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Full Length Research Paper

Multi-standard project selection and scheduling model under constrained periodical budget and stochastic value-based time limit

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This paper proposes a mathematical programming model to select projects and their quality-standards corresponding to successively providing new products in the market. The proposed model involves the situation in which each new product development (NPD) program can be differentiated as multiple categories. Each project has multiple choices of quality/technology standards. This work proposes an approach to treat the multi-category and multi-standard project selection problem in which the scheduling is also considered concurrently under constrained periodical budget. The proposed approach consists of the 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 stochastic 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.

Key words: New product development, project selection and scheduling, multi-choice of quality-standards, brand image, value-based time limit.

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). NPD is a process by which an organization transforms data on market opportunities and technical possibilities into information assets for commercial (Clark and Fujimoto, 1991). It includes the enhancement of the brand image of an enterprise and its marketing position (Robert, 1993). Restated, capable of influencing overall operational performance during product development, a company continuously attempts to identify important factors in product development.

The success of the NPD is closely associated with the selection of research and development (R&D) projects under a resource-constrained scenario (Pedro and Francisco, 2009; Robert et al., 1999; Rutsch et al., 2006). The project selection problem related to a NPD program can be usually expressed as a multi-category and multi-standard project selection problem under a budget- and time-constrained scenario. 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

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project in a category. In general, each project usually has 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 aforementioned 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 aforementioned project selection problem occurs in an actual scenario, however, most R&D project selections under a constrained budget fail to consider the case in which the budget is periodically needed – resulting in project scheduling delays (Asher, 1962; Cooper and Kleinschmidt, 1988; Hall and Nauda, 1990; Meade and Presley 2002; Henriksen and Palocsay, 2008; Nishihara and Ohyama, 2008). To conclude, the conventional project selection model can not respond to some NPD actual scenarios as aforementioned.

Except the mentioned NPD practices, most traditional project selection models also fail to consider project the scheduling concurrently. Sun and Ma (2005) developed a packing-multiple-boxes model, capable of selecting R&D projects and their associated scheduling. However, they not only fail to consider the NPD actual scenarios as stated-above but fail to consider intangible factors when scheduling projects. Intangible factors refer to those that are immeasurable by a quantitative method such as the controlling influence of the project leader and the intuitive experience of an engineer. Except for the mentioned works, relevant literature has not examined project selection from the perspective of brand-image creation. In general, the price of a product and the corresponding quality-standard may lead directly to purchase intention and repurchase intention of consumers (Lichtenstein et al., 1993). "Brand image" has also been shown as the key factor whether consumers have bought or not (Fichter and Jonas, 2008; Kwon and Sharron, 2009; Maxwell et al., 2008). Restated, 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 analysis, we propose an approach to treat the multi-standard and multi-allocation project selection problem. The proposed approach consists of four major components. First, we revise slightly the definition of the four project advancement strategies defined by Chang and Chen (2007) in order to benefit the application of our problem. The four strategies are developed to assist decision makers in selecting projects that involve intangible factors. Again, we also discuss simply, the major advantages and disadvantages of these strategies. Secondly, we borrow the concepts of Chang and Yang (2011) to establish a measurement of brand-image of a consumer. Indeed, they 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. Thirdly, we provide a computable model in which the selection of quality-standard and resource-allocation proposal of a project under constrained project duration and constrainedly periodical budget are considered. Finally, we 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. Consequently, the proposed approach can identify an optimal portfolio of quality standards and resource-allocation proposals for new products, as well as the associated optimal schedule. Such an optimal solution maximizes the expected brand-image score of consumers, which benefits the long-run average profitability.

CHOICE OF PROJECT ADVANCEMENT STRATEGY

R&D project success largely depends on tangible and intangible factors. Tangible factors refer to those that can be measured by a quantitative method such as the number of engineers and the amount of budget invested. Intangible factors refer to those that are immeasurable by a quantitative method 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 assist decision makers in selecting projects that involve intangible factors. In this paper we slightly revise the definition of the four project advancement strategies to benefit the application of our problem, as described thus.

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 that CSAS refers to centralizing the available amount of periodical budget into a R&D project and the remaining budget available from the previous period can

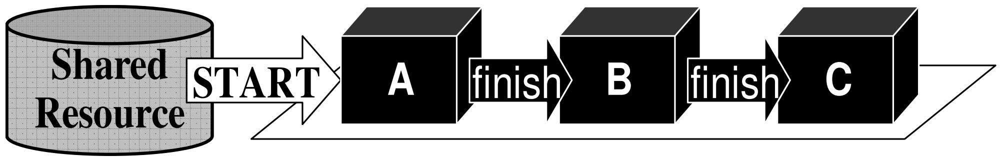

Figure 1. CSAS chart.

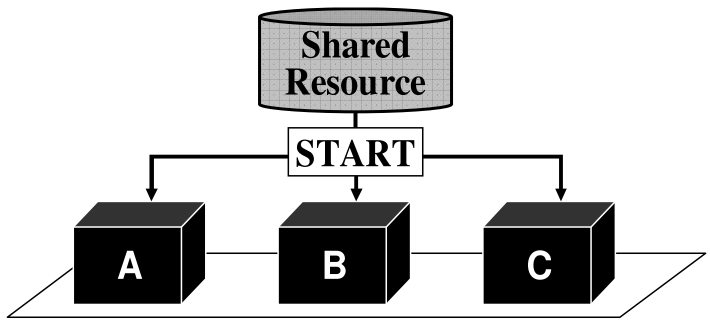

Figure 2. DSAS chart.

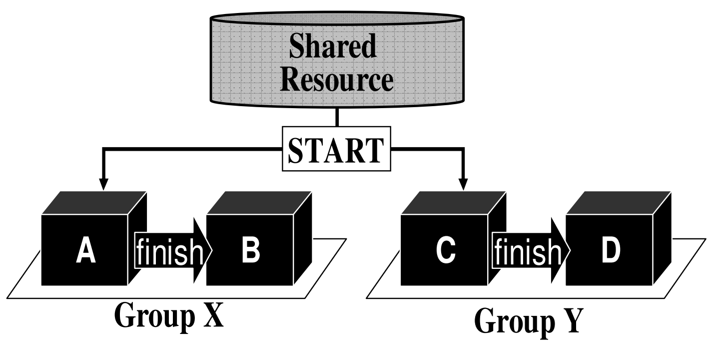

Figure 3. The chart of Type I MAS.

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: A, B and C. Figure 1 displays CSAS.

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: A, B and C. Figure 2 displays DSAS.

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 and B} and {C and 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

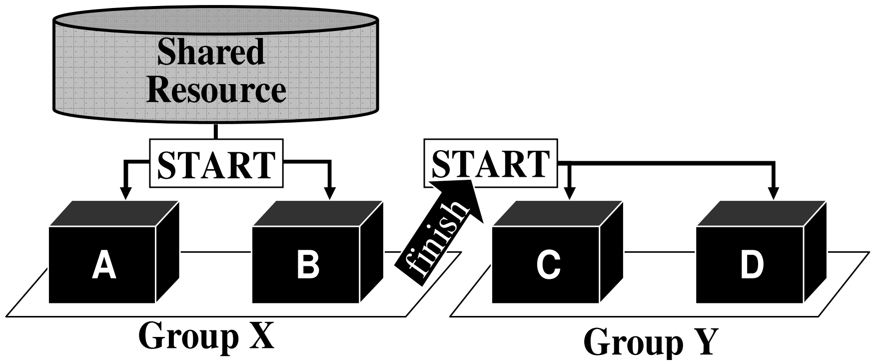

Figure 4. The chart of Type II MAS.

Table 1. The level of quality-standards for indicators.

Quality-standards Indicator	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

moving ahead between categories X and Y with CSAS, that is, 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.

This work suggests that one should borrow a project advancement strategy for solving some certain 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.

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', that is, 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 150 hp, 19.3 kg-m, and 12.4 km/l. Again, the ideal quality standard of the engine system that the manufacturer hopes to promote is the portfolio of indicator values 155 hp, 22.7 kg-m, and 13.8 km/l.

Furthermore, as discussed earlier, 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 (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 largely influence perceived quality (Chang and Yang, 2011). 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:

A_1: Evaluating the brand image of consumers depends on the market share of products within a target market.

A_2: The market share of a new product in a target market depends on the ability to identify the portfolio of quality standards for a new product and evaluate the brand image of consumers. Corresponding to our assumptions regarding consumer behavior, consumers in a given target market are divided into Groups 1 and 2. The consumers in Group 1 determine their brand-image score of products offered by a particular firm only based on their perception with respect to whether a particular product offered by this firm is popular. However, consumers in Group 2 determine the brand-image score based on their perception with respect to whether all products offered by this firm are popular. Based on this premise, further assumption that the brand-image score for a consumer is evaluated 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 that a specific new product is going to be best seller. However, these same consumers believe that it is not reliable or give it a brand-image score at level 0 if they feel otherwise. Correspondingly, consider consumers in Group 2 who believe that any product offered by a firm is reliable or give it a brand-image score at level 1 if they feel that all new products are going to be best sellers. However, these same consumers believe that it is not reliable or give it a brand-image score at level 0 if they feel otherwise. 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 Groups 1 and 2 who assign the new products a brand-image score at level 1, indicated as follows:

$$V(z_1,z_2,\ldots,z_J)=\sum_j V_j(z_j)+\beta(z_1,z_2,...,z_J) \quad (1)$$

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, for example, z_j^l, for each new product such that nearly all consumers in Group 2 perceive that all new products are best sellers as $z_j \geq z_j^l$ 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:

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

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):

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

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

Furthermore, with respect to using Constraint 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 (Constraint 3) is almost equivalent to the following problem (Constraint 4):

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

A computable formulation

The requirements of concerned problem

For the purpose of giving a computable formulation, all requirements of our concerned problem are listed as follows:

i. Each project in a specific R&D category has multiple choices of quality-standards.
ii. The amount of budget available in a period constrains the quality-standard selection of a product.
iii. The remaining available budget of previous period can be used in next period.
iv. 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.
v. 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 particular new product.
vi. Despite an additional influx of funds for each period, the total cost for conducting all projects is limited to a certain budgetary amount.
vii. A random value-based time limit associates with each new product, which limits the finish time of all projects in this new product.

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 regard to project k contributing to the market share of new product j when project k's quality-standard is at level l;

M_{jk} - Number of alternatives regarding the amount of cost investing in each period for project k in new product j, $m = 1,2,\cdots,M_{jk}, \forall j$;

R_{jk}^m - Amount of cost corresponding to alternative m of project k in new product j, $m = 1,2,...,M_{jk}, \forall j,k$;

D_{jkl}^m - Period of time required to invest in the cost R_{jk}^m for achieving the goal at assigned quality-standard l for project k in new product j, $l = 0,1,2,...,L_{jk}$, $m = 1,2,\cdots,M_{jk}, \forall j,k$;

B_0 - Budget available for each period;

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

ACB - Total amount of budget available for conducting all projects;

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

c_j^t - The required cost at time t for conducting the projects in new product j.

Decision variables:

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

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

t_j - Period of time required to invest in cost for new product j;

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

s_{jk} - Start time of conducting project k in new product j;

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

S_j - Start time of conducting projects in new product

j (note that $S_j = t$ refers to new product j is started at the end of period $t-1$ or at the beginning of period t);
f_j - Finish time of new product j (note that $f_j = t$ refers to new product j is finished at the end of period $t-1$ or at the beginning of period t).

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_{jk}^m is non-decreasing in D_{jkl}^m. 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:

$$S_{jk} = f_j - \sum_{l=0}^{L_{jk}} \sum_{m=1}^{M_{jk}} D_{jkl}^m \cdot y_{jk}^m \cdot \tilde{y}_{jk}^l, \forall j, k. \qquad (5)$$

and

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

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

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

Where c_j^t denotes the required cost at time t for conducting the projects in category j. Because R_{jk}^m is non-decreasing in D_{jkl}^m, it yields:

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

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

Specifying random value-based time limit

For the purpose of giving a computable formulation, our concerned problem that completion time of new product j is no more than the value-based time limit, that is, $f_j \le T_j$, and T_j is a random number is considered here. Furthermore, as is generally assumed, the decision-makers treat the parameter of value-based time limit as a stochastic parameter. Interviewing the decision-maker in charge of process control, the value-based time limit is expressed as a stochastic parameter.

Furthermore, it is assumed that value-based time limit T_j of new product j obeys a normal distribution with mean μ_j and variance σ_j. Accordingly, we can obtain the constraint rewritten as follows:

$$\Pr\{T_j \ge f_j\} = \Pr\left\{\frac{T_j - \mu_j}{\sigma_j} \ge \frac{f_j - \mu_j}{\sigma_j}\right\} \ge 1 - \alpha \qquad (9)$$

where $X_j = \frac{T_j - \mu_j}{\sigma_j}$ is a standard normal random variable with mean 0 and variance 1. This yields:

$$\Pr\left\{X_j \ge \frac{f_j - \mu_j}{\sigma_j}\right\} \ge 1 - \alpha \qquad (10)$$

where X_j is a standard normal random variable.

Letting x_α denote the α-fractile of the standard normal distribution, then it yields $\Pr\{X_j \le x_\alpha\} = \alpha$. Accordingly, the constraint of $\Pr\{T_j \ge f_j\} \ge 1 - \alpha$ is realized if and only if:

$$\frac{f_j - \mu_j}{\sigma_j} \le Z_\alpha \qquad (11)$$

That is, constraint (11) can be rewritten as the following deterministic form:

$$f_j \leq \mu_j + Z_\alpha \sigma_j, \ \forall j \quad (12)$$

The proposed computable model

Therefore, the multi-standard and multiple-resource-allocation project selection problem can be formulated as follows:

Objective function:

$$\text{Maximize } \tilde{V} = \sum V_j(z_j) \quad (13)$$

Subject to:

$$z_j = \sum_{l=1}^{L_{jk}} \sum_{k=1}^{K_j} \sum_{m=1}^{M_{jk}} w_{jkl} \cdot \tilde{y}_{jk}^{l} \cdot y_{jk}^{m} + w_{jk0} \cdot \tilde{y}_{jk}^{0}, \forall j \quad (14)$$

$$z_j \geq z_j^l, \forall j \quad (15)$$

$$f_j \leq \mu_j + Z_\alpha \sigma_j, \ \forall j \quad (16)$$

$$\sum_{k=1}^{K_j} \sum_{l=1}^{L_{jk}} \sum_{m=1}^{M_{jk}} R_{jk}^{m} \cdot D_{jk}^{m} \cdot y_{jk}^{m} \cdot \tilde{y}_{jk}^{l} = b_j \cdot t_j \ \forall j \quad (17)$$

$$t_j \geq \sum_{l=1}^{L_{jk}} \sum_{m=1}^{M_{jk}} D_{jkl}^{m} \cdot y_{jk}^{m} \cdot \tilde{y}_{jk}^{l}, \forall j, k \quad (18)$$

$$\sum_{j=1}^{J} b_j \cdot t_j \leq ACB \quad (19)$$

$$b_j \leq B_0, \forall j \quad (20)$$

$$S_{jk} = f_j - \sum_{l=1}^{L_{jk}} \sum_{m=1}^{M_{jk}} D_{jkl}^{m} \cdot y_{jk}^{m} \cdot \tilde{y}_{jk}^{l}, \forall j, k \quad (21)$$

$$f_{jk} = f_j, \forall j, k \quad (22)$$

$$f_j = \sum_{i=1}^{j} t_i, \forall j \quad (23)$$

$$S_1 = 0 \quad (24)$$

$$S_j = f_{j-1}, \forall j \geq 2 \quad (25)$$

$$\sum_{l=0}^{L_{jk}} \tilde{y}_{jk}^{l} = 1, \forall j, k \quad (26)$$

$$\sum_{m=1}^{M_{jk}} y_{jk}^{m} \leq 1, \forall j, k \quad (27)$$

$$y_{jk}^{m} = 0,1, \ m = 1,2,\ldots,M_{jk}, \forall j, k \quad (28)$$

$$\tilde{y}_{jk}^{l} = 0,1, \ d = 1,2,\ldots,M_{jk}, \forall j, k \quad (29)$$

$$b_j \geq 0, \forall j \quad (30)$$

$$t_j \geq 0, \forall j \quad (31)$$

where constraint (14) warrants the consistency of the definitions regarding the market share of a new product, constraint (15) ensures that the market share z_j^l is expected realized at very least, constraint (16) ensures that the probability that the value-based time limit is greater than the finish time of a new product will be greater than $1-\alpha$, constraint (17) warrants the consistency of the definitions regarding the amount of cost invested in a new product, constraint (18) ensures that the time period invested in a specific new product satisfies the requirements of each project in this new product, constraint (19) ensures that the amount of cost invested in all R&D new products is not more than the total budget available, constraint (20) ensures that the average amount of cost invested in each period for new product j is not more than the amount of budget available for each period, constraints (21) to (24) warrants the consistency of the definitions regarding the start time and finish time of a project, constraint (25) ensures just a level of quality-standard is assigned to a project and constraint (26) ensures that at most only a proposal about invested cost for project k in new product j can be selected.

Notably, the result of $\tilde{y}_{jk}^{0} = 1$ means that project k in new product j is not selected and the subsystem k of product j is not developed or upgraded as well. Therefore, after the afore 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.

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_{jkl} may help decision-makers to understand the percentage of realizing w_{jk}. Furthermore, let $\tilde{w}_{jk}$ denote the normalized weight so that:

$$\tilde{w}_{jk} = \frac{w_{jk}}{\sum_m w_{jm}} \tag{32}$$

According to constraint (11), constraint (14) can be rewritten as:

$$\tilde{z}_j = \sum_{l=0}^{L_{jk}} \sum_{k=1}^{K_j} \sum_{m=1}^{M_{jk}} \tilde{w}_{jk} u_{jkl} \cdot \tilde{y}^l_{jk} \cdot y^m_{jk} + \tilde{w}_{jk} u_{jk0} \cdot \tilde{y}^0_{jk}, \forall j \tag{33}$$

Notably, $\tilde{z}_j$ can be predicated as the percentage of achieving the target market share of new product j (that is, $\sum_k w_{jk}$). Similarly, constraint (15) can be rewritten as:

$$\tilde{z}_j \ge \frac{z^l_j}{\sum_k w_{jk}}, j = 1, 2, \ldots, J \tag{34}$$

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, for example, $U_j(z_j)$, Therefore, the objective functions have the following equivalent relationships:

$$\text{Maximize } \sum V_j(z_j) \cong \text{Maximize } \sum w_j U_j(z_j) \tag{35}$$

where $0 \le U_j(z_j) \le 1$, 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 $U_j(z_j)$.:

$$U_j(z_j) = z_j^{\beta_j}, \ \beta_j > 0, \forall j \tag{36}$$

The afore 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 examine 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 $\tilde{w}_j = \frac{w_j}{\sum_m w_m}$, then one may employ the pair-wise comparison method like proposed one by AHP to evaluate $\tilde{w}_j$. Based on this, the proposed objective function (13), and constraint (14) and (15) can be rewritten as follows:

$$\text{Maximize } \sum \tilde{w}_j z_j^{\beta_j} = \text{Maximize } \sum \tilde{w}_j \cdot (\sum_k w_{jk})^{\beta_j} \tilde{z}_j^{\beta_j} \tag{37}$$

Subject to:

$$\tilde{z}_j = \sum_{l=1}^{L_{jk}} \sum_{k=1}^{K_j} \sum_{m=1}^{M_{jk}} \tilde{w}_{jk} u_{jkl} \cdot \tilde{y}^l_{jk} \cdot y^m_{jk} + \tilde{w}_{jk} u_{jk0} \cdot \tilde{y}^0_{jk}, \forall j$$

(38)

$$\tilde{z}_j \ge \frac{z^l_j}{\sum_k w_{jk}}, j = 1, 2, \ldots, J \tag{39}$$

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

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)
	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)
P_{jk} Projects (w_{jk})	P12 Body and 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)

$$\tilde{z}_j = r_{j(0)} + \sum_{q=1}^{Q_j} a_{j(q)}, \quad \text{for } \tilde{z}_j \in [0,1] \tag{40}$$

$$\tilde{z}_j^{\beta_j} \approx r_{j(0)} + \sum_{q=1}^{Q_j} \rho_{j(q)} \cdot a_{j(q)}, \ \forall j \tag{41}$$

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

With above results, Objective function (19) can be repressed as a linear form as follows:

$$\text{Maximize } \sum \tilde{w}_j \cdot (\sum_k w_{jk})^{\beta_j} (\sum_{q=1}^{Q_j} \rho_{j(q)} \cdot a_{j(q)}) \tag{42}$$

Therefore, the constraints (38) and (39) also can be rewritten as follows:

$$\sum_{q=1}^{Q_j} a_{j(q)} = \sum_{l=1}^{L_{jk}} \sum_{k=1}^{K_j} \sum_{m=1}^{M_{jk}} \tilde{w}_{jk} u_{jkl} \cdot \tilde{y}_{jk}^{l} \cdot y_{jk}^{m} + \tilde{w}_{jk} u_{jk0} \cdot \tilde{y}_{jk}^{0}, \forall j \tag{43}$$

$$\sum_{q=1}^{Q_j} a_{j(q)} \geq \frac{z_j^l}{\sum_k w_{jk}}, \ j = 1, 2, \ldots, J \tag{44}$$

$$0 \leq a_{j(q)} \leq r_{j(q)} - r_{j(q-1)} \tag{45}$$

NUMERICAL EXAMPLE

Here, we present an example of new car development to demonstrate the proposed model. The aim of the decision maker is to select the most appropriate projects and their quality standards so as to maximize the expected brand-image judgment of consumers. In general, consumer's criteria for buying a car may differ, owing to the individual preference of consumers. For instance, the criteria of a consumer towards buying a specific type of car may include power engine system, body and dimension, and security system, etc. In this case, we take common car styles as an example and divide these cars into five products.

They are Sedans, Hatchbacks, SUVs, Minivans, and Coupes. Each new product includes three projects with regard to the attempt of resigning/upgrading a specific subsystem of a cars, it can be seen in Table 3. The parameters of $\tilde{w}_j$ and $\tilde{w}_{jk}$ are shown in Table 2 as well.

Beside, the parameters of this model are given by $\alpha = 0.1$, $ACB = 166$, $B_0 = 12$, the value of parameter, $r_{j(q)}$, and the other values of parameters in this model are also shown in Tables 3 and 4 as well.

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

The results of Table 7 can be depicted as Figure 5. To illustrate, the chosen projects in new product 2 (that is, Hatchbacks) are project 2 (the improvement of engine system) and project 3 (the improvement of safety system). The quality-standard assigned for these two projects are respectively at levels 2 and 1, and 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 2, 4, 2, 2 and 2 units, respectively. Finally, the total cost required to achieve the assigned quality standards of these two projects is 42 units, which are obtained by calculating the value of $b_2 \cdot t_2$.

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.

Parameter	New product 1	New product 2	New product 3	New product 4	New product 5
μ_j	8	9	8	7	7
σ_j	2	1.2	1	2.2	2
z_j^l	0.17	0.1	0.18	0.1	0.19
T_j	11	24	39	53	65
β_j	0.8	0.9	0.9	0.8	0.8

Table 5. Percentage of realization of w_{jk} (that is, 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

DISCUSSION

The project selection problem relating to a NPD program is expressed as a multi-category and multi-standard R&D project selection problem under a budget- and time-constrained context in this work. Almost conventional project selection model can not respond some NPD actual scenarios, in which the quality standards assigned for each project are at multiple levels; the amount of cost for achieving a specific quality-standard of a project is needed periodically; and the contribution of a project declines over time. In addition to the aforementioned 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 afore factors into account, this work has developed a four component approach to select and schedule projects for a NPD program. We release four issues that involve the theoretical and practical contributions of the proposed approach.

First, most consumer evaluation studies of a brand

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

Standard	New product 1									New product 2								
	Budget amount									Budget amount								
	P11			P12			P13			P21			P22			P23		
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

Standard	New product 3									New product 4									New product 5								
	Budget amount									Budget amount									Budget amount								
	P31			P32			P33			P41			P42			P43			P51			P52			P53		
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 7. The values of decision variables to propose model.

Variable	New product 1	New product 2	New product 3	New product 4	New product 5
Project selected (level)	P11(1),13(1)	P22(2), P23(1)	P31(1), P32(1), P33(1)	P42(1),P43(1)	P52(1), P53(1)
b_j	6	6	6	5	6
t_j	4	7	6	4	4
S_{jk} (project)	0(P11) 0(P13)	2(P22) 3(P23)	6(P31) 6(P32) 6(P33)	8(P42) 8(P43)	10(P52) 10(P53)
f_{jk} (project)	2(P11) 2(P13)	6(P22)	8(P31) 8(P32) 8(P33)	10(P42) 10(P43)	12(P52) 12(P53)
S_j	0	2	6	8	10
f_j	2	6	8	10	12

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 (that is, Groups 1 and 2); the results of the proposed model significantly contribute to new product development literature.

Secondly, past studies on project selection model normally consider only total budget constraints during the duration of all projects. In contrast with this, 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

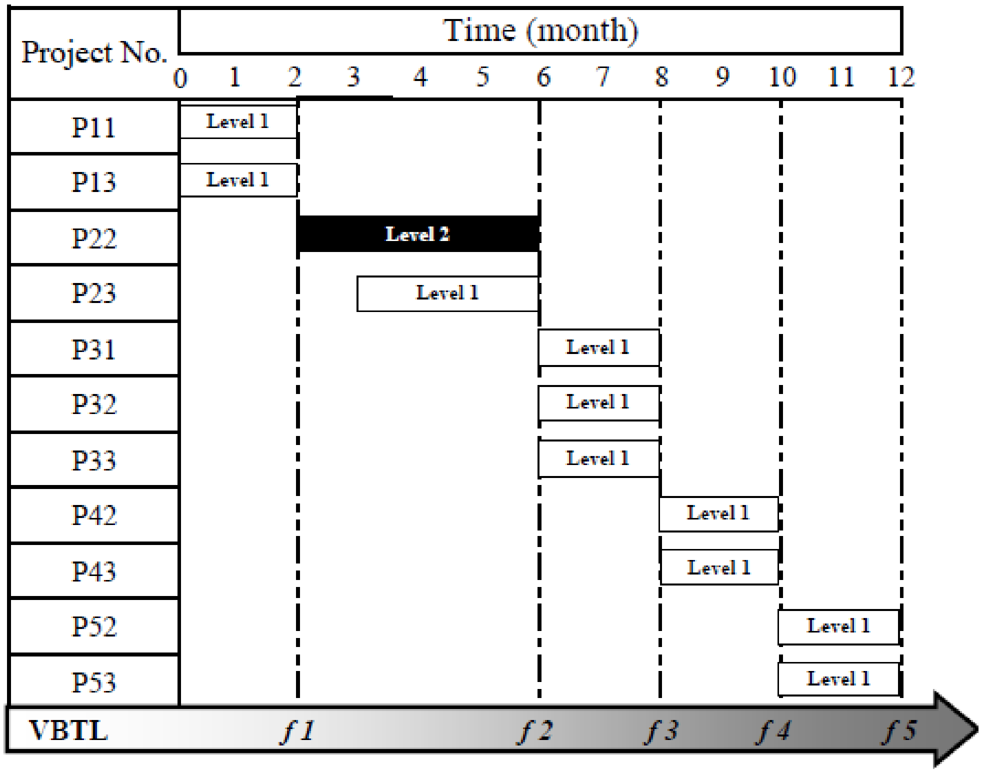

Figure 5. Project schedule of this numerical example.

results provide a valuable reference for future research efforts that consider these factors.

Thirdly, most project selection studies fail to concurrently consider the scheduling problem. In contrast to this, in the 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 transform 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. Therefore, the proposed four component approach is obviously useful in terms of project selection practices, especially for new product development.

CONCLUSION

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 closely examine this issue.

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