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Multi-category and Multi-standard Project Selection under Constrainedly Periodical Budget and Ambiguous Value-based Time Limit

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Abstract

This paper considers the differentiation of each new product development program as multiple categories. Each R&D category involves redesigning/upgrading a specific current product. Each project has multiple choices of quality/technology standards. This work propose an approach to treat the multi-category and multi-standard 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 brand-image score of consumers as the objective function for ultimately increasing long-run average profitability, (3) formulating a computable model in which periodical budget constraints are involved and ambiguous value-based time limits are specified, and (4) transforming the objective function into an appropriate form in which the parameters can be estimated more easily and the objective value can be predicated as a clear managerial implication.

Keywords: New product development, project selection and scheduling, multi-choice of quality standards, brand image

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具預算限制及模糊價值期限下之多類別與多等級之專案選擇

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摘要

本文將新產品開發（new product development）的計畫區分為多種研發（R&D）類別。每種研發類別代表著一種可以再設計 / 升級（redesigning/upgrading）的特定產品。類別當中的每項專案執行品質（技術）都擁有多重的等級可供選擇。鑑此，本文提出一個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。本文的內容係由四個部分組成：(1) 專案推移策略的選擇係專案排序時考量軟性因素做為專案排程的架構，(2) 將消費者對產品的品牌印象引用為長期的平均獲利最大化之目標函數，(3) 將週期性預算限制及模糊價值期限轉換為一可計算之模式，(4) 轉換目標函數轉換為一適當格式，以使參數更容易被估計，進而使最終結果被解釋為具管理意涵的內容。

關鍵詞：新產品開發、專案選擇與排程、多重品質等級選擇、品牌印象

1. Introduction

One way for a firm to maintain an advantage over its rivals is continually developing new products. This requires a new product development (NPD) strategy at the core of its business efforts. NPD is the process by which an organization uses its resources and capabilities to create a new product or improve an existing one (Lynne, 2003). A potential source of competitiveness for many firms, NPD allows organizations to transform data on market opportunities and technical possibilities into commercial valuable information assets (Clark and Fujimoto, 1991). Accordingly, companies using NPD can improve their performance in new product development, and newly developed products can become a key factor to their ongoing success. However, R&D project selection and resource allocation among projects determine the success of NPD (Pedro and Francisco, 2009; Robert et al., 1999; Rutsch et al., 2006). 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. Again, each project involves multiple choices regarding quality/technology standards. R&D project selection under budgetary constraints typically fails to consider the periodic need for a budget, or that the budget available in each period limits product quality standard selection (Cooper and Kleinschmidt, 1988; Hall and Nauda, 1990; Henriksen and Palocsay, 2008; Meade and Presley 2002; Nishihara and Ohyama, 2008). Furthermore, such projects also fail to consider that the contribution of a R&D project/category is limited to a specific time horizon, referred to hereafter as ‘the value-based time limit’ since a manifest value-loss occurs if a specific product is developed after the offerings of key competitors. Notably, the value-based time limit is usually vague. To conclude, the conventional project selection model cannot apply to certain real world NPD scenarios.

Besides the above NPD practices, most traditional project selection models also fail to simultaneously consider project scheduling. Sun and Ma (2005) 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 (Lichtenstein et al., 1993). “Brand Image” has also been identified as the key determinant of consumer purchase decisions. Restated, consumer brand image clearly influences their purchase intention (Fichter and Jonas, 2008; Kwon and Sharron, 2009; Maxwell et al., 2008). 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 and Chen (2007) 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 (2011) to establish a measurement measure of consumer brand-image. Indeed, Chang and Yang (2011) suggested 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.

2. The Problem and Advancement Strategy

2.1 The Problem Descriptions

The firm should apply the concepts described above in product development under scheduling and deadline for avoid trailing to competitors in launching new product offerings to the market. Thus, the specified time of offering new products to the market should be considered concurrently with budgetary investment in R&D projects. Furthermore, the execution and decision ability of project leaders must affect the executive results. As described above, this study aims to construct a model for project selection and investment scheduling that incorporates intangible factors (for example, the ability of the project leader), periodic budget constraints and that simultaneously consider the value-based time limit. To achieve this, this study extends the definition presented by Chang and Chen (2007) of the mathematic scheduling framework of Types II mixed advancement strategies. Additionally, this work assumes that product market share affected consumer perceptions of brand image. Consumer perception of brand image affects repurchases intention and thus long-term average profitability. Accordingly, this study employs consumer perceptions of brand-image as the objective function of the decision. Furthermore, the budget investment almost has periodicity, and the R&D products must be completed within the specified time. Accordingly, this investigation formulated a computable model that involves periodical budget constraints and specifies ambiguous value-based time limits. Finally, practicality demands the model parameters be easy to estimate. The objective function thus is transformed into an appropriate form in which the parameters can be estimated more easily and the objective value lies in its clear implications for management.

Based on above-mentioned, there are bad or good brand-image to products that is depending on the quality-standard of R&D projects to select. Thus, the definition of quality-standard to this work is 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, $j=1, 2, \ldots, J$ Assume there are multiple choices of quality-standards for project k in product j, numbered by levels 0, 1, ..., 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, fuel consumption, and torque. 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 160hp, 13.4km/l, and 20.3kg-m. Again, the ideal quality standard of the engine system that the manufacturer hopes to promote is the portfolio of indicator values 169hp, 14.9km/l, and 23.1kg-m.

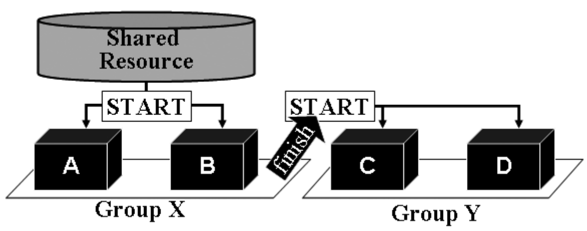
▼ Table 1　The level of quality-standards for indicators

Indicators \ Quality-standards	level 0	level 1	level 2	level 3 (L_{jk})
Horsepower (hp)	160	163	166	169
Fuel consumption (km/l)	13.4	13.7	14.3	14.9
Torque (kg-m)	20.3	20.9	21.6	23.1

2.2　The 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 and Chen (2007) 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 to help in their application to the proposed problem, as described below.

The centralized sequential advancement strategy (CSAS) refers to the centralization of the available periodical budget into a R&D project, and making leftover budget from previous periods available for use in subsequent periods. Furthermore, the periodical budget is transferred to another project once the project achieves its assigned quality standard. The decentralized synchronized advancement strategy (DSAS) scenario, the same as CSAS, is presented, which refers to decentralizing the available periodical budget into all R&D projects until all projects achieve their assigned quality standards. Again, the allocated policy for each period may vary owing to the variable cost of investment in different projects. Types I and II mixed advancement strategies (Type I, Type II MAS): When considering projects A, B, C and D, the four projects are divided into two categories: {A & B} and {C & D}, termed “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. Meanwhile, type II MAS refers to deploying the DSAS within categories X and Y, while moving ahead between categories X and Y with CSAS, namely periodically transferring the budget to the projects in category Y for the assigned quality standards of all projects in category X, as shown in Figure 1.



▲ Figure 1 The chart of Type II MAS

This study suggests that one should borrow a project advancement strategy to solve problems caused by intangible factors, to maximize performance during project implementation. 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 the project leader, leading to growth in 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, which reduces progress and quality variation. However, these strategies are less efficient in resource utilization. Additionally, the new product may have inferior quality standards when the time horizon involving the decision maker has elapsed, reducing competitiveness. In practice, these strategies are selected based on what has been set up the situation and made actually the set up and actual situation. This work focuses only on the type II MAS model.

3. Scheduling Framework and Decision Objective

3.1 Scheduling Framework

As discussed in the introduction, consumer image of a brand obviously influences their purchase intention. Thus, a firm may have high average long-term profitability if its associated decision makers provide new products by creating long-term brand image. Based on this premise, this study employs consumer expected brand-image scores as the objective function for ultimately increasing long-run average profitability. Most consumer evaluation studies of brand image suggested that consumer perceptions of quality should strongly influence consumer assessments of brand image (Alan et al., 1996; Colleen and Tara, 2003; Frank et al., 2006; Israel and Eugene, 1996; Martin, 1995; Ming, 2002; Timothy, 1997). However, the preferences of the majority of consumers strongly influence perceived quality (Chang and Yang, 2011). From this perspective, consumers may determine the brand-image score based on their perceptions of the market share of one or more products. Consequently, two assumptions can be made regarding consumer behavior:

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

A2: Consumer perceptions of the market share of a new product depend on their ability to identify the portfolio of quality standards of that new product.

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 assign 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, $V(z_1, ..., z_j, ..., z_J)$ 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 $(z_1, ..., z_j, ..., z_J)$. 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 $(z_1, ..., z_j, ..., z_J)$. Correspondingly, $V(z_1, ..., z_j, ..., z_J)$ 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:

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

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.

3.2 The Decision Objective

Assume there is a minimum value of market share, e.g., z^l_j, for each new product such that nearly all consumers in Group 2 perceive that all new products are best sellers as $z_j \geq z^l_j$ 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 $\beta(z^l_1, z^l_2, ..., z^l_J)$ should closely approach the value of $\beta(1, 1, ..., 1)$. Thus, this study further assumes that

$$\beta(1,1,\ldots,1) - \beta\left(z_1^l, z_2^l, \ldots, z_J^l\right) < \varepsilon \tag{2}$$

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):

$$\underset{P\in\Omega}{\text{Maximize}} \quad V(z_1,\ldots,z_j,\ldots,z_J) \tag{3}$$

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 $\beta(z_1, z_2, \ldots, z_J)$ 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).

$$\underset{\substack{P\in\Omega \\ z_j \ge z_j^l, \forall j}}{\text{Maximize}} \quad \tilde{V}(z_1,z_2,\ldots,z_J) = \sum_{j=1} V_j(z_j) \tag{4}$$

4. 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.
- A specific value-based time limit is associated with each R&D category, thus limiting the quality-standard selection of a product as well.
- The non-equal amount of cost is invested in each period for realizing a specific

quality-standard of a project in a particular R&D new product.

- The remaining budget available from the previous period can be used in the next period.
- There exists only a portfolio of the cost and period to realize a specific quality-standard of a project in a specific R&D new product.
- Despite an additional influx of funds for each period, the total cost for conducting all projects is limited to a certain budgetary amount.

4.2 Notations

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

Parameters

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;
D_{jkl}	Number of periods required to invest in cost for achieving quality-standard l of project k in new product j, $l=0, 1, 2, ..., L_{jk}$;
R^d_{jkl}	Amount of cost required to invest in d-th period for achieving the quality-standard l for project k in new product j, $l=0, 1, 2, ..., L_{jk}$, $d=1, 2, ..., D_{jkl}$;
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

I_{jkl}	Binary variable that takes value 1 if the assigned quality-standard is at level l for project k in new product j, and 0 if otherwise;
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 $S_j=f_j-1$, $j=2$, ..., J. However, assume that R^d_{jkl} is non-decreasing in d for any j, k, l. Based on this premise, this work further determines Δ_j value as follows:

$$\Delta_j = B_0 t_j + \Delta_{j-1} - b_j t_j,\ j = 1,\ldots,J \tag{5}$$

And the value of Δ_j refers to the remaining budget available once the projects in R&D product j are completed, then $\Delta_0=0$.

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,

$$S_{jk} = f_j - \sum_{l=0}^{L_{jk}} D_{jkl} \cdot I_{jkl}, \forall j,k. \tag{6}$$

and

$$f_{jk} = f_j, \forall j,k \tag{7}$$

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

$$\sum_{t=S_j}^{\tilde{t}} c_j^t \le B_0 \cdot (\tilde{t} - S_j + 1) + \Delta_{j-1}\ ,\ S_j \le \tilde{t} \le f_j - 1 \tag{8}$$

Because R^d_{jkl} is non-decreasing in d or any j, k, l, it yields

$$\sum_{t=S_j}^{\tilde{t}} c_j^t \le b_j \cdot (\tilde{t} - S_j + 1) + \Delta_{j-1},\ S_j \le \tilde{t} \le f_j - 1 \tag{9}$$

Therefore, for a project schedule that satisfies the condition of $b_j \le B_0$, this solution also satisfies the condition of (8).

4.4 Specifying Fuzzy Value-based Time Limit

For the purpose of giving a computable formulation, this section considers our concerned problem that completion time of new product j is no more than the value-based time limit, e.g., $f_j \leq T_j$, and T_j is a fuzzy number. Furthermore, as is generally assumed, the decision-makers treat the parameter of value-based time limit as an ambiguity parameter. Interviewing the decision-maker in charge of process control, the ambiguous value-based time limit is expressed as a fuzzy number. For example, the value-based time limit of new product 1 described with linguistic expression "about 10 time units", e.g., a, can be restricted by a fuzzy number A with the membership function,

$$\mu_A(r) = \max\left(0,\ 1 - \frac{|r-10|}{0.6}\right) \tag{10}$$

For simplicity, we deal the problem with symmetric triangular fuzzy numbers. Then, this paper restrict to describing the essence of fuzzy mathematical programming with possibilistic linear programming. A possibilistic linear function value cannot be determined uniquely since its coefficients are ambiguous, i.e., non-deterministic (Inuiguchi and Ramík, 2000).

The fuzzy number A is depicted in Figure 2. As shown in Figure 2, "10" is the most plausible value for fuzzy number A as it takes the highest membership value. The membership value of the fuzzy number A, $\mu_A(r)$, shows the possibility degree of the event that the value-based limit time of new product 1 when A is r. In this sense, μ_A can be considered as a possibility distribution of the value-based time limit of new product 1 and r can be regarded as a possibilistic value restricted by the possibility distribution μ_A.

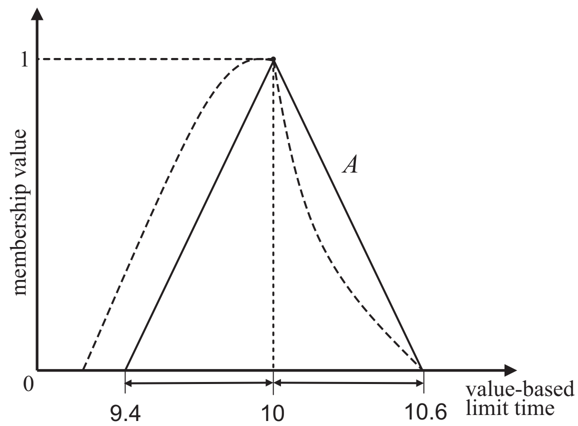
Moreover, the necessity measure of a fuzzy number is defined as follows (Inuiguchi and Sakawa, 1995):

$$\mathrm{Nes}(A \geq \mathrm{g}) = 1 - \sup(\mu_A(r) \,|\, r < g) \tag{11}$$

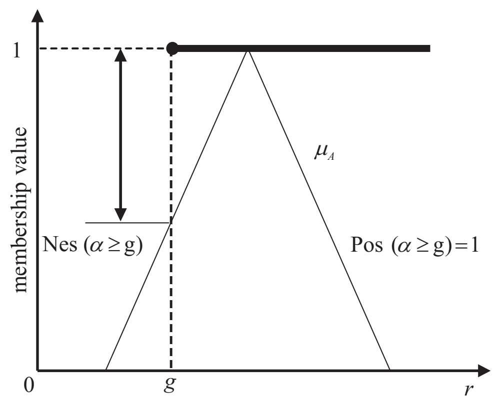
where μ_A is the membership function of the fuzzy number A. Thus Nes($A \geq g$) show the minimum possible degree to what extent A is bigger than g, as shown in Figure 3.

Moreover, we assume that the value-based time limit T_j obeys a normal distribution $N(m_j, \sigma_j^2)$ with mean m_j and the variance σ_j^2. Thus, the probability density function $f_{T_j}(r)$ is defined by

$$f_{T_j}(r) = \frac{1}{\sqrt{2\pi}\sigma_j}\exp\left(-\frac{(r-m_j)^2}{2\sigma_j^2}\right) \tag{12}$$



▲ Figure 2　A symmetric triangular fuzzy number<10, 0.6>



▲ Figure 3　Minimum possible degree of $A \geq g$

As a result of above mention, we have normal fuzzy number T_j with the membership function can be defined as follow (Inuiguchi and Ramík, 2000):

$$\mu_{T_j}(r) = \exp(-(\frac{r - T_j^c}{v_j})^2) = \exp(-(\frac{f_j - T_j^c}{v_j})^2) \tag{13}$$

This paper wherein considers that T_j is a normal fuzzy number with center value T_j^c and spread value v_j. Note that spread value v_j is equal to $\sqrt{2}\sigma_j$ where σ_j is a standard deviation of the corresponding normal random variable. Another, according to the definition of the necessity measure of a fuzzy number, we can obtain the following constraint of necessity measure.

According to the definition of the necessity measure of a fuzzy number, we can obtain the following constraint of necessity measure.

$$\text{Nes}\left\{ T_j \geq f_j \right\} \geq h_0, \forall j \tag{14}$$

where $h_0 \in (0, 1]$ is a predetermined value.

Constraint (14) ensures that the minimum possible degree that the value-based time limit is bigger than the finish time of a R&D new product will be greater than h_0, when the value-based time limit is treated as a fuzzy number. Therefore, we can translate to a linear constraint by the constraint (13) and (14), which in processing as follow:

$$\begin{aligned}
&\text{Nes}\left\{ T_j \geq f_j \right\} \geq h_0 \Rightarrow \ 1 - \sup(\mu_{T_j}(r) \,|\, r < f_j) \geq h_0 \\
&\Rightarrow 1 - \left[\exp(-(\frac{f_j - T_j^c}{v_j})^2) \right] \geq h_0 \Rightarrow \ \exp(-(\frac{f_j - T_j^c}{v_j})^2) \leq 1 - h_0 \\
&\Rightarrow -(\frac{f_j - T_j^c}{v_j})^2 \leq \ln(1 - h_0) \Rightarrow \ (\frac{f_j - T_j^c}{v_j})^2 \geq -\ln(1 - h_0) \\
&\Rightarrow \left| \frac{f_j - T_j^c}{v_j} \right| \geq \sqrt{-\ln(1 - h_0)} \Rightarrow \ -\frac{f_j - T_j^c}{v_j} \geq \sqrt{-\ln(1 - h_0)} \\
&\Rightarrow f_j - T_j^c \leq -\sqrt{-\ln(1 - h_0)}\ v_j \Rightarrow f_j \leq T_j^c - \sqrt{-\ln(1 - h_0)}\ v_j
\end{aligned}$$

Accordingly, the constraint (14) can be written as

$$f_j \leq T_j^c - \sqrt{-\ln\left(1 - h_0\right)}\ v_j, \forall j \tag{15}$$

Constraint (15) is translated to a linear format which in obtained by using the fractile approach (Kataoka, 1963).

4.5 The Proposed Computable Model

Therefore, the multi-standard project selection problem can be formulated as follows:

Objective Function:

$$\text{Maximize } \tilde{V} = \sum V_j(z_j) \tag{16}$$

Subject to

$$z_j = \sum_{l=1}^{L_{jk}} \sum_{k=1}^{K_j} w_{jkl} \cdot I_{jkl} + w_{jk0} \cdot I_{jk0}, \forall j \tag{16.1}$$

$$z_j \geq z_j^l, \forall j \tag{16.2}$$

$$f_j \leq T_j^c - \sqrt{-\ln\left(1-h_0\right)}\ v_j, \forall j \tag{16.3}$$

$$\sum_{k=1}^{K_j} \sum_{d=1}^{D_{jkl}} \sum_{l=0}^{L_{jk}} R_{jkl}^d \cdot I_{jkl} = b_j \cdot t_j, \forall j \tag{16.4}$$

$$t_j \geq \sum_{l=0}^{L_{jk}} D_{jkl} \cdot I_{jkl}, \forall\ j,k \tag{16.5}$$

$$\sum_{j=1}^{J} b_j \cdot t_j \leq ACB \tag{16.6}$$

$$b_j \leq B_0, \forall j \tag{16.7}$$

$$S_{jk} = f_{jk} - \sum_{l=0}^{L_{jk}} D_{jkl} \cdot I_{jkl}, \forall j,k \tag{16.8}$$

$$f_{jk} = f_j, \forall j,k \tag{16.9}$$

$$f_j = \sum_{i=1}^{j} t_i, \forall j \tag{16.10}$$

$$S_1 = 0 \tag{16.11}$$

$$S_j = f_{j-1}, \forall j \geq 2 \tag{16.12}$$

$$\sum_{l=0}^{L_{jk}} I_{jkl} = 1, \forall j,k,\ l \tag{16.13}$$

$$I_{jkl} = 0,\ 1\ \forall j,k,l \tag{16.14}$$

$$b_j \geq 0, \forall j \tag{16.15}$$

$$t_j \geq 0, \forall j \tag{16.16}$$

where (16.1) warrants the consistency of definitions regarding the market share of a new product; (16.2) ensures that the market share z_j^l is expected realized at very least, (16.3) denotes that the minimum possible degree that the value-based time limit is smaller than the finish time of a R&D new product will be greater than h_0, (16.4) warrants the consistency of the definitions regarding the amount of cost invested in a new product; (16.5) ensures that the time period invested in a specific new product satisfies the requirements of each project in this category; (16.6) ensures that the amount of cost invested in all R&D categories does not exceed the total available budget; (16.7) 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; (16.8)-(16.12) warrants the consistency of the definitions regarding the starting time and completion time of a project; (16.13) ensures just a level of quality-standard is assigned to a project; and (16.14) ensures only that a level of quality standard is assigned to a project.

Notably, the result of $I_{jk0}=1$ 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.

5. 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}. Again, 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_{kjl} may help decision-makers to understand the percentage of realizing w_{jk}.

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

$$\tilde{w}_{jk}=\frac{w_{jk}}{\sum_m w_{jm}} \tag{17}$$

According to (17), constraint (16.1) can be rewritten as

$$\tilde{z}_j = \sum_{l=1}^{L_{jk}} \sum_{k=1}^{K_j} \tilde{w}_{jk} u_{jkl} \cdot I_{jkl} + \tilde{w}_{jk} u_{jk0} \cdot I_{jk0}, \forall j \tag{18}$$

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 (16.2) can be rewritten as

$$\tilde{z}_j \geq \frac{z_j^l}{\sum_k w_{jk}}, j = 1, 2, \ldots, J \tag{19}$$

Let w_j denote the anticipated 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 $z_j = \sum_k w_{jk}$ about product *j*. Therefore, $\sum_j w_j$ denotes is the target performance of brand-image creation. However, as is generally assumed, there exists a continuous and strictly increasing function, e.g., $U_j(z_j)$, Therefore, the objective functions have the following equivalent relationships:

$$\text{Maximize } \sum V_j(z_j) \cong \text{Maximize } \sum w_j U_j(z_j) \tag{20}$$

where $0 \leq U_j(z_j) \leq 1$, and $U_j(1) = 1$, $U_j(0) = 0$.

Notably, that $U_j(z_j)$ can be predicated as the percentage of realizing the value of w_j given the value of z_j. Moreover, this study suggests using the following function to evaluate $U_j(z_j)$.

$$U_j(z_j) = z_j^{\beta_j}, \ \beta_j > 0, \forall j \tag{21}$$

The above function is characterized by its ability not only to easily evaluate parameter β_j by using log-transform and linear regression method, but also to accurately represent the strictly increasing linear, concave and convex functions. For the latter, it is strictly increasing linear if $\beta_j = 1$, strictly increasing concave if $0 < \beta_j < 1$, and strictly increasing convex if $\beta_j > 1$. Owing to the technique complexity, this work does not examines situations in which $U_j(z_j)$ is strictly increasing convex. However, if $U_j(z_j)$ is strictly increasing concave then the proposed model is a separable convex programming problem. Thus, several effective methods such as a piecewise-linear approximation can be adopted to derive the model.

In addition, letting $\tilde{w}_j = \dfrac{w_j}{\sum_m w_m}$, then one may employ the pair-wise comparison method like proposed one by AHP to evaluate $\tilde{w}_j$. Based on the above, the proposed objective function (20), and constraint (16.1)-(16.2) can be rewritten as follows:

$$\text{Maximize } \sum \tilde{w}_j z_j^{\beta_j} = \text{Maximize } \sum \tilde{w}_j \cdot (\sum_k w_{jk})^{\beta_j} \tilde{z}_j^{\beta_j} \tag{22}$$

Subject to

$$\tilde{z}_j = \sum_{l=1}^{L_{jk}} \sum_{k=1}^{K_j} \tilde{w}_{jk} u_{jkl} \cdot I_{jkl} + \tilde{w}_{jk} u_{jk0} \cdot I_{jk0}, \forall j \tag{22.1}$$

$$\tilde{z}_j \geq \frac{z_j^l}{\sum_k w_{jk}}, j = 1, 2, \ldots, J \tag{22.2}$$

Moreover, if we take Q_j breaking points from interval (0, 1] noted by $r_{j(q)}$, $q=0, 1, ..., Q_j$ then there exist some $a_{j(q)}$, $0 \leq a_{j(q)} \leq r_{j(q)} - r_{j(q-1)}$, so that

$$\tilde{z}_j = r_{j(0)} + \sum_{q=1}^{Q_j} a_{j(q)}, \quad \text{for } \tilde{z}_j \in [0,1] \tag{23}$$

$$\tilde{z}_j^{\beta_j} \approx r_{j(0)} + \sum_{q=1}^{Q_j} \rho_{j(q)} \cdot a_{j(q)}, \quad \forall j \tag{24}$$

where $r_{j(0)}=0$, $r_{j(Q_j)}=1$, and $\rho_{j(q)} = \dfrac{r_{j(q)}^{\beta_j} - r_{j(q-1)}^{\beta_j}}{r_{j(q)} - r_{j(q-1)}}$.

With above results, Objective function (22) can be repressed as a linear form as follows:

$$\text{Maximize } \sum \tilde{w}_j \cdot (\sum_k w_{jk})^{\beta_j} (\sum_{q=1}^{Q_j} \rho_{j(q)} \cdot a_{j(q)}) \tag{25}$$

Therefore, the con.straints (22.1) and (22.2) also can be rewritten as follows:

$$\sum_{q=1}^{Q_j} a_{j(q)} = \sum_{l=1}^{L_{jk}} \sum_{k=1}^{K_j} \tilde{w}_{jk} u_{jkl} \cdot I_{jkl} + \tilde{w}_{jk} u_{jk0} \cdot I_{jk0}, \forall j \tag{25.1}$$

$$\sum_{q=1}^{Q_j} a_{j(q)} \geq \frac{z_j^l}{\sum_k w_{jk}}, \; j=1,\ 2,\dots,\ J \tag{25.2}$$

$$0 \leq a_{j(q)} \leq r_{j(q)} - r_{j(q-1)}$$

6. Numerical Experiment

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 w_{jk} .

Table 2　Projects of the new product of car types

New product j $\tilde{w}_j$	Sedans 0.13	Hatchbacks 0.25	SUVs 0.2	Minivans 0.2	Coupes 0.22
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)

Beside, the parameters of this model are given by h_0=0.9, ACB=196, B_0=10, the value of parameter, $r_{j(q)}$, and the other values of parameters in this model are also shown in Table 3 and Table 4 as well.

Table 3 The values of $r_{j(q)}$ is adopted in this model

$r_{j(q)}$	j=1	j=2	j=3	j=4	j=5
q=0	0	0	0	0	0
q=1	0.23	0.3	0.2	0.13	0.3
q=2	0.42	0.54	0.45	0.24	0.44
q=3	0.65	0.76	0.67	0.45	0.6
q=4	0.83	0.88	0.88	0.76	0.8
q=5	1	1	1	1	1

Table 4 The other values of parameters are adopted in this model

Parameters	New product 1	New product 2	New product 3	New product 4	New product 5
z_j^l	0.17	0.1	0.18	0.1	0.19
σ_j	2	1.2	1	2.2	2
T_j^c	12	18	26	32	40
β_j	0.9	0.9	0.9	0.8	0.8

Table 5 lists the values of u_{jkl}. Table 6 shows the periodical costs and the period required to invest in a project in order to achieve a specific assignment of a quality standard. The Appendix provides further details. The values of above parameters are arbitrarily settings.

Table 5 Percentage of realization of w_{jk} (i.e., u_{jkl})

l	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
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	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
2	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
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

▼ Table 6 Periodical cost and the period required to invest in a project for achieving a specific assignment of quality-standard

Budget amount	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		
	Standards									Standards									Standards									Standards									Standards								
Period	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	3	3	3	3	3	3	3	4	4	3	4	4	4	4	4	4	4	4	4	4	5	3	3	4	4	5	5	4	4	4	3	3	3	4	5	5	4	5	4	3	3	3	4	5	6
2	4	3	4	3	3	3	4	4	4	4	4	4	4	4	5	4	4	4	4	5	5	3	3	4	4	5	5	4	4	4	3	3	3	4	5	5	4	5	4	3	3	3	4	5	6
3	4	4	4	3	3	4	4	5	5	4	4	4	4	4	5	5	4	5	5	5	5	4	3	5	5	5	5	4	4	5	3	3	4	4	5	5	4	5	4	4	4	4	4	5	6
4	5	4	4	3	4	4	5	5	5	5	4	5	4	5	5	5	5	5	5	5	5	4	4	5	5	5	5	4	5	5	4	4	4	4	5	6	5	5	5	4	4	4	4	5	6
5		4	5	4	4	4			5		5	5	4	5	5		5	5			5	5	4	5		5	5		5	5	4	4	4			6			5	5	4	4			
6						4					5	5			6			5					4	5			5			5		4	4						6		4	5			
7																							5	6								5	5												

Therefore, the values of I_{jkl}, b_j, t_j, S_{jk}, f_{jk}, S_j, f_j can be obtained (Table 7), as indicated from the data of Tables 2~6 (LINGO 8.0 was used to do so).

Table 7 The values of decision variables to propose model

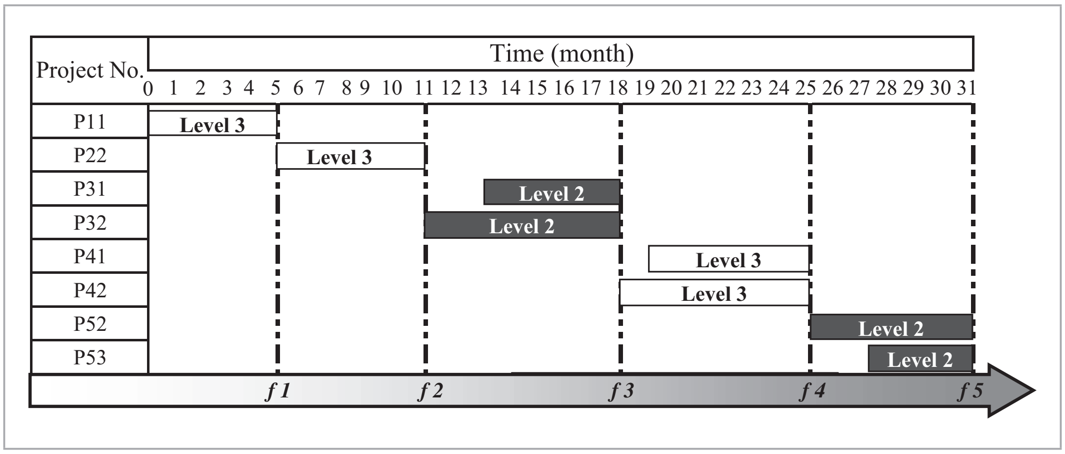
New product	Sedans	Hatchbacks	SUVs	Minivans	Coupes
Project selected (level)	P11 (3)	P22 (3)	P31 (2), P32 (2)	P41 (3), P43 (3)	P52 (2), P53 (2)
b_j	4	5	6.43	7.71	7
t_j	5	6	7	7	6
S_{jk} (project)	0	5 (P22)	13(P31) 11(P32)	19(P41) 18(P42)	25(P52) 27(P53)
f_{jk} (project)	5	11 (P22)	18(P31) 18(P32)	25(P41) 25(P42)	31(P52) 31(P53)
S_j	0	5	11	18	25
f_j	5	11	18	25	31

The results of Table 7 can be depicted as Figure 4. To illustrate, the execution order of each new product (NP) is NP1 → NP2 → NP3 → NP4 → NP5. However, the time period of time invested in Sedans, Hatchbacks, SUVs, Minivans and Coupes are respectively 5, 6, 7, 7 and 6 units, respectively. In addition, the chosen projects in new product 5 (i.e., Coupes) are project 2 (the improvement of engine system) and project 3 (the improvement of body & dimension), and the quality-standard assigned for these two projects are respectively all at level 2. Finally, the total cost required to achieve the assigned quality standards of these three projects is 42 units, which are obtained by calculating the value of $b_5 \cdot t_5$.

7. Conclusion

7.1 Concluding Remark

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



▲ Figure 4　Project schedule of this example

limited to a vague time horizon. Besides the above tangible factors, previous studies of R&D selection problems also overlooked intangible influences on project performance, such as decision-maker managerial and control capabilities. While taking the above factors into account, this study has developed an approach to project selection for a new product development program. The proposed approach can be summarized as comprising the following four components: (1) selecting a project advancement strategy to provide a scheduling framework for taking into account soft factors in the scheduling process, (2) employing consumer brand-image score as the objective function for ultimately increasing long-term average profitability, (3) formulating a computable model that involves periodical budget constraints and specifies ambiguous value-based time limits, and (4) providing a closed form objective function to facilitate easy parameter estimation. Consequently, the proposed approach can identify an optimal portfolio of quality standards for new products and the associated optimal schedule, thus maximizing consumer expectations regarding brand-image score, benefiting long-term average profitability.

7.2　Applications and Further Research

This study examined a case study from the automobile industry (Japanese Honda Motors). However, the concepts proposed in this study are widely applicable, whether in communications, consumer electronics products or biotech. For example, the iPhone smart-phone has various features that determine its quality, such as the resolution of the optical lens as expressed in pixels, embedded touch panel technology, battery life etc. Similarly, the quality of a tablet PC is determined by features such as the CPU, memory, HD capacity, screen resolution, enclosure size etc. Moreover, R&D and testing of medicines or health foods is affected by factors such as medicinal quality and input dosage. Besides being applied to fields such as those described above, the method proposed in this investigation can also be applied in different industries with matching advancement strategies and conditions to help firms achieve the results they desire.

Accordingly, firms can use redesign/upgrading of product performance or quality to stimulate the project group to conduct R&D on product quality. In this procedure, enterprises can use the concepts proposed in this study to select suitable projects. Furthermore, the soft factor condition can be considered to determine the ability of the project leader. Moreover, decision makers can involve themselves in project execution to ensure appropriate variables influence key project decisions and management.

This study has several limitations and raises questions which warrant further research. First, this work considers only the schedule solution in which a project starts at the latest time possible within the duration of the invariant schedule. Therefore, the schedule solution derived using the proposed model may fail to provide buffer time for each project, leading to projects being delayed in response to delays in project progress. Future studies should seek improved solutions to this problem. Furthermore, owing to this study only considering the case in which the type II mixed advancement strategy serves as a project scheduling framework, future studies should closely examine other issues.

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