# Sensitivity Analysis on Optimal Budget Allocation for NPD Projects

Sungjae Park and Hoo-Gon Choi

Department of Systems Management Engineering, Sungkyunkwan University, Suwon, Republic of Korea

**Abstract**: *In a firm, profitability is the most important measure for evaluating all ongoing new product development (NPD) projects during budget planning time. The profitability depends on core parameters such as the income (sales × price), development cost, and project difficulty. It affects the budget size allocated to a project. After the optimal budget allocation is made for all ongoing projects to maximize the total profit, the core parameter values should be varied to observe how much they affect the profit figures for the optimal budget sizes. In this study, a sensitivity analysis was conducted to determine the changes in profit with variations in the core parameters. The results showed that the development cost and project difficulty significantly affect the profit figures. By observing the behaviors of the core parameters with the profit figures, a firm can manage its budget more effectively and efficiently.*

**Keywords:** *core parameter, NPD project, profitability, sensitivity analysis*

## 1. Introduction

One way for a firm to obtain more competitive advantages is to develop successful new products and launch them to market at the right time. However, this is hard to achieve because the success of a new product development (NPD) project is hindered by many unexpected risks and uncertainties. According to a survey, two-thirds of NPD projects fail to meet the target date, and more than half earn no profit on their investment. More than 40% of the respondents believed that NPD projects need more investment [1]. A typical endogenous risk is the project difficulty related to the project characteristics [2]. The project difficulty can be characterized by the level of product complexity, competition, schedule tightness, resource tightness, program structure, project management, business relationship, and technology changes. Examples of exogenous uncertainties include market changes, economic shifts, government regulations, currency exchange rates, interest rates, oil prices, and commodity prices. These risks and uncertainties can impact an NPD project to cause schedule delays, increase costs, and reduce profits. Therefore, both effective and efficient response strategies should be prepared to minimize such impacts. Hilson [3] classified four types of response strategies for risks and four types for uncertainties: avoid, transfer, mitigate, and accept for risks; exploit, share, enhance and ignore for uncertainties. The response strategy should be carefully selected in terms of the schedule and cost owing to the various characteristics of risks and uncertainties [4].

A firm should allocate a limited budget to each NPD project during budget planning. The firm assesses the performances of the projects to determine the successes and allocates the budgets to them. The profitability predicted during that time is a common measure of whether or not a project is expected to be successful. Hwang [4] proposed a framework to estimate the profit ratio (PR) of NPD projects in which the development cost is computed by considering the nonrecurring cost, recurring cost, and response cost paid for both internal and external risks under optimal response strategies. In his model, the profit is determined by the sales volume and price estimated during the production ramp-up stage. However, his PR model does not consider the project difficulty, which can affect both the profit and costs. If a project with a high level of difficulty has high costs, it may generate a large profit if successful. The present authors previously developed a modified PR model [5] based on Hwang's model and used it to allocate the budget to maximize the total profit expected for all ongoing projects. The budget allocated to a project was assumed to potentially be more or less than requested. If the project has a larger budget than requested, it should create more profit. The budget allocation plan for all ongoing NPD projects was also assumed to be made at time $t$ instead of gate $i$ between any two consecutive stages of the NPD process. Because each project progresses at a different pace based on its characteristics, all ongoing projects were evaluated in terms of their predicted profits, costs, and PRs at time $t$.

In this study, the modified PR model was consolidated through a sensitivity analysis on parameters such as the income, development cost, and project difficulty to observe the profit change. Any variation in such parameters affects the estimated profit for a given project. This study was focused on finding profit changes dependent on the development cost and project difficulty. Some experiments were conducted with virtual data to demonstrate the budget allocation pattern with variations in the parameters.

## 2. PR Model and Budget Allocation Model

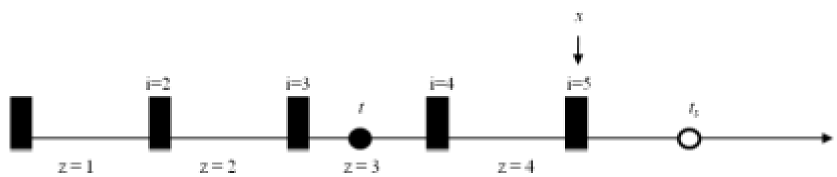


Fig. 1: NPD process

Fig. 1 shows the NPD process, in which the PR is predicted at the end of each stage or the budget planning time $t$. If the PR of a certain project is higher than planned, this project is continued to the next stage $z$. The prediction is made at the upcoming budget planning time based on the estimated sales in the market from time $x$ to $t_s$, the total cost paid up to the current stage, and the total cost to be paid for the proceeding stages to time $x$. The total cost includes both fixed and variable costs for project teams and response costs for the internal risks.

The profit is defined by the expected income minus the total project cost for the period between $x$ and $t_s$. Equations (1) and (2) present the income and project cost. All notations related to these equations are summarized in Table I.

TABLE I: Nomenclature

| | |
|---|---|
| $p$ | project |
| $t_s$ | time point at which the new products are on sale |
| $x_p$ | time point at which the production begins for the new product developed by project $p$ |
| $t$ | budget planning time for all ongoing projects. |
| $i$ | gate between two consecutive stages |
| $B$ | total available budget |
| $S_p(t_s)$ | estimated sales volume of project $p$ at time $t_s$ |
| $P_p(t_s)$ | estimated price per product unit of project $p$ at time $t_s$ |
| $ES_p(t_s)$ | sales volume change of project $p$ caused by external risks at time $t_s$ |
| $Income_p$ | income expected from project $p$ |
| $Cost_p$ | development cost estimated for project $p$ |
| $TRC_p(x)$ | total response cost to be paid until $x$ for project $p$ |
| $ERC_p(x)$ | estimated response cost to be paid for internal risks until $x$ for project $p$ |
| $RRC_p(x)$ | sum of estimated fixed and variable cost to be paid until $x$ for project $p$ |
| $f_p$ | function for supplementary income to be obtained from additional budget allocation and project difficulty of project $p$ |
| $g_p$ | cost function depending on project difficulty of project $p$ |
| $DF_p$ | project difficulty of project $p$ |
| $W_p$ | allocated budget of project $p$ |
| $a_p$ | allocation proportion of budget to be planned for project $p$ |

$$Income_p^* = (\int_0^{t_s} S_p(x)P_p(x)dx)ES_p(t_s) + \{\int_0^{t_s} S_p(x)P_p(x)dx\}ES_p(t_s) f_p[\{W_p - Cost_p^*(x,t_s)\}, DF_p] \quad (1)$$

$$Cost_p^* = TRC_p(x) + g_p(DF_p) \tag{2}$$

where

$$TRC_p(x) = RRC_i(x)\,\mathrm{ES}_p(t_s) + ERC_i(x)$$

## 2.1. Budget Allocation Model

Equation (1) consists of the expected sales income during the time interval between $x$ and $t_s$, the sale volume change due to exogenous risks or uncertainties, and any income variations ($f_p$) due to the budget size changes. The project difficulty ($DF_p$) affects both the project cost and income variations. A higher level of difficulty needs a larger budget, as given by the function $g_p(DF_p)$. If a project receives the same budget as $Cost_p$, the project $p$ can make the estimated income ($Income_p$). If a project receives more budget than required, more income can be made and vice versa. Therefore, $f_p$ can be any value between -1 and +1 as a three-dimensional function. An example of the function $f_p$ is a sigmoid function, where project is expected to have a larger income with a larger budget and higher difficulty.

The profit and profit ratio are determined according to Equations (3) and (4), respectively:

$$Profit_p = Income_p(x_p, t_s) - Cost(x_p, t_s) \tag{3}$$

$$Profit\,Ratio_p = Profit_p \,/\, Cost_p(x_p, t_s) \tag{4}$$

If a project is expected to have a low profitability or profit ratio, it would be stopped or not proceed to the next development stage. When the budget planning time arrives, the firm decides the total amount of available budget for surviving projects and optimizes the allocation to maximize the profits. In this study, the budget planning time was assumed to be $t$ instead of gate $i$ because each project progresses at a different pace. Equation 5 presents the budget allocation model, where $a_p$ is the budget proportion for project $p$ as a decision variable to maximize the total profit of all ongoing projects:

$$\begin{aligned} &Max \quad Z = \sum_{\forall p} Profit_p \\ &s.t \\ &Cost_p(x_p, t_s) \times a_p = W_p \qquad \forall p \\ &\sum_{\forall p} W_p \le B \\ &a_p \ge 0 \qquad \forall p \end{aligned} \tag{5}$$

To maximize the total profit $Z$, the development cost required by project $p$ is adjusted by $a_p$. The maximum budget ($B$) prepared by the firm is the total sum of the budget allocated to all ongoing projects.

# 3. Sensitivity Analysis

As shown in Equations (1)–(5), the profit figure is affected by various parameters such as the estimated income, development cost, project difficulty, budget size, and response costs for both endogenous and exogenous risks. These parameters vary due to many causes; the main ones are changes in customer requirements, market, technologies, macro- and micro-economic environment, and government regulations. These changes should be adapted to develop better design and manufacturing in a more economical manner. Project managers must be able to analyze the impacts, especially the profit, of such changes with the use of rational methods. The most commonly used method for analyzing parameter variations is sensitivity analysis. In this study, a sensitivity analysis was performed to investigate the behavior of profit changes stemming from changes in the development cost and project difficulty. Note that the income change due to the budget size $f_p$ is defined as a three-dimensional function. This means that the function types affect the profit figures differently and needs to be studied through a supplementary analysis. The results from the sensitivity analysis demonstrated the acceptable variation in the parameters to maintain the current profit figure obtained with Equation (5). The relationship between the profit and these parameters can be specified to predict the changes in the profit.

# 4. Numerical Examples

## 4.1. Budget Allocation Results

The budget allocation model and sensitivity analysis were examined with some numerical examples. First, the income variations due to budget size changes were observed when $f_p$ was defined as tanh [$\{W_p - Cost_p(x,t_s)\}DF_p$ / 10], the project difficulty ranged from 0 to 10, and the difference between the development cost ($Cost_p(x,t_s)$) and allocated budget ($W_p$) ranged from -5 to +5. The cost function for the project difficulty was assumed to be a linear function. As shown in Fig. 2, the income variation of project p was more sensitive to changes in the allocated budget at a higher difficulty than at a lower difficulty. Second, the budget allocation pattern was observed for four ongoing projects along with the individual values for the estimated incomes, development costs, difficulties, income variations, and project difficulty cost functions when the total budget was assumed to be 20. Table II presents the budget allocation results, where the maximum total profit was 13.351. Although projects 1 and 4 had identical incomes and sums of the fixed/variable cost and risk response cost ($TRC_p(x)$), the budget allocation model determined that project 4 should have a budget of up to 8.349, while no budget was allocated to project 1. This result was caused by the difference in project difficulties and the costs related to difficulty. The budget allocation results for projects 2 and 3 can be explained by the lower values for both $TRC_p(x)$ and $DF_p$. Note that different cases will generate different results. However, the allocation pattern can be varied with different parameters and function types; the allocation of rational budget sizes to all ongoing projects should be investigated.

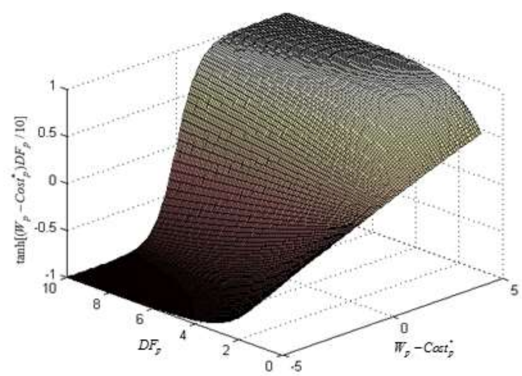


Fig. 2: Income variation with changes in the project difficulty and budget size

TABLE II: Budget allocation results

| $p$ | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $Income_p(x,t_s)$ | 10 | 15 | 15 | 10 |
| $TRC_p(x)$ | 3 | 1 | 2.5 | 3 |
| $DF_p$ | 3 | 7 | 9 | 6 |
| $f_p$ | tanh[$\{W_p$-$Cost_p(x,t_s)\}DF_p$/10] | | | |
| $g_p(DF_p)$ | $1.4DF_p$ | $1.3DF_p$ | $DF_p$ | $0.7DF_p$ |
| $W_p$ | 0 | 11.651 | 0 | 8.349 |

## 4.2. Sensitivity Analysis Results

When parameters such as the estimated income, development cost, and project difficulty were changed, the expected profit figures also changed. Therefore, the sensitivity analysis in this study was conducted by assuming that each parameter changed randomly within ±20% for project 4 as many as 500 times. As shown in Figure 3, the profit increased with the income and decreased when the cost and project difficulty were increased. A linear regression model was used to develop the relationships among the parameters (Table III). Because all parameters' p-values were less than 0.05, they were found to be statistically significant. For example, the income affected the profit positively, and the cost had the largest negative impact.

The cost function for the project difficulty was assumed to be a linear function, as given in Table II. If a project has a high level of difficulty, it may require high development costs and lead to a high income. For the sensitivity analysis, an exponential function was additionally defined, and the relationship between the profit and the parameters was investigated. As shown in Figure 4, the profit was more sensitive to variations in the income, cost, and difficulty compared to the linear function case. In contrast to the linear function case, those changes were widely spread out, and no specific trends were observed, especially for the income and cost. The profit fluctuated in a decreasing manner more sharply as the difficulty increased. This occurred because the cost increased exponentially as the difficulty increased. Table IV presents the regression results, where the largest negative coefficient was assigned to the project difficulty.

TABLE III: Linear regression results between profit and three parameters ($g_p(DF_p)$: linear function)

| | Coefficients | | | |
|---|---|---|---|---|
| | Estimate | Std. error | t-value | p-value |
| (Intercept) | 15.8652 | 0.2945 | -86.7127 | 2E-209 |
| Income | 1.6800 | 0.0162 | 103.4364 | 0 |
| Cost | -4.0220 | 0.0651 | -61.7827 | 4.3E-235 |
| Project difficulty | -2.0561 | 0.027102 | -75.8669 | 4.4E-275 |
| Multiple R-squared = 0.9896 | | | | |

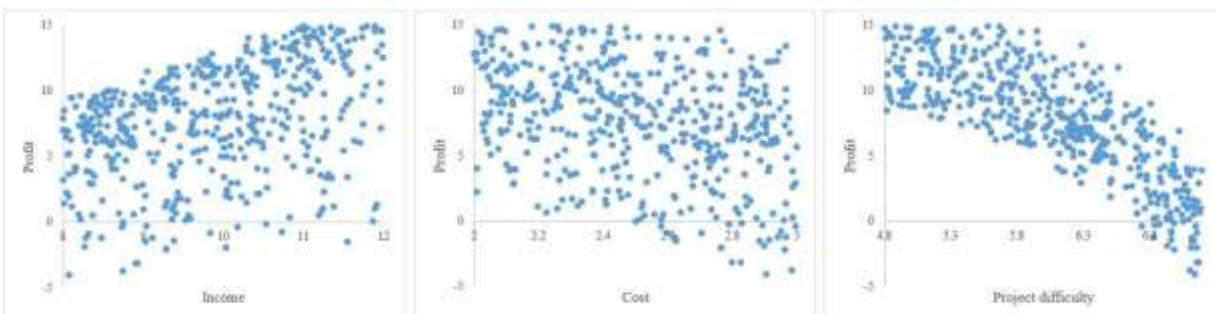


Fig. 3: Changes in profit with changes in the income development cost and project difficulty ($g_p(DF_p)$: a linear function

TABLE IV: Linear regression results between profit and three parameters ($g_p(DF_p)$: exponential function)

| | Coefficients | | | |
|---|---|---|---|---|
| | Estimate | Std. error | t-value | p-value |
| (Intercept) | 35.5488 | 0.8444 | 42.0980 | 7.5E-166 |
| Income | 1.4709 | 0.04657 | 31.5845 | 8.2E-121 |
| Cost | -4.8439 | 0.1867 | -25.9474 | 2.04E-94 |
| Project difficulty | -4.9863 | 0.0777 | -64.1575 | 2.6E-242 |
| Multiple R-squared = 0.9634 | | | | |

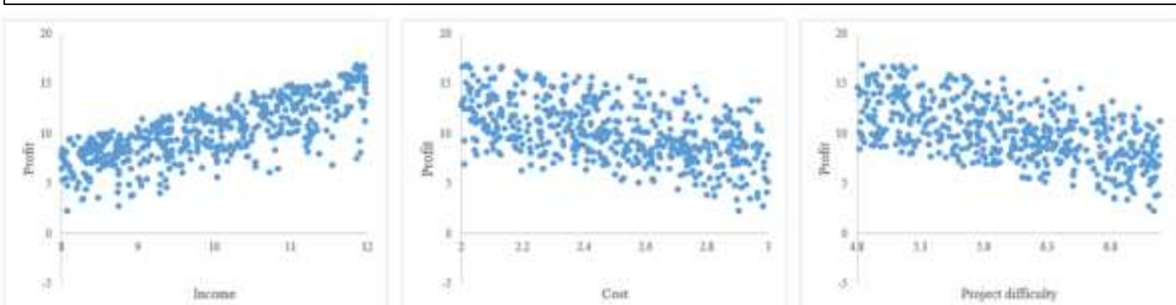


Fig. 4: Changes in profit with changes in the income development cost and project difficulty ($g_p(DF_p)$: linear function

## 5. Discussion and Conclusion

A competitive firm launches multiple NPD projects and manages them to achieve a high probability of success in terms of the quality, cost, and schedule with core competent capability. The firm should evaluate all ongoing projects by using these factors at a specified time, either a gate or a budget planning time, to decide which projects should continue to be supported. One of the most critical criteria for evaluating the projects is the profitability expected from the market. In this study, the budget allocation model previously developed by the authors [5] was used to determine the budget sizes for the projects, and a sensitivity analysis was conducted on core parameters of the model such as the estimated income, development costs, and project difficulty. Because the profit figures change with variations in such parameters, the sensitivity analysis was necessary to investigate the model performance. The relationship between the profit and parameters was developed with linear regression models. Numerical examples showed that the profit figures are strongly affected by the development costs. Although these results were obtained as a matter of course, they emphasize that the above approaches are essential for a firm or project manager to manage various parameter changes and their patterns more effectively and efficiently. This study should be extended further to utilize historical data regarding the profit, income, cost, project difficulty, and budget allocation. Such data can be obtained from previous NPD projects that either failed or succeeded, which would provide not only the function types for the income variations and development cost variations due to project difficulty but also the values of all variables composing the critical parameters. Various statistical or data mining methods can be applied to generating the appropriate functions and estimating all related variables.

## 6. Acknowledgment

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