	1.7	3.1	2.0	2.9	2.0	0.8
	Relative Weight	21%	8%	13%	8%	14%	9%	13%	9%	4%

Figure 8. Technology QFD II for Medical Market

3.3. Technology Mapping for R&D Strategy

The technology map plays an important role in decision-making in a market-pull R&D strategy. The technology map consists of technology relative worth and technology level gap. Technology level gap is the required technology improvement to satisfy customer requirements. This technology level gap estimation needs a proper metric of technology level. But, technology level has many factors: intellectual property, experience of the engineers, organization flexibility, originality, applicability, etc. As a result, deriving a metric for technology level is a big challenge. This study focuses on developing a R&D strategy decision-making methodology, but developing an evaluation method of technology level is not the focus of this study. So, this case study uses a simplified method for estimating the technology level gap: investment cost level to reach the required target.

Table 1 shows the technology investment level for each technology using 1-10 ratings, where 1 is the smallest and 10 is the largest. Table 1, the body core warming technology has the highest investment level. Since the company licensed this technology from an external organization, it is easy to imagine that improving this technology is difficult and needs high investment. On the other hand, seal technology has the lowest investment level. In this case, higher grade O-rings are sufficient to improve the sealing function of the product. Therefore, it needs the least investment. Similar qualitative discussions based on our engineering experience determined the investment level for other technologies. The table also includes relative level gap calculated from the investment level.

Table 1. Technology Level Gap for Medical Market

Technology of Medical Market	Body Core Warming Tech	Seal Tech.	Vacuum Tech.	Sensing Tech.	Heat Control Tech.	Electrical Tech.	Power management Tech.	Information Tech.	Molding Design Tech.
Investment Level	8	1	3	2	5	6	7	4	3
Relative Level Gap	21%	3%	8%	5%	13%	15%	18%	10%	8%

Figure 9 shows the technology map for this medical market. In this map, the x-axis is relative worth of the technology, and the y-axis is the relative technology level gap. The four regions in the map can guide decision-making in developing the appropriate R&D strategy marketing in light of the market needs.

As discussed earlier, technology development items with high worth and high gap suggest R&D Collaboration. In this case, body-core warming, power management and heat control fall in into this group. Collaboration with an external organization is a reasonable R&D strategy for these items. Items with high worth and low gap are suitable for in-House R&D. The company should perform internal R&D on vacuum technology. Technology items with low worth and high gap are candidates for out-sourcing. The company should out-source electrical technology. Low-worth and low-gap items are low priority technology. The company does not need any R&D strategy on molding design, information technology, sensing technology, and seal technology at this time.

As demonstrated, the technology map can guide decision-making for creating a R&D strategy using both market information and the company's technology capability.

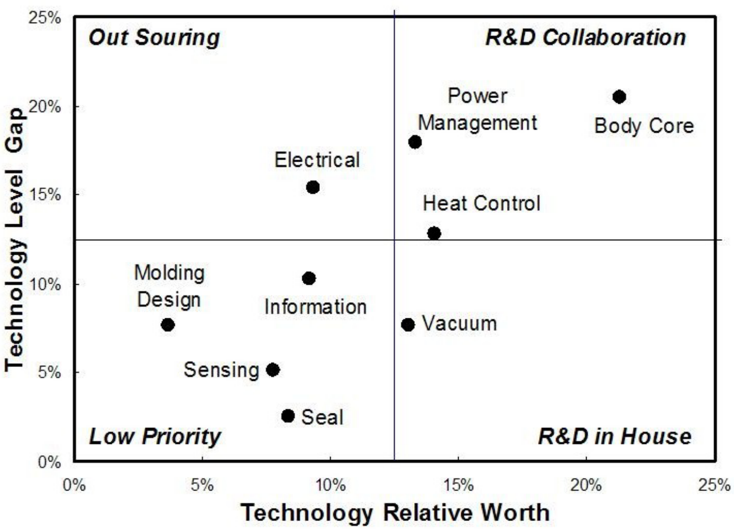

Figure 9. Technology Map for Medical Market

4. CASE STUDY II: TECHNOLOGY-PUSH R&D FRAMEWORK IN A NEW MARKET

4.1. <u>Technology QFD development for new market</u>

This section applies the technology-push R&D strategy decision-making framework on the same case study. In the 2004 dfM project, the company intended to expand its business from the medical market to the outdoor recreational market using its core technology and product design. Figure 10 shows the product schematic of a body-core warming product for the outdoor market. Fig.10 is one concept in the 2004 dfM project. This project primarily considered the product development viewpoint. In developing this concept, the project team gathered outdoor market information and redesigned the original medical product based on analysis results using dfM methodologies. In this section, the case study focuses on the management of technology viewpoint and considers the appropriate R&D strategy for this situation.

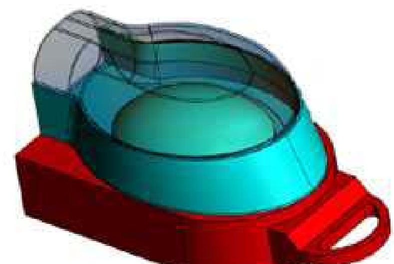

Figure 10. A New Product Schematic

The first step is to figure out the CR in the new market. Usually, there are many different CR among the different markets. If a company has no idea which market to target, this process becomes very difficult: at best, the company will have an ambiguous target. In this case study, a body-core warming product for the outdoor market is the (ambiguous) target of the company. Engineers can list new CR by conceptualizing usage scenarios within the outdoor market. This case study lists four new CR: long power life, portable, rugged, and fashionable. New CRs requires appropriate EM for proper measurement. This case study added battery capacity and # of prototype designs as suitable EMs. And new EMs requires new technology to satisfy them. This case study introduced battery technology and CAE technology as new technologies for the company.

Technology QFD also needs CR weights. But it is difficult to obtain the CR weights of non-existing products at this stage since the customer cannot easily indicate their preference without product information. The technology-push R&D framework uses unit CR weight for the first technology QFD.

Figure 11 shows the Technology QFD I for the outdoor market. This technology QFD I includes CR and EM of both the medical and outdoor markets. Also, this new Technology QFD requires a new correlation matrix including new CR and EM. As described before, all CR weights are unit weights of 1 in this QFD. Figure 12 shows the Technology QFD II for the outdoor market. The Technology QFD II includes new EM, new technologies and the new correlation matrix for the outdoor market. Since the CR weights are tentative, the output of Technology QFD II is not yet the required technology worth.

		Engineering Metrics										
Customer Requirements	Customer Weights	Volume	Weight	Vacuum Pressure	Heat Output	Water Resistance	Drop Test	Power Consumption	Time to Reheat	Time to Initiate	Battery Capacity	# prototype design
Cleanable	1	3	1			9	1					3
Small size	1	9	3									9
Light weight	1	3	9									3
Fast-Reheating	1			3	3			3	9	3		
Adaptable	1	3	3	1	1	3	3		3	3		3
Safe	1			3	9	1	3	3				1
Easy to use	1	3	3	1	1	1	3		9	9		3
Reliable	1			3	3	3	3		9	3		3
Long Power Life	1			3	3			9	3		9	
Portable	1	9	9			3	3					3
Rugged	1		3			9	9					3
Fashionable	1											9
	Raw score	30	31	14	20	29	25	15	33	18	9	40
	Relative Weight	11%	12%	5%	8%	11%	9%	6%	13%	7%	3%	15%

Figure 11. Technology QFD I for Outdoor Market

Engineering Metrics	Phase I Relative Weights	Technology: Body Core Warming	Seal	Vacuum	Sensing	Heat Control	Electrical	Power management	Information	Molding Design	Battery	CAE
Volume	11%			3			3			3	9	9
Weight	12%			3			1			3	9	3
Vacuum Pressure	5%	9	9	9	3		1	3	3	3		3
Heat Output	8%	9			3	3	3	3	3		1	3
Water Resistance	11%		1				1			3	3	
Drop Test	9%		3				1			3	1	
Power Consumption	6%			3	1	3	1	9	3			3
Time to Reheat	13%	9	3	3	3	3	3	3	3			3
Time to Initiate	7%		3	3		3	3					3
Battery Capacity	3%					3	3	3			9	1
# prototype design	15%											9
	Raw score	2.3	1.5	1.9	0.8	1.1	1.7	1.4	0.9	1.5	2.9	2.5
	Relative Weight	12%	8%	10%	4%	6%	9%	7%	5%	8%	16%	14%

Figure 12. Technology QFD II for Outdoor Market

4.2. Technology Sensitivity Chart

A technology sensitivity chart plays an essential role in the technology-push R&D process. The conjoint matrix in the Technology QFD are essentially technology sensitivities. Equation (3) calculates the conjoint matrix from correlation matrices of Technology QFD I and II. Figure 13 shows the calculated conjoint matrix. This study uses technology sensitivities normalized by total magnitude of the conjoint matrix. This means that a 100% technology improvement enables improvement of all CR at the unit scale of 1.

A high technology sensitivity indicates that a particular CR requires a sizable improvement in the corresponding technology in order to be satisfied sufficiently. Figure 14 shows the technology sensitivity chart that represents the technology sensitivities in the conjoint matrix of Figure 13.

Conjoint QFD Matrix	Body Core Warming	Seal	Vacuum	Sensing	Heat Control	Electrical	Power management	Information	Molding Design	Battery	CAE
Cleanable	0.00%	0.23%	0.23%	0.00%	0.00%	0.38%	0.00%	0.00%	0.80%	1.22%	1.09%
Small size	0.00%	0.00%	0.69%	0.00%	0.00%	0.57%	0.00%	0.00%	0.69%	2.07%	3.27%
Light weight	0.00%	0.00%	0.69%	0.00%	0.00%	0.34%	0.00%	0.00%	0.69%	2.07%	1.55%
Fast-Reheating	2.58%	1.21%	1.38%	0.92%	1.03%	0.98%	1.38%	1.03%	0.17%	0.06%	1.21%
Adaptable	0.86%	0.75%	0.86%	0.29%	0.40%	0.77%	0.29%	0.29%	0.75%	1.28%	1.66%
Safe	2.07%	0.71%	0.69%	0.75%	0.69%	0.71%	1.21%	0.86%	0.40%	0.29%	1.03%
Easy to use	1.89%	1.40%	1.55%	0.63%	1.09%	1.42%	0.63%	0.63%	0.63%	1.17%	2.35%
Reliable	2.58%	1.43%	1.21%	0.86%	0.86%	1.03%	0.86%	0.86%	0.52%	0.29%	1.55%
Long Power Life	1.55%	0.69%	1.21%	0.69%	1.38%	1.09%	2.58%	1.03%	0.17%	1.61%	1.21%
Portable	0.00%	0.23%	1.03%	0.00%	0.00%	0.80%	0.00%	0.00%	1.38%	3.33%	2.58%
Rugged	0.00%	0.69%	0.17%	0.00%	0.00%	0.40%	0.00%	0.00%	1.21%	1.21%	0.69%
Fashionable	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.55%

Figure 13. Conjoint Matrix for Outdoor Market

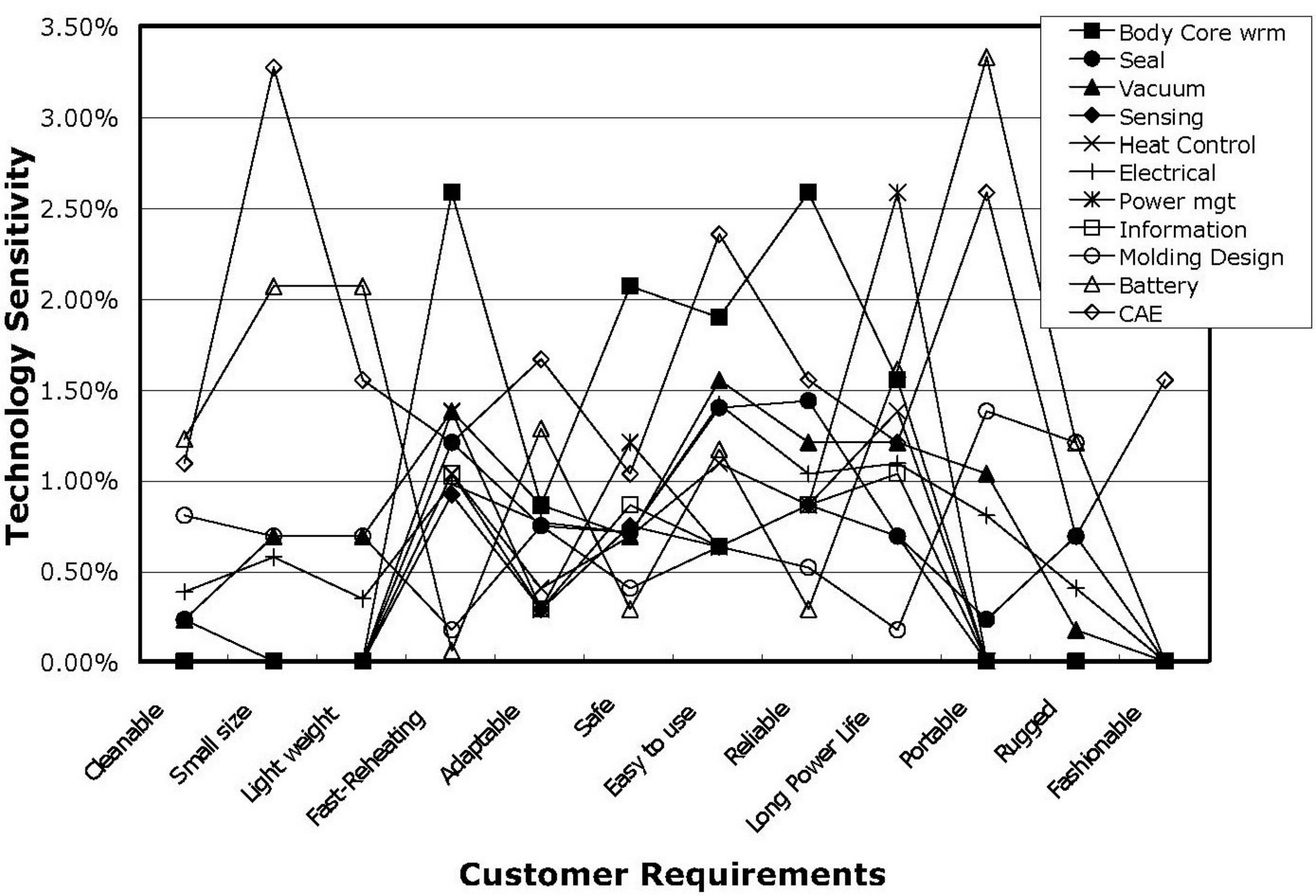

Figure 14. Technology Sensitivity Chart

The technology sensitivity chart helps to identify high technology sensitivity combinations of CRs and technology. Such high sensitivity combinations can help guide discussion on overall sensitivity analysis.

1. CAE technology has high sensitivities on the CRs of small size, easy to use and portable. Only this technology influences the new CR of fashionable. Improvement of CAE technology has effective influence on these CR improvements.
2. Battery technology has high impacts on CRs of small size, light-weight and portable. If these CRs are important in a new market, the company has to improve this technology.
3. Body core warming technology has high impact on CRs of fast-reheating, safe and reliable. The company already licensed this technology from an external institute. But, to improve these CRs in the new market, the company needs some extra R&D efforts on this technology.
4. Power management technology has high impact on the CR of long power life.

These sensitivity analyses help engineers to understand relationships between CR and technology improvement.

4.3. Technology-push R&D Strategy

In this case study, since a product in the outdoor market does not exist at this moment, it is difficult to get potential customer's preferences on the product directly. So, a market research method to get the new CR weights is key. Future product images with attractive features make the market research more effective. This future product image helps potential customers indicate their preferences for the new product features. In this process, the future product images that require very difficult R&D typically makes market research ineffective because it is difficult to link customer information to the company's actual R&D strategy and product development. But the future product images that logically relate to the company's technology improvement scenarios make this link easy and the company can relate the market research results to the company's R&D strategy. The technology sensitivity chart helps to create future product images. This case study created four future product images:

1. The body-core warming product with selling points of small, portable, easy to use and fashionable. CAE technology improvement is the key.
2. The body-core warming product with selling points of light-weighted, small and high portability. Battery technology improvement is the key.
3. The body-core warming product with selling points of fast function and high reliability. Body-core warming technology improvement is the key.
4. The body-core warming product with selling points of long power life. Power management technology is the key.

Combinations of these future product images increase selling points of the product. Market research using these future product images enables obtaining CR weights from the potential customers. Table 2 shows the CR weights in the outdoor market. The 2004 dfM project results helped in estimating these CR weights.

Now Technology QFD can calculate the needed technology worth using the CR weights. Table 3 shows the technology relative worth in outdoor market.

Table 2. CR weight in Outdoor Market

CR of Outdoor Market	Cleanable	Small size	Light weight	Fast-Reheating	Adaptable	Safe	Easy to use	Reliable	Long Power Life	Portable	Rugged/Water proof	Fashionable
Weight	3	9	9	3	3	9	9	9	9	9	3	3

Table 3. Technology Relative Worth

Technology of Outdoor Market	Body Core Warming	Seal	Vacuum	Sensing	Heat Control	Electrical	Power management	Information	Molding Design	Battery	CAE
Relative Worth	12%	7%	11%	4%	6%	9%	8%	5%	7%	16%	14%

In the technology-push R&D paradigm, the technology map also guides decision-making as in the market-pull R&D strategy framework. Technology map plots relative technology worth and technology gap. Similar to the last section, this study uses the simplified investment evaluation of estimating technology level gap. Table 4 shows the technology level gap.

Table 4. Technology Level Gap for Outdoor Market

Technology of Outdoor Market	Body Core Warming	Seal	Vacuum	Sensing	Heat Control	Electrical	Power management	Information	Molding Design	Battery	CAE
Investment Level	4	1	3	2	5	6	7	4	3	8	4
Relative Level Gap	9%	2%	6%	4%	11%	13%	15%	9%	6%	17%	9%

Figure 15 shows the technology map for the outdoor market. As in the market-pull R&D, the four divided regions guide decision-making of the technology-push R&D strategy.

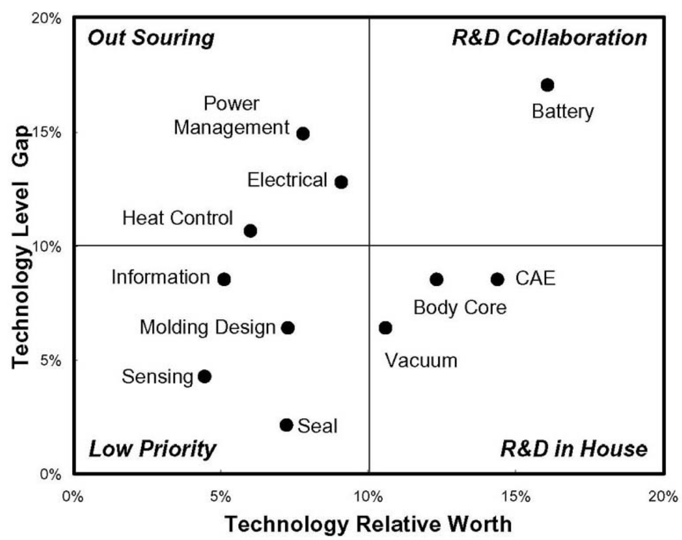

Figure 15. Technology Map for Outdoor Market

Technology development items with high worth and high gap suggest R&D Collaboration. In this case, battery technology falls in into this group. Items with high worth and low gap are suitable for R&D in-House. The company should perform internal R&D on vacuum technology, body core warming technology and CAE technology. Items with low worth and high gap are candidates for out-sourcing. The company should out-source electrical technology, heat control technology and power management technology. Low worth and low gap items are low priority technology. The company does not need any R&D strategy on molding design, information technology, sensing technology, and seal technology at this moment.

The technology map guides decision-making of R&D strategy reasonably for both market-pull R&D and technology-push R&D. This structured methodology helps to handle a cycle of radical and incremental innovation based on logical relationship between market and technology information.

5. CONCLUSION

5.1. Summary

This study developed the R&D strategy decision-making methodology for both incremental and radical innovation using a new application of QFD. A medical product case study illustrated the utility of this methodology.

The market-pull R&D strategy decision-making framework guides incremental innovation. In this framework, Technology QFD, which is a new adaptation of Project QFD, is the key tool. This framework derives technology worth from market information, and the technology map guides decision-making R&D strategy.

The technology-push R&D strategy decision-making framework seeks radical innovation. An inverse usage of QFD, which can derive market opportunity from technology improvement, plays a key role. A technology sensitivity chart helps engineers to create future product visions that have a logical alignment with the company's technology strategy. Conversely, market research using future product vision provides feedback from future market information to a R&D strategy. The technology map guides the technology-push R&D decision-making using the same framework as the market-pull R&D.

The new structured methodology utilizing a new application of QFD helps to handle a cycle of radical and incremental innovation based on logical relationship between market and technology information.

5.2. Limitations & Future work

This study faces some challenges in actual implementation and needs further study and improvement.

In this framework, the technology map guides decision-making on R&D strategies. The technology map consists of technology level gap. Our framework uses a simplified investment level method as a metric of technology. But the actual technology level depends on many factors such as intellectual property, experience level of engineers, organization flexibility, originality, applicability, etc. This study did not adequately address these non-technical issues. To make the technology map more reliable, a study on possible quantitative metrics of technology level becomes important.

The first step in the technology-push R&D framework is listing new CRs in the new market. This case study assumed that the company can expand its market from medical to outdoor, and added new CRs for the new market. This new CR creation process is critical to the technology-push R&D framework, because new CRs should be something new and valuable for potential customers. To our knowledge there are few practical methodologies to create new CRs. This process strongly depends on an engineer's personal skill. This topic is also an important future research task.

In the R&D strategy framework, four regions of the technology map guide decision-making. However, there is no guideline on how to precisely define the boundary between regions. Our strategy framework discusses this only from a qualitative viewpoint; we acknowledge that it may be difficult to make decisions for technology items in the middle of the map. This research needs more detailed evaluation study for finer quantification of worth and gap.

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