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Minimizing Risk Costs through Optimal Responses in NPD Projects

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***Abstract*—**In rapidly changing market environment, firms are investing a lot of time and resources into new product development (NPD) projects to make profit and to obtain competitive advantage. However, failure rate of NPD projects is becoming high due to various internal and external risks which hinder successful NPD projects. To reduce the failure rate, it is critical that risks have to be managed effectively and efficiently through good strategy, and treated by optimal responses to minimize risk cost. Four strategies are adopted to handle the risks in this study. The optimal responses are characterized by high reduction of risk costs with high efficiency. This study suggests a framework to decide the optimal responses considering the core risks, risk costs, response efficiency and response costs for successful NPD projects. Both binary particles warm optimization (BPSO) and multi-objective particle swarm optimization (MOPSO) methods are mainly used in the framework. Although several limitations exist in use for real industries, the frame work shows good strength for handling the risks with highly scientific ways through an example.

***Keywords*—**NPD projects, risk cost, strategy, optimal responses, Particle Swarm Optimization.

I. Introduction

THE importance of new product development (NPD) is recognized by typical firms to survive from tough competition in the market. Competitive advantages come from a product or service being better in terms of quality, cost, delivery, and technology. Although many firms have become aware of the importance of the NPD projects, the failure rate of NPD projects is very high [1]. The Product Development and Management Association (PDMA) reported that about 41% of NPD projects carried out by the top 20% of companies have failed in terms of profitability [2].Many reasons can cause the NPD projects failed or stopped. One of the critical reasons is that the cost from risks is not handled properly through appropriate responses. Many risks are involved in NPD, and these affect a project either positively or negatively. The manager must develop effective and efficient plans to respond against such risks, which include product complexity, economic cycle shift, technical risks, customer needs change, currency exchange rates, inflation rate, oil price, stock prices, etc. The risk management process In ISO 31000 has four steps which are risk identification, risk analysis, risk evaluation and risk treatment, and many firms implement these steps similarly in practice [3]. For successful NPD projects, risks should be recognized and responded in advance to minimize the cost from those. Although most companies perform risk management, the cost from risks is still a critical problem. To minimize the risk cost, firms decide optimal responses through good response strategy with considerations of all risks occurred in NPD projects. This study suggests a framework to determine the optimal responses to maximize total response efficiency. The framework works with both binary particle swarm optimization (BPSO) and multi-objective particle swarm optimization (MOPSO) algorithms that are adapted to determine the optimal responses. In general, PSO has the ability to navigate entire solution space, simplicity, ease of implementation, and the computation speed that become faster due to the efficiency of the operation. The PSO also has a lower risk to fall into local minima than other optimization algorithms.

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II. Relevant Literature Review

There are many studies available in NPD risk management areas. Cooper et al. [4] and Polk et al. [5] summarized success factors and obstacles of NPD project. Ghosh and Jintanapakanont [6] and Gu et al. [7] classified NPD project risks and suggested the method to decide the importance of risks. Nagi and Wat [8] suggested the method of evaluating the severity of risks using fuzzy theory. Kim et al. [9] used Multi-response Optimization (MRO) method to determine weights of risks when project manager sets weights of success factors for projects to be successful. A project is evaluated by its own success factors. Four success factors and their related risks were considered to obtain the core risks or the most critical risks. Also, there are some studies focused on responses against risks. Zhi [10] presented that selection of appropriate responses is the most important process in risk management because either effective or efficient responses can reduce or eliminate impacts of risks for project success. Hillson [11] classified the risks into two types: threat and opportunity depending on their impacts. The threat type risks would affect negatively and the opportunity type risks give positive impacts on projects. He suggested four types of response strategies for threat type risks: Avoid, Transfer, Mitigate and Accept. For opportunity type risks, another four strategies were suggested that are Exploit, Share, Enhance and Ignore. Kwan [12] presented that responses selection should be relied on severity, impact and probability of risk occurrences. Also, David [13] evaluated total risk cost by using a matrix composed by impact and probability of risk occurrences.

TABLE I
EXAMPLE OF RISK RESPONSES

Risks	Responses
Critical resources may not be available when required	Undertake resource planning as part of project plan
	Book internal and external resources in advance
	Identify and provide necessary training in advance
Testability is not enough to be considered	Product can be tested to ensure desired quality
	Subassemblies and modules are structured to allow independent testing
	Testing can be performed by standard test instruments
	Test instruments have adequate access
Product life and reliability may not be adequate	Ensure design life and reliability are incorporated in requirements specifications
	Design for life and reliability
	Undertake early life and reliability testing
Inappropriate technology solution may be adopted	Ensure all options are identified at concept study phase
	Evaluate options against specification

The previous studies give plenty of clues to handle risks and select appropriate responses through scientific approaches. However, it is important for project manager to consider synthetically various risks and responses and to obtain optimal solutions through powerful algorithms. The optimal solutions should involve the most valuable strategy to handle various risks by which risk impact or degree is minimized through maximum response efficiency and minimum response cost. For realization of synthetic considerations for risks and responses, this study develops a framework that generates the optimal solutions with better strategy and to support project manager who should manage NPD projects effectively and efficiently.

III. THE IMPORTANCE OF RISK RESPONSES

Risk occurrences in NPD projects are probabilistic events that hinder project success. Therefore, project manager must prepare for appropriate responses to minimize their impacts on the corresponding project on the basis of optimal plan. If the responses are not effective or efficient for the risks, the project could fail in terms of profit making and financial aspects of a firm because significant impact might be extant. Also, the responses against the risks require additional expenses that increase total project cost. Therefore, the plan must be developed with serious considerations of both minimizing the impact and total project cost in order to obtain the optimized responses for the risks. Table I presents some example risks and their possible responses.

In general risk management process, risks are handled through identification, analysis, evaluation and treatment process. Fig. 1 shows stages of risk assessment and risk treatment. The aim of risk identification is to generate a comprehensive list of risks based on those events that might create, enhance, prevent, degrade, accelerate or delay the achievement of NPD objectives. Risk analysis involves understanding of risks to provide an input to risk evaluation.

Also, the purpose of risk evaluation is to assist in making decisions based on the outcomes of risk analysis, about which risks need treatment and the priorities for treatment implementation [3].

It should be noted that the responses selected only for a specific risk would be ineffective or inefficient in terms of time and cost since the risk is correlated with other risk occurrences. Also, the project's success can be evaluated by four different bases: customer, finance, technology, and project management [14]. Each base is characterized by its own risks and requires prioritized responses. Therefore, project manager decides optimal responses on the basis of overall aspects of risks. In this study, a framework is developed to obtain the optimal responses under various strategies for responding against risks such as Avoid, Transfer, Mitigate, and Accept. The response strategy is selected by project manager with consideration of risk types.

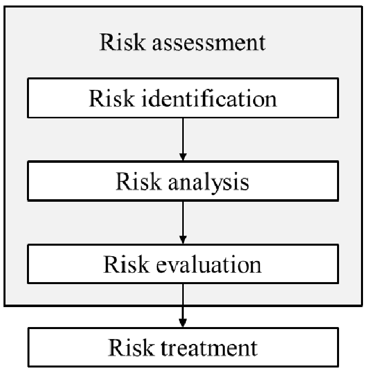

Fig. 1 Risk assessment and risk treatment

IV. THE FRAMEWORK FOR OPTIMAL RESPONSES

Fig. 2 presents the framework developed in this study that consists of three components connected each other as a loop. The loop must be activated whenever risks are occurred in NPD process.

A. Requirements for the Framework

The framework requires three input data which are risk cost, response cost, and response efficiency for every risk. The risk cost (RC) is defined by risk impact expected by project manager. The impact can be converted into project length. For example, a risk is expected to have high impact, project completion time scheduled previously might be delayed and more expenses are required [15]. Equation (1) presents the risk cost where T is the delay time due to the impact and U is a conversion coefficient (cost/unit time).

$$RC = T + U \tag{1}$$

Both response cost (RSC) and response efficiency (RSE) are obtained from past experience on similar NPD projects or historical data. That is, the response costs paid for responding to risks can be derived from accounting data as shown in (2). α is a coefficient to compensate RSC by reflecting interest rate, inflation rate, etc. The response efficiency is defined by the changes of the RSC, that is, the difference between the risk costs before and after applying a response against a risk. Equation (3) shows the RSE.

$$RSC = Historical\ RSC + (Historical\ RSC \times \alpha) \tag{2}$$

$$RSE = Historical\ RC^{before} - Historical\ RC^{after} \tag{3}$$

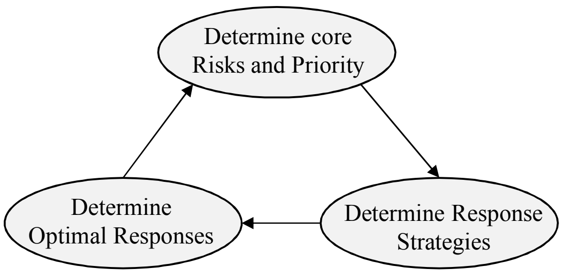

Fig. 2 Framework for decision of optimal responses

B. Determination of Core Risks and Their Priorities

A firm usually pursues NPD project success with its available resources such as people, facility, technology, time and budget. The amount of available resources allocated to the projects is varied by the number of projects and the number of risks occurred. Nevertheless, it is almost impossible that a firm supports all projects and responds to all risks. Therefore, the firm should select the most promising projects through GO/KILL decision at every NPD stage, and respond to the most significant risks efficiently on the basis of management experience and optimal models. This study focuses on risk management to select the core risks and optimal responses under the available resources. A core risk means that it should be responded with higher priority than other risks. The multiple responses optimization method (MRO) was used to determine the core risks along with the optimal responses that maximize the total response efficiency gain [9]. It should be noted that the core risks and their responses were determined with consideration of four different success measuring bases referred in Section III.

C. Strategies for Selecting Responses

Different response strategies are available for handling risks. Each strategy consists of detailed responses. The most desirable responses under a strategy for a risk are selected by minimizing RC in this study. Hillson [11], [16] suggested four independent strategies as follows:

1) Avoid—seeking to eliminate the uncertainty by making it impossible for the risk to occur (i.e. reduce probability to zero), or by executing the project in a different way which will achieve the same objectives but which insulates the project from the effect of the risk (i.e. reduce impact to zero).
2) Transfer—identifying another stakeholder better able to manage the risk, to whom the liability and responsibility for action can be passed
3) Mitigate—reducing the size of the risk in order to make it more acceptable to the project or organization, by reducing the probability and/or the impact
4) Accept—recognizing that residual risks must be taken, and responding either actively by allocating appropriate contingency, or passively doing nothing except monitoring the status of the risk.

The selection of a strategy is surely dependent on risk types, their characteristics, available resources, projected efficiency, and impact on projects.

D.Determination of Optimal Responses

Total response cost should be less than total available budget allocated to a project. Also, a certain response selected for a risk might not enough to overcome completely the impact of the corresponding risk. This means that multiple numbers of responses may be required for making the impact or RCbezero. Project manager often decides which detailed responses are effective for a given risk among many kinds of responses under selected response strategy.

The developed framework uses both binary particle swarm optimization (BPSO) method and multi-objective PSO (MOPSO). The BPSO is used to obtain the optimal strategy among four different strategies, and the MOPSO generates the optimized responses within the optimal strategy that minimize RC for the core risks within a given budget. Then, the optimal strategy for a risk is compared with manager’s strategy to check if there exits inconsistency between them. The number of inconsistent strategies should be minimized.

When the final responses are applied for a risk, the risk impact or risk cost should be overcome by their efficiencies. Equation (4) presents the applicable efficiency $E\ (\geq 0)$ which is determined by the difference between sum of RSE and RSC for all final responses selected for a risk. Due to multiple number of risks, total response efficiency (TRE) can be computed for all risks as shown in (5). Also, total risk cost (TRC) for all risks is defined as sum of risk cost (RC) for each risk. Furthermore, (7) is efficiency degree (ED) as the difference between TRE and TRC. The ED is a measure how much risk impacts or risk costs are diminished by response efficiency. The BPSO produces the final responses that minimized TRC or maximize ED.

$$E = \sum RSE^{selected} - \sum RSC^{selected} \tag{4}$$

$$TRE = \sum E \tag{5}$$

$$TRC = \sum RC \tag{6}$$

$$ED = TRE - TRC \tag{7}$$

V. BPSO AND MOPSO

A. Binary Particle Swarm Optimization (BPSO)

Basically PSO is the algorithm to find out an optimal solution in continuous solution space. Therefore, PSO cannot resolve discrete problem including binary problem. To overcome this limitation, BPSO algorithm which can resolve discrete problem such as scheduling, routing and so on was developed. In original PSO algorithm, each particle's velocity is a real value. But in BPSO, velocity (*v(t)*)is defined by a special function such as sigmoid function as shown in (8), then the function value is compared with random value and is converted to an integer value, 0 or 1 as shown in (9). *r(t)*is a uniform function to generate a random value between 0 and 1[17].

$$f(v(t)) = \frac{1}{1+e^{-v(t)}} \tag{8}$$

$$x(t+1) = \begin{Bmatrix} 0, \ r(t) \geq f(v(t)) \\ 1, \ r(t) < f(v(t)) \end{Bmatrix} \tag{9}$$

B. Multi-Objective Particle Swarm Optimization (MOPSO)

In PSO algorithm, the fitness function should be set accurately and precisely to obtain high quality solutions. This study develops a composite fitness function that consists of three functions for selecting core risks with constrained resources, maximizing either TRE or ED, and minimizing the number of inconsistent strategies. These functions are set for MOPSO to produce the final strategy and responses. Equation (10) presents the composite fitness function where f_i and w_i are i^{th} function and its weight, respectively [18].

$$\begin{aligned} Fitness\,Function &= \{\omega_1 f_1, \omega_2 f_2, ..., \omega_n f_n\} \\ &= \omega_1 \times f_1 + \omega_2 \times f_2 + ... + \omega_n \times f_n \end{aligned} \tag{10}$$

VI. AN ILLUSTRATIVE EXAMPLE

The framework developed in this study may be described by an example. The following assumptions are made in the example:

- The project manager has conducted plenty of NPD projects in the past. This means that he or she can recognize what risks can occur and how much cost incurred from risks.
- The firm can obtain risk responses, risk efficiency, and response cost from historical data using data mining methods and statistical approaches.

A. Input Data Sets

Input data sets required to use the developed framework are given for five core risks, their risk costs, project manager's strategies such as Mitigate, Accept, Transfer and Avoid, RSEs, and RSCs in Table II. It is assumed that five responses are available for each strategy. Therefore, total number of available responses is 20.As mentioned in Section III, project manager should select the strategy for each risk with consideration of the success basis. It is noted that the core risks along with their priorities are selected by the MRO method [9].

TABLE II
INPUT DATA SETS

Risk[1] No.	Risk Cost	Manager's Strategy[2]	Response[3] Efficiency				Response[3] Cost			
1	300	3	200	150	•••	230	50	120	•••	70
2	400	3	350	220	•••	180	200	150	•••	150
3	300	2	240	320	•••	190	100	250	•••	140
4	500	2	80	170	•••	330	130	210	•••	60
5	450	1	140	350	•••	360	200	80	•••	190

[1] These risks are the core risks obtained by (15). Refer to Section V-B
[2] 1 = Avoid, 2 = Transfer, 3 = Mitigate, 4 = Accept
[3] Total number of available responses is 20

B. Fitness Functions

Equation (11) is the fitness function for MOPSO, and (12), (13) and (14) are set for ED (f_1), priorities of core risks (f_2), the number of inconsistent strategies (f_3), respectively.

$$Fitness\,Function = \{\omega_1 f_1, \omega_2 f_2, \omega_3 f_3\} \tag{11}$$

$$f_1 = \sum_{i=1}^{n} ED_i \qquad \text{N = total number of risks} \tag{12}$$

where

$$ED_i = \max(E_{i1}, E_{i2}, ..., E_{is_i}) - RC_i$$

$$E_{ij} = \sum_{k=1}^{S_{ij}} x_{ijk} \times (RSE_{ijk} - RSC_{ijk})$$

i	:	i^{th} risk
j	:	j^{th} strategy
k	:	k^{th} response
S_i	:	total number of response strategies of ith risk factor
S_{ij}	:	total number of responses for i^{th} risk in j^{th} strategy
x_{ijk}	:	selection results for i^{th} risk in j^{th} strategy with k^{th} response through BPSO (x_{ijk} = 0 or 1)

RSE_{ijk} : response efficiency for i^{th} risk in j^{th} strategy with k^{th} response

RSC_{ijk} : response cost for i^{th} risk in j^{th} strategy with k^{th} response

$$f_2 = \sum_{i=1}^{N} p_i \tag{13}$$

where p_i = priority of i^{th} risk obtained from MRO method [9]

$$f_3 = \sum_{i=1}^{N} y_i \tag{14}$$

where y_i = inconsistency strategy or not (y_i = 0 or 1)

Another important constraint is total amount of budget allocated the project (B) to respond against risks as shown in (15).

$$\sum RSC \text{ (of selected responses)} \leq \text{B} \tag{15}$$

The only decision variable in this model is x_{ijk} (either 0 or 1) to determine the optimal responses and strategies for i^{th} risk.

C. Results

Both BPSO and MOPSO of DEA library [19] are executed to obtain the optimal solutions for strategy and responses under a project manager's strategy set to each risk. Total number of particles and epochs are 100 and 180, respectively. The length of each particle is 20 digits due to total number of available responses. Each digit has either 0 or 1 depending on selection of a response for a risk. Then, BPSO generates the optimal responses and MOPSO selects the optimal strategy for each risk. Fig. 3 shows the convergence speed in which the outcomes from MOPSO have been converged since 40th epoch. Table III presents the final results for the given example in which Risks 1, 3, 4, and 5 should be treated by project manager's strategies to maximize ED, and the original strategy given by manager for Risk 2 should be changed from Mitigate to Accept. With this optimal solution, total risk cost is reduced from 1950 to 100. This means that the impacts from five core risks are remained as much as 100. The remaining risk cost must be removed further by selecting better strategy and responses that project manager agonize over.

VII. Conclusion and Discussions

Either internal risk or external risk affects the success of NPD projects positively or negatively. Especially, the risks with negative impacts hinder smooth progress of NPD process. Therefore, project manager should develop good strategies how to respond against risks effectively and efficiently.

TABLE III
Optimized Strategies and Responses

Risk No.	Manager's Strategy[1]	Responses					Initial Risk Cost	Risk Cost Reduction	Optimal Strategy
		1	2	3	4	5			
1	3	0	0	1	0	1	300	50	3
2	3	0	1	1	1	1	400	100	4
3	2	1	0	0	0	1	300	-230	2
4	2	0	0	1	0	0	500	150	2
5	1	1	1	0	0	0	450	30	1
							1950	100	diff. = 1

[1] 1 = Avoid, 2 = Transfer, 3 = Mitigate, 4 = Accept

Additionally, predicting what types of risks would occur and the impact degrees of risks are critical as well. A better strategy can be established when the manager has a plenty of NPD experiences. The tremendous amount of data such as risk types, risk costs, response types and expenses, and response efficiency related to projects can be accumulated from the experiences and analyzed to apply the scientific methods for risks. Since additional costs or expenses are required for responding to various risks, the scientific methods should be capable of generating optimal strategies and responses.

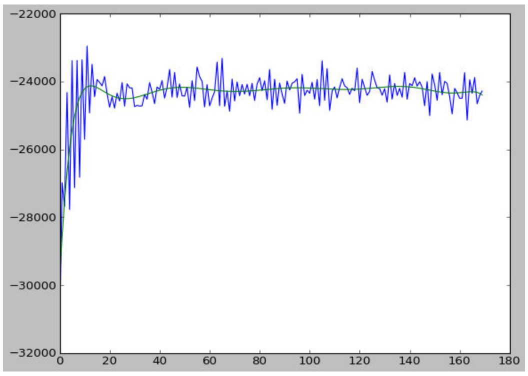

Fig. 3 Convergence speed of MOPSO results

In this study, a framework is suggested to obtain the optimal strategies and responses for all kinds of negative risks. The framework contains both BPSO and MOPSO algorithms as scientific methods to minimize the risk costs (risk impact). The major drawback of the framework is convergence of the solutions which is still unstable. Such situation has not been improved as the number of epochs is increased. Therefore, further study would be continued to obtain better results with other outstanding algorithms.

The developed framework has several constraints for actual applications in industries as follows:

1. A firm must have historical database related to past NPD projects.
2. A firm must measure the risk impact, response efficiency, and response cost for each risk.
3. The framework has not been validated and verified by using real industry data.
4. The risk cost must be removed completely no matter what strategies and responses are activated.

Although the above constraints should be released in the future, the developed framework can be regarded as the first in NPD project management areas, and has the strength to handle various risks.

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REFERENCES

[1] T. M. Yeh, F. Y. Pai, and C. C. Yang, "Performance improvement in new product development with effective tools and techniques adoption for high-tech industries," *Quality and Quantity,* Vol. 44, No. 1, pp. 131-152, Jan. 2010.

[2] T-A. Chiang and Z. H. Che, "A fuzzy robust evaluation model for selecting and ranking NPD projects using Bayesian belief network and weight-restricted DEA," *Expert Systems with Applications*, Vol. 37, No. 11, pp. 7408-7418, Nov. 2010.

[3] ISO 31000:2009, Risk Management—Principles and Guidelines. Geneva: International Standards Organisation, 2009.

[4] R. G. Cooper, "The Invisible Success Factors in Product Innovation," *Journal of Product Innovation Management*, Vol.16, pp.115-133, Mar. 1999.

[5] R. Polk, R.E. Plank and D.A. Reid, "Technical Risk and New Product Success: An Empirical Test in High Technology Business Markets," *Industrial Marketing Management*, Vol.25, pp.531-543, Nov. 1996.

[6] S. Ghoshand J. Jintanapakanont, "Identifying and assessing the critical risk factors in an underground rail project in Thailand: a factor analysis approach," *International Journal of Project Management*, pp. 633-643, Nov. 2004.

[7] X.Gu, C.Cai, H. Song, J. Song, "Research on R&D project risk management model," *Communications in Computer and Information Science*, 35, pp.552-558, June 2009.

[8] E. W. T. Ngai andF. K. T. Wat, "Fuzzy decision support system for risk analysis in e-commerce development," *Decision Support Systems*, 40, pp. 235-255, Dec. 2003.

[9] CS Kim, JS Kim, SW Lee and HG Choi, "Evaluating Effects of External Factors on Success of NPD Projects," *Journal of Management Science*, Vol. 1, No. 1, March 2013.

[10] H.Zhi, "Risk management for overseas construction projects," *International journal of project managemen*t, Vol. 13, No. 4, pp. 231-237, Aug. 1995.

[11] D. Hillson, "Extending the risk process to manage opportunities," *International Journal of Project Management*, Vol. 20, pp. 235-240, Apr. 2002.

[12] TW. Kwan and HKN Leung, "A Risk Management Methodology for Project Risk Dependencies," *IEEE Transactions on Software Engineering*, Vol. 37, No.5, pp. 635-648. Sep. 2011.

[13] B. David and T. Raz, "An integrated approach for risk response development in project planning," *The Journal of the Operational Research Society*, Vol. 52, No. 1, pp. 14-25, Jan. 2001.

[14] SM Park, JS Kim, SW Lee and HG Choi, "Degree of Uncontrollable External Factors Impacting to NPD," *Proceedings of the 2nd International Conference on Design and Product Development*, pp. 136-141, Dec. 2011.

[15] YG Yang, JS Kim, SW Lee and HG Choi, "Time-dependent Analysis for evaluating the Risk Factors of NPD Projects," *International Conference on Industrial Engineering*, Feb. 2013.

[16] D. Hillson, "Developing effective risk responses," *Proceedings of the30th Annual Project Management Institute Seminars and Symposium*, October 1999. Philadelphia USA, 1999.

[17] J. Kennedy and R. C. Eberhart, "A discretebinary version of the particle swarm algorithm," *Proceedings of the 1997 IEEE Conference on Systems, Man, and Cybernetics*, pp. 4104–4109, Oct. 1997.

[18] C. A. Coello and M. S. Lechuga, "MOPSO: A Proposal for Multiple Objective Particle Swarm Optimization," *Proceedings of the 2002 IEEE Congress on Evolutionary Computation*, pp.12-17, May. 2002.

[19] F. A. Fortin, F. A. Rainvile, M. A. Gardner, M. Parizeau and C. Gagne, "DEAP: Evolutionary Algorithms Made Easy," *Journal of Machine Learning Research*, No. 13, pp. 2171-2175, 2012.

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