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An Enterprise Human Resource Allocation Management Model Based on CMMI

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***Abstract*—To improve the human resource management level of enterprises, this paper designs a practical human resource statistics method based on the characteristics of CMMI. We first put forward the hypothesis of capability difference, and on this basis, we establish the human resource allocation model in the process of CMMI implementation, and provide corresponding solutions. In case analysis, linear programming, regression analysis, AHP are used to quantify the information or data obtained, to overcome the limitation of traditional knowledge and the uncertainty of standard implementation result, which finally verifies the effectiveness and practicability of our model.**

Keywords-CMMI; Enterprise resources; human resources; configuration management; management model

I. INTRODUCTION

With the process improvement idea being paid more and more attention by software developers, capability maturity model integration has been widely used. Due to the novelty, complexity and fuzziness of CMMI, as well as the difficult control of human resources, many organizations have the maladjustment of human resources allocation in the process of implementing CMMI [1]. It is mainly reflected in the following aspects: the lack of management talents and the surplus of programmer talents, the uneven distribution of all kinds of talents in different stages of CMMI implementation, and the lack of suitable personnel in suitable positions. The reason lies in the limitation of qualitative analysis of human resource management and control. This qualitative analysis is based on the concept of human resource management, focusing on change management and human nature management. Managers' subjective factors (management experience, knowledge structure, personal preferences, etc.) play a decisive role in the structure of human resource allocation [2].

Typical qualitative analysis methods include establishment management and post and personnel planning. The so-called establishment essentially refers to the human resource allocation needed to complete the work tasks. The establishment management is used for human resource allocation, which includes two aspects: organization setting and personnel staffing. The former focuses on the amount of human resources needed to implement CMMI, while the latter focuses on the amount of existing human resources of the organization. The establishment of post and personnel plan is to make long-term post setting and personnel allocation plan according to the development objectives of the organization. According to the development requirements of the organization, it can use the personnel supply and demand forecasting method to prepare the personnel supply and demand balance plan, so that the organization can determine the personnel according to the labor quota. However, the establishment management method can not solve the matching problem between the existing resources and the required resources, that is, the optimal allocation of organizational human resources; the establishment of post and personnel plan requires planners to master the relevant knowledge of human resource planning, work design principle, labor organization, and the formulation of plan itself is very complex. What's more, these methods are put forward according to the conventional human resource management requirements, without considering the particularity and complexity of implementing CMMI. Practice has proved that the implementation of CMMI needs its own human resource allocation method. Based on practical application, this paper puts forward a qualitative and quantitative analysis method human resource allocation model.

II. THEORY AND METHOD OF CMMI MODEL

It is quite good to use CIMI to guide the improvement of software process in enterprises, but the important thing that enterprises should do is not only software process improvement. The most important thing for enterprises is the survival and development [3-4]. Everything can not be separated from creating economic value. However, most domestic enterprises are not able to provide such good preconditions. The most scarce resources of enterprises are often personnel, funds and time. The leaders of enterprises certainly want to use resources in the fastest place to make money. When software process improvement and other things that make money directly "conflict with resources", we have to "break down the east wall and make up the west wall", which often reduces the resources of software process improvement.

When using CIMI model to implement process improvement, it is necessary to establish the organizational function and role of QA (quality assurance) and implement the activity of "process and product quality assurance". The purpose of these activities is to enable project staff and managers at all levels to properly understand the work products and processes in the whole project life cycle, so as to support the delivery of high-quality products and services. However, QA is a weak link in the process of CMMI implementation [5].

The CIMI model is based on the background of western corporate culture and contains the idea of separation of powers. Administration, judicature and legislation correspond to senior managers, QA and SEPG in CMMI

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model respectively, that is software process improvement group. The specific structure is shown in figure 1:

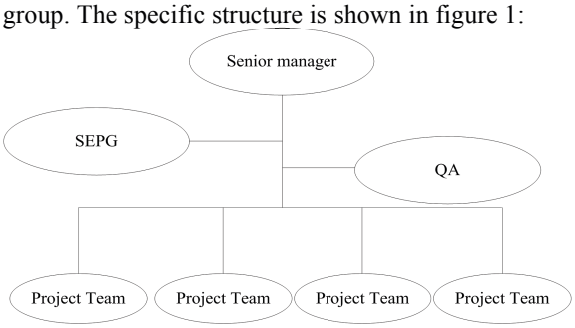

Figure 1. Software process improvement group

It can be seen from the figure that the goal of QA activities is to monitor the implementation of software development tasks from the perspective of a third party by means of independent review, provide developers and management with information and data reflecting product and process quality on whether the project is following their own plans, standards and procedures, improve project transparency, and assist the software engineering team to deliver high-quality software products [6]. Therefore, the objective evaluation of process and product quality assurance is the key to the success of the project, which is generally provided by the QA team independent of the project. Everyone engaged in QA activities should be trained in quality assurance. Those engaged in QA activities of a product should not be directly involved in the development or maintenance of the product. At the same time, there should be an independent channel to report problems to the appropriate management, so as to report non-conforming problems level by level when necessary [7].

However, in some organizations, it may be more appropriate to implement process and product quality assurance roles without requiring such independence. For example, in an organization with an open and quality-oriented cultural environment, peers can assume (part or all) the role of process and product quality assurance, and the quality assurance function can be embedded in the process [8].

QA shall have the following responsibilities:

(1) Ensure the quality of work products by monitoring the development process;

(2) Ensure that the developed products and development process meet the corresponding standards and procedures;

(3) Ensure that the non conformity problems existing in the product and process are handled, and report the problems to the senior management when necessary;

(4) Ensure that the plans, standards and procedures formulated by the project team are suitable for the needs of the project team and meet the needs of the review;

(5) Provide feedback to developers.

Therefore, for domestic IT and software enterprises, how to understand and establish QA mechanism and make better use of CMMI model for process improvement is very important. However, there are some misunderstandings about the significance and understanding of QA in domestic TT and software enterprises, which lead to that QA activities become mere formality or do not play its real role in the implementation of process improvement activities [9].

CMM level model is divided into five levels: initial level, repeatable level, defined level, managed level and optimized level. Initial level - software process is characterized by disorder, sometimes chaos, almost no clear definition of XX steps, success completely depends on personal efforts and heroic core tasks. Repeatable level: it establishes the basic project management process to track cost, progress and function, and has the necessary process criteria to repeat the success of similar projects in the past. Defined level - the software process of management and engineering has been documented and standardized, and integrated into the standard software process of the whole software development organization. All projects adopt the standard software process modified according to the actual situation to carry out and maintain the software. Managed level - detailed metrics for software engineering and product quality are developed. Software process and product quality are understood and controlled by members of the development organization. Optimization level: quantitative analysis is strengthened, and the process can be continuously improved through feedback from process quality and new ideas and technologies [10].

CMMI is based on process and supported by the software organization's own system to achieve the goal of quantitative and controllable process to cope with the changing software development process. The higher the capability maturity of an organization, the more its project development and project results can rely on controllable and reliable software processes, rather than on unstable and unpredictable personal capabilities, such as a project leader or a core technical personnel.

III. HUMAN RESOURCE STATISTICS

In the process of CMMI implementation, human resources include all the related technical and management personnel in the organization. All human resources can be divided into different categories:

(1) By organization

From the perspective of CMMI implementation group, it includes software engineering group (SEG), software engineering process group (SEPG), software process improvement group (spit), system engineering group (set), system testing group (STG), software related group (SRG), implementation improvement group (eig), software process evaluation group (SPAG), training group (TG), etc.

(2) By role

Starting from the traditional function view of the organization, it includes a series of roles such as senior manager, project manager, software manager, employee, analyst, programmer and engineer.

Human resource statistics is the premise of optimizing the allocation of human resources. Statistics should be carried out according to two different categories. Statistics by role is easy to do, how many senior managers and programmers there are in an organization It is often clear at a glance that the category and number of roles are related to

the functional structure of the organization. The product of the number of roles and the time of standard implementation is called the value of human resource ownership in the process of standard implementation. It can be seen that the unit of human resources is the combination of number unit and time unit, which is called "man day" (the same as workload unit). The formula is as follows:

Role human resource ownership=Number of roles Standard implementation time (person / day) (1)

According to the Organization statistics, we should strictly refer to the CMMI implementation flow chart, carefully estimate the human resources required by each practice, and mark the results in the flow chart. In the process of estimation, the practice should be extended to the corresponding sub responsibilities. In this way, the workload of all sub responsibilities is accumulated, and the organization demand value is obtained. When using this method, the estimation target is decomposed small enough to obtain historical data through standardized design, and can be adjusted in time according to the feedback of practice. In particular, when the whole CMMI implementation process is divided into several stages, the statistics should also be carried out by stages, whether it is the statistics of human resource ownership value or organization demand value. The allocation of human resources in different stages does not conflict with each other.

IV. DIFFERENTIATION OF HUMAN RESOURCE EXPLORATION ABILITY

A. Propagation Modeling

Can we think that the human resource status of an organization will meet the needs of CMMI implementation on the premise that the role ownership value meets the organization's demand value? In fact, this is not the case. In practice, due to the difference of roles, that is, the different abilities of roles in different jobs are not consistent, which has a great impact on the optimal allocation of human resources. Practice has proved that there are differences in the ability of different types of roles to perform organizational functions. Some roles (such as senior manager) can be competent for most types of organizational work, while others are relatively single. Therefore, in the statistics of human resources, we need to consider the role differences, we use the ability coefficient to express this difference. It is undeniable that different individuals (different staff) in the same role are different in their competence for the same job, but this difference is not significant in practice and can be ignored in the process of modeling. In the process of CMMI implementation, the level of capability coefficient mainly depends on two factors: suitability and proficiency. Suitability reflects the matching degree between the role and the type of work (the related factors include the power given by the organization and the attention paid by the role to different types of work, and the ideal suitability is I). The higher the suitability is, the greater the ability coefficient is; Proficiency reflects a role's proficiency in the work in a specific organization (such as professional knowledge, experience, experience, etc. the ideal proficiency is I). The higher the proficiency, the greater the ability coefficient. From the perspective of management, suitability is based on situational factors, and proficiency is based on internal factors. obviously:

Capacity factor of role= Suitability × Proficiency (2)

The evaluation of suitability and proficiency is subjective. In order to make the evaluation results conform to the objective reality as much as possible, we can formulate detailed evaluation standards according to the actual situation of the organization, and use expert evaluation, AHP and other methods to evaluate. The evaluation criteria of suitability and proficiency are given in table I and table 2 respectively. The corresponding score is calculated according to the evaluation standard. Because the fitness and proficiency are not greater than I, it needs to be standardized and converted into a number between 0 and 1. In order to facilitate the calculation of the standard implementation personnel and understand the differences in the abilities of all roles in the organization, the ability coefficient differentiation table is given in Table 3 for subsequent example calculation.

Table 1. Suitability evaluation criteria

	Is the power given appropriate	Is the driving field of power appropriate	Is the role's attention appropriate
Quite suitable	5	5	5
Very suitable	4	4	4
Fairly appropriate	3	3	3
Sometimes suitable	2	2	2
Never fit	1	1	1

Table 2 Proficiency evaluation criteria

	Master the professional knowledge closely related to the work	Experience in the same or similar work	Relevant work experience
Fully abundant	5	5	5
Very abundant	4	4	4
Quite abundant	3	3	3
Sometimes abundant	2	2	2
Never rich	1	1	1

Table 3 Capacity coefficient differentiation table

	Manager	Analyst	Programmer	General staff
Software engineering group	0.9	0.7	0.6	0.9
	0.7	0.8	0.8	0.5
Software engineering process group	0.9	0.8	0.4	0.4
	0.7	0.8	0.4	0.9
Software process improvement group	0.6	0.9	0.5	0.5
	0.8	0.4	0.9	0.6
System engineering group	0.6	0.9	0.6	0.7
	0.4	0.9	0.9	0.4
System test group	0.5	0.8	0.8	0.6
	0.8	0.4	0.5	0.7
Software related	0.7	0.5	0.9	0.7

groups	0.9	0.6	0.8	0.9
Implementation	0.6	0.5	0.9	0.7
improvement group	0.7	0.6	0.6	0.9
Software process	0.9	0.7	0.5	0.5
assessment team	0.8	0.9	0.6	0.5
Training group	0.8	0.6	0.6	0.8
	0.7	0.5	0.9	0.8

In Table 3, the first row is the role name, and the first column is the organization name. Fill in *a* and *b* in each cell corresponding to the role and organization. In Table 3, *a* is fitness, *b* is proficiency, $a,b \in [0,1]$.

The human resources of the organization can be divided into four types according to their roles, and each type of role corresponds to nine organizations in CMMI implementation, reflecting different capability coefficients. Taking the corresponding cell of manager and software engineering group as an example, assuming a=0.9 and B=0.7, it means that the senior manager is very suitable to engage in the work of software engineering group (suitability reaches 0.9), and basically has the skills to engage in the work (proficiency reaches 0.7). The comprehensive evaluation shows that the ability coefficient of the role corresponding to the software engineering group is 0.63.

According to the above method, based on the division of two types of human resources, through the cross statistics of organizational human resources, the ability coefficients of different roles in different organizations are obtained. So far, this paper analyzes the human resources from two perspectives, and obtains the value of human resources owned by the organization's role and the demand value of the organization, as well as the ability coefficient of different organizations corresponding to different roles. On the basis of these data, we can start to establish the human resource allocation model.

V. UMAN RESOURCE ALLOCATION MODEL

At a certain stage of the standard implementation process, the standard implementation time is t days, and there are m roles. The number of people in each role is $x_i(i=1,\ldots,m,)$, in the formula, $1,\ldots,k$ is the role of manager, and $k<m$, n . And organizations, and their demand values are $N_j(j=1,\ldots,n)$. The human resource input of role i in organization III is $M_{ij} \geq 0$, and the corresponding capability coefficient is $C_{ij} \geq 0$.

(1) Model hypothesis

The personnel of the same kind of role have the same ability coefficient (i.e. the same suitability and proficiency) in any organization;

The workload of all roles in the same kind of organization is directly proportional to their capacity coefficient;

At any stage of the implementation process, the sum of human resource ownership value is not less than the sum of organization demand value, that is:

$$\sum_{i=1}^{m} x_i t \geq \sum_{j=1}^{n} N_j \tag{3}$$

The hypothesis of effective coefficient of human resource ownership value of role.

In practice, roles have different ability coefficients in different organizations, so that the same kind of roles will show different production efficiency when they work in the same kind of organizations. This paper introduces the effective coefficient to explain this phenomenon. The effective coefficient n_{ij} of role i in organization j is defined as the ratio of the ability coefficient of the role in the organization and the maximum ability coefficient of the role in all organizations, that is:

$$\eta_{ij} = \frac{C_{ij}}{\max\limits_{j=1,\ldots,\mu}\{C_{ij}\}} 100\% (i=1,\ldots,m) \tag{4}$$

(2) Modeling constraints

At a certain stage of the implementation process, the sum of human resources invested by any role in all organizations is not greater than its own value of human resources:

$$\sum_{j=1}^{n} M_{ij} x_i t (i=1,\ldots,m) \tag{5}$$

At a certain stage of the implementation process, the sum of effective workload undertaken by various roles of any organization shall not be less than the demand value of the organization:

$$\sum_{i=1}^{m} M_{ij} \eta_{ij}{}^3 N_j (j=1,\ldots,n) \tag{6}$$

The principle of productivity priority is to let the role engage in the work with the maximum efficiency as far as possible. If the sum of the ability coefficients of all the roles is y_1 , then:

$$y_1 = \sum_{i=1}^{m}\sum_{j=1}^{n} M_y \eta_{ij} \tag{7}$$

The principle of management role priority is to assign as few specific tasks as possible to senior managers, project managers, software managers and other management roles, so that they have time to engage in management activities. If the total workload of management personnel is y_2 , then:

$$y_2 = \sum_{i=1}^{k}\sum_{f=1}^{n} M_{ij} (k<m) \tag{8}$$

If the objective function is $z = \max\{y_1 - y_2\}$, the mathematical expression of human resource allocation model is:

$$z = \max(\sum_{i=1}^{m}\sum_{j=1}^{\infty} M_{ij}\eta_{ij} - \sum_{i=1}^{k}\sum_{j=1}^{n} M_{ij})(k < m)$$

$$\sum_{j=1}^{n} M_{ij} \le x_i t(i = 1,\ldots,m) \quad (9)$$

$$\sum_{i=1}^{m} M_{ij}\eta_{ij} \ge N,(j = 1,\ldots,n)$$

(3) Analysis of results

For solving the model, if there is no solution, it does not meet equation (5) or equation (6). The computer software is used to analyze and find out the constraint condition which has been destroyed, and make corresponding adjustment. The adjustment can be made in two ways: changing x_i or *t*. When the standard implementation time is fixed, change x_i, that is, increase the number of standard implementation; when the number of standard implementation is fixed, change *t*, that is, extend the standard implementation time. The two aspects can also be considered together until the optimal solution or satisfactory solution is found.

Detailed design of human resource allocation model, the design process is as follows:

(1) The project manager shall cooperate with the detailed designers to get familiar with the outline design scheme, and reach a consensus among or within the project teams. The project manager determines the detailed designers, considers the progress, technical difficulty and risks, formulates the stage work plan and determines the stage export criteria. If necessary, ask the Department Manager or senior management to solve the problem;

(2) According to the design methods, tools, requirements documents and software system architecture design documents, the main interfaces and attributes of each functional module should be refined step by step, and each user interface should be refined if necessary;

(3) Refine the data structure and algorithm of each functional module, improve its efficiency, confirm and improve the algorithm and processing flow of reuse software and module unit, and ensure the consistency of the system;

(4) Processing data flow and fully considering system limitations, gradually improve the system integration scheme;

(5) Specify the person in charge of requirement tracking to track the requirement status, improve the requirement function matrix, and register it in bug collection Manager if any problem is found;

(6) Repeat the above steps until the export criteria are met.

VI. APPLICATION EXAMPLES

The statistics of human resources are shown in Table 4, and the demand value of organizations is shown in Table 5.

Table 4 Ownership value of role human resources

Role type	Number of roles	Ownership value of human resources
Manager	3	120
Analyst	5	200
Programmer	12	480
General staff	7	280

Table 5 Organization demand value

Organization	Demand value
SEG	221
SEPG	75
SPIT	93
SET	159
STG	0
SRG	35
EIG	191
SPAG	162
TG	35

The capacity coefficient is shown in Table 3. On the basis of Table 3, the capacity coefficient is transformed into effective coefficient according to formula (4), as shown in Table 6.

Table 6 Effective coefficient

	Manager	Analyst	Programmer	General staff
Software engineering group	0.875	0.691	0.667	0.234
Software engineering process group	0.875	0.790	0.222	0.563
Software process improvement group	0.667	0.444	0.625	0.469
System engineering group	0.333	1	0.750	0.438
System test group	0.556	0.395	0.556	0.656
Software related groups	0.875	0.370	1	0.984
Implementation improvement group	0.583	0.370	0.750	0.984
Software process assessment team	1	0.778	0.417	0.391
Training group	0.778	0.370	0.750	1

Human resource allocation model:

The implementation time is t days, there are m roles, the number of roles is $x_i(i = 1,\ldots,m,)$, in the formula, $1,\ldots,k$ is the role of manager, and $k < m$, n organizations, and their demand values are $N_j(j = 1,\ldots,n)$. The human resource input of role i in organization I is $M_{ij} \ge 0$, and the corresponding capability coefficient is $C_{ij} \ge 0$. The sum of the ability coefficient of all roles is y_1, and the total workload of managers is y_2. Obviously:

$t = 40, m = 4, k = 1, n = 9; x_1 = 3, x_2 = 5, x_3 = 12, x_4 = 7;$

$N_1 = 221, N_2 = 75, N_3 = 93, N_4 = 159, N_5 = 0, N_6 = 35, N_7 = 191, N_8 = 162, N_8 = 65$

From equation (5) to equation (8), we can see that the human resource allocation model is as follows:

$$z = \max(\sum_{i=1}^{4}\sum_{j=1}^{9} M_{ij}\eta_{ij} - \sum_{i=1}^{1}\sum_{j=1}^{9} M_{ij}) \quad (10)$$

For this kind of complex linear programming problem, the demand is helpful to computer software. This paper uses LINDO 6.1 to solve it. In the process of calculation, if there is no feasible solution to the original problem, it is

necessary to adjust the plan to extend the implementation time, or introduce human resources from outside the organization. The former method is adopted here. Through continuous adjustment, the optimal solution of the model can be obtained when the standard implementation time is 45 days. At this time, the 9th and 13th inequalities in the model are redundant. The adjusted value of human resource ownership is shown in Table 7.

Table 7 Ownership value of role human resources (adjusted value)

Role type	Number of roles	Ownership value of human resources
Manager	3	135
Analyst	5	225
Programmer	12	540
General staff	7	315

In the case of little influence on the actual scheme, the decimal part of the solution is rounded, and the human resource allocation scheme is obtained from the model solution, as shown in Table 8.

Table 8 Human resource allocation scheme

	Manager	Analyst	Programmer	General staff
Software engineering group	0	0	331	0
Software engineering process group	0	76	0	26
Software process improvement group	0	0	149	0
System engineering group	0	114	60	0
System test group	0	0	0	0
Software related groups	0	0	0	36
Implementation improvement group	0	0	0	194
Software process assessment team	135	35	0	0
Training group	0	0	0	59

Of course, the final human resource allocation plan should be adjusted according to the actual situation of the organization.

VII. CONCLUSIONS

In order to improve the effectiveness of human resource management, this paper proposes a model of human resource allocation management based on CMMI. The performance of the model is verified by theory and experiment. The model has high management effectiveness in human resource allocation management. Therefore, the model can meet the requirements of human resource allocation management.

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