A Portfolio Model for National IT R&D Strategy Project Selection Methods

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***Abstract*— In this paper, we offer a new strategic portfolio model for national IT R&D project selection in Korea. A risk and return (R-R) portfolio model was developed using an objectively quantified index on the two axes of risk and return, in order to select a strategic project and allocate resources in compliance with a national IT R&D strategy. We strategize using the R-R portfolio model to solve the non-strategy and subjectivity problems of the existing national R&D project selection model. We also use the quantified evaluation index of the IT technology road map (TRM) and the technical level reports (TLR) for the subjectivity of project selection, and try to discover the weights using the analytic hierarchy process (AHP). In addition, we intend to maximize the chance for a successful national IT R&D project, by selecting a strategic portfolio project and balancing the allocation of resources effectively and objectively.**

***Index Terms*— Strategic Portfolio, Project Portfolio, R-R Portfolio, AHP, Project selection, Strategic project**

I. INTRODUCTION

THERE are two ways for a project to be successful: doing a project right, and doing the right project [1]. With the recent rapid increase in Korea's national budget for information technology (IT) and information and communication technology (ICT) [2] from $320 million in 2003 to $401 million in 2008, 'doing the right project' has been emphasized more in the national IT R&D field. This issue can be studied using two types of access. The first type uses scoring and financial methods for the selection of each project. The second type uses a portfolio model for the project portfolios. Access in the existing project selection has the problems of non-strategy and subjectivity. Many studies have also been actively conducted on scoring and on financial and portfolio models for national IT R&D project selection [3]-[6]. Nevertheless, most of these studies focus mainly on the development of evaluation techniques or on the proper allocation of resources [7], while the strategic aspects are not taken into consideration.

The optimal model for a national IT R&D strategy is required to allocate the limited resources for a national IT R&D project more effectively, rather than just more efficiently [8], [9]. Also, it is necessary to develop a proper method for selecting an objectively quantified strategic model that can maximize the success of a national IT R&D project.

The portfolio model shows a high alignment with management and national R&D strategies, but it is adjusted not to its own project but to a project portfolio. It also has a weakness in that it is subjective in project selection. To supplement this weakness, we created a strategy selection model made up of three steps. The first step is to classify strategy projects. The second step is to select the evaluation items of a project. Finally, the last step is to select an individual project following the strategy.

In this paper, a model for the classification of project portfolios that align with a national IT R&D strategy is developed, and at the same time evaluation items for the classification of project portfolios are chosen. In this step, evaluation items fitting a national IT R&D strategy are selected. Afterward, projects are classified following the strategy, and evaluation items are chosen. All projects are then evaluated, and the priority of each project is given.

In this paper, an attempt was made to develop a smiling-curve innovation strategy [10] as the national IT R&D strategy of Korea, along with a strategic portfolio model for optimal project selection. An R-R portfolio model on the two axes of risk and return was utilized among strategic portfolio models for national R&D project selection in compliance with management strategies. Subjective determination of priority projects is generally considered to be a disadvantageous trait in terms of the previous R-R portfolio model, and thus an IT technology road map (TRM) index and technical-level report were used as an evaluation index to improve the objectivity of priority projects. Also, the evaluation items and selection weight of an R&D project are those used in choosing a strategy project applying the analytic hierarchy process (AHP), as shown in Fig 1.

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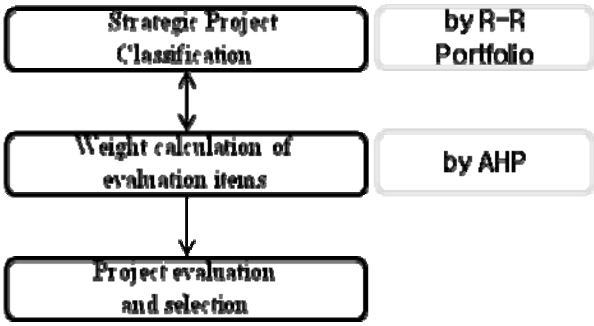

Fig. 1. Strategic project selection step.

The strategic portfolio model developed in this paper can be used to help evaluate an R&D budget, and to ultimately select a strategic project suitable for a national IT R&D strategy and maximize the project's success.

II. UNDERSTANDING PORTFOLIO MANAGEMENT

The management of an R&D portfolio is a concept that indicates the prior evaluation of an R&D project, a go/kill, establishment of the balance and mixture between projects, the priority of projects, and the personnel/material allocation of project resources.

The management of an R&D portfolio has three goals. The first goal is the maximization value of the portfolio. Its main purpose is to achieve commercial success including financial indexes such as long-term earnings, rate of return on investment, net present value, and so on. Following this purpose, resources are allocated to maximize a portfolio's value [11], [12]. The main techniques for this are an index and check-list.

The second goal is to balance the portfolio. Following this goal, a balance between projects is emphasized according to market, product category, technology, and project type (new product/ improvement/cost/reduction/maintenance/basic research, and so on). A bubble diagram and map are used as the main techniques.

The last goal is to manage the portfolio under a strategic direction. That is, based on the management strategies, the selection of an R&D project, and resource allocation, are emphasized. The accomplishment under the third goal is 'the strategic portfolio management' of R&D. Of course, there are clashes among the three goals. For example, since most portfolio management for maximizing the value of an R&D project is short-term and avoids risk or focus on a specific point, such management can fail to maintain balance among projects. Also, portfolio management based on a business strategy can overlook financial goals. However, a strong alignment between R&D strategy and business strategy is currently emphasized due to the rapid change of business and technology environments.

Souder and Cooper classified the tools for R&D project selection into a scoring model, financial model, and portfolio model [13], [14]. The portfolio model is characterized by a dynamic decision process designed for R&D strategy-based project positioning, by improving both the scoring model's subjectivity and the financial model's attributes between factors [13], as well as the R&D project's uncertainty, limited budget, and multiple attributes. Although there is complexity in resolving both the impossibility of a model application without objective data and a model's multiple attributes [15], a significant improvement in current computer systems makes it possible to deal with the complexity of data processing, and eventually more emphasis has been put upon the development of a portfolio model for the effective allocation of resources [16].

In addition, a strategic portfolio model has been intensively studied to select an R&D project consistent with the management strategy [17]. A wide variety of strategic portfolio models are used. These include bubble diagrams [18], which are designed for a balance between businesses by taking a bubble size and color in consideration, and a BCG (Boston Consulting Group) matrix (star, cash cow, question, and dog) on the two axes of market share and market growth. Most researchers have only focused on the problem of how to effectively allocate resources, without considering the problem of how to maximize a project portfolio. They consider only how the limited resources for each project will be balanced. When a strategic project is selected from projects positioned in a project group consistent with the management strategy in accordance with allotted resources, the previous portfolio models are so subjective that the scoring model cannot be used to make a decision on the priority project. In the model used in this paper, therefore, we put more emphasis on retaining objectivity while minimizing the subjectivity in project selection.

III. STRATEGIC R-R PORTFOLIO MODEL

A. Constitution of a model

We used a portfolio model that reflects the various strategic demands for strategic project selection and resource allocation that meet a national IT R&D policy. Out of various portfolio models, we made one based on an R-R portfolio model, of which the frequency of use is the greatest at 44.4%, that adopts risk and return as its two axes [18]. The model for the selection of a strategic project portfolio is made up of three steps. The first step is to analyze a national IT R&D strategy. The second step is to develop a portfolio model coinciding with the national IT R&D strategy. The third step is to select a project portfolio coinciding with the strategy, as shown in Fig. 2.

In the process, an R-R portfolio model coinciding with Korea's IT R&D strategy is applied, and at the same time evaluation items for the classification of strategy project portfolios are chosen.

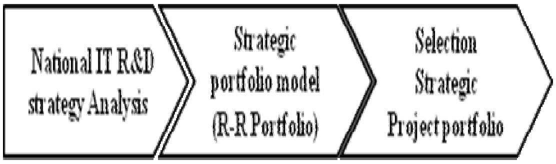

Fig. 2. Concept model of an R-R Portfolio.

B. National IT R&D strategy

Korea's role in the area of worldwide IT has recently been redefined to be a technology leader from a catch-up position. With the recent rapid increase in Korea's national budget for IT from $320 million in 2003 to $401 million in 2008, as shown in Table 1, it has been necessary to formulate a new IT R&D strategy. As a result, an IT R&D smile-curve innovation strategy [10] was formulated in 2008.

TABLE 1.
IT R&D BUDGET IN KOREA

(million $)

Division	2003	2004	2005	2006	2007	2008
R&D budget	320	350	389	453	438	401

The existing IT R&D strategy was included in the comfort zone of the application project, which made it easy to obtain visible results by only building a road map and managing milestones. Today, however, the national IT R&D strategy is a smile-curve innovation strategy, as shown in Fig. 3, aiming to maximize the value creation at both extremes of fourth generation R&D invention and innovation, which consist of the 'core' technology of invention and 'commercial' technology of innovation, used to carry out the smile-curve strategy.

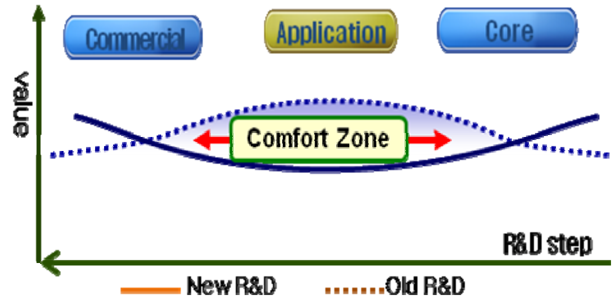

Fig. 3. National IT R&D strategy (smiling curve).

Taiwan's business and academic circles recently designed the "Smile Curve" model of labor division with China [19]. In this model, Taiwan's manufacturing industries intensely developed two-pronged higher value sectors on the smiling curve of value chains; the lower value sector, located on the mid-stream of the value chain of the curve, is to be carried out in China.

As the smiling curve strategy is one that avoids the area of application research that easily achieves visible results and creation, but focuses on fundamental research and commercialization, it simultaneously produces future fundamental research, and cutting-edge commercialized products and services in both extreme areas.

C. R-R portfolio model

A new strategic portfolio model was developed on the two axes of risk and return, which are most widely used [18] for strategic project selection and resource allocation of portfolio models (44.4%) in compliance with the national IT R&D strategy. In addition, an R-R portfolio model was developed in connection with the smile-curve innovation as a national IT R&D strategy, as shown in Fig. 4.

In order to develop a portfolio model coinciding with the smiling curve, which is a national IT R&D strategy, we considered the meaning of the value of the smiling curve's x axis and of the return of an R-R portfolio's x axis as being identical. When the values of ROI, ROA, and ROE are used for the measurement of return, it is generally thought that they have the same meaning. Under the hypothesis, while a new engine technology with a low risk and high return target is the commercial project of a national IT R&D strategy, a challenging technology with a high risk and high return target is a core project and coincides with the commercial and core area of the smiling curve strategy.

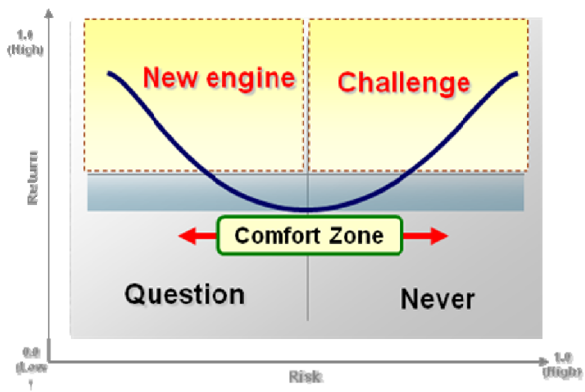

Fig. 4. Alignment with the smiling curve

1) New engine target

As a low risk, high return technology, the new engine target is a strategic project used to carry out a commercial technology development project for a new engine (the commercial project).

2) Challenge target

The challenge target is a high risk, high return technology to implement the core technology project in terms of risk management (the core technology project).

3) Question target

This is a low risk, low return technology used to re-determine if a budget is invested in R&D (the application project).

4) Never target

The never target, a high risk, low return technology, is a holding project of an R&D budget (the application project).

IV. EVALUATION ITEMS BY AHP

A. Evaluation Index

An R-R portfolio model on the two axes of risk and return was utilized among strategic portfolio models for national R&D project selection in compliance with management strategies. Because the subjective determination of priority projects was generally considered to be a disadvantageous trait in terms of the previous R-R portfolio model, an IT technology road map (TRM) index and technical-level report (TLR) were used as an evaluation index to improve the objectivity of priority projects, as shown in Fig. 5.

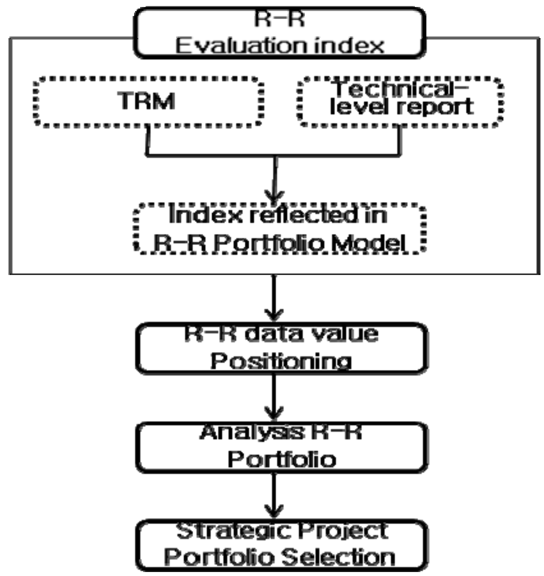

Fig. 5. Strategic project portfolio selection flow chart.

First, we proposed over 16 sub-criteria for R&D project selection on the basis of the findings of relevant literature [20]. Weighing indexes, such as an IT TRM and TLR, were used as the input of risk and return to evaluate the subjectivity of the R-R portfolio model. The values of risk and return were obtained by weighing individual criteria. Then, the value of the R-R aspect was positioned in the project target so that an appropriate strategic project could be selected. We selected the evaluation items by referring to a data envelopment analysis (DEA) and AHP for R&D projects of preceding researches [21]. For the return aspect, we set up a connection of vision/strategy, an expected benefit and effect in the aspect of technology/market, along with the originality of a product as evaluation criteria. For the risk aspect, we set up the risk under the aspect of technology/market, along an input budget, as the evaluation criteria, as shown in Table 2.

TABLE 2.
EVALUATION CRITERIA.

Aspects	Criteria(w_j)	Sub Criteria(u_j)
Risk	Technology	Technology level, gap & maturity
	Marketability	Market size, Competition, Growth & maturity
	Budget	Investment in R&D budget
Return	Vision	Strategic alignment
	Technology	Technology importance, Urgency & ripple effect
	Marketability	Commercialization, Market share & revenue
	Originality	IPR & international standard

The content of each evaluation item offers evaluation criteria for the application of quantified indexes of the technical-level report and TRM, which are the sources of quantified data, as shown in Tables 3 and 4.

The criteria using TLR as a data source is the technology of risk and return. The criteria using TRM as a data source are the marketability of risk and return and the vision criteria of return. We used materials regarding intellectual property rights (IPR) and international standards for the evaluation of a return's originality.

TABLE 3.
RISK SUB CRITERIA.

Criteria (Data source)	Sub Criteria	Evaluation criteria
Technology (TLR)	Technology level	Technology level 100% compared to top technology level
	Technology gap	The period of a technology attainment compared to top technology level
	Technology maturity	Maturity of a main technology.
Marketability (TRM, TLR)	Market size	Market size per year
	Market competition	The number of competitors in a target market and the ease of entering a market
	Market growth	Market growth rate for five years after the development of a product
	Market maturity	Market maturity of an applied product
Budget (Expert)	Investment in R&D budget	Investment of an R&D in its period

TABLE 4.
RETURN SUB CRITERIA.

Criteria (Data source)	Sub Criteria	Evaluation criteria
Vision (TRM)	Strategic alignment	Strategic alignment
Technology (TLR)	Technology importance	Technology importance
	Technology urgency	The period in which a technology reaches a proper level
	Technology ripple effect	Ripple effect on other technology developments
Marketability (TRM)	Commer-cialization	Period for technology transfer or for a technology to become a project
	Market share	Expected sales per year
	Market revenue	Expected market share per year
Originality (IPR)	IPR & international standard	Possible capability of securing IPR

B. Evaluation weight

We used Satty's analytic hierarchy process (AHP) [22], one of the multi-criteria decision making techniques, to objectify the indexes of the risk and return used in an R-R portfolio model by quantifying them.

This paper analyzed the AHP process using four steps.

- Step 1: Convert a complicated, vague decision-making problem into a hierarchy structure made up of three items: goal, criteria, and alternatives.
- Step 2: Carry out pair-wise comparisons by adopting evaluation criteria of the items of each class.
- Step 3: Presume the relative weight among decision-making factors using an eigenvector method. That is, when eigenvector W is sought through $A \cdot W = \lambda max \cdot W$ (here, A indicates a square matrix obtained with a pair-wise comparison, λmax is a maximum eigen value of A, and W is an eigenvector), a normalized weight can be obtained by dividing each factor of W with $\sum w_i$.
- Step 4 : The last step is a process in which the relative weight of evaluation criteria calculated in each class is aggregated to seek the relative weight and priority of alternatives in the lowest class. It seeks composite relative weights of alternatives to know the effect and importance of the alternatives in the lowest class when the most normal goal of the decision-making in the top class is achieved. The aggregated weight of an alternative can be sought through $W_i = \sum (w_j)(u^i_i)$ (W_i means the aggregated weight of the i-th alternative, W_j the relative weight of evaluation criterion j, and u^i_i the weight of the i-nth alternative for evaluation criterion j). The aggregated weight of these alternatives is also called the relative weight or priority of these alternatives, and offers the base of an alternative choice or resource distribution.

The overall weight of the project was calculated using the AHP based on the following formula:

$$W_i = \sum_j (w_j)(u^i_j),$$

where W_i is the overall weight of *ith* project, w_j is the relative weight of evaluation criterion, j, and u^i_j is the weight of the *ith* project to the evaluation criterion, j.

Choosing the weight for an evaluation item is an important problem in the selection of a project and the constitution of an evaluation system along with the setup of an evaluation item. After conducting a survey, we calculated a consistent weight and a relative weight through pair-wise comparisons in the evaluation criteria of technology, marketability, financial resources, vision, and the originality of a product as shown in Table 5.

TABLE 5.
CRITERIA WEIGHTS.

Aspects	Criteria(w_j)	Weights	
		New engine	Challenge
Return	Vision Technology Marketability Originality	0.136 0.294 0.462 0.108	0.196 0.381 0.204 0.219
Risk	Technology Marketability Budget	0.415 0.480 0.105	

In the area of return, we sought a weight by dividing the new engine and challenge. This is because originality is highly preferred in challenge projects.

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V. STRATEGIC PROJECT SELECTION

A. Strategic project portfolio selection case

We applied this model to 170 projects that had been proposed to the R&D of information and communications of the Ministry of Information and Communication in 2008.

In the first step, we set up a new engine and challenge target as strategic areas, and selected 71 projects as new engines and 61 projects as challenge targets out of the 170 proposal projects. The number of the selected projects is 132 as shown in Table 6.

TABLE 6.
SELECTED RESULTS OF THE STRATEGIC PROJECT PORTFOLIO (1ST STEP).

Project fields	Target		Total
	New engine	Challenge	
Semiconductor	8	13	21
Display	4	7	11
LED, FTTH	9	7	16
Home network	14	3	17
Digital TV	9	3	12
Broadcasting, satellite	0	11	11
Mobile phone	2	8	10
BcN	5	3	8
SW	9	0	9
Post computing	4	2	6
Information security	4	4	8
Digital contents	3	0	3
Total	71	61	132

It is possible, for example, to select a project on the basis of (A) and (B) in Fig. 6, by positioning 11 candidate projects related to information security in an R-R portfolio, and then reflecting the amount of R&D budget. Line (A) in Fig. 4 has eight selected projects consisting of four commercial technology projects (denoted as 8, 9, 10 and 5) and 4 core technology projects (denoted as 6, 11, 7 and 3).

Upon seeing the process in which an R&D project portfolio is selected, we can find that there is a lot of negotiation and compromise. While going through negotiation and compromise, the R&D budget and project period are revised from their original project portfolio. The selection of a strategic project portfolio is also chosen through negotiation and compromise as its budget and period are considered.

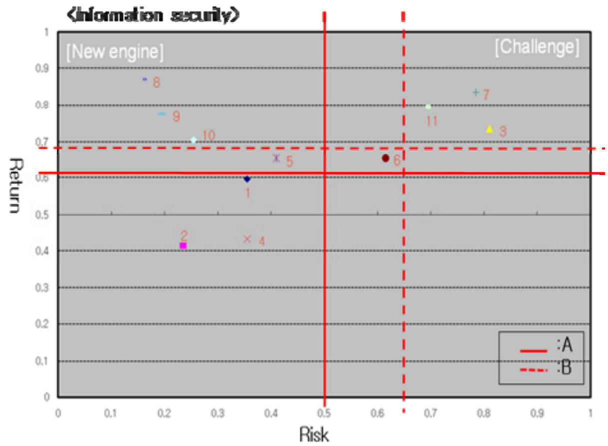

Fig. 6. Strategic project portfolio selection.

B. Strategic Project selection case

As the selection of a strategic project is the second step, out of the 132 project portfolios selected from 170 proposal projects, we selected strategic projects that meet a national R&D strategy and budget and that have an optimal resource allocation plan. The strategic project is selected focusing on the projects of a new engine and challenge target of the R-R portfolio, so as to select and emphasize highly valued commercial and core technologies of the smiling curve, as shown in Fig. 7.

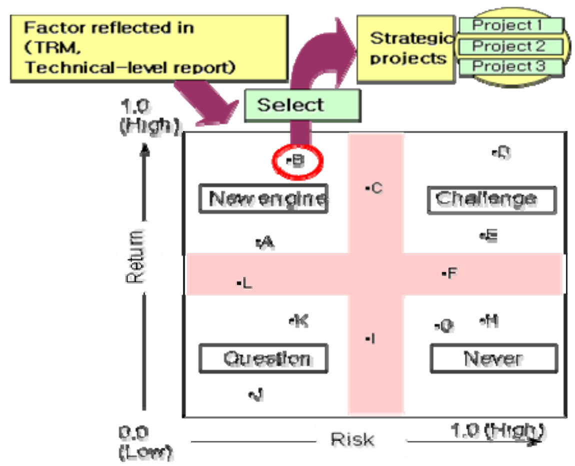

Fig. 7. Strategic project selection of R-R portfolio model.

Considering the limited R&D budget, out of the 132 candidate projects in the first step, we selected 46 projects as a new engine target fitting the national R&D policy and 41 projects as challenge targets. Thus, the number of selected projects is 87. Appropriate projects for a national R&D strategy are selected by reflecting the limited amount of R&D budget on the basis of individual targets. The commercial technology project is selected using the new engine target with low risk and high return, as shown in Table 7.

TABLE 7.
SELECTED RESULTS OF THE STRATEGIC PROJECT (2ND STEP).

Project fields	1st Step selection	Target		Total
		New engine	Challenge	
Semiconductor	21	6	8	14
Display	11	2	4	6
LED, FTTH	16	2	6	8
Home network	17	7	1	8
Digital TV	12	9	3	12
Broadcasting, satellite	11	0	8	8
Mobile phone	10	2	6	8
BcN	8	4	2	6
SW	9	6	0	6
Post computing	6	3	1	4
Information security	8	3	2	5
Digital contents	3	2	0	2
Total	132	46	41	87

As the final selection of an LED and FTTH project, considering their budgets, we selected two projects out of nine for the new engine, and six projects out of seven for the challenge target, bearing in mind the core technology of the LED project, as shown in Fig. 8.

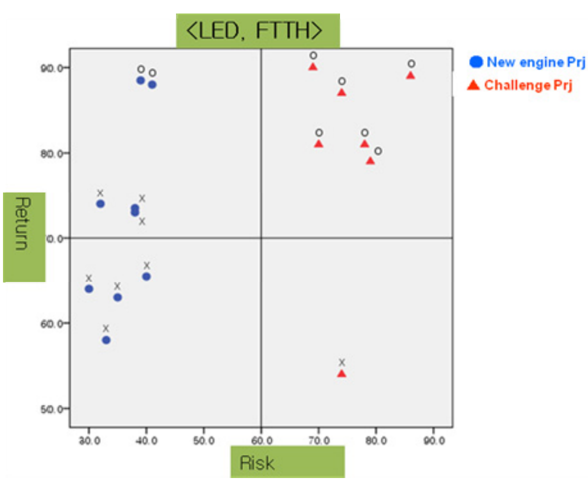

Fig. 8. Strategic project selection.

VI. MODEL VERIFICATION

With 170 candidate information and communication research and development projects of the Ministry of Information and Communication, an analysis using Pearson's correlation coefficient was done to examine the degree of correlation between risk and return variables used in the present model. The analysis results indicated that there is a statistically significant correlation between risk and return.

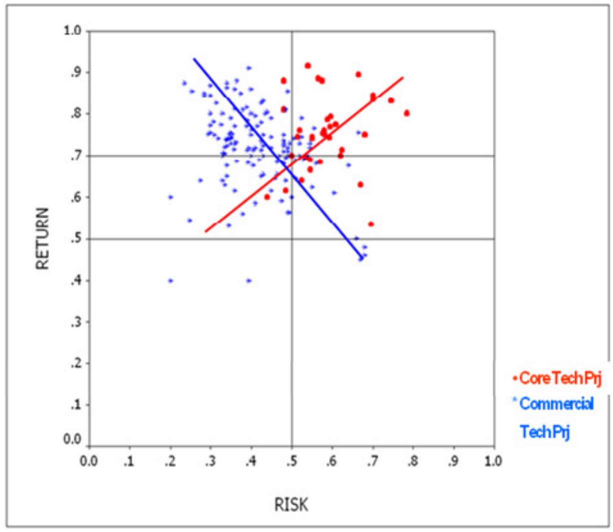

Fig. 9. Pearson correlation: challenge target = 0.181, new engine target = -0.320 (correlation coefficient is significant at the 0.05 level).

The correlation coefficient of the new engine target shows -0.320, a negative correlation, indicating that the lower the risk, the higher the return. The challenge target shows a positive correlation of 0.181. It seems that the higher the risk, the higher the return. The correlation is statically significant at the 0.05 level. Namely, it was shown that when the 170 candidate projects were compared, there was a statistically significant correlation between risk and return, as shown in Fig. 9.

Also, the analysis results of the project selection following the evaluation grade show that although 3 projects among 132 projects in the first step had low evaluation grades, they were selected as final projects. They belong to a low level, 2.3% of the total projects.

For the LED and FTTH projects, projects with an evaluation grade of A were selected, but projects with an evaluation grade of B were dropped, as shown in Fig. 11.

The broadcasting & satellite project shows that two projects with evaluation grades of B were selected as final ones, but three projects with evaluation grades of A were dropped, as shown in Fig. 12. This can be analyzed that when a final decision maker selected a strategic project, the quantified selection values were minimized.

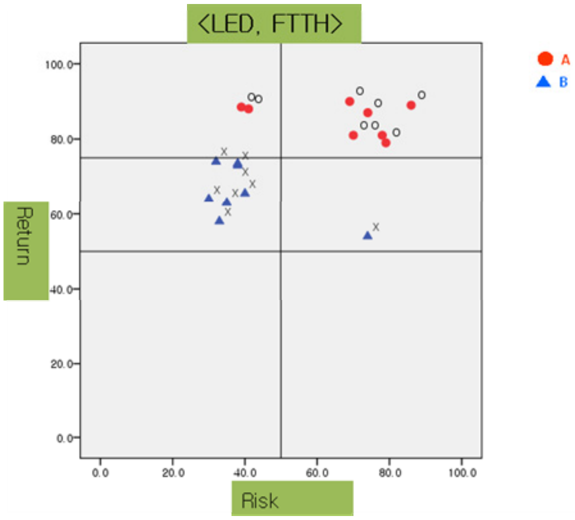

Fig. 10. Project Selection (1) according to evaluation grade.

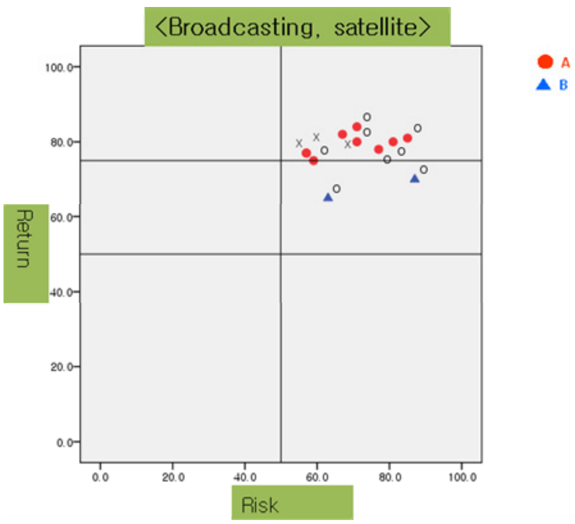

Fig. 11. Project Selection (2) according to evaluation grade

VII. CONCLUSION

This paper aimed to develop a strategic portfolio model for project selection coinciding with a national IT R&D policy, by objectively and strategically approaching a portfolio model that reflects both the scoring model's subjectivity and the financial model's simplicity.

The portfolio model shows a high connection with a strategic project, but has a weak point in that the selection of a project portfolio's unit and the project itself are subjective. Thus, we used an AHP for the objectivity of project selection and the selection of an individual project.

The portfolio model is frequently used by private companies to select a project effectively with a limited amount of resources. In particular, the most widely used R-R portfolio model was used in this paper. The four targets, new engine, challenge, question, and never, were developed on the two axes of risk and return.

The present paper offers the value and mapping of smiling curve innovation, which is one of the national IT R&D strategies. In addition, weighing indexes, such as TRM and R&D performance plan, were used as an evaluation index to improve the objectivity of the present model. The 170 candidate information and communication research and development projects selected by the Ministry of Information and Communication (MIC) in 2008 were analyzed to examine the degree of Pearson's correlation, in order to test the model used in this paper. As a result, it was shown that there is a statistically significant correlation.

Also, the analysis results of the project selection following evaluation grades showed that three projects of 132 candidate projects had a low evaluation grade but were selected as final projects.

This is because in the selection process of an IT R&D strategic project, the subjectivity of a final decision maker was minimized. This model cannot be a standard for the selection of all national IT R&D strategic projects, but offers a model for the selection of a project coinciding with a national policy.

The model developed in this paper will contribute to maximizing the effective value of national IT R&D projects and in selecting the optimal project effectively. Moreover, this model will play an important part in the selection of R&D project and the allocation of resources in other areas.

REFERENCES

[1] R. G. Cooper , S. J. Edgett, and E. Kleinschmidt, "New Problems, New Solutions: Making Portfolio Management More Effective," *Research Technology Management*, pp.18-33, Mar-Apr., 2000.

[2] S. J. Yeon, "A Strategic Grid for Implementing Ubiquitous Computing," *ETRI Journal*, vol. 29, no. 2, pp.252-254, April 2007.

[3] N. R. Baker, "R&D Project Selection Models: an Assessment," *IEEE Transactions on Engineering Management*, pp. 165–171, 1974.

[4] M. J. Liberatore, "Titus GJ. The Practice Management Science in R&D Project Management," *Management Science*, pp.962–975, 1983.

[5] R. L. Schmidt and J. R. Freeland, "Recent Progress in Modeling R&D Project Selection Process," *IEEE Transactions on Engineering Management*, pp.189–201, 1992.

[6] A. D. Henriksen and A. J. Traynor, "A Practical R&D Project-Selection Scoring Tool," *IEEE Transactions on Engineering Management*, pp. 46-72, 1999.

[7] L. P. Santiago and P. Vakili, "Optimal Project Selection and Budget Allocation for R&D Portfolios," in *Technology Management: A Unifying Discipline for Melting the Boundaries*, pp. 275-281, 2005.

[8] R. G. Cooper, “Debunking the Myths in New Product Management,” *Research and Technology*, vol. 37, no. 4, pp. 38–40, 1994.
[9] R. G. Cooper, “Developing New Products on Time, in Time,” *Research Technology Management*, vol. 38, no. 5, pp.49-58, 1995.
[10] Korea MIC, “Korea IT R&D Strategy Plan,” 2008.
[11] J. Choungsirakulwit, “Portfolio Management of Option-Based Investment in Technology Research and Development,” *6th IEEE/ACIS ICIS*, 2007.
[12] W. R. Bitman, "R&D Portfolio Management Framework for Sustained Competitive Advantage," presented at *2005 IEEE International Engineering Management Conference*, 2005.
[13] W. E. Souder, "A System for Using R&D Project Evaluation Methods," *Research Technology Management*, vol. 21, no. 5, pp. 29-37, 1978.
[14] R. G. Cooper, S. Edgett. and E. Kleinschmidt, "Best Practices for Managing R&D Portfolios," *Research Technology Management*, July-Aug., pp.20-33, 1998.
[15] Taeho Ahn, *et al.*, “R&D Project Portfolio Selection Problem,” *Journal of the Korean MS Society*, Mar., pp.1-10, 2008.
[16] B. Jackson, "Decision Methods for Selecting Portfolio of R&D Projects," *Research Technology Management*, vol. 26, no. 5, pp.21-26, 1983.
[17] I. C. MacMillan and R. G. McGrath, "Crafting R&D Project Portfolios," *Research Technology Management*, vol. 45, pp. 48, 2002.
[18] R. G. Cooper, *et al*., “R&D Portfolio Management Best Practice Study,” *IRI*, Washington D.C., 1997.
[19] P. K. Chiang, "Current Situation in Taiwan's Economic Problems and Countermeasures," *National Policy Foundation Study*, Taipei, 2002.
[20] Y. G. Hsu, G. H. Tzeng, J. Z. Shyu, “Fuzzy Multiple Criteria Selection of Government-Sponsored Frontier Technology R&D projects,” R&D Management, pp. 539-550, 2003.
[21] C. C. Huang, *et al.*, “A Fuzzy AHP Application in Government-Sponsored R&D Project Selection,” *Omega 36*, pp.1038-1052, 2008.
[22] T. L. Satty, *Analytic Hierarchy Process*, New York, McGraw-Hill, 1980.

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