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Dynamic Programming Approach for Determining Optimal Levels of Technical Attributes in QFD under Multi-Segment Market

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다수의 개별시장 하에서 QFD의 기술속성의 최적 값을 결정하기 위한 동적 계획법

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Quality function deployment (QFD) is a useful method in product design and development to maximize customer satisfaction. In the QFD, the technical attributes (TAs) affecting the product performance are identified, and product performance is improved to optimize customer requirements (CRs). For product development, determining the optimal levels of TAs is crucial during QFD optimization. Many optimization methods have been proposed to obtain the optimal levels of TAs in QFD. In these studies, the levels of TAs are assumed to be continuous while they are often taken as discrete in real world application. Another assumption in QFD optimization is that the requirements of the heterogeneous customers can be generalized and hence only one house of quality (HoQ) is used to connect with CRs. However, customers often have various requirements and preferences on a product. Therefore, a product market can be partitioned into several market segments, each of which contains a number of customers with homogeneous preferences. To overcome these problems, this paper proposes an optimization approach to find the optimal set of TAs under multi-segment market. Dynamic Programming (DP) methodology is developed to maximize the overall customer satisfaction for the market considering the weights of importance of different segments. Finally, a case study is provided for illustrating the proposed optimization approach.

Keywords : Quality Function Deployment, Dynamic Programming, Multi-Segment Market

1. Introduction

Quality function deployment (QFD) is a widely adopted customer-oriented methodology in order to assist product design and development by analyzing customer requirements (CRs) [1]. The basic concept of QFD is to utilize a set of charts called the houses of quality (HoQ) to translate CRs into technical attributes (TAs) and subsequently into parts characteristics, process plans, and manufacture operations [3]. A HoQ typically contains information on relationship between CRs and TAs, and among TAs and benchmarking data [4]. Based upon the information contained in a HoQ, the target levels for the TAs of a product can be determined to achieve a high level of customer satisfaction.

A comprehensive review of the related literature reveals many studies on QFD optimization. In these studies, the levels of TAs are assumed to be continuous while they are often taken as discrete. In real world, the levels of individual TAs

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can be discrete, which means each TA has a few alternatives. What engineers need to do is to choose the best one among all the possible alternatives of TAs. Furthermore, it is relatively easy to assign customer satisfaction and related cost for a TA to a single level than to clarify the precise relationships among them. For example, an experienced engineer can specify the cost to achieve a certain degree of requirement on a TA based on her or his knowledge. It is then possible to decide the extent of customer satisfaction for one aspect of a CR in the given degree of the TA. Then the optimization approach is applied to find a way of obtaining the optimal set of TAs from a limited number of their alternatives [6, 12].

In the abovementioned research, one of the assumptions with regard to the QFD optimization problem is that, the requirements of heterogeneous customers in a market can be generalized and hence only one HoQ is used to connect with CRs. However, customers who have different beliefs with respect to social issues (e.g., religion, politics, work, drugs, women's right) or personal interests (e.g., family, home, job, food, self-achievement, health, clubs, friends, shopping) may have different purchasing behavior or preferences [13]. Consequently, customers in a product market may have different responses towards a new product. Therefore, a product market can be partitioned into several market segments, each of which contains a number of customers with homogeneous preferences, and HoQ should be developed as many market segments as partitioned. Eventually the maximum overall customer satisfaction for homogeneous customers in a product market needs to be achieved in a more reasonable way.

To overcome these problems, this paper proposes an optimal solution approach that incorporates dynamic programming (DP) in QFD to find the optimal set of TAs under multi-segment market. The approach is based on the proposed model by Lai et al. [6], and it extends to multiple market segments.

The remaining of this paper is organized as follows. Section 2 overviews the related works and Section 3 introduces the proposed solution approach. In Section 4, a numerical example is shown to illustrate the proposed methodology. Finally, conclusions are drawn in Section 5.

2. Related Work

Since the proposed methodology in this paper is for solving the optimization problems to maximize customer satisfaction under resource constraints in QFD under multi-segment market, the literature review is focused on the following areas; optimization methods in QFD and models under multi-segment market.

Linear programming is a well-known method which has recently been applied to finding the best set of TAs. This model is generally used to allocate resources to the different TAs in order to maximize the overall customer satisfaction [2, 5, 7, 9, 11, 12, 14]. In these studies, it is assumed that the levels of TAs can be any point in a continuous range while they are often considered discrete in real-world applications. For example, the dimensions of computer monitors could not get 15.7500, 16.2500. Their dimensions have real levels of about 1,500, 1,700 or 1,900. That is, the levels of computer monitor dimensions have discrete range. They do not have a continuous range.

Integer programming is also used to optimize product design under certain resource constraints [10, 14]. This approach attaches the greatest attention to the most important TAs. However, effort is devoted to the selection of TAs to the extent that other TAs are overlooked. The disposed TAs may greatly hinder customer satisfaction.

Since, although integer and linear programming perform well in certain circumstances, there are still some problems with them mentioned as the above, DP is proposed to solve this type of optimization problem where levels of the TAs are discrete, as well as to overcome the problem of lack of solutions in integer and linear programming [6].

There seems to be few studies regarding QFD optimization under multi-segment market. Luo et al. developed a methodology which involves a market survey, fuzzy clustering, QFD and fuzzy optimization to achieve the optimal target settings of engineering characteristics of a new product under multi-segment market [8].

3. Dynamic Programming Approach

DP is such a tool that fits the situation which is to find a way of obtaining the optimal levels of TAs from a limited number of their alternatives under multi-segment market within the constraint imposed by budget availability. DP is a useful mathematical technique developed especially for making a set of interrelated decisions. The set of interrelated decisions in QFD under multi-segment market consists of decisions on the level of each TA in each market segment.

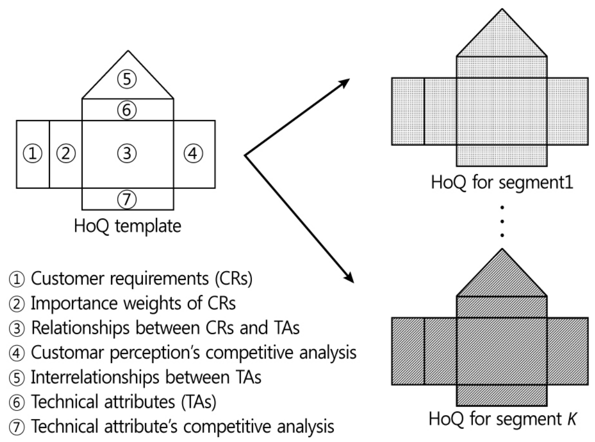
DP provides a systematic procedure for determining the optimal combination of decisions. In the following, we will describe the optimal solution procedure of using DP to find a combination of the optimal levels of TAs under multi-segment market.

3.1 The Optimization Model

The first step is to build a HoQ for each market segment. Suppose that a product has I CRs and J TAs, and there are T market segments. It is also assumed that one market segment corresponds to one HoQ. The HoQs of the market segments in a product market have the same house structure, house roof (TAs correlation matrix), relationship between CRs and TAs, and levels of TAs of the competitors' products and the firm's existing products. Therefore, we define a HoQ only containing these items as a HoQ template of the product.

As shown in <Figure 1>, the HoQ of a market segment may be different from that of another segment in the following aspects :

- The weights of importance of CRs (on the left side of the house), representing the priorities of CRs;
- The benchmarking scores of the existing products (on the right side of the house), representing the customer perception of the competitors' product and the firm's existing products on CRs;
- The CRs-TAs relationship matrix (in middle of the house), in which an element represents the quantitative level of strength of the relationship between a CR and a TA.



<Figure 1> An Example of HoQ Template Under Multi-Segment Market

For market segment t, we can obtain the relative importance of CR i from the other several CRs, w_{it} (i = 1, 2, ⋯, I; t =1, 2, ⋯, T), which is the scaled weight of importance of the ith CR ($0 \le w_{it} \le 1$ and $\sum_{i=1}^{I} w_{it} = 1$), and the relationship between the CR i and the TA j, r_{ijt} (i =1, 2, ⋯, I; j = 1, 2, ⋯, J; t = 1, 2, ⋯, T). Wasserman proposed a useful approach to normalize the relationship matrix considering the inter-relationships among the TAs [14]. In this paper, it is assumed that the relationship matrix has already been normalized.

In order to utilize DP, we need to incorporate some additional information into the traditional HoQ. We add the alternatives of every TA and corresponding customer satisfaction information to the traditional HoQ. As the result, <Figure 2> shows the extended HoQ. The other parts of the HoQ remain the same.

In this HoQ, it is assumed that TA 1 has a alternatives and TA 2 has b alternatives, TA j has p, ⋯, TA J has q alternatives. TA_{jkt} (j = 1, 2, ⋯, J; k = 1, 2, ⋯, K; t = 1, 2, ⋯, T) means the kth alternative of TA j in market segment t. Cr_{ijkt} refers to the customer satisfaction level (CSL) of CR i acquired by TA_{jkt}.

Then the related cost information can be summarized as in <Table 1>, which gives the levels for each alternative of each TA in each market segment. For market segment t, C_{jkt} is the cost of alternative TA_{jkt} and CR_{jkt} means the overall customer satisfaction achieved by alternative TA_{jkt}. Assume that the overall customer satisfaction, CR_{jkt}, is the weighted sum of each customer satisfaction of each CR acquired by TA_{jkt} in market segment t. Then, CR_{jkt} is computed from the following formula :

$$CR_{jkt} = \sum_{i=1}^{I} w_{it} Cr_{ijkt}$$

where I is the number of CRs.

Because the number of customers and the expected profit of a market segment are different from those of other segments, in order to achieve the overall customer satisfaction (OCS) for the whole market, a trade-off of customer satisfaction for each segment is required among the market segments. Assuming that the OCS of the whole market is the weighted sum of the customer satisfaction of the individual market segments, the objective function of this optimization problem can be formulated as

		Technical attribute 1		Technical attribute 2		⋯	Technical attribute j		⋯	Technical attribute J	
Customer requirement 1	w_{1t}	r_{11t}		r_{12t}		⋯	r_{1jt}		⋯	r_{1Jt}	
		TA_{11t}	Cr_{111t}	TA_{21t}	Cr_{121t}		TA_{j1t}	Cr_{1j1t}		TA_{J1t}	Cr_{1J1t}
		⋯	⋯	⋯	⋯		⋯	⋯		⋯	⋯
		TA_{1at}	Cr_{11at}	TA_{2bt}	Cr_{12bt}		TA_{jpt}	Cr_{1jpt}		TA_{Jqt}	Cr_{1Jqt}
Customer requirement 2	w_{2t}	r_{21t}		r_{22t}		⋯	r_{2jt}		⋯	r_{2Jt}	
		TA_{11t}	Cr_{211t}	TA_{21t}	Cr_{221t}		TA_{j1t}	Cr_{2j1t}		TA_{J1t}	Cr_{2J1t}
		⋯	⋯	⋯	⋯		⋯	⋯		⋯	⋯
		TA_{1at}	Cr_{21at}	TA_{2bt}	Cr_{22bt}		TA_{jpt}	Cr_{2jpt}		TA_{Jqt}	Cr_{2Jqt}
⋯	⋯	⋯		⋯		⋯	⋯		⋯	⋯	
Customer requirement i	w_{it}	r_{i1t}		r_{i2t}		⋯	r_{ijt}		⋯	r_{iJt}	
		TA_{11t}	Cr_{i11t}	TA_{21t}	Cr_{i21t}		TAj_{1t}	Cr_{ij1t}		TA_{J1t}	Cr_{iJ1t}
		⋯	⋯	⋯	⋯		⋯	⋯		⋯	⋯
		TA_{1at}	Cr_{i1at}	TA_{2bt}	Cr_{i2bt}		TA_{jpt}	Cr_{ijpt}		TA_{Jqt}	Cr_{iJqt}
⋯	⋯	⋯		⋯		⋯	⋯		⋯	⋯	
Customer requirement I	w_{It}	r_{I1t}		r_{I2t}		⋯	r_{Ijt}		⋯	r_{IJt}	
		TA_{11t}	Cr_{I11t}	TA_{21t}	Cr_{I21t}		TA_{j1t}	Cr_{Ij1t}		TA_{J1t}	Cr_{IJ1t}
		⋯	⋯	⋯	⋯		⋯	⋯		⋯	⋯
		TA_{1at}	Cr_{I1at}	TA_{2bt}	Cr_{I2bt}		TA_{jpt}	Cr_{Ijpt}		TA_{Jqt}	Cr_{IJqt}

<Figure 2> The Extended HoQ for Market Segment *t*

<Table 1> Cost Information for Market Segment *t*

TA	Cost	CSL	TA	Cost	CSL	⋯	TA	Cost	CSL	⋯	TA	Cost	CSL
TA_{11t}	C_{11t}	CR_{11t}	TA_{21t}	C_{21t}	CR_{21t}	⋯	TA_{j1t}	C_{j1t}	CR_{j1t}	⋯	TA_{J1t}	C_{J1t}	CR_{J1t}
⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯	⋯
TA_{1at}	C_{1at}	CR_{1at}	TA_{2bt}	C_{2bt}	CR_{2bt}	⋯	TA_{jpt}	C_{jpt}	CR_{jpt}	⋯	TA_{Jqt}	C_{Jqt}	CR_{Jqt}

$$\text{OCS} = \sum_{t=1}^{T}\sum_{j=1}^{J}\xi_t CR_{jt}(X_{jt})$$

where X_{jt} is the amount of funds allocated to TA *j* in market segment *t*; $X_{jt} \in \{x_{j1t}, x_{j2t}, \cdots, x_{jKt}\}$, $CR_{jt}(X_{jt})$ is the customer satisfaction achieved when a budget of X_{jt} has been allocated to TA *j* in market segment *t*, and ξ_t is the normalized weight of importance of market segment *t* ($0 \le \xi_t \le 1$ and $\sum_{t=1}^{T}\xi_t = 1$).

If the number of customers in a market segment is estimated according to historical sales data of the firm and salesmen's knowledge, ξ_t can be obtained as

$$\xi_t = q_t \Big/ \sum_{t=1}^{T} q_t$$

where q_t is the estimated number of customers in market segment *t*.

All the information needed for DP is now available. The DP is computed based on <Table 1>. The overall optimization model is

$$\max \quad OCS = \sum_{t=1}^{T}\sum_{j=1}^{J}\xi_t CR_{jt}(X_{jt})$$

$$\text{s.t.} \quad \sum_{t=1}^{T}\sum_{j=1}^{J} X_{jt} \le B$$

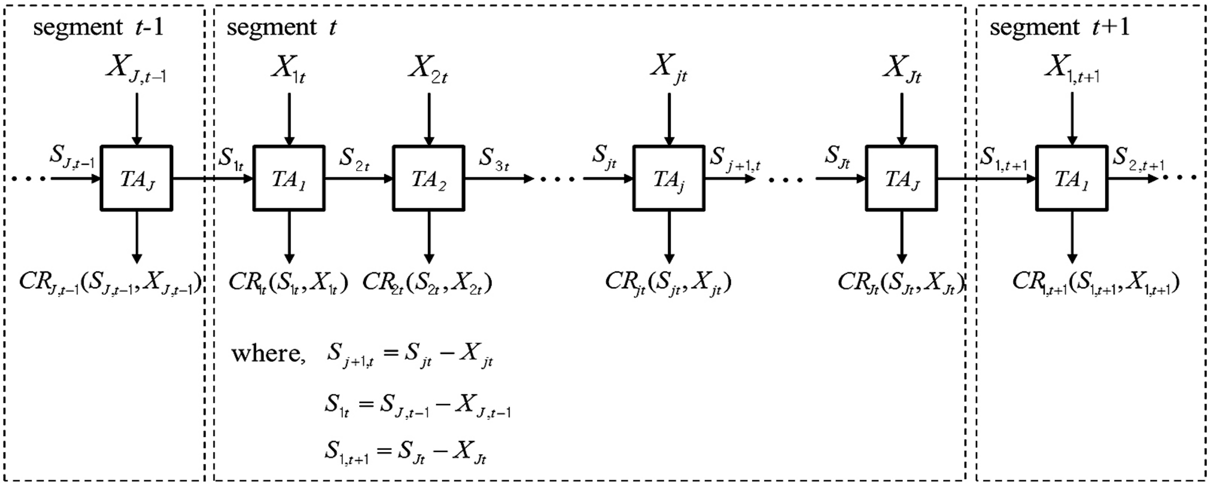
$$X_{jt} \in \{x_{j1t}, x_{j2t}, \cdots, x_{jKt}\},\ j = 1, 2, \cdots, J,\ t = 1, 2, \cdots, T$$

where *B* is the total budget for *T* market segments.

3.2 The Algorithm of Dynamic Programming

DP approach is developed to solve the optimization problem considered in this paper. Both the problem of allocating funds to each TA in each market segment and the problem of selecting alternatives of TAs in each market segment could be handled by DP.

Referring to <Figure 3>, allocation of funds to each TA in each market segment using DP approach results in the following backward recursive relationship :



<Figure 3> Dynamic Programming Model

$$f_{JT}(S_{JT}) = \max\{\xi_T CR_{JT}(S_{JT}, X_{JT}) | X_{JT} \le S_{JT}\},$$
$$S_{JT} \in \{0, 1, \cdots, B\}$$
$$\vdots$$
$$f_{jt}(S_{jt}) = \max\{\xi_T CR_{jt}(S_{jt}, X_{jt}) + f_{j+1,t}(S_{jt} - X_{jt}) | X_{jt} \le S_{jt}\},$$
$$S_{jt} \in \{0, 1, \cdots, B\}$$
$$\vdots$$
$$f_{11}(S_{11}) = \max\{\xi_1 CR_{11}(S_{11}, X_{11}) + f_{21}(S_{11} - X_{11}) | X_{11} \le S_{11}\},$$
$$S_{11} \in \{B\}$$

where the state variable S_{jt} represents the amount of fund which is available for allocation to TA j in market segment t; $0 \le S_{jt} \le B$, X_{jt} is an amount of fund allocated to TA j in market segment t, and $f_{jt}(S_{jt})$ is the optimal customer satisfaction obtained from TA j in market segment t to the end of the problem (TA J in market segment T). From the formulation, we must evaluate these recursive functions in the reversion order of their definition. Thus, we solve for f_{JT}, then $f_{j-1,T}$, $\cdots$, and finally f_{11}.

4. A Numerical Example

A simple example modified from Lai et al. and Yamashina et al. is introduced to illustrate the application of the proposed approach in this research [6, 15]. The problem is to determine the optimal levels of the TAs of a washing machine according to the CRs in two market segments. Five CRs are identified to represent the biggest concern of the customers of the washing machine for the two market segments. They are "thorough washing", "quiet washing", "thorough rinsing", "less damage to clothes" and "short washing time". From the view point of engineer's design of the washing machine, five TAs are also identified, i.e. "washing quality (%)", "noise level (dB)", "washing time (min)", "rinsing quality (%)" and "clothes damage rate (%)". The relationship between CRs and TAs as well as the relative importance of CRs for market segment 1 and 2 are illustrated in the HoQ template in <Table 2> and <Table 3>, respectively. Since we are not focusing on the competitive analysis information and the interrelationship between TAs, they are not shown in <Table 2> and <Table 3>. Each TA has three alternatives.

We also need the cost information related to the TA alternatives and the total budget for the two market segments. For calculation, the accumulative customer satisfaction achieved by each TA alternative is also needed. The total budget is assumed to be 24. It is also assumed that the numbers of customers in two market segments, q_1 and q_2, were estimated as 12,000 and 9,000, respectively. These data are used to represent the importance of the market segments. All this information is listed in <Table 4> and <Table 5>.

The problem in this example is to decide how much fund should be allocated to each TA to maximize overall customer satisfaction in the two market segments. This problem can be expressed as

<Table 2> The HoQ for Market Segment 1

		Washing Quality(%)		Noise Level(db)		Washing Time(min)		Rinsing Quality(%)		Clothes Damage Rate(%)	
		Level	Satisfaction level	Level	Satisfaction level	Level	Satisfaction level	Level	Satisfaction level	Level	Satisfaction level
Thorough washing		0.3125		0		0.0625		0.3125		0.3125	
		90	0.65	45	0	30	0.8	95	1	0.5	0.8
	0.313	95	0.85	50	0	35	0.9	90	0.7	0.7	0.9
		98	1	60	0	40	1	80	0.4	1	1
Quiet Washing		0.3		0.5		0.1		0.1		0	
		90	1	45	1	30	1	95	0.85	0.5	0
	0.25	95	0.8	50	0.7	35	0.9	90	0.9	0.7	0
		98	0.7	60	0.4	40	0.6	80	1	1	0
Thorough rinsing		0.3		0		0.1		0.5		0.1	
		90	0.5	45	0	30	1	95	1	0.5	1
	0.188	95	0.9	50	0	35	0.6	90	0.8	0.7	0.9
		98	1	60	0	40	0.5	80	0.4	1	0.8
Less damage to clothes		0.231		0.077		0.077		0.231		0.384	
		90	1	45	1	30	1	95	1	0.5	1
	0.125	95	0.8	50	0.9	35	0.9	90	0.6	0.7	0.8
		98	0.7	60	0.9	40	0.8	80	0.5	1	0.5
Short washing time		0.714		0		0.143		0.143		0	
		90	0.7	45	0	30	1	95	0.6	0.5	0
	0.125	95	0.9	50	0	35	0.8	90	0.8	0.7	0
		98	1	60	0	40	0.6	80	1	1	0

<Table 3> The HoQ for Market Segment 2

		Washing Quality(%)		Noise Level(db)		Washing Time(min)		Rinsing Quality(%)		Clothes Damage Rate(%)	
		Level	Satisfaction level	Level	Satisfaction level	Level	Satisfaction level	Level	Satisfaction level	Level	Satisfaction level
Thorough washing		0.2875		0		0.1712		0.258		0.2833	
		92	0.7	54	0	39	1	81	0.7	1	1
	0.3265	94	0.8	50	0	36	0.9	83	0.8	0.8	0.8
		96	1	46	0	33	0.8	85	1	0.6	0.6
Quiet Washing		0		1		0		0		0	
		92	1	54	0.5	39	0	81	0	1	0
	0.0067	94	0.85	50	0.7	36	0	83	0	0.8	0
		96	0.75	46	1	33	0	85	0	0.6	0
Thorough rinsing		0.285		0		0.1828		0.2849		0.2738	
		92	0.6	54	0	39	1	81	0.5	1	0.8
	0.2237	94	0.8	50	0	36	0.9	83	0.7	0.8	0.9
		96	1	46	0	33	0.8	85	1	0.6	1
Less damage to clothes		0.2688		0		0.1495		0.2688		0.3129	
		92	1	54	0	39	0.6	81	0.5	1	0.5
	0.4156	94	0.9	50	0	36	0.8	83	0.6	0.8	0.7
		96	0.7	46	0	33	1	85	1	0.6	1
Short washing time		0.2152		0		0.3119		0.2654		0.2165	
		92	0.8	54	0	39	0.5	81	1	1	0.7
	0.0275	94	0.9	50	0	36	0.7	83	0.8	0.8	0.8
		96	1	46	0	33	1	85	0.6	0.6	1

<Table 4> Cost and Customer Satisfaction Level for Market Segment 1

Washing Quality(%)			Noise Level(db)			Washing Time(min)			Rinsing Quality(%)			Clothes Damage Rate(%)		
Level (%)	Cost	Satisfaction	Level (db)	Cost	Satisfaction	Level (min)	Cost	Satisfaction	Level (%)	Cost	Satisfaction	Level (%)	Cost	Satisfaction
90	3	0.4342	45	5	0.2143	30	4	0.5362	95	3	0.5220	0.5	4	0.3219
95	4	0.4844	50	3	0.1643	35	2	0.4754	90	2	0.4397	0.7	2	0.3148
98	5	0.5077	60	2	0.1214	40	1	0.4183	80	1	0.3645	1	1	0.3005

<Table 5> Cost and Customer Satisfaction Level for Market Segment 2

Washing Quality(%)			Noise Level(db)			Washing Time(min)			Rinsing Quality(%)			Clothes Damage Rate(%)		
Level (%)	Cost	Satisfaction	Level (db)	Cost	Satisfaction	Level (min)	Cost	Satisfaction	Level (%)	Cost	Satisfaction	Level (%)	Cost	Satisfaction
92	3	0.3459	54	3	0.0014	39	1	0.3486	81	1	0.2467	1	1	0.3139
94	4	0.3620	50	4	0.0020	36	2	0.3630	83	2	0.2954	0.8	2	0.3323
96	5	0.3744	46	5	0.0029	33	3	0.3785	85	4	0.4210	0.6	3	0.3697

<Table 6> Computational Results in Stage 52

S_{52}	$\{CR_{52}(S_{52}, X_{52}) \mid X_{52} \le S_{52}\}$			f_{52}	X_{52}^*
	$X_{52}=1$	$X_{52}=2$	$X_{52}=3$		
0	-	-	-	-	-
1	0.3139	-	-	0.3139	1
2	0.3139	0.3323	-	0.3323	2
3~24	0.3139	0.3323	0.3697	0.3697	3

$$\max \quad OCS = \sum_{t=1}^{2}\sum_{j=1}^{5}\xi_t CR_{jt}(X_{jt})$$

$$\text{s.t.} \quad \sum_{t=1}^{2}\sum_{j=1}^{5} X_{jt} \le 24$$

$$X_{jt} \in \{x_{j1t}, x_{j2t}, x_{j3t}\}, \; j = 1, 2, \cdots, 5, \; t = 1, 2$$

DP approach is applied to this problem. The objective is to distribute the limited budget to all TAs and maximize overall customer satisfaction for the two market segments.

DP formulation of this problem is as follows : stage *jt* = TA *j* in market segment *t*; decision variable X_{jt} = the amount of fund allocated to TA *j* in market segment *t*; and state variable S_{jt} = the amount of fund which is available for allocation to TA *j* in market segment *t*; $0 \le S_{jt} \le 24$. Return function $f_{jt}(S_{jt})$ = the total customer satisfaction achieved from TAs *j* in market segment *t* to the end of the problem (the fifth TAs in the second market segment). The functions are defined as :

$$f_{52}(S_{52}) = \max\{\xi_2 CR_{52}(S_{52}, X_{52}) \mid X_{52} \le S_{52}\}, \quad S_{52} \in \{0, 1, \cdots, 24\} \qquad (1)$$

$$f_{42}(S_{42}) = \max\{\xi_2 CR_{42}(S_{42}, X_{42}), + f_{52}(S_{42} - X_{42}) \mid X_{42} \le S_{42}\}, \quad S_{42} \in \{0, 1, \cdots, 24\}$$

$$\vdots$$

$$f_{11}(S_{11}) = \max\{\xi_1 CR_{11}(S_{11}, X_{11}) + f_{21}(S_{11} - X_{11}) \mid X_{11} \le S_{11}\}, \quad S_{11} \in \{24\}$$

At stage 52, we deal with the fifth TA for the second market segment, "clothes damage rate." $f_{52}(S_{52})$ is computed using eq (1). The results are shown in <Table 6>. The first column shows the state variable, and the second, third, and fourth columns representing three alternatives of TA, "clothes damage rate", and the allocated funds show the corresponding customer satisfaction with different state, respectively. The fifth and sixth columns represent the maximal return $f_{52}(S_{52})$, and the corresponding optimal alternative and its funds among the three alternatives of TA, "clothes damage rate', respectively.

Stages 42-11 can be carried out in the same way as stage 52. The optimal solution to the example is summarized in <Table 7>. The overall customer satisfaction for this example is 3.3346.

<Table 7> Summarization of Results

Segments	Technical attributes	Alternatives	Customer satisfaction level	Cost
1	Washing quality(%)	95%	0.4844	4
	Noise level(db)	60db	0.1214	2
	Washing time(min)	35min	0.4754	2
	Rinsing quality(%)	95%	0.5220	3
	Clothes damage rate(%)	1%	0.3005	1
2	Washing quality(%)	92%	0.3459	3
	Noise level(db)	54db	0.0014	3
	Washing time(min)	39min	0.3486	1
	Rinsing quality(%)	85%	0.4210	4
	Clothes damage rate(%)	1%	0.3139	1

5. Conclusions

In this paper, a methodology for determining the optimal set of TAs in QFD under multi-segment market is proposed. Based on the discussions made in this research, the following points can be summarized and concluded:

- Different from the existing QFD approaches, the proposed methodology considers a product market with multiple segments, each of which contains a number of customers with homogeneous preferences. It can be considered as a necessary extension of the existing QFD optimization approaches.
- DP approach is established to find the set of the optimal levels of TAs in QFD under multi-segment market. The approach utilizes only a group of discrete points containing information about customer satisfaction, TAs, and the cost to find the optimal product design. Therefore, comparing with other optimization approaches considering the continuous levels of TAs, it requires less time and resources.

Further extensions to the model and solution methodology can be considered as follows :

- In this research, we assumed that overall customer satisfaction is the sum of each customer satisfaction on each CR in each segment. In real world, however, overall customer satisfaction can be products of each customer satisfaction on each CR, or a mix of sum and product. An advanced DP approach need to be developed for the more complicated situations.
- In this paper, it is assumed that all the numbers are deterministic. Due to imprecision and uncertainty caused by the human subjective judgments, the number of customers in market segments and costs need to be expressed as fuzzy numbers or with probabilities in the mathematical model. It could be an interesting area of further research to develop a fuzzy or probabilistic DP approach for this problem.

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