Selecting Quality-standard and Resource-allocation Proposal under Constrainedly Periodical Budget for Projects in New Product Development

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ABSTRACT

This paper aims to propose an approach to select quality-standard and resource-allocation proposal for projects in new product development. We consider each R&D category involves redesigning or upgrading a specific current product. This work propose an approach to treat the multi-standard and multi-allocation project selection problem in which the scheduling is also considered concurrently under constrained periodically budget. The proposed approach consists of following four components: (1) selecting a project advancement strategy to serve as a scheduling framework for taking into account soft factors in scheduling process, (2) employing the expected brand-image scores of consumers as the objective function for ultimately increasing average profitability, (3) providing a model in which the selection of quality-standard proposal of a project, as well as the multi-project scheduling are involved, and (4) transforming the objective function into an appropriate form in which the parameters can be estimated more easily and the objective value has a clear managerial implication.

Keywords: new product development, quality-standard, resource-allocation proposal, brand-image judgment, project selection and scheduling

新產品開發之預算限制下資源配置與多等級專案選擇

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摘 要

本文將新產品開發的計畫區分為多種研發類別。每種研發的類別代表著一種可以再升級的特定產品。類別當中的每項專案執行品質都擁有多重的等級可供選擇。鑑此，本文提出多類別及其多等級的專案選擇性問題，該問題亦同時考量每期預算限制下的專案排程議題。本文的內容分為四個部分：(1)專案推移策略考量軟性因素做為專案排程的架構，(2)將消費者對產品品牌印象引用為長期平均獲利最大化之目標函數，(3)提供專案排程之品質等級與資源配置選擇之模型，(4)轉換目標函數為一適當的格式，而能使參數更易被估計，而使最終結果被解釋為具管理意涵的內容。

關鍵字：新產品開發、專案選擇與排程、品質等級、品牌印象、資源配置

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Ⅰ. INTRODUCTION

Over the recently years, new product development or NPD had become a vital business process and a major contributor to business excellence of company [1]. NPD is the process by which an organization uses its resources and capabilities to create a new product or improve an existing one [2]. As a highly promising source of competitiveness for many firms, NPD allows an organization to transform data on market opportunities and technical possibilities into information assets for commercial [3]. In short, the importance of NPD includes: (i) it is one of the sources of enterprise's competitive advantage, (ii) it can strengthen the brand images of enterprises, and (iii) it may strengthen the position of market marketing. Restated, capable of influencing overall operational performance during product development, a company continuously attempts to identify important factors in product development.

However, R&D project selection and resource allocation among projects determine the success of NPD [4, 5, 6]. The project selection problem related to NPD can be generally being expressed as a multi-category and multi-standard project selection problem under budgetary and time constraints. Indeed, each R&D category involves redesigning or upgrading a specific current product, and the effort to redesign/upgrade a specific subsystem of an existing product is treated as a project in a category. In general, each project has usually multiple choices of quality/technology standards and a multiple amount of cost is invested in each period for realizing a specific quality-standard of a project. On the other hand, there are multiple choices of resource-allocation proposals for the realization of a specific quality-standard. Moreover, the contribution of a R&D project/category is limited to a specific time horizon. Such a time horizon is referred to hereinafter as 'the value-based time limit, since a manifest value-loss occurs if a specific product is developed after the major competitor offerings. This standpoint tells us the multi-project scheduling should be also considered concurrently whenever one attempts to resolve the above multi-standard and multi-allocation project selection problem. Again, the scenario as abovementioned tells us the amount of budget available in each period and value-based time limit constrains the quality-standard and resource-allocation selection of a project. Although abovementioned project selection problem occurs in an actual scenario, most R&D project selection works involving a constrained budget fail to do it [7, 8, 9, 10]. To conclude, the conventional project selection model can not respond some NPD actual scenarios as abovementioned. Besides the above NPD practices, most traditional project selection models also fail to simultaneously consider project scheduling. Sun and Ma [11] developed a packing-multiple-boxes model, capable of simultaneously selecting and scheduling R&D projects. However, their model not only failed to consider the real world NPD scenarios outlined above, but also failed to consider intangible factors in project scheduling. Intangible factors are immeasurable using a quantitative method, such as the controlling influence of the project leader and the intuitive experience of an engineer. Besides the above works, the literature has not examined project selection from the perspective of brand-image creation. Generally, product price and corresponding quality may lead directly to consumer purchase intention and repurchase intention [12]. Generally, product price and corresponding quality may lead directly to consumer purchase intention and repurchase intention [13, 14 15]. Thus, firms may achieve high average long-term profitability if their decision makers provide new products by creating long-term brand image.

Based on the above analysis, this study proposes an approach to treating the multi-category and multi-standard project selection problem that simultaneously considers scheduling and budget. The proposed approach comprises four main components. First, this study slightly revises the definition of the four project advancement strategies of Chang & Chen [16] improves their applicability to the target problem. The four strategies are developed to help decision makers select projects that involve intangible factors. Once again, this study simply discusses the main advantages and disadvantages of these strategies. Second, this study borrows the concepts of Chang and Yang [17] to establish a measurement measure of consumer brand-image. Furthermore, Ho et al., [18] also presented that consumer perception regarding whether the majority of consumers prefer the offerings of a firm significantly influences consumer brand image regarding the firm. According to this perspective, consumers may determine the brand-image score based on their perception of the market share of one or more products. Third, this study provides a computable model involving periodical budget constraints and specified value-based time limits. Finally, this study recommends a closed form objective function that allows for easy parameter estimation. Consequently, the proposed approach can identify an optimal portfolio of quality standards for new products and an associated optimal schedule, thus maximizing the expected brand-image score of consumers and benefiting the long-term average profitability. This paper consists of seven sections that cover the concept of this research. Section 2 reviews the literature about project advancement strategy. Section 3 considers a brand image of consumers to effects the consumer purchase intentions. Then the consumer perception as to whether the majority of consumers prefer the offerings of a firm should significantly influence the brand image of a consumer about the firm. From this perspective, consumers may determine the brand-image score based on their perception with respect to the perception of market share of one or more products. Based on above, this work definition of quality-standard first and using the concept of consumer's behavior to divide consumers to two groups for modeling. Section 4 considers a computable model formulation with concerned problem to project selection. In this work, the project selection issues including the budget allocation with period, generating the periodical budget constraints and presents the evaluation of model parameter. In Section 5, we further consider the object function how to translating more easily computable. In Section 6, we present an example of new car development to demonstrate the effectiveness of the proposed model. Finally, we conclude the paper with discussing its applicability and results of the proposed models and providing future research directions in section 7.

Ⅱ. CHOICE OF PROJECT ADVANCEMENT STRATEGY

R&D project success largely depends on tangible and intangible factors. Tangible factors are those that can be measured quantitatively, such as number of engineers and budget invested. Intangible factors are those that can only be measured qualitatively, such as the controlling influence of the project leader and the intuitive experience of an engineer. Chang & Chen developed four project advancement strategies to help decision makers select projects that involve intangible factors. This study slightly revises the definitions of the four project advancement strategies about the remaining available budget of projects from the previous period can be used in the next period that to help in their application to the proposed problem, as described below.

Centralized sequential advancement strategy (CSAS): A multi-project problem in which each project has multiple choices of quality-standards is given. Again, a non-equal amount of cost must be invested in each period for realizing a specific quality-standard. Accordingly, we redefine CSAS as centralizing the available amount of periodical budget into a R&D project and the remaining budget available from the previous period can be used in the next period. Furthermore, we transfer the periodical budget to another project once the assigned quality standard of this project is achieved. Correspondingly, all projects ultimately achieve their quality standards assigned. Assume there are three projects: A, B and C. Figure 1 displays CSAS.

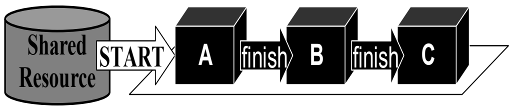

Fig.1. CSAS chart

Decentralized synchronized advancement strategy (DSAS): The scenario same as CSAS is given, DSAS refers to decentralizing the available amount of periodical budget into all R&D projects until all projects achieve their quality standards assigned. Again, the allocated policy for each period may vary since the cost required to invest in each period for any project may vary. Assume there are three projects: A, B and C. Figure 2 displays DSAS.

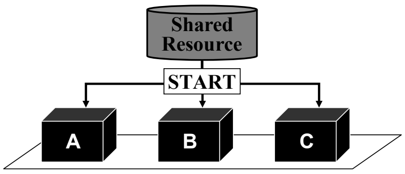

Fig.2. DSAS chart

Types I and II mixed advancement strategies (Type I, Type Ⅱ MAS): While considering projects A, B, C and D, divide the four projects into two categories: {A & B} and {C & D}, which are referred to as "X" and "Y", respectively. Type I MAS refers to deploying CSAS within categories X and Y, while moving ahead between categories X and Y with the DSAS as shown in Figure 3. Whereas Type II MAS refers to deploying the DSAS within categories X and Y, while moving ahead between categories X and Y with CSAS, i.e. transferring the periodical budget onto the projects in category Y for only the assigned quality standards of all projects in category X, as shown in Figure 4.

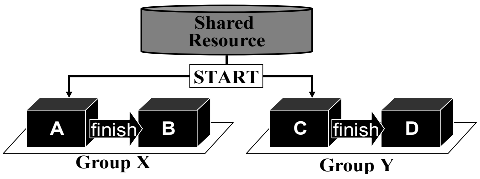

Fig.3. Chart of Type I MAS

This work suggests that one should borrow a project advancement strategy for solving some setting problems caused by intangible factors, in order to achieve the highest performance while implementing these projects. DSAS or type I MAS is generally characterized by its resource-utilization efficiency. However, DSAS or type I MAS is limited mainly in the diversification of the managerial skills of a project leader, leading to growth variation of progress and quality. In contrast with DSAS or type I MAS, CSAS or type II MAS is characterized by its emphasis on the project-managerial role of a project leader, subsequently reducing the variation of progress and quality. However, these strategies are less efficient in terms of resource utilization. Additionally, the new product may be developed with an inferior quality standard when the time horizon involving the decision maker has elapsed, subsequently lowering competitiveness. In practice, these strategies are selected based on what has been set up the situation and made actually. This work focuses only on the Type II MAS model.

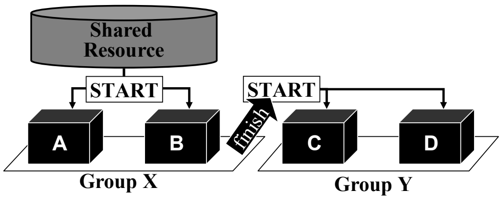

Fig.4. Chart of Type II MAS

Ⅲ. MAXIMIZING THE BRAND-IMAGE JUDGEMENTS OF CONSUMERS

Consider a (J, K_j) multi-standard project selection problem, where J denotes the number of new product developments, and K_j represents the number of projects for product $j, j = 1,2,\cdots,J$. Assume there are multiple choices of quality-standards for project k in product j, numbered by levels $0,1,\cdots,L_{jk}$. Where level 0 refers to 'do nothing', i.e. the subsystem corresponding to project k in product j is not selected or upgraded. Also, L_{jk} denotes the ideal quality standard. A vehicle industry example is employed to explain the concept of quality-standard more clearly as follows: Supposing a manufacturer would like to increase the quality of a particular car by upgrading the efficiency of the car's engine system. Let us consider that the quality indicators of the engine system are horsepower, torque, and fuel consumption. Table 1 shows the definitions of different quality-standards of this illustrative example. The results of Table 1 tell us that the values of these indicators for current state are respectively 150hp, 19.3kg-m, and 12.4km/l. Again, the ideal quality standard of the engine system that the manufacturer hopes to promote is the portfolio of indicator values 155hp, 22.7kg-m, and 13.8km/l.

Table 1. The level of quality-standards for indicators

Quality-standards Indicators	level 0	level 1	level 2	level 3 (L_{jk})
Horsepower (hp)	150	152	154	155
Torque (kg-m)	19.3	19.9	21.4	22.7
Fuel consumption (km/l)	12.4	12.8	13.2	13.8

Furthermore, as discussed in introduction, the brand image of consumers obviously influences their purchase intention. Thus, a firm may have a high profitability on average in the long run if its decision makers provide new products by creating brand image in the long-run. Based on this premise, this study employs the expected brand-image scores of consumers as the objective function for ultimately increasing long-run average profitability. Most consumer evaluation studies of a brand image suggested that perceived quality of a consumer should profoundly impact the consumer evaluation of a brand image [19, 20, 21, 22, 23, 24].

However, the preferences of the majority of consumers may also influence the brand-image score of a consumer. For details, Chang and Yang suggest that consumer perception as to whether the majority of consumers prefer the offerings of a firm should significantly influence the brand image of a consumer about the firm. From this perspective, consumers may determine the brand-image score based on their perception with respect to the perception of market share of one or more products. With this result, two assumptions of consumer behavior can be followed:

A1: The brand-image score of a consumer depends on his/her market share perception of the firm within a target market.

A2: The market share perception of a consumer about a new product depends on the ability to identify the portfolio of quality standards for this new product.

In general, the higher market share perception of a consumer about the offerings of a firm means that he/she perceives the majority of consumers prefer these offerings. Thus, A1 describes that the higher perception of market share of one or more products implies the higher brand image score of a consumer. Moreover, A2 describes that the higher quality of a new product may imply a higher best-selling perception of a consumer (i.e., a higher market share perception).

Based on the assumptions of this investigation regarding consumer behavior, consumers in a given target market are divided into Groups 1 and 2. Consumers in Group 1 assign brand-image scores to products of a particular firm based simply on their perceptions of the popularity of particular products offered by that firm. However, consumers in Group 2 determine the brand-image score based on their perceptions of the popularity of all the products offered by this firm. Based on this premise, further assume that the brand-image score for a consumer is assessed based on levels 0 and 1. For instance, consider consumers in Group 1 who believe that any product offered by a firm is reliable or give it a brand-image score at level 1 if they feel a specific new product is going to be best seller. However, these same consumers believe a product is unreliable or assign it a brand-image score at level 0 if they feel otherwise. Correspondingly, consider consumers in Group 2 who believe a product offered by a firm is reliable and assigns it a brand-image score at level 1 if they feel all new products are going to be best sellers. However, if these same consumers believe that a product is unreliable they will give it a brand-image score at level 0. Let z_j denote the market share for new product j. Based on the definition of z_j, $V(z_1,\cdots,z_j,\cdots,z_J)$ is further defined as the total anticipated number of consumers who give the new products a brand-image score at level 1 as the portfolio of market shares for all products is at level $(z_1,\cdots,z_j,\cdots,z_J)$. Still, $V_j(z_j)$ refers to the anticipated number of consumers in Group 1 who perceive that product j is a popular commodity as its market share is at level z_j, and $\beta(z_1,z_2,...,z_J)$ represents the anticipated number of consumers in Group 2 who perceive that all new products are best sellers once the portfolio of market shares is at level $(z_1,\cdots,z_j,\cdots,z_J)$. Correspondingly, $V(z_1,\cdots,z_j,\cdots,z_J)$ can be derived as the summation of consumers in Group 1 and Group 2 who assign the new products a brand-image score at level 1, indicated as follows:

$$V(z_1,z_2,\ldots,z_J)=\sum_j V_j(z_j)+\beta(z_1,z_2,\ldots,z_J) \tag{1}$$

Notably, the market share of a certain product offered by a firm defined here is determined based on the percentage of the number of products in the current market. Thus, z_j is a real number on interval [0,1] for any product j.

Assume there is a minimum value of market share, e.g., z_j^l, for each new product such that nearly all consumers in Group 2 perceive that all new products are best sellers as $z_j \ge z_j^l$ for all j. According to the definition of $\beta(z_1, z_2, ..., z_J)$, $\beta(1,1,...,1)$ denotes the maximum number of consumers in Group 2 who assign the new products a brand-image score at level 1. As mentioned earlier, consumers assign the new products a brand-image score at level 1 if they feel that the new products are going to be best sellers. Based on this postulation, the value of $\beta(z_1^l, z_2^l, ..., z_J^l)$ should closely approach the value of $\beta(1,1,...,1)$. Thus, this study further assumes that

$$\beta(1,1,...,1) - \beta\left(z_1^l, z_2^l, ..., z_J^l\right) < \varepsilon \qquad (2)$$

where ε is an extremely small number.

Next, consider a project selection problem with multiple choices of quality standards for each project. Whenever a quality standard is assigned to a project of a new product, a specific portfolio of cost and time intervals must be invested in. Therefore, if P is allowed to be a feasible portfolio of quality standards for all projects that satisfy the resource constraints and the value-based time limit conditions, then the framework of the proposed project selection model can be formulated simply as follows (according to A1-A2):

$$\underset{P \in \Omega}{\text{Maximize}} \; V(z_1, \cdots, z_j, \cdots, z_J) \qquad (3)$$

where Ω denotes the set consisting of all feasible portfolios of quality standards for the entire project.

Furthermore, with respect to using (2), the value of $\beta(z_1, z_2, ..., z_J)$ can be treated as a constant once the value of z_j is limited to the condition of more than the value of z_j^l. Because such a constant also denotes the maximum number of consumers in Group 2 who assign the new products a brand-image score at level 1, optimization problem (3) is almost equivalent to the following problem (4).

Ⅳ. A COMPUTABLE FORMULATION

4.1. The requirements of concerned problem

For the purpose of giving a computable formulation, this section first lists all requirements of our concerned problem as follows:

- Each project in a specific R&D category has multiple choices of quality-standards.
- The amount of budget available in a period constrains the quality-standard selection of a product.
- The remaining budget available from the previous period can be used in the next period.
- A multiple amount of cost is invested in each period for realizing a specific quality-standard of a project in a particular R&D new product.
- It is only permissible that the same amount of cost is invested in each period for realizing a specific quality-standard of a project in a specific R&D category.
- Despite an additional influx of funds for each period, the total cost for conducting all projects is limited to a certain budgetary amount.

A specific value-based time limit is associated with each R&D category, thus limiting the quality-standard selection of a product as well.

4.2. Notations

Again, a list of extra notations is given as follows:

Parameters

j Index of a R&D product, $j = 1,2,...,J$

k Index of a project related to a new product development. For example, $k = 1,2,\cdots,K_j$ corresponding to R&D product j;

l Index of a quality-standard related to a project in a R&D product development. For example, $l = 0,1,2,...,L_{jk}$ corresponding to project k in R&D product j;

w_{jkl} Weight with regards to project k contributing to the market share of new product j when the quality standard of project k is at level l;

M_{jk} Number of alternatives regarding the amount of cost investing in each period for project k in R&D category j (or new project j), $m = 1,2,\cdots,M_{ik}, \forall j$;

R_{jk}^m Amount of cost corresponding to alternative m of project k in R&D category j,

$m = 1,2,..., M_{ik}, \forall j,k$;

D^m_{jkl} Time period required for investment to the cost R^m_{jk} for achieving the goal at assigned quality-standard l for project k in R&D category j, $l = 0,1,2,..., L_{jk}$, $m = 1,2,\cdots, M_{ik}$;

B_0 Available budget for each period;

T_j Value-based time limit for each new product j, $j = 1,2,..., J$

ACB Total amount of available budget to conduct all projects;

Δ_j The remaining budget available once the projects in R&D product j are completed;

c^t_j The required cost at time t for conducting the projects in category j.

Decision variables

y^m_{jk} Binary variable that takes the value of 1 if periodical budget alternative m is adopted and 0 if otherwise, $m = 1,2,..., M_{ik}, \forall j,k$;

$\tilde{y}^l_{jk}$ Binary variable that takes the value of 1 if the selected quality-standard is at level l and 0 if otherwise, $l = 0,1,2,..., L_{jk}$ $\forall j,k$;

t_j Period of time required for investment in new product j;

b_j Average amount invested in each period for new product j;

S_{jk} Starting time of conducting project k in new product j;

f_{jk} Completion time of conducting project k in new product j;

S_j Initiation of projects in new product j (note that $S_j = t$ refers to new product j is initiated at the end of period $t-1$ or at the beginning of period t);

f_j Completion time of new product j (note that $f_j = t$ refers to new product j is completed at the end of period $t-1$ or at the beginning of period t)

4.3. Generating the periodical budget constraints

The model is further formulated by first determining the sequence of R&D products, while assuming that a larger product-index j implies a longer time horizon of T_j; in addition, a larger value of T_j implies a lower priority for investing in this R&D product. Therefore, it yields that $S_1 = 0$ and $S_j = f_{j-1}, j = 2,\cdots, J$. However, assume that R^m_{jk} is non-decreasing in D^m_{jkl}. Based on this premise, this work further defines Δ_j as follows:

$$\Delta_j = B_0 t_j + \Delta_{j-1} - b_j t_j,\ j = 1,\cdots, J$$

and

$$\Delta_0 = 0$$

The value of Δ_j refers to the remaining budget available once the projects in R&D product j are completed. Given the technical complexity of the proposed problem, this work considers only a schedule in which a project starts at the latest time under a given invariant schedule-duration of the program involving all projects, thus allowing us to formulate a model by using mathematical programming and obtaining a nearly optimal solution. In this case,

$$S_{jk} = f_j - \sum_{l=0}^{L_{jk}} \sum_{m=1}^{M_{jk}} D^m_{jkl} \cdot y^m_{jk} \cdot \tilde{y}^l_{jk}, \forall j,k. \quad (5)$$

and

$$f_{jk} = f_j, \forall j,k \quad (6)$$

Therefore, a feasible project schedule must satisfy the following constraint:

$$\sum_{t=S_j}^{\tilde{t}} c^t_j \le B_0 \cdot (\tilde{t} - S_j + 1) + \Delta_{j-1},\ S_j \le \tilde{t} \le f_j - 1 \quad (7)$$

Where c^t_j denotes the required cost at time t for conducting the projects in category j.

Because R^m_{jk} is non-decreasing in D^m_{jkl}, it yields

$$\sum_{t=S_j}^{\tilde{t}} c^t_j \le b_j \cdot (\tilde{t} - S_j + 1) + \Delta_{j-1},\ S_j \le \tilde{t} \le f_j - 1 \quad (8)$$

Therefore, for a project schedule that satisfies the condition of $b_j \le B_0$, this solution also satisfies the condition of (7).

4.4. The proposed computable model

Therefore, the multi standard and multiple resource allocation model can be approximately formulated as follows:

Objective Function:

$$\text{Maximize } \tilde{V} = \sum V_j(z_j) \quad (9)$$

Subject to

$$z_j = \sum_{l=0}^{L_{jk}} \sum_{k=1}^{K_j} \sum_{m=1}^{M_{jk}} w_{jkl} \cdot \tilde{y}^l_{jk} \cdot y^m_{jk}, \forall j \quad (9.1)$$

$$z_j \ge z^l_j, \forall j \quad (9.2)$$

$$\sum_{k=1}^{K_j}\sum_{l=0}^{L_{jk}}\sum_{m=1}^{M_{jk}}\sum_{d=1}^{D_{jkl}^m} R_{jk}^m \cdot D_{jkl}^m \cdot y_{jk}^m \cdot \tilde{y}_{jk}^l = b_j \cdot t_j, \forall j \quad (9.3)$$

$$t_j \geq \sum_{l=0}^{L_{jk}}\sum_{m=1}^{M_{jk}} D_{jkl}^m \cdot y_{jk}^m \cdot \tilde{y}_{jk}^l, \forall j,k \quad (9.4)$$

$$\sum_{j=1}^{J} b_j \cdot t_j \leq ACB \quad (9.5)$$

$$b_j \leq B_0, \forall j \quad (9.6)$$

$$S_{jk} = f_j - \sum_{l=0}^{L_{jk}}\sum_{m=1}^{M_{jk}} D_{jkl}^m \cdot y_{jk}^m \cdot \tilde{y}_{jk}^l, \forall j,k \quad (9.7)$$

$$f_{jk} = f_j, \forall j,k \quad (9.8)$$

$$f_j = \sum_{i=1}^{j} t_i, \forall j \quad (9.9)$$

$$S_1 = 0 \quad (9.10)$$

$$S_j = f_{j-1}, \forall j \geq 2 \quad (9.11)$$

$$f_j \leq T_j, \forall j \quad (9.12)$$

$$\sum_{l=0}^{L_{jk}} \tilde{y}_{jk}^l = 1, \forall j,k \quad (9.13)$$

$$\sum_{m=1}^{M_{jk}} y_{jk}^m = 1, \forall j,k \quad (9.14)$$

$$y_{jk}^m = 0,1 \;\; m = 1,2,\ldots, M_{jk}, \forall j,k \quad (9.15)$$

$$\tilde{y}_{jk}^l = 0,1 \;\; d = 1,2,\ldots, L_{jk}, \forall j,k \quad (9.16)$$

$$b_j \geq 0, \forall j \quad (9.17)$$

$$t_j \geq 0, \forall j \quad (9.18)$$

where (9.1) warrants the consistency of definitions regarding the market share of a new product; (9.2) ensures that the market share z_j^l is expected realized at very least; (9.3) warrants the consistency of the definitions regarding the amount of cost invested in a new product; (9.4) ensures that the time period invested in a specific new product satisfies the requirements of each project in this category; (9.5) ensures that the amount of cost invested in all R&D categories does not exceed the total available budget; (9.6) ensures that the average amount of cost invested in each period for new product j does not exceed the amount of the available budget for each period; (9.7)-(9.11) warrants the consistency of the definitions regarding the starting time and completion time of a project; (9.12) ensures that the completion time of a new product does not exceed the associated value-based time limit; (9.13) ensures just a level of quality-standard is assigned to a project and (9.14) ensures only that a level of quality standard is assigned to a project. Notably, the result of $\tilde{y}_{jk}^0 = 1$ implies that project k in new product j is not selected; in addition, the subsystem k of product j is not developed or upgraded as well. Therefore, after the above model is derived, our results indicate the projects selected in each new product, the quality standards assigned each project in a particular new product, and the baseline schedule for implementing the chosen projects.

4.5. Evaluation of model parameter w_{jkl}

Let N_j denote the anticipated consumer population for purchasing product j in a target market; N_{jk} denote the anticipated consumer population for making a decision regarding purchase of product j, which depends on the quality standard of subsystem k. Furthermore, let N_{jkl}^e denote the anticipated consumer population for making a decision as whether to purchase product j, as offered in the firm, while assuming that the assigned quality standard of subsystem k is at the level $l\,(1 = 1,2,\cdots,L_{jk})$. The value of w_{jkl} can then be obtained based on the following formula:

$$w_{jkl} = \frac{N_{jk}}{N_j} \cdot \frac{N_{jk}^e}{N_{jk}} = \frac{N_{jkl}^e}{N_j} \quad (10)$$

After the value of parameter w_{jkl} is obtained, the value of parameter u_{jkl} can also be obtained by estimating the value of w_{jkl}/w_{jk}. Notably, despite the possible difficulty in obtaining the actual individual values of N_j and N_{jkl}^e, a questionnaire method can be easily adopted to evaluate $\frac{N_{jkl}^e}{N_j}$.

V. FURTHER CONSIDERATION OF OBJECTIVE FUNCTION

The function form of $V_j(z_j)$ must be determined first to derive the proposed problem.

For simplicity, $w_{jk,L_{jk}}$ is replaced with w_{jk}. Considering $V_j(z_j)$ can be approximated by a linear function and letting $V_j(z_j)=w_j z_j$, $z_j \in \left(0, \sum_k w_{jk}\right]$.

Because the evaluation of parameter w_j is quite difficult in application, we further transform objective function (9) to a particular closed form. This transformation attempts not only to estimate parameters more easily but also to provide the objective value a clear managerial implication. The details related to this transformation are as follows:

First, a situation is considered in which there exists a strictly increasing function, e.g., u_{jkl}, such that $w_{jkl}=w_{jk}u_{jkl}$, where $0 \le u_{jkl} \le 1$ and $u_{jk0}=0, u_{jk,L_{jk}}=1$. Notably, the target market share of new product j is the value of $\sum_k w_{jk}$. Additionally, introducing parameter u_{jkl} may help decision-makers to understand the percentage of realizing w_{jk}.

Furthermore, let $\tilde{w}_{jk}$ denote the normalized weight so that

$$\tilde{w}_{jk} = \frac{w_{jk}}{\sum_m w_{jm}} \tag{11}$$

According to (11), constraint (9.1) can be rewritten as

$$\tilde{z}_j = \sum_{l=0}^{L_{jk}} \sum_{k=1}^{K_j} \sum_{m=1}^{M_{jk}} \tilde{w}_{jk} u_{jkl} \cdot \tilde{y}_{jk}^{l} \cdot y_{jk}^{m}, \forall j \tag{12}$$

Notably, $\tilde{z}_j$ can be predicated as the percentage of achieving the target market share of new product j (i.e. $\sum_k w_{jk}$). Similarly, constraint (9.2) can be rewritten as

$$\tilde{z}_j \ge \frac{z_j^l}{\sum_k w_{jk}}, j=1,2,\ldots,J \tag{13}$$

Let $\tilde{N}_j$ be the expected consumer population in Group 1 for giving the brand-image score at level 1 as the market share is at the value of $\sum_k w_{jk}$ about new product j, $Y_j(z_j)$ be the expected percentage of consumer population in Group 1 for giving the brand-image score at level 1 as the market share is at the value of z_j, and $Y_j(z_j)=\alpha_j z_j$. Based on of above results, it yields

$$\text{Maximize} \sum V_j(z_j) = \text{Maximize} \sum \frac{V_j(z_j)}{\tilde{N}_j} \cdot \frac{\tilde{N}_j}{\sum \tilde{N}_i} = \text{Maximize} \sum \frac{\tilde{N}_j}{\sum \tilde{N}_i} Y_j(z_j)$$

$$\text{Maximize} \sum \alpha_j \cdot \frac{\tilde{N}_j}{\sum \tilde{N}_i} z_j = \text{Maximize} \sum \alpha_j \cdot \frac{\tilde{N}_j}{\sum \tilde{N}_i} \cdot \sum_k w_{jk} \cdot \frac{z_j}{\sum_k w_{jk}}$$

$$= \text{Maximize} \sum \alpha_j \cdot \frac{\tilde{N}_j}{\sum \tilde{N}_i} \cdot \sum_k w_{jk} \cdot \tilde{z}_j = \text{Maximize} \sum \tilde{w}_j \cdot \tilde{z}_j$$

where $\tilde{w}_j$ refers to the normalized weight of $\alpha_j \cdot \frac{\tilde{N}_j}{\sum \tilde{N}_i} \cdot \sum_k w_{jk}$.

Based on above results, the proposed objective function (9), and constraint (9.1)-(9.2) can be rewritten as follows:

$$\mathit{Maximize} \sum_{j=1}^{J} \tilde{w}_j \tilde{z}_j \tag{14}$$

Subject to

$$\tilde{z}_j = \sum_{l=0}^{L_{jk}} \sum_{k=1}^{K_j} \sum_{m=1}^{M_{jk}} \tilde{w}_{jk} u_{jkl} \cdot \tilde{y}_{jk}^{l} \cdot y_{jk}^{m}, \forall j \tag{14.1}$$

$$\tilde{z}_j \ge \frac{z_j^l}{\sum_k w_{jk}}, j=1,2,\ldots,J \tag{14.2}$$

Importantly, $\tilde{w}_j$ and z_j^l can be evaluated by designing a questionnaire to obtain consumer-related information in Group 1 or Group 2. For instance, consider two new products A and B. A consumer can be instructed to answer the following question: "What circumstance influences their brand image?". If claiming that the popular new products are either A or B, a consumer can be classified as belonging to Group 1. However, if claiming that the popular new products are both A and B, this consumer can be classified as belonging to Group 2. Moreover, a second problem can request a consumer to answer a question regarding how to obtain $\tilde{w}_j$ and z_j^l. The question is "What is the minimum size of a market share for a particular new product in order to enable them to consider this new product popular?". The values of $\frac{\tilde{N}_j}{\sum \tilde{N}_i}$ can be estimated by utilizing the data related to the above two questions. The values of α_j can be estimated by utilizing the simple regression method and the data related to the above two questions. On the other hand, one can obtain the $\tilde{w}_j$ value by computing and normalizing the multiplication of the estimated values of α_j, $\frac{\tilde{N}_j}{\sum \tilde{N}_i}$, and $\sum_k w_{jk}$. Notably, z_j^l can also be evaluated by some methods after the information related to the above two questions are obtained. For instance, one may evaluate the value of z_j^l by computing the median or average value of observed samples.

Moreover, according to the definitions of related notations, we know that $\alpha_j \cdot \tilde{N}_j \cdot \sum_k w_{jk}$ is the target performance of brand-prestige creation for product j (i.e., $\alpha_j \cdot \tilde{N}_j \cdot \sum_k w_{jk} = w_j \sum_k w_{jk}$). Based such results and the fact that $\sum \tilde{N}_i$ is a constant in the normalized process of parameter $\alpha_j \cdot \frac{\tilde{N}_j}{\sum \tilde{N}_i} \cdot \sum_k w_{jk}$, it yields that $\sum_{j=1}^{J} \tilde{w}_j \tilde{z}_j$ is the percentage of realizing the overall target performance of brand-prestige creation (i.e., $\sum_j w_j \sum_k w_{jk}$).

To conclude, such transform for w_j to $\tilde{w}_j$ and z_j to $\tilde{z}_j$ not only transform original model (9)-(9.18) into a real solvable form but also provide the objective value a clear managerial implication.

Ⅵ. ILLUSTRATIVE EXAMPLE

This section demonstrates the effectiveness of the proposed model using an example involving new car development. Decision makers select the most appropriate projects and related quality standards to maximize consumer judgments regarding brand-image. Consumer criteria for purchasing a car typically vary with individual preference. For instance, consumer criteria for purchasing a specific car may include the power engine system, body and dimension, and security system. Car styles are adopted here as an example, and the cars are divided into five products, namely sedans, hatchbacks, SUVs, minivans, and coupes. Each new product includes three projects with the intention of redesigning/upgrading a specific subsystem of a car type (Table 2). Table 2 also lists the parameters of $\tilde{w}_j$ and $\tilde{w}_{jk}$. The value of z_j^l for $j = 1,2,\ldots,5,$ is given by 0.17, 0.1, 0.18, 0.1, and 0.19. Table 3 lists the values of u_{jkl}. Table 4 shows the periodical costs and the period required to invest in a project in order to achieve a specific assignment of a quality standard.

Given $B_0 = 14$, $ACB = 200$, T_j for $j = 1,2,\ldots,5,$ is given by 5, 10, 14, 17, 21 as well as α_j for $j = 1,2,\ldots,5,$ is given by 0.35, 0.6, 0.4, 0.3, and 0.2, the values of I_{jkl}, t_j, b_j, S_{jk}, f_{jk}, S_j, f_j can be obtained (Table 5), as indicated from the data of Tables 2, 3 and 4 (LINGO 8.0 was used to do so). Figure 5 summarizes the results of Table 5. For illustration, the selected projects in new product 4 (i.e., Box car) are project 2 (upgrade the load of car) and project 3 (redesign of Body & dimension). The quality standards assigned for these two projects are all at level 2. In addition, the execution order of each new product (NP) is NP1→NP2→NP3→NP4→NP5.

Table 2. Projects of the category of car types

Category j ($\tilde{w}_j$)	Sedans (C1) 0.2	Hatchbacks (C2) 0.3	SUVs (C3) 0.25	Minivans (C4) 0.15	Coupes (C5) 0.1
P_{jk} Projects (w_{jk})	P11 Engine system (0.7)	P21 Suspension system (0.5)	P31 Engine system (0.55)	P41 Engine system (0.6)	P51 Suspension system (0.4)
	P12 Body & dimension (0.35)	P22 Engine system (0.75)	P32 Suspension system (0.5)	P42 Transmission system (0.6)	P52 Engine system (0.6)
	P13 Transmission system (0.35)	P23 Safety system (0.4)	P33 Body & dimension (0.35)	P43 Body & dimension (0.5)	P53 Body & dimension (0.5)

Table 3. Percentage of realization of w_{jk} (i.e., u_{jkl})

	New product 1			New product 2			New product 3			New product 4			New product 5		
	P11	P12	P13	P21	P22	P23	P31	P32	P33	P41	P42	P43	P51	P52	P53
l 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.4	0.5	0.6	0.4	0.5	0.7	0.5	0.5	0.5	0.3	0.5	0.4	0.5	0.4	0.5
	0.6	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.8	0.8	0.7	0.8	0.6	0.7
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

However, the time periods invested in sedans, hatchbacks, SUVs, minivans and coupes are 4, 4, 4, 4 and 3 units, respectively. Finally, the total cost required to achieve the assigned quality standards of these two projects is 30 units, which are obtained by calculating the value of $b_4 \cdot t_4$.

Table 4. Periodical cost and the period required to invest in a project for achieving a specific assignment of quality-standard

Standards	New product 1									New product 2								
	P11			P12			P13			P21			P22			P23		
	Budget amount									Budget amount								
Period	3	4	5	4	5	6	5	6	7	3	4	5	3	4	6	5	6	7
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1
3	0	1	1	0	1	1	0	1	1	0	0	1	0	0	1	1	1	1
4	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1
5	1	1	2	1	2	2	1	1	1	1	1	1	1	1	2	1	2	2
6	1	2	2	1	2	2	1	1	2	1	2	2	1	2	2	2	2	2
7	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2
8	2	2	3	2	2	3	2	2	3	2	2	2	2	2	3	2	2	3
9	2	3	3	3	3	3	2	3	3	2	3	3	2	3	3	2	3	3
10	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Standards	New product 3									New product 4									New product 5								
	P31			P32			P33			P41			P42			P43			P51			P52			P53		
	Budget amount									Budget amount									Budget amount								
Period	4	5	6	3	5	6	3	4	6	3	4	5	2	3	5	5	6	7	2	4	5	4	6	7	3	4	5
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	1	1	1	0	0	1	0	0	1	0	0	1
3	0	1	1	0	1	1	0	1	2	1	1	1	0	1	1	1	2	2	0	1	1	0	1	2	1	1	1
4	1	1	1	0	1	2	1	1	2	1	1	2	1	1	2	2	2	2	1	1	2	1	1	2	1	1	2
5	1	1	2	1	1	2	1	2	2	1	2	2	1	1	2	2	2	2	1	2	2	1	2	2	1	2	2
6	1	2	2	1	2	2	2	2	3	2	2	2	2	2	2	2	2	3	2	2	3	2	2	2	2	2	2
7	2	2	3	1	2	2	2	2	3	2	2	3	2	2	3	2	3	3	2	3	3	2	2	3	2	2	2
8	2	3	3	2	2	3	2	3	3	3	3	3	2	3	3	3	3	3	2	3	3	2	3	3	2	3	3
9	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
10	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Table 5. Values of decision variables for the proposed model

	New product 1	New product 2	New product 3	New product 4	New product 5
Project selected (level)	P11(2), P12(1)	P21(1), P22(2), P23(1)	P31(1), P32(2), P33(2)	P42(2),P43(2)	P51(2)
b_j	12.5	10	13.5	7.5	4
t_j	4	4	4	4	3
S_{jk} (project)	0	4(P21),4(P22) 6(P23)	10(P31),8(P32), 9(P33)	12(P42),14(P43)	16(P51)
f_{jk} (project)	4	8(P21),8(P22) 8(P23)	12(P31),12(P32), 12(P32)	16(P42),16(P43)	19(P51)
S_j	0	4	8	12	16
f_j	4	8	12	16	19

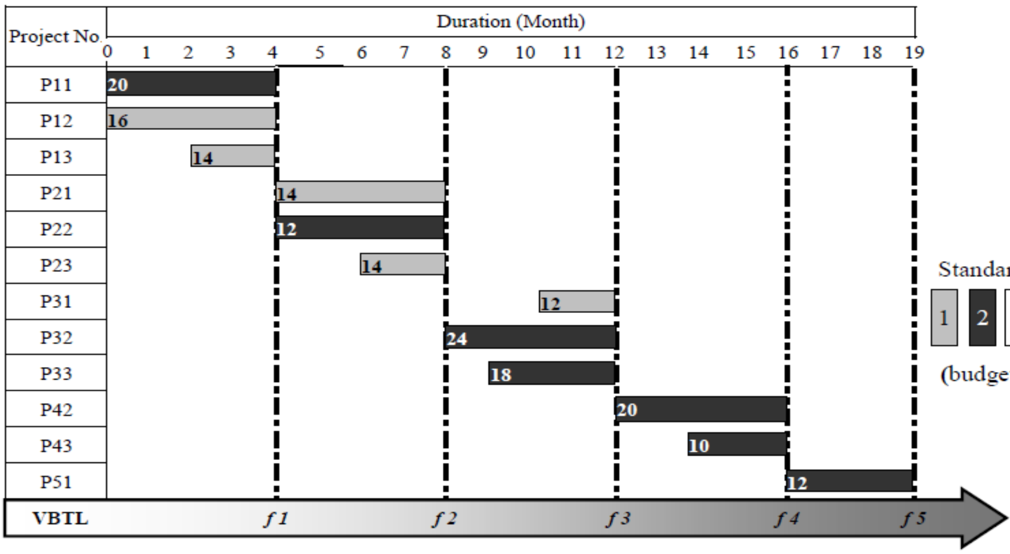

Fig.5. Project schedule of this example

Ⅶ. DISCUSSION AND CONCLUSION

The problem of new product development under budgetary constraints can be formulated as a R&D project selection problem. Conventional budget-constrained R&D project selection problems fail to consider circumstances in which multiple quality standards are assigned for each project; the costs required to be periodically injected for a project to achieve a specific quality-standard; and the contribution of a project is limited to time horizon. In addition to the above mentioned tangible factors, previous studies regarding a R&D project selection problem have also failed to consider intangible factors that influence the project performance such as the managerial and control capabilities of decision makers. Obviously, such a study cannot respond entirely to all practical elements. While taking the above factors into account, this study has developed an approach to project selection for a new product development program. We release four issues that involving the theoretical and practical contributions of the proposed approach to discuss as follow:

First, most consumer evaluation studies of a brand image suggested that perceived quality of a consumer should profoundly impacts the consumer evaluation of a brand image. However, individual consumption of a consumer and the preferences of the majority of consumers largely influence perceived quality. Therefore, this work assumes that consumer perception as to whether the majority of consumers prefer the offerings of a new product can significantly influence the brand image of a consumer. From this view, consumers may determine the brand-image score based on their perception with respect to the perception of market share of one or more products. Moreover, this work considers two consumer types (i.e., Group 1 and Group 2), the results of the proposed model significantly contribute to new product development literature.

Second, past studies on project selection model normally consider only total budget constraints during the duration of all projects. In contrast with above, this model considers the selection of quality-standard and resource-allocation proposal of a project under constrained project duration and constrainedly periodical budget. Subject to technique complexity, this work considers only the schedule solution in which a project starts at the latest time under the invariant schedule duration. Therefore, the schedule solution derived by the proposed model may fail to provide buffer time for each project. However, our results provide a valuable reference for future research efforts that consider the above factors.

Third, most project selection studies fail to concurrently consider the scheduling problem. In contrast to, in this project selection model, we not only proposed the scheduling problem but involved the factors such as the quality standard assigned for each project, in which multiple grades are available and the resource-allocation and time limited considerations to achieve a specific quality-standard of a project are multiple proposals available.

Finally, we provide a closed form of objective function in which not only parameters can be estimated more easily but the objective value can be predicated as a clear managerial implication. Therefore, the proposed 4-component approach is obviously useful in terms of project selection practices, especially for new product development.

In conclusion, the proposed model can find the portfolio of quality standards for new products and their associated optimal schedule, which maximizes the expected brand-image score of consumers, which benefits the long-run average profitability. Therefore the refinement of this study may increase long-run average profitability. Owing to that this work does not consider a case in which type I mixed advancement strategy serves as a project scheduling framework and buffer time for projects, future research should more closely examine this issue.

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