A Maturity Model for Large and Complex Programs/Projects Management

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***Abstract*—In this paper, the features of the national key science and technology programs of China are analyzed. The related management maturity models studied abroad are also introduced. The weights of each management factor in the execution process of the national key science and technology programs are calculated through the combination of Analytic Hierarchy Process and Entropy Method. Therefore, a management maturity model which can be suitable to the national key science and technology programs of China is proposed. China High resolution Earth Observation System (CHEOS), which is one of 16 national key science and technology programs of China, is selected as a study case. By utilizing Fuzzy Comprehensive Evaluation (FCE), the management maturity level of CHEOS is assessed. The assessment result can provide an aid to the decision-making of the CHEOS management. Furthermore, a new management method for the national key science and technology programs of China is advanced.**

Keywords-national key science and technology program of China; program/project management; maturity model; analytic hierarchy process; entropy method; fuzzy comprehensive evaluation

I. INTRODUCTION

A. *Features of the national key science and technology programs of China*

To accomplish the nation goals, the national key science and technology programs of China are to form great strategic product, key technology and/or major project through breakthrough in core technology and integration of resource under specific time limits. Therefore, each key science and technology program is a large and complex system. In summary, there are 6 main features of the China national key science and technology programs [1][2][3]:

(1) Government dominance: The national key science and technology program is an important organization form to fulfill the national strategic demands. The implementation of these projects must serve the national goals and reflect the national interests, i.e., the government must arrange the strategic plans and funding allocations under consideration of the national interests and future strategies. Thus, it is the government that supports a main area till the realization of a local leap-forward development and drives the breakthroughs in strategic industries.

(2) Resource integration: The formation of the great strategic product and key common technology comes from the comprehensive integration of different subjects and/or various areas. That is to say, the implementation of the national key science and technology programs demand the information opening, the resource sharing and the collaborative innovation among every participating department.

(3) Management complexity: Due to the limitation of the power and resource of a single existing organization, the interdisciplinary and interdepartmental features of the program are hard to overcome. Furthermore, during the implementation of the program, there are numbers of stake-holders and funding resources, which are much beyond the prowess of normal project management.

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(4) Investment enormity: The implementation of each national key science and technology program demands enormous amount of investment.

(5) High risk: There are different kinds of risks e.g., the technology risk, the policy risk and the market risk etc involved in the national key science and technology programs. Therefore, the implementation of the program is under influence of many factors, all degrees of uncertainty and risks.

(6) Influence universality: The national key science and technology programs are to accomplish national goals and to meet the national demands. The results of technology research and application coming from these programs are the source of the original innovation and the proprietary intellectual property, hence reflect the core competitiveness of China. Ultimately, the outcome of the program can form a deciding influence in the related area and have a wide influential effect on the whole economy of the nation.

B. Current project management maturity models

1) The concept and significance of project management maturity model

The project management maturity model can express the management ability of an organization, and the model can also help to implement the project according to the scheduled goal and condition.

The project management maturity model provides an assessment method and an improvement framework for project management as a new idea. Based on the process of project management, the organization can range the level of project management from chaos to order and forms an upgrade platform step by step. The current management level is the basic of the higher management level. The upgrade of the ability of the project management maturity is also the accumulation of project management level. With the help of the project management maturity model, the organization can find the defects of the project management and recognizes the weak link of the project management and then improves the project management ability steadily.

2) Organizational project management maturity model

Organizational project management maturity model (OPM3) is a new standard which was released by Project Management Institute in 2003 [4].

To improve project management ability of an organization, and associate the project with organization strategy tightly, OPM3 provides the method. To confirm the state of an organization and formulate plans, OPM3 supplies plenty of knowledge for users to acknowledge project management and provides a standard to assess the project management ability.

OPM3 consists of three dimensions, the first dimension presents maturity levels, the second dimension presents project management areas and project management processes, the third dimension presents three domains of the project management. The maturity level includes Standardizing, Measuring, Controlling and Continuously Improving. The project management area includes Project Integration Management, Project Scope Management, Project Timeline Management, Project Cost Management, Project Quality Management, Project Human Resource Management, Project Communication Management, Project Risk Management and Project Purchasing Management. The project management process includes Initiating Process Group, Planning Process Group, Exceuting Process Group, Monitioring & Controlling Process Group and Closing Process Group. The domain of the project management includes Project Management, Program Management and Portfolio Management.

3) K-PMMM

K-PMMM was advanced by Kerzner [5] in 2001, this model is mainly used by enterprise, and the level of the project management maturity is Common Language, Common Processes, Singular Methodology, Benchmarking and Continuous Improvement.

The design of the questionnaire for K-PMMM is different from other models. The questionnaire provides several objective self-assessment questions in different aspects. In each level, there are different kinds of questions, e.g., there are 80 choice questions in the first level. Through analyzing the answer to these questions, organization can find the project management problems of an organization may have and then improves the project management ability.

4) Capability maturity model for software

To fulfill the United State Federal Government's appeal to assess the ability of software suppliers, CMU started to study CMM (Capacity Maturity Model) in 1986 and released the CMM 1.0 in 1991.

CMM has a detailed description for the definition, implementation, measurement and improvement of software. The core of CMM treats software development as a whole process, organization researches the development and maintenance of software to accomplish the commercial goal in a more scientific and standard way. The maturity level of

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CMM includes Initial, Repeatable, Defined, Managed and Optimizing. CMM provides a process improvement framework by assimilating experiences from other software development process.

The process of software development includes many activities; these activities contain technology management of software development, quality management, risk management and so on. CMM strives to improve the management ability of software development. The definition of each maturity level is depicted by CMM definitely. CMM supplies a series of approaches, which help the organization to improve the process of software development step by step. So, the ability of software development is improved by CMM gradually.

II. MATURITY MODELS FOR NATIONAL KEY SCIENCE AND TECHNOLOGY PROGRAM OF CHINA

The propose of the maturity model for national key science and technology programs of China is based on CMM; both the ability of software development and the management of national key science and technology program of China are based on process, the maturity model sees activities of software development as an integer, the development of the software is not to create breakthrough technologies solely. It is the same as the management of national key science and technology programs of China.

A. The maturity levels and features of national key science and technology program of China

The partition of each maturity level is to establish the standard for each maturity level, and then the definition for each maturity level is established according to the standard of each maturity level. The divide of each maturity level is based on some significant models. There are 5 levels: Disordered level, Repeatable level, Standardized level, Predictable level, Optimized level, the levels are showed in Figure 1, and the definition of each level is as follows in Table 1:

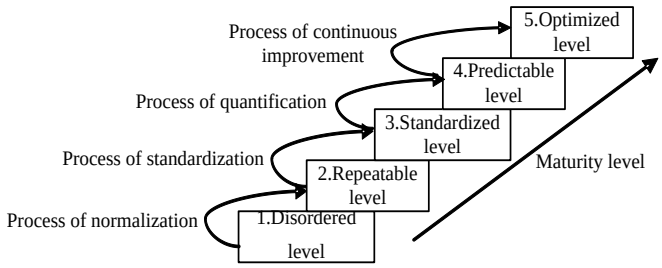

Figure 1. The five levels of maturity model

TABLE I. THE DEFINITON OF EACH MATURITY LEVEL

Level	Definition
Disordered level	The management in this level is disordered; some management factors such as quality, the maturity of technology, investment and risk can not be predicted. The conditions to implement the project are poor, when the problems occur in the process of the project; the organization is likely to give up the plan that has already existed and turns to solve the current problems. And the current problems are solved by the experience of personal; this way can not present the ability of a system.
Repeatable level	The management in this level has an effective organization to manage the project, the management organization of the project forms relative policies about the project and some mature methods to solve the problems. The organization manages these projects according to experience. The management in this level is institutionalization and repeatability.
Standardized level	The management activities in this management level are full, and the standard of the organization is based on these series of activities. The organization makes norm and standard for management plan, quality and so on. There are plenty of useful information can be used and shared, it also becomes the habit of the organization. At the same time, some management factors such as quality, risk and investment can be controlled.
Predictable level	The organization makes quantitative analysis for the project in this management level, in different stage of the project, there has a quality method corresponding to the stage. And some management factors such as quality, risk and investment can be quantified in the process of management. This way can reduce the uncertainty during the process of the project.
Optimized level	The organization optimizes the process of the management continuously, the weaknesses and advantages will be found with different measures to achieve the goal of preventing defects. At the same time, the organization analyses the cost and the benefit of the project, and then some suggestions are proposed according to the analysis. The characteristic of this management level is that the ability of project management can improve continuously by itself in order to prevent the same mistake.

B. The structure of national key science and technology program of China

The content of each dimension is: there are 5 maturity levels in the 1st dimension; it includes Disordered level, Repeatable level, Standardized level, Predictable level, Optimized level, the 2nd dimension is project management evaluation factor system, it includes 10 management areas about national key science and technology program of China, there are 41 second-class targets, the 3rd dimension is the process of project management, it is the life cycle of national key science and technology program of China, it includes Initiating Process Group, Planning Process Group, Executing Process Group, Monitoring & Controlling Process Group, Closing Process Group. The structure of model is shown in Figure 2, the evaluation index system of national key science and technology program of China is shown in Table 2:

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TABLE II. THE EVALUATION SYSTEM FOR THE NATIONAL KEY SCIENCE AND TECHNOLOGY PROGRAM OF CHINA

Criteria	Main Factors
Project management	Project approval management
	Project implement and acceptance check management
	Project process management
	Chief engineer and general director management
Project quality control and management	The construction of quality management system
	Quality plan
	Quality control
	Quality assurance
	Quality improvement
Project technology maturity management	Confirmation of principle for key technology
	Construction of evaluation criterion and indicator system
	Applied research for assessment of the project technology maturity
	Evaluation of the pilot and extension service for the project technology maturity
Project investment management	Assessment for investment feasibility
	Investment examine and approve
	Investment supervise and check up
	The assessment of investment effect
Achievement and intellectual property management	The policy of the intellectual property management and the research of the institutional system
	The key cycle of management about the assessment of the intellectual property problems
	The research on achievement and intellectual property management
Risk management	Risk management of project technology
	Risk management of project cost
	Risk management of project process
	Risk management of project quality
Technical support management	The analysis of technical support management factors
	The analysis of technical support management flow
	The design of auxiliary methods for technical support
Security and secrecy management	Secret-level setting
	The construction of confidentiality rules and regulations
	The design of secrecy policy
	The control of security process management
	The design of scheme for security technology
Decision support management	Auxiliary decision support analysis for the project
	Decision correlation analysis for the project
	The design of the method for the implementation of the decision support

The full meaning in Figure 2: PPAPM represents project planning and project management, PM represents project management, PQCAM represents project quality control and management, PTMM represents project technology maturity management, PIM represents project investment management, AAIPM represents achievement and intellectual property management, RM represents risk management, TSM represents technical support management, SASM represents security and secrecy management, DSM represents decision support management.

C. The quantification of national key science and technology program of China evaluation index system

The implementation of the national key science and technology programs of China is effected by many factors; it may lead some unpredictable problems if these factors are analyzed only by experts' experiences. Therefore, evaluation factor system is assessed by the methods of Analytic Hierarchy Process [7] and Entropy Method [8], while the management maturity level of the national key science and technology programs of China is assessed by utilizing Fuzzy Comprehensive Evaluation [9]. The design of the evaluation system is qualitative analysis, by utilizing the methods such as Analytic Hierarchy Process, it combines qualitative analysis with quantities analysis; it compensates the defect of quantities analysis.

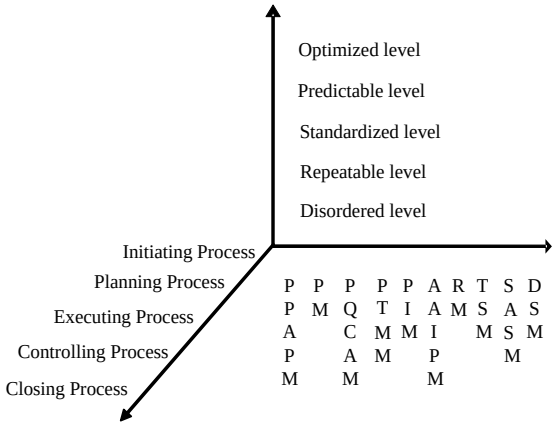

Figure 2. The three dimension structure of national key science and technology program of China

The quantification of the model of the national key science and technology programs of China is mainly assessed by Analytic Hierarchy Process and Entropy Method. The experts which have project management experience score the evaluation index system for each index, then the score of each evaluation index is arranged, the evaluation index is selected by the score of each index, and the final evaluation index system is formed. Then, the participants of the project score the weights of each management factors and a questionnaire about maturity level, the participants of the project are those people who have participated some projects; for example, if we want to assess the management maturity level of China High resolution Earth Observation System, we choose those people who have participated the project of China High resolution Earth Observation System to score the weights of each management factors and a questionnaire about maturity level, then, the model of national key science and technology program of China is built through calculating the weights of each factors, the score and the weight present the importance of each evaluation index, the model can be used to evaluate the

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maturity level of the national key science and technology programs of China.

III. CASE STUDY

A. The profile of China High resolution Earth Observation System

China High resolution Earth Observation System (CHEOS), one of the 16 national key science and technology programs of China is selected as a case study; the aim of this program is mainly to develop the satellite, airplane and stratospheric airship's high resolution earth observation. With the use of medium and low resolution earth observation, a high resolution earth observation with all-weather, all-time capabilities are formed.

The implementation of the CHEOS is aimed at enhancing the ability of earth observation, mastering the initiative of information and resource and grasping the situation of economy, resource, and environment, CHEOS is an essential system to our nation, it has a significant meaning for protecting our nation and enhancing national strength.

B. The confirm of evaluation index and evaluation level

(1) The confirm of evaluation index system

There are 10 first-class targets and 41 second-class targets in the maturity model of CHEOS, the details of each level: $U=\{U_1,U_2,U_3,U_4,U_5,U_6,U_7,U_8,U_9,U_{10}\}$={project planning and project management, project management, project quality control and management, project technology maturity management, project investment management, achievement and intellectual property management, risk management, technical support management, security and secrecy management, decision support management}.

(2) The confirm of maturity level

The maturity level of CHEOS: $V = \{V_1,V_2,V_3,V_4,V_5\}$ = {Disordered level, Repeatable level, Standardized level, Predictable level, Optimized level}.

C. The confirm of the weights of evaluation index

1) The confirm of initial weights via Analytic Hierarchy Process

(1) The hierarchical structure of evaluation index system

The evaluation index system is divided into 3 levels: target layer, criterion layer and factor layer.

(2) Comparison and judgment matrix

The judgment matrix is designed through questionnaire and expert's graded approach, the value of each matrix reflects the degree of importance of each index.

The model uses a_{ij} to represent the relative importance between i and j, $U=(a_{ij})_{m\times n}$ represents comparison and judgment matrix.

$$U=\begin{bmatrix} U_1/U_1 & \cdots & U_1/U_{10} \\ U_2/U_1 & \cdots & U_2/U_{10} \\ \vdots & \vdots & \vdots \\ U_{10}/U_1 & \cdots & U_{10}/U_{10} \end{bmatrix}=\left[a_{ij}\right]_{n\times n} \quad (1)$$

(3) Calculation of the weight

The model uses the formula of $UW=\lambda_{max}W$ to calculate the eigenvalues, λ_{max} is the eigenvalue of U, W is the weight of evaluate factors.

2) Update weights via Entropy method

(1) The fundamental of Entropy method

In information theory, information entropy is a concept to measure the amount of information. If a system is very orderly, the value of information entropy is small, and the reverse situation is also true. So, information entropy is a way to measure a system's degree of order [6], the expression is:

$$H(x)=-\sum_{i=1}^{m} p(x_i)\ln p(x_i) \quad (2)$$

x_i represents the state of i, $p(x_i)$ represents the probability of i.

For example, there are m experts score n evaluation factors, the judgment matrix is $X=(x_{ij})_{m\times n}$, j is a factor, if the value between each factor is large after the expert's assessment, the weight of the factor should be high, conversely, the weight of the factor should be low. So, the weight of each factor can be adjusted through Entropy Method.

(2) Weight adjustment

Step 1: calculate the weight of x_{ij}

$$p(x_{ij})=x_{ij}/\sum_{i=1}^{m} x_{ij} \quad (3)$$

Step 2: calculate the entropy of e_j

$$e_j=-k\sum_{i=1}^{m} p(x_{ij})\ln p(x_{ij}) \quad (4)$$

Step 3: calculate the otherness factor of g_j

To the factor of j, if the otherness of x_{ij} is small, and the entropy of e_j is big; when the entropy of e_j is equal to e_{max}, the factor of j makes no difference; when the value of each factor

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is big and the entropy of e_j is small, the factor contributes more to the evaluation system.

Define $G=(g_1,g_2,\ldots,g_n)$ as otherness coefficient vector, among $g_j=1-e_j$, if the otherness factor of g_j is big, this factor plays an important role in the model.

Step 4: weight adjustment

After the factor of b_j is calculated through Analytic Hierarchy Process, the factor is adjusted by utilizing the otherness coefficient of g_j.

$$a_j = b_j \times g_j, j = 1,2,3,...,n \quad (5)$$

The weigh of the factor is obtained after the normalization of a_j

$$w_j = a_j / \sum_{j=1}^{n} a_j, j = 1,2,3,...,n \quad (6)$$

D. The assessment of the maturity level of CHEOS

(1) There are 5 maturity levels in CHEOS: $V=\{V_1,V_2,V_3,V_4,V_5\}$={Disordered level, Repeatable level, Standardized level, Predictable level, Optimized level}

The value of each maturity level is: Disordered level = 1, Repeatable level = 2, Standardized level = 3, Predictable level = 4, Optimized level = 5.

The weight vector is: $V=(1,2,3,4,5)^T$

(2) The weight of each criteria layer

The weight of criteria layer and factor layer are presented by vector through Analytic Hierarchy Process and Entropy Method: Define $W = (W_1,W_2,W_3,\ldots,W_{10})$ as the weight of criteria layer, define $w_1 = (w_{11},w_{12},w_{13},w_{14},w_{15},w_{16}),\ldots,w_{10} = (w_{101},w_{102},w_{103})$ as the weight of each factor layer.

(3) The confirmation of judgment matrix

For example, to the technical support management of criteria layer, the judgment matrix is:

$$R_8 = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{15} \\ r_{21} & r_{22} & \cdots & r_{25} \\ r_{31} & r_{32} & \cdots & r_{35} \end{bmatrix}$$

$r_{ij}(j=1,2,3,4,5)$ represents the probability of r_i which scores j:

$$r_{ij} = \frac{\text{number of the questionnaire which i scores j}}{\text{number of the questionnaire}} \quad (7)$$

The judgment vector of B_8 is calculated by the weight of w_8 and the judgment matrix of R_8:

$$B_8 = w_8 \times R_8 = (w_{81}, w_{82}, w_{83}) \times \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{15} \\ r_{21} & r_{22} & \cdots & r_{25} \\ r_{31} & r_{32} & \cdots & r_{35} \end{bmatrix} = (b_{81}, b_{82}, \ldots, b_{85}) \quad (8)$$

E. The method to analysis and improvement the management factors

S_i is a vector of criteria layer *i (i=1,2,3,…,10)*:

$$S_i = R_i \times V^T \quad (9)$$

The coordinate system is divided into 4 areas in order to improve the indexes of CHEOS, X axis represents the score of each index, and Y axis represents the weight of each index, then the indexes are labeled in the coordinate system, the management index is improved via analyzing the points in the coordinate system. The coordinate system is as follows in Figure 3:

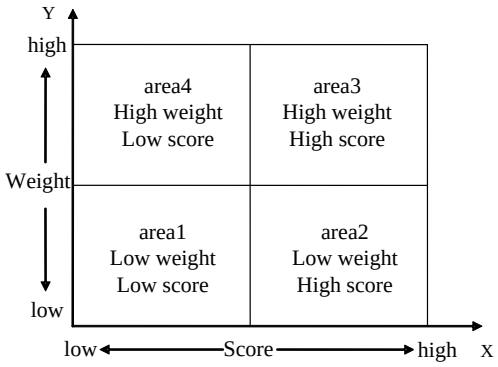

Figure 3. The analysis and improvement of the management factors

Area 1: Low weight, low score

The management activities in this area have a low weight and low score, low score illustrates the project manager pays little attention to these management activities. Low weight illustrates these management activities have poor importance in the process of management, according to the coordinate system that can conclude these management factors are the weaknesses of the CHEOS, compare with the activities in area 4, those activities also has a low score, but the weight of these activities in area 1 is lower than area 4, so the management of CHEOS should pay more attention to area 4. And the activities in area 1 should be improved correspondingly.

Area 2: Low weight, high score

The activities where belong to this area have a low weight, in compare with a high score, manager pays enough attention to these kind of activities, but these activities are not so important compare with the activities in area 4 because of its

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low weight. So, more attention should be paid in other area other than the activities in area 2.

Area 3: High weight, high score

The activities in this area both have a high weight and score. These activities play an important role in project management, and manager pays enough attention to these activities. These activities don not need to be improved so frequently, but these activities have a significant meaning in the national key science and technology programs of China, so the management should focus on these activities continuously.

Area 4: High weight, low score

The activities in area 4 have a low score, but the weight of these activities are high, so the activities in this area have an important function in the process of CHEOS, but the management of the CHEOS pays not enough attention to these activities, so the management ability in these aspects are poor. So, these activities are the objects which the project mainly improves. The improvement of these activities can promote the maturity level of the CHEOS and urge the implementation of the project successfully.

IV. CONCLUSION AND FUTURE WORK

This paper studied the modeling of the project management maturity for the national key science and technology programs of China by updating the current management maturity models. The applicability of the proposed management maturity model with consideration of the features of the programs is demonstrated through a real case study, which proves the compatibility of the proposed model with the present conditions of China.

The paper aims to introduce the maturity model into the management of the national key science and technology programs of China. According to the process and the result of research, the evaluation index system is to be improved through combining more management features of the national key science and technology programs. Although the maturity model is successfully introduced into the management of the programs, the method of assessment is still simple, mostly analytic hierarchy process or fuzzy comprehensive evaluation; so, that further work is planned to make improvement.

In conclusion, the management of the national key science and technology programs of China is a complex systems engineering issue. The introduction of the maturity model is just an explorative trial. Therefore, more theoretical and practical research on the application of the maturity model for the management of the national key science and technology programs of China is still needed.

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