An Optimization Model of CMMI-Based Software Project Risk Response Planning

Chun-guang Pan, and Ying-wu Chen

Abstract—Risk response planning is of importance for software project risk management (SPRM). In CMMI, risk management was in the third capability maturity level, which provides a framework for software project risk identification, assessment, risk planning, risk control. However, the CMMI-based SPRM currently lacks quantitative supporting tools, especially during the process of implementing software project risk planning. In this paper, an economic optimization model for selecting risk reduction actions in the phase of software project risk response planning is presented. Furthermore, an example taken from a Chinese software industry is illustrated to verify the application of this method. The research provides a risk decision method for project risk managers that can be used in the implementation of CMMI-based SPRM.

Keywords—Software project, risk management, CMMI, risk response planning.

I. INTRODUCTION

SOFTWARE project risk management is a relatively new research area in software engineering. It first came to the forefront with Boehm's tutorial on risk management [1]. This subject has made great progress in theories, methods as well as techniques and tools for about thirty years' development. Nowadays, the development of software process improvement (SPI) for software engineering practice has achieved greatly, which benefits software project risk management a lot. The combination of risk management and process management has also been a hotspot on the research of software project risk management. CMMI is one of the models of SPI and becomes more popular recently. In CMMI, risk management processes are a requirement for the Integrated Software Management key process area (KPA) at the third capability maturity level [2]. And risk management is merged into the same framework with process management. Thus, the CMMI-based SPRM can utilize more useful information of software organizations and make the software development in the direction of regularity and prediction. But at present, the risk management methods in the CMMI-based SPRM are still incomplete. A deep discussion will be made in the future. During the implementation of CMMI-based SPRM, this paper proposes an economic

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optimization model that describes a risk abatement actions selection problem in the phase of risk response planning and an example of this model is illustrated. The model provides a risk decision-making method for software project management people.

II. CMMI-BASED SOFTWARE PROJECT RISK MANAGEMENT

Risk can be defined as the exposure to the probability that an event with adverse consequences might occur. All projects involve some amount of risk, resulting from them being temporary endeavors aimed at achieving some unique set of predetermined time, cost and performance objectives [3]. In software development projects, various risks are a key problem affecting performance, which may have undesirable consequences due to the uncertainties of the requirements, technologies, personnel, process, and organization.

CMMI provides guidance for improving software organization's processes and ability to manage the development, acquisition, and maintenance of products and services. In CMMI, risk management was in the third capability maturity level, which provides a framework for software project risk identification, assessment, risk planning, risk control.

The risk management process in the project execution was defined based on the CMMI model and has eight activities (Fig. 1) [4].
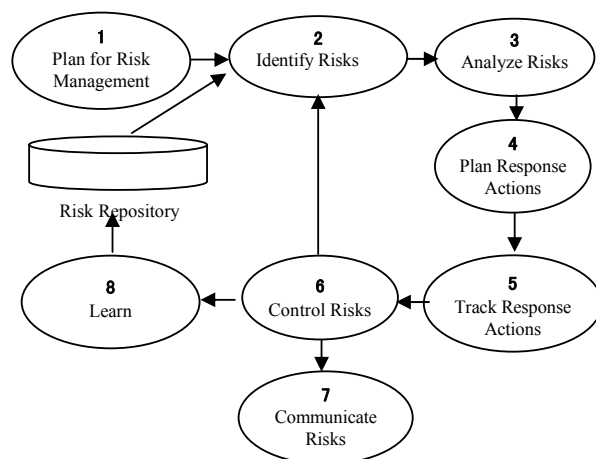

Fig. 1 Risk Management Process, based on the CMMI model

In Fig. 1, risk response planning is an important phase of implementing risk management. It is the process of developing

options, and determining actions to enhance opportunities and reduce threats to the project's objectives. Then, selecting the best risk response from several options is often required [5].

In CMMI-base SPRM, risk repository and process database have played a crucial role. Risks of a project can be drawn from taxonomy-based risk checklist and other information about risk management can be found in the risk repository. Therefore, the process database is becoming a foundation for quantitatively managing software risk. In addition, the experiences of software project managers and experts can also help the execution of project risk management. Thus, CMMI-base SPRM can utilize more useful information of software organizations and relative persons, which will integrate the quantitative and qualitative methods of risk management.

This paper describes a risk abatement actions selection problem in implementing software project risk response development. Then, we focus on an economic optimization model for selecting risk reduction actions, so as to provide an efficient support for managers to make a risk decision.

III. OPTIMIZATION MODEL FORMULATION

A. The Risk Abatement Actions Selection Problem

In CMMI-based SPRM, the project risk response is based on the project planning. By several negotiations with project customers, software organization has understood customers' requirements gradually. Generally, the project work breakdown structure (WBS) according to software requirement specifications has been made and risk analysis for the software project has finished.

The WBS is a deliverable-oriented grouping of project elements that organizes and defines the total scope of the project. Elements at the lowest level of the WBS are called work packages, while elements at intermediate levels are called WBS branches. We will refer to each work package or WBS branch as a work element. The WBS serves as the basis for the analysis of risk actions. Some risk reduction actions may affect a single specific work package, while others may affect multiple work packages, a branch of the WBS, or even the entire project.

We assume that a risk event either happens or does not happen. By risk analysis, the risk events that will have serious adverse consequences should be taken more attention. Based on the project WBS, managers give the risk events from every work element and their probability. And managers also give the probable impact while these risk events occur. Here, the entries contain the impact caused by the events, if it occurs, to the work element, stated in monetary terms.

Based on the historical records from risk repository and experiences of experts, project managers propose lots of risk reduction actions to reduce threats to the project's objectives. Then, the experts will evaluate the cost of implementing these actions. The risk reduction actions may reduce the risk probability and/or risk impact. But on the whole, it will make sense only if implementing these risk reduction actions can truly reduce the total cost of this project. This is a risk abatement actions selection problem. One needs to address the

selection of the best combination of risk reduction actions for a given project scope and a given set of predicted risk events.

B. The Economic Optimization Model

Assuming that the work elements of the software project are all the components of the WBS. We define $s = 1,2,\cdots,S$ as the set S of work elements and $r = 1,2,\cdots,R$ as the set R of risk events. The probability of occurrence of a risk event r depends on its source s. We define a probability matrix $P = (p_{r,s})_{R \times S}$, where its element $p_{r,s}$ is the probability that source s will cause a risk event r. The occurrence of a risk event may impact one or more work elements of the software project. We define an impact matrix $M = (m_{r,w})_{R \times w}$, where its element $m_{r,w}$ is a monetary loss to work element w caused by risk event r. Our model allows us to include positive risk events, sometimes referred to as 'opportunities', which are events that can cause savings or additional profit. In such case, the entry will be negative. We define the expected impact matrix as the matrix G, where G is the product of the transposed probability matrix and the impact matrix. Then, each cell in the matrix G contains the sum of the impacts caused by the row work element, weighted by the probability of occurrence of the corresponding risk events. The sum of all the elements of the matrix G yields the total risk exposure of the project.

The matrix G can be expressed as (1) and the total expected risk loss (ERL) be expressed as (2):

$$G = P' \times M = (g_{s,w})_{S \times W} = (\sum_{r=1}^{R}(p_{s,r} \times m_{r,w}))_{S \times W} \quad (1)$$

$$ERL = \sum_{s=1}^{S}\sum_{w=1}^{W}(g_{s,w}) = \sum_{s=1}^{S}\sum_{w=1}^{W}(\sum_{r=1}^{R}p_{s,r} \times m_{r,w}) \quad (2)$$

By risk analysis, software project managers give the risk abatement actions and the cost of implementing them. We define $a = 1,2,\cdots,A$ as the set A of risk abatement actions and c_a as the abatement action cost, where the cost vector of risk abatement actions $C = (c_1, c_2, \cdots, c_A)$.

Let $X_{a \times a}$ be a diagonal matrix with $X_{a \times a} = 1$ if action a is chosen and 0 otherwise. The matrix $X_{a \times a}$ is called action selection matrix. Let e_a be a column identity vector, where action a 1 and 0 otherwise. The abatement actions costs (AAC) can be expressed while a set of risk abatement actions were taken as follows:

$$AAC(X) = C \cdot X_{i,i} \cdot e_i = \sum_{i=1}^{A} c_i \cdot x_{i,i} \quad (3)$$

Risk abatement actions modify the probability and/or the impact of risk events. We define $v_{r,s,a}$ as the effect factor of action a on the probability of risk r originated from risk source s, where $V_{r,s} = (v_{r,s,1}, v_{r,s,2}, \cdots, v_{r,s,A})$ and $u_{r,w,a}$ as

the effect of action a on the impact of risk r originated from risk source s, where $U_{r,w} = (u_{r,w,1}, u_{r,w,2}, \cdots, u_{r,w,A})$. In general, the modified probability of risk event r from source w is given by $f(p_{r,s}, v_{r,s})$ and the modified impact of the risk event r from source w is given by $h(m_{r,w}, u_{r,w})$.

Let $v_{r,s} = \prod_{\substack{j=1 \\ x_{j,j} \neq 0}}^{A} v_{r,s,j} \cdot x_{j,j}$ and $f(p_{r,s}, v_{r,s}) = p_{r,s} \times v_{r,s}$.

The modified probability matrix can be expressed as (4):

$$F_P(X) = (f(p_{r,s}, v_{r,s}))_{R \times S} \underset{\Delta}{=} (f_{r,s})_{R \times S} \qquad (4)$$

Let $u_{r,w} = \min_{\substack{j=1,2,\cdots,A \\ x_{j,j} \neq 0}} \{ u_{r,w,1} \cdot x_{1,1}, u_{r,w,2} \cdot x_{2,2}, \cdots, u_{r,w,A} \cdot x_{A,A} \}$ and

$h(m_{r,w}, u_{r,w}) = \min\{ m_{r,w}, u_{r,w} \}$. The modified impact matrix can be expressed as (5):

$$H_M(X) = (h(m_{r,w}, u_{r,w}))_{R \times W} \underset{\Delta}{=} (h_{r,w})_{R \times W} \qquad (5)$$

Then, the modified total expected risk loss of this project can be expressed as (6):

$$ERL(X) = \sum_{s=1}^{S} \sum_{w=1}^{W} (F_p(X)' \times H_M(X)) = \sum_{s=1}^{S} \sum_{w=1}^{W} (\sum_{r=1}^{R} f_{s,r} \times h_{r,w}) \qquad (6)$$

Often there are logical constraints that limit the combinations of actions that can be selected. For instance, if we chose to exclude a certain task from the project plan due to its high risk, then it would not be possible to select actions that involve alternative resources or technologies for this task. The model allows two types of pairwise constraints: exclusion, which means the two actions exclude each other, and implication, which means that the selection of one action requires that another specific action be selected too. We define $q_{i,j} = 1$ if actions i and j exclude each other, and $b_{i,j} = 1$ if selection of action i implies selection of action j, and 0 otherwise.

Thus, the model can be expressed as:

$$\text{Minimize} \quad TEC(X) = AAC(X) + ERL(X)$$
$$s.t. \begin{cases} x_{i,i} + x_{j,j} \leq 1 & \forall q_{i,j} = 1, \ i, j \in A \\ x_{i,i} \leq x_{j,j} & \forall b_{i,j} = 1, \ i, j \in A \\ x_{i,i} \in \{0,1\} & \forall i \in A \end{cases} \qquad (7)$$

Generally, the model (7) is a basic form. Further extension of this model may include other information according to the actual case. For example, a budget constraint can be included on the abatement actions spending. In such a case, the model can be expressed as (8):

$$\text{Minimize} \quad TEC(X) = AAC(X) + ERL(X)$$
$$s.t. \begin{cases} x_{i,i} + x_{j,j} \leq 1 & \forall q_{i,j} = 1, \ i, j \in A \\ x_{i,i} \leq x_{j,j} & \forall b_{i,j} = 1, \ i, j \in A \\ x_{i,i} \in \{0,1\} & \forall i \in A \\ AAC(X) \leq B \end{cases} \qquad (8)$$

IV. APPLICATION EXAMPLE

The example presented here is drawn from a Chinese software industry that has passed through the CMM3 certification. This company will carry out a national taxation system for the government. The taxation system consists of two parts: the enterprise taxation sub-system and the individual taxation sub-system. The enterprise taxation sub-system is very important for the system and its main function modes are seven: Initialization, Data maintenance, Data real-time, Appropriation control, Purview control, System loading, and Security control. Table I shows a part of this project WBS.

TABLE I
A PART WBS OF THE NATIONAL TAXATION SYSTEM

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1.0 the national taxation system
  1.1 the individual taxation sub-system
  1.2 the enterprise taxation sub-system
    1.2.1-Preliminary design
        1.2.1.1-Technical preliminary design
        1.2.1.2-Marketing analysis
    1.2.2-Design
        1.2.2.1- Function mode design
        1.2.2.2-Interfaces of function mode design
        1.2.2.3-Application design
    1.2.3-Coding
        1.2.3.1-Coding of function mode
        1.2.3.2-Coding of function modes interface
        1.2.3.3-Application coding
    1.2.4-Integration
    1.2.5-Tests
    1.2.6-Operation and Maintenance
        1.2.6.1-Operation
        1.2.6.2-Training
        1.2.6.3-Maintenance
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For the enterprise taxation sub-system, the managers gave 12 risk events and the probability matrix P and the impact matrix M.

$$P_{12 \times 16} = \begin{bmatrix} 0.5 & & & & & & & & & & & & & & & \\ & & & 0.3 & & & & & & & & & & & & \\ & & 0.3 & & & & & & & & & & & & & \\ & & & & 0.2 & & & & & & & & & & & \\ & & & & & & 0.2 & & & & & & & & & \\ & & & & & & & & 0.15 & & & & & & & \\ & 0.3 & & & & & & & & & & & & & & \\ & & 0.1 & & & & & & & & & & & & & \\ & & & & 0.2 & & & & & & & & & & & \\ & & & & & & & & 0.2 & & & & & & & \\ & & & & & & & & & & 0.1 & & & & & \\ & & & & & & & & & & & 0.2 & & & & \end{bmatrix}$$

$$M_{12 \times 16} = \begin{bmatrix} 100 & & & & & & 20 & 40 \\ & & & & & & 20 & 20 \\ & & & & & & 10 & 5 \\ 200 & & & & & & & 30 \\ & & 40 & & & & & \\ & & & 30 & & & & \\ 20 & 50 & & & & & & 50 \\ & -30 & & -20 & & -20 & & \\ & & 30 & & & & & 35 \\ & & & 15 & & & & \\ & & & & 5 & 10 & & \\ & & & & 0.2 & & & \end{bmatrix}$$

The 12 risk events are imprecise definition of requirements, inappropriate definition of the database structure, unsuitable design of function mode interfaces, definition of a too-complicated GUI, key project personnel leaving, inexperienced personnel, unsuitable development tools, no technology knowledge gap, logic errors during coding, performance of partial tests, overload of the system due to the GUI, unsatisfactory level of training.

Table II shows the risk reduction actions and their corresponding costs (also in one hundred RMB).

TABLE II
RISK REDUCTION ACTIONS AND THEIR CORRESPONDING COSTS

1.Reduction of the requirements of the sub-system	150
2.Hiring a consulting company for the design phase	25
3.Dividing the project into phases to enable interim tests	40
4.Searching for relevant information for the design phase	10
5.On site customer surveys in order to optimize the GUI	10
6.Hiring a consulting company to improve the GUI design	20
7.Hiring additional programmers for the coding phase	60
8. Giving a raise to the programmers for the coding phase	30
9.Coding with alternative development tools	20
10.In-depth check of the test design documents	10
11.Testing critical parts of the code before the integration phase	2
12.Hiring a consulting company for the training stage	10
13.Editing a comprehensive user guide	5

The effects are listed in Table III. A single action can have several effects of both types, each affecting a single work element. Each row in Table III corresponds to one effect and represents a vector that is applied to modify the appropriate column of either matrix P or matrix M, depending on its type. The columns in Table III correspond to the risk events in the rows of matrices P and M.

The modifying functions in this case were chosen as multiplication for P effects and minimum for M effects. The values for the P effects are stated in terms of factors that multiply the probabilities in the P matrix. The values for the M effects are stated in terms of hundreds of Yuan, and they substitute the current values in the M matrix if they are smaller than they are.

The model (7) is an $0-1$ integer programming, which can be solved by existing software of Operations Research (OR). For this example, with the OR software LINDO, we would have selected actions 1,2,5,6,8,9,10,11,12 that yield the optimum. The total cost is 36327 Yuan (27700 Yuan of AAC and 8627 Yuan of ERL).

TABLE III
EFFECTS OF RISK REDUCTION ACTIONS

Action ID	Effect Type	Effect ID	Work element	Risk Event											
				1	2	3	4	5	6	7	8	9	10	11	12
1	P	1a	1.2.1	0.60											
	P	1b	1.2.2								1.50				
	P	1c	1.2.3			0.80						0.80			
	P	1d	1.2.2.3				0.70								
	P	1f	1.2.6.2												0.80
	M	1g	1.2.3							20					
2	P	2a	1.2.1	0.20											
	P	2b	1.2.1.1							0.80					
	P	2c	1.2.2								1.50				
	P	2d	1.2.2.3				0.60								
3	P	3a	1.2.3									0.20			
	P	3b	1.2.4										0.30		
4	P	4a	1.2.2								2.00				
	P	4b	1.2.2.1			0.60									
	P	4c	1.2.2.3		0.70										
	P	4d	1.2.2.3				0.90								
	M	4e	1.2.3.2						20						
5	P	5a	1.2.1	0.50											
	P	5b	1.2.2.3				0.90								
6	P	6a	1.2.1	0.60											
	P	6b	1.2.2.1			0.90									
	P	6c	1.2.2.3				0.90								
7	P	7a	1.2.3									1.20			
	P	7b	1.2.4										1.10		
8	P	8a	1.2.3									0.80			
	P	8b	1.2.3.1						0.8						
9	P	9a	1.2.2								1.20				
	P	9b	1.2.2.1			0.90									
10	P	10a	1.2.4										0.80		
	P	10b	1.2.6.1											0.90	
11	P	11a	1.2.3									0.90			
	M	11b	1.2.4									20			
	M	11c	1.2.6.3										25		
	M	11d	1.2.6.1											10	
12	P	12a	1.2.6.2												0.30
13	M	13a	1.2.6.3												5

V. CONCLUSION

This paper presents a method of selecting risk reduction actions in the phase of software project risk response planning. During the implementation of CMMI-based SPRM, how the software project managers carrying out risk analysis, making an useful risk response planning and selecting risk reduction actions is very important. The economic optimization model presented here demonstrates how a practical and relatively common problem (what is the best way to go about reducing

project risks?) can be treated with mathematical optimization tools and techniques, which provides an efficient support for managers to make risk decisions.

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