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A Risk Management System Framework for New Product Development (NPD)

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***Abstract* — As the interval of technical innovation cycles has become shorter, the life cycle of products has been shortened. Due to the diversification of customer needs, the functions and performance of products should be improved quickly. In markets with fierce competition, the successful development of new products that ensure improved functions and performance is required for corporate survival. Most enterprises have difficulties in new product development. Diverse risk factors that occur during product development are obstacles for the successful development of new products. Thus, risk factors that may occur during new product development (NPD) need to be recognized in the project planning step, and a risk management system, measuring the impact of the risk factors on all project steps, needs to be developed. In this study, the AHP, fuzzy model, Markov process, and evolution strategy models are described to predict risk factors that may occur while working on NPD, both individual and integrated risk factor degrees can be calculated, and optimized responding activities against risk factors can be selected to minimize responding time and costs. Then, a systematic framework for risk management is proposed for handling risk factors, risk degrees, integrated risk degree, and responding activities with corresponding data flow diagrams.**

Keywords - New Product Development(NPD), AHP, fuzzy model, evolution strategy, risk degrees, integrated risk degree, responding activity, risk management framework, data flow diagram

I. INTRODUCTION

In fiercely competitive markets, the release of new products with innovative functions and performance is a required strategy for corporate survival and required factor for having the advantage in corporate competition. It is reported that the success rate of projects for new product development is, however, very low. Worldwide, approximately 80% of manufacturer new product development projects fail before completion. More than half of the 20% of successful cases fail to return investment costs and become profitable. Higher costs and more time have been used than expected to achieve the project goals [1][2][3].

The main reasons why most of the companies have failed in the development of new products are as follows: an increase in time and costs in all the phases and stages for NPD due to their sequential processes, difficulties in constructing reasonable development schedules and resource distribution plans, failures to respond effectively or efficiently to the diverse risk factors that occur in development processes, and the insufficiency of a comprehensive decision-making system based on qualitative and quantitative information and materials obtained while working on past product development projects. Another reason is that as the life cycle of products has been shortened, the product types demanded by customers have been diversified, and technology has become more complex, risk factors and their risk degrees, which denote the impact of the risk factors to NPD projects, have not been able to be assessed. Predicted risk factors have not been able to be properly dealt with. These reasons point to the need for systematic risk management systems throughout all required steps in NPD.

The purpose of this study is to find the risk factors that may occur in each phase of a NPD project in advance and to develop a systematic risk management framework. This would enable predicting the possibility of project success by determining the impact extent of risk factors during the project phases and the integrated risk degree of the entire project. The framework can also propose the optimized responding activities against various risk factors not only to minimize the project time and costs but also to reduce the risk degrees computed in each phase and the integrated risk degree in the entire project.

II. RELEVANT STUDIES RELATED TO RISK MANAGEMENT

Some parts of the previous studies related to risk management methods in NPD can be summarized as follows: Savci and Kayis [4] established a risk classification system in order to identify risk factors in NPD projects. Ahmed et al. [5] and Dey [6] proposed the AHP method for risk analysis, and evaluated the impact of each risk factor in a project by performing pair-wise comparison. Bowles and Pelaez [7] applied the fuzzy theory to assess risk factors. Choi and Ahn [8] proposed a method for the evaluation of multiple risk factors on the basis of concurrent engineering and for assessing the impact of risk factors.

Many studies on risk analysis and management have been performed, but systematic research on how a risk management system is built has been rare. In particular, there are few systematic studies on the establishment of risk management systems for NPD. As in similar studies about other fields, Carr and Tah [9] developed a Hierarchical Risk Breakdown Structure (HRBS) as a model of risk evaluation and analysis for risk management in construction projects. As a risk evaluation method, the fuzzy model was used. Wu at al. [10] used Graphical Evaluation and Review Technique (GERT) as a model for managing risk factors during product development based on concurrent engineering. Ngai and Wat [11] developed the Fuzzy Decision Support System (FDSS) as a risk analysis model where the fuzzy set theory is applied to the uncertainty of risk factors that occur during the development of e-commerce. In the previous studies, risk management systems are still mainly intended for the development of finance, construction, R&D projects, etc. Also, it is difficult to convert the results into reliable information due to a dependence on experts' subjectivity.

Since there are few scientific risk management systems available for NPD to predict risk factors, to assess the impact of risk factors, and to prepare for responding activities against each risk factor, this study proposes a primitive framework for managing risk factors effectively and efficiently.

III. Risk Factor Categories and Risk Degrees

The definitions of risks are different from research areas; however, a risk is typically defined as "an event that may hinder the achievement of project goals due to unwanted results". In this study, a risk factor is defined as an event that can occur and may negatively affect total costs, required time, and the quality of new products in a new product development project. TABLE I shows an example of risk factors examined, collected, and categorized under this definition.

Risk degree denoting the impacts of risk factors is shown in (1).

$$R = P \times I \tag{1}$$

Where R is risk degree, P is the probability of risk occurrence (0~1), and I is risk factor impact (0~1).

In order to calculate the risk degree of an entire project, risk factors that may occur in the project should be identified as many as possible and (1) should be used to calculate individual risk degrees. Each risk degree is synchronized in each product development phase, and then an integrated risk degree for an entire project. The development phase in NPD is divided into six steps such as planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up[12]. The occurrence probability of each risk factor should be also determined.

IV. Detailed Methodologies

In order to synchronize risk degree in a phase and calculate the integrated risk degree of an entire project, the degree of each risk factor needs to be calculated. In this study, both the AHP [14] and fuzzy models [8] are used for developing a systematic risk management framework.

A. Calculation of Relative Impact for Risk Factors

In order to estimate the impact of a risk factor in (1), the importance level of each risk factor needs to be examined with respect to an entire project. The AHP model that enables the quantification of risk factor impacts in decision-making under multiple criteria is appropriate for determining the importance level. The AHP model is categorized into "relative evaluation" and "absolute evaluation". In most of the research methods, "relative evaluation" was used because there are few risk factors to be compared. In this study, however, all detailed risk factors are considered together; thus, "absolute evaluation" is used. In "absolute evaluation", if there are many pairs to be compared, it will be difficult to compare all pairs at the same time. Thus, factors are categorized into higher-level or lower-level. Pair-wise comparisons were performed for only higher-level factors in order to determine relative importance level. Lower-level factors are given weights under a specific criterion, and weight for higher-level factors is multiplied by the weight of a lower-level factor to set the final weight.

B. Calculation of Risk Impact Depending on the Difficulty Level of Projects

The importance of each risk factor is calculated by performing the AHP analysis to be done by experts in the field. Even though experts' experiences and knowledge can be quantified by the AHP analysis, this output value still implies the subjectivity and ambiguity of experts. Therefore, the subjectivity and ambiguity needs to be reduced. The fuzzy method is used for this purpose.

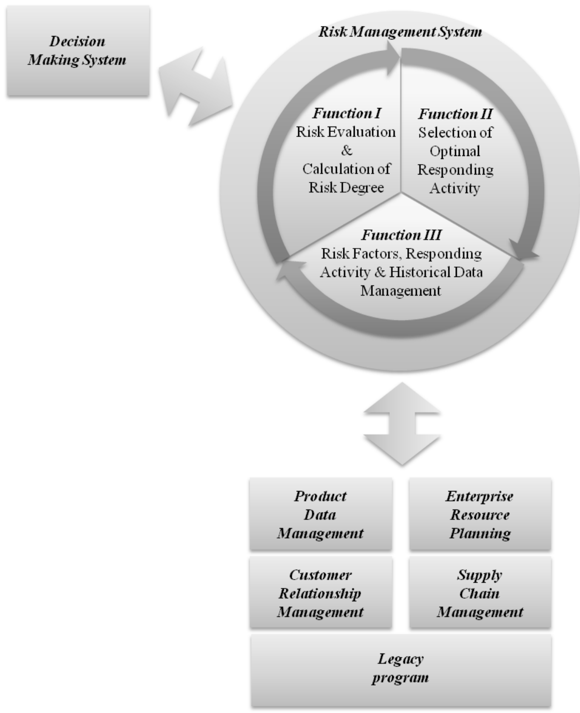

Figure 1. Risk Management Framework and Network Architecture

TABLE I. Classification of risk factors by phase and functions [a]

Category[b]	Risk Factor	Phase[c] 0	1	2	3	4	5	Function: Project Mgt.	Marke-ting	Design	Mfg.
R	Critical resources may not be available when required	O	O	O	O	O	O	O	O	O	O
P	Failure to effectively mix internal and external expertise	O	O	O	O	O	O	O	O	O	O
T	Inadequate user documentation	O	O	O	O	O	O	O	O	O	O
T	Incorrect system requirements	O	O	O	O	O	O	O	O	O	O
P/S	Lack of integration	O	O	O	O	O	O	O	O	O	O
P/S	Lack of proper management control structure	O	O	O	O	O	O	O	O	O	O
P	Lack of senior management support	O	O	O	O	O	O	O	O	O	O
R	Litigation in protecting intellectual property	O	O	O	O	O	O	O	O	O	O
O	Low interest rate	O	O	O	O	O	O	O	O	O	O
O	Sudden change of foreign exchange rate	O	O	O	O	O	O	O	O	O	O
P	Team members not familiar with the task(s) being automated	O	O	O	O	O	O	O	O	O	O
O	Change in organizational management during the project	O	O	O	O	O	O	O			
P	Lack of available project management skill	O	O	O	O	O	O	O			
P/S	Project objectives are poorly defined.	O	O	O	O	O	O	O			
P/S	Unplanned work that must be accommodated	O	O	O	O	O	O	O			
T	Cutting edge, demanding technical effort	O	O	O	O	O	O		O	O	O
T	Inappropriate user interface	O	O	O	O	O	O		O	O	
P	Lack of business analysts with business and technology knowledge	O	O	O	O	O	O		O		
T	Inadequate specification		O	O	O	O	O		O	O	O
T	Insufficient or incorrect design information		O	O	O	O	O			O	O

a. These are some examples of more than 200 risk factors. More risk factors would be collected and classified by functions and phases in further research

b. Risk factor related to people(P), technology(T), resources(R), process/planning/scheduling(P/S), and others(O)

c. The phases mean the sequential steps in NPD such as planning(0), concept development(1), system-level design(2), detail design(3), testing and refinement(4), and production ramp-up(5).

The membership function used in the fuzzy method is a triangle function which has a simple structure and is easy to calculate. The impact of a risk factor may vary depending on the organizations that perform NPD projects, environments surrounding project team, or the difficulty of product development. Therefore, a different type of membership function should be used for a different difficulty. A method proposed by Choi and Ahn [8] can be used to define the difficulty. They used a 9x5 matrix, so called the Influencing Dimensions Matrix (IDM) [13], that represents 9 different dimensions such as product complexity, product technology, program structure, program futures, competition, business relationship, team scope, resource tightness, and schedule tightness along with 4 different levels such as A, B, C, and D. Each dimension is defined by a level for determining the difficulty of a NPD project.

C. Calculation of Risk Occurrence Probability

In order to calculate risk occurrence probability in (1), the Markov process method is used. The Markov process consists of state sets, a transition probability matrix, and an initial state matrix. A state is defined by the range of frequencies of a risk factor observed in past projects. The transition probability between states is computed in a Markov chain. The initial state matrix is defined as the occurrence frequency of risk factors that may occur in recent projects. Then, the probability of risk occurrence of a certain risk factor is obtained by multiplying the initial state probability with the transition probability [8]. In order to apply a risk occurrence model based on the Markov process, past data on the frequency of risk factors should be sufficient and reliable.

D. Calculation of Integrated Risk Degree

In order to calculate the integrated risk degree, or to synchronize risk degrees for an entire project, the risk degree of each development phase is integrated first [14]. The harmonic mean of individual risk degrees for any and all risk factors that may occur in each phase is calculated by using (2). The reason for using harmonic mean is that more than one risk factor may occur simultaneously in a step.

$$R_p = \frac{n}{\sum_{i=1}^{n} \frac{1}{r_i}} \tag{2}$$

After the harmonic mean is obtained in each phase, the integrated risk degree of the entire project is calculated by, arithmetic mean as shown in (3). The reason for this is that project phases are worked on in sequence [8].

$$R_{ALL} = \frac{\sum_{p=0}^{5} R_p}{6} \tag{3}$$

where p is a development phase.

E. Selection of the Optimal Responding Activity

In this study, the evolution strategy [15] is used as a method for selecting the optimal responses to risk factors. The reason for this is that more than one proper response to risk factors may be available. Selecting responses for diverse risk factors is an NP Hard problem.

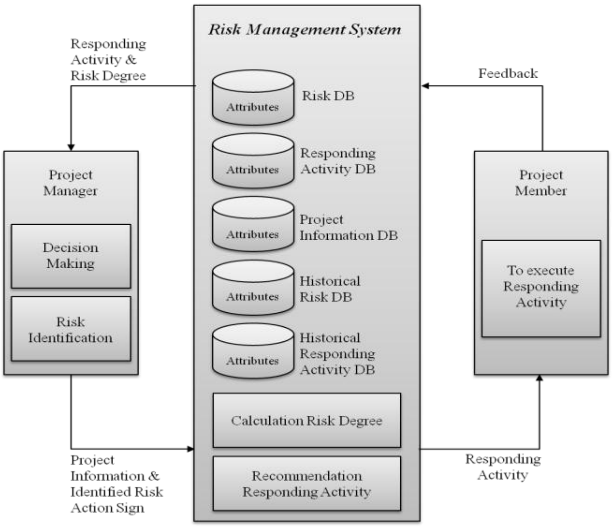

Figure 2. Risk Management System Framework

Choi et al. [14] used LP to resolve this problem and to obtain the optimal responding activities not only for minimizing responding time and costs but also for reducing risk degrees. However, if the number of risk factors and responding activities increases, it will take very long time to select the optimal response activity against risk factors. Therefore, this study uses the evolution strategy in which fitness function for minimizing responding costs is given as (4):

$$fitness = \frac{1}{N_{RA} \times C_{RA}} \quad (4)$$

where N_{RA} is the number of responding activities while C_{RA} is costs for executing each responding activity. It should be noted that more than one risk factor should be dealt with one responding activity. Thus, the genes representing responding activities are allowed to be redundant for risk factors and a smaller number of responding activity is selected if the execution cost is the same as other responding alternatives. The main constraint to perform the evolution strategy is the maximum budget available for a fitness function.

V. Design of Risk Management Framework

A. System Frameworks

The organizational position of the risk management system proposed in this study is shown in Fig. 1. A risk management system cannot exist as an independent system because risk factors consume corporate resources and risk response activities should use the organization's available resources. Therefore, a risk management system must link with corporate resources systematically. The proposed structure of the risk management framework has three main functions as shown in Fig. 2. The first function is for managing various databases related to project information, risk factor types and frequencies, and responding activities. The second function calculates degrees of individual risk degrees of the development phases and integrated ones for the entire projects. The third function is for the recommendation of optimized responding activities to various risk factors.

The database architecture and attributes of the risk management system are as follows and each database is systematically connected and used in all risk management process steps:

- Risk Database: The attributes of the risk database include: Number of Risks, Risk Factor, Phase for Project, Category of Resource, Functional Classification, and Number of Activities. These attributes include when and where risk factors occur in a project, the frequency range and types of risk factors, and effects on resources. Also, various responding activities for risk factors need to be taken into consideration. In this case, more than one responding activity for risk factors can exist.
- Responding Activity Database: The attributes of a responding activity database include: Number of Activities, Description of Activity, Available Resources, Functional Classification, and Effectiveness. Risk factors affect to available resources, to functional categories such as project management, marketing, design, manufacturing, etc, and to each responding activity. An appropriate responding activity with a given effectiveness against a risk factor should reduce the risk degree.
- Project Information Database: The attributes of a project database include Project ID, Project Name, Project Period, Project of IDM Level defining the difficulty, Available Resource, Risk Degree of Phase, and Integrated Risk Degree of Project. This database has data on projects, step-by-step risk degrees after analysis, and the integrated risk degree. The results of additional analysis are updated, and continue to be administered.
- Historical Risk Database: The historical risk database has attributes such as Number of Historical Risk Factors, Historical Risk Factors, Required Resources, Phases For Projects, Categories of Resources, Functional Classification, Risk Factors Occurrences, Number of Historical Activities. This database is used to calculate the probability of past risk factors occurrences.
- Historical Responding Activity Database: The historical responding activity database maintains a record of Number of Historical Activity, Description of Historical Activity, Required Resources, Disposal Time, Disposal Cost, and Effectiveness. This database maintains the records of responding activities against risk factors that have occurred in the past, responding activities

against risk factors that have not been able to be controlled, and time and costs for handling risk factors.

An integrated risk degree is computed by following the steps of data flow diagram shown in Fig. 3 based on the applied methodologies. Also, the optimized responding activities are selected by following the steps shown in Fig. 4. Other valuable data or information available in the legacy system can be added by creating an appropriate format for both data flow diagrams.

VI. DISSCUSION AND IMPLICATION

Traditional methods or frameworks available for risk analysis in NPD are too unsystematic or abstract to be applied in real industries. In addition, their applications are limited to finance, construction, R&D project management, etc. Thus, those who try to handle those risk analysis models, especially for NPD, may have difficulties in setting the scope of risk factors and in determining responding activities at the project planning stage. Even though the developed framework is still at the primitive stage, the risk management framework for NPD proposed in this study would help overcome the difficulties of decision-making. In this study, risk factors that may occur while working on NPD are categorized by functions and development phases. Based on risk factors examined, collected, and categorized, a framework is developed enabling the risk degree analysis of multiple factors through the AHP and fuzzy models, setting of risk priorities on the basis risk degrees, and the analysis of related responding activities for optimizing time and costs. Those companies involved in NPD can determine whether to work on or stop a NPD project by applying the framework to actual work at the planning stage or in process.

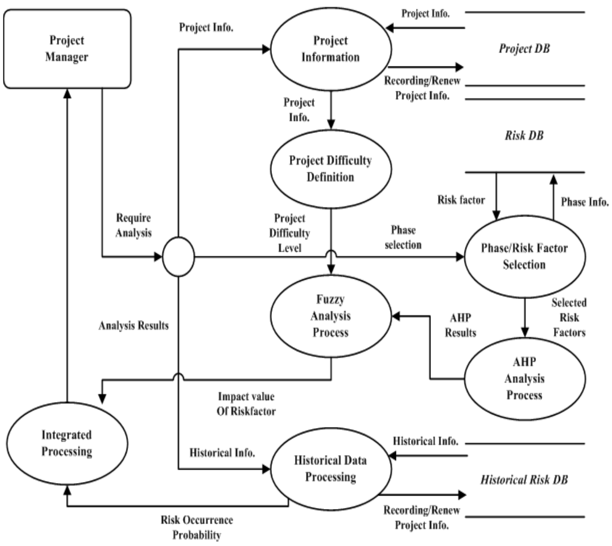

Figure 3. Data Flow Diagram for Integrated Risk Degree.

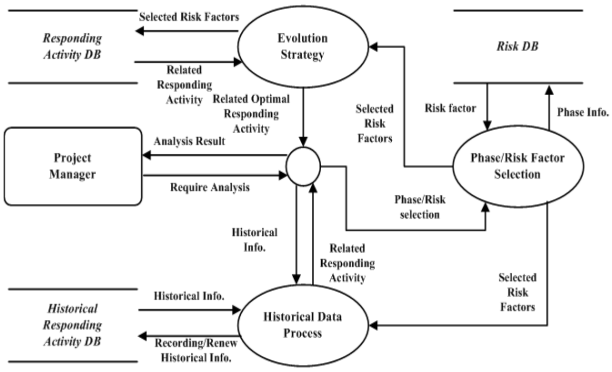

Figure 4. Data Flow Diagram for Responding Activity.

When the current primitive stage of the developed risk management framework fully matures, the success probability of a NPD project can be improved in both the enterprise level and plant level.

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