

A RESEARCH ON MAINTENANCE STRATEGY OF MARINE CONSTRUCTION EQUIPMENT SYSTEM BASED ON “RFD”

Sun Guang-xi

Jiangsu Branch of CCCC Third Harbor Engineering Co. Ltd., Lianyungang, Jiangsu, 222042, China

E-mail: ccwww.cc@163.com

Abstract

Research the characteristics of marine construction equipment systems and its Hall three-dimensional morphology. Quality Function Deployment (QFD) methodology was used to analyze the reliability of the equipment system and its ABC category. Make use of the method that the FMEA combines together with QFD to carry on RFD for the construction equipment system. To introduce the “implementation difficulty” and “revise importance” item in the RFD matrix, and to put forward a new idea about equipment management that is based on project and ABC classification of equipment system should be dynamic. It also recommended the establishment of an orchestration management mechanism of the construction equipments system and to divided the operating process of equipments system into category.

Key Words: QFD, Reliability Function Deployment (RFD), project equipment management, maintenance strategy, ocean engineering, RCM.

1 Introduction

The existing strategy research of equipment maintenance is for industrial equipment and military equipment more, but for construction equipment less. For the enterprises is more, and less for the project. Modern engineering Construction is becoming more mechanized. The influence of equipment performance and reliability is growing for the project construction quality, construction progress, construction safety and construction costs. Particularly large marine construction works, such as the Yangshan Deepwater Port project (see Figure 1.0-1) and the Hangzhou Bay Bridge project (see Figure 1.0-2), rely on equipment a higher level. Such projects are big investment, long construction period, complex construction environment and the big impact at home and abroad. Construction equipment for these projects are variety and quantity, and the most of them are large-scale equipment even giant equipment. The single set equipments is worth hundreds of thousands, millions of dollars at every turn, even amount by tens of millions. Therefore, the maintenance of the construction equipment systems is extremely important. The request of the research of the maintenance strategy is urgent.

In this study, take the Yangshan Deepwater Port project, the Hangzhou Bay Bridge project and other large ocean engineering project as the background, to make use of RFD method to research the construction equipment maintenance strategy.



Figure 1.0-1 Yangshan Deepwater Port project

Note: Yangshan deepwater port project in April 2002 started construction, planning in 2020 for completion of all. The total investment is estimated to reach 18-20 billion U.S. dollars. Yangshan deepwater port construction has had a huge international impact.

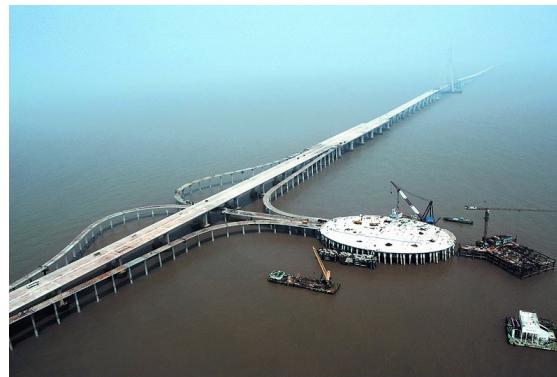


Figure 1.0-2 Hangzhou Bay Bridge project

Note: The Hangzhou Bay Bridge project on November 14, 2003 started construction, May 1, 2008 completion of the opening, with a total investment of about 1.8 billion U.S. dollars. Bridge of 36 km, is the world's longest bridge.

2 Construction equipment system engineering

2.1 Defining the construction equipment system engineering

Construction equipment system engineering is timely deployment and guarantee of an effective system of construction equipment, and it can satisfy the need of engineering construction under the expenses and time condition that can bear. The process of construction

organization of a large engineering project is similar to command a battle not a few. Now, learn from the U.S. military standard MIL - STD - 499A of the definition of military equipment systems engineering, construction equipment systems engineering can be defined as:

“Construction equipment systems engineering apply the science and technology achievements in: ①It converted the project construction needs into a set of system performance parameters and system technology status describe with the definition and integration and analysis and design and testing and evaluation of the iterative process repeated. ②Integrated the related technology parameters, to ensure all the interface compatibility of physical functions and procedures, in order to optimize the whole system definition and design. ③To integrate the reliability, maintenance, safety, survivability, human-engineering and other factors related into the work of the whole project, to meet the costs, progress, security and technology performance.” [4]

Above-mentioned “guarantee”, refers to the construction equipment systems guarantee the project objectives, including construction quality, construction progress, construction security, environmental protection and investment target etc.

2.2 The characteristics of construction equipment system

The construction equipment system has following characteristics:

(1) It's a large and complex system. Construction equipment system is from a number of sub-systems. Such as the Yangshan Deepwater Port project construction equipment from the harbor works, waterway works, road works, bridge works, civil works, environmental engineering and port equipment works, etc. Each subsystem can be divided into several levels of the smaller systems, each small system consist of several sets of equipment, and each set of the equipment itself is a system – the many of which is a very complex system. Therefore, construction equipment system is a large and complex system.

(2) It's an open system. Marine construction equipment systems are subjected to the external environmental influence bigger, such as storms, climate, geological conditions and so on. The elements of the marine construction equipment systems and the relationship between them are with the marine environment related. The choices which include the type and layout and operation mode will be different in different environmental conditions.

(3) It's a dynamic system. With the progress of works, the first parts of the works had been completed, and their construction equipments have been withdrawn from the construction one after another too. So, the total number and the kinds of the construction equipment are changing with the progress of the works. In addition, construction

equipment system is a "flow". When a project finished, the equipment system will be transferred to another project, not only location different, but also the characteristics and the environmental conditions of the new project is not same. Therefore the equipment configuration will also be difference.

2.3 3D structure of construction equipment system engineering

Hall's three-dimensional structure^[1] is A.D. Hall's methodology who is a U.S. systems engineering expert. It is to solve large and complex system of planning, organization, management way of thinking, which has been widely used. According to Hall's 3D structure, construction equipment system engineering activities can be divided into seven phases which each divided into seven processes. And the completion of these phases and processes required various professional knowledge and skills. So, the 3D space structure of the system engineering of the construction equipment constituted from the “time,” “logic” and “knowledge” dimension. Such as Figure 2.3 has show.

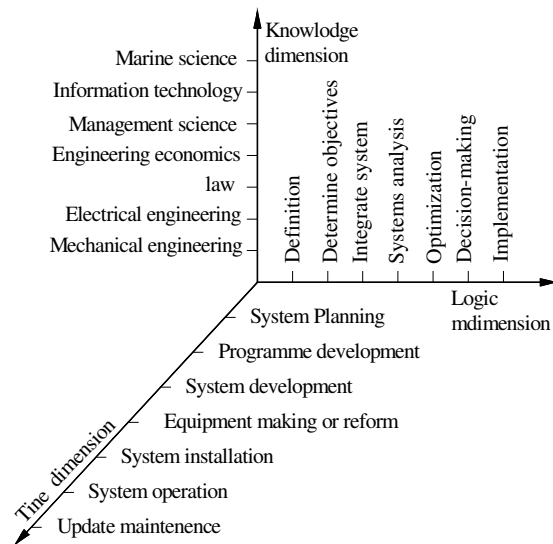


Figure 2.3 The construction equipment system's 3D structure

The “Time” dimension: Said the activities of construction equipment systems engineering can be divided into seven phases from start to finish in chronological order. ①Planning phase: To research the construction needs, objectives and the necessary equipments. ② Programme phase : Put forward a concrete plan of the equipment system according to the policy and the objectives. ③System development phase : Development, transformation and disposal of the equipment system, as well as development of equipment management system which include policy, objectives, procedures, operate specifications, improvement, related to records and so on. Make detailed and specific production plans. ④Production phase: To produce all the parts that the systems need, and make the installation programme. ⑤Installation phase : To install the system

and make the site layout and the specific operational programme. ⑥Operation phase: The system put into operation, serve the expected use. ⑦Update phase: To improve or repeal the old system, build up the new system.

The “Logic” dimension: It means the work that is carried out within every phase of the “Time” dimension, and the process that should be followed in thinking. They are: ① Definition: Find out the problem to be solved and the exact requirements of the system, to identify the direction of action. ②Determine objectives: Determining the objectives and the sub-objectives of the mission and developing the criteria for evaluation. ③Integrate system : To develop system architecture that can complete the scheduled task, to build up the models, policies, and a variety of programs. ④Systems analysis: To Analyze the performance and the features system program, as well as the extent and degree that scheduled mission can be completed. ⑤ Optimization : Generate and select the policies, activities, control method and system-wide program, as far as possible to achieve the best or reasonable, at least satisfactory. ⑥Decision-making: the Selection of action. ⑦ Implementation: To implement the above-mentioned programs.

The “Knowledge” dimension: That is need for a variety of professional knowledge, skills and technology for completing the tasks of the various shades and processes. This is a dimension of discrete, no one after another, which support the plane that is constituted by the logic dimension and the time dimension. The knowledge for marine construction equipment systems engineering include: logistics engineering, reliability engineering, management science, engineering economics, human engineering, law, mechanical engineering, electrical engineering, information technology, ocean science, environmental science, construction techniques and so on. The project management should employ the appropriate professionals and train them based on three-dimensional structure. If necessary, we should employ an advisory body for the project.

3 Reliability Function Deployment (RFD) of construction equipment system

3.1 Reliability Function Deployment (RFD) process

Reliability Function Deployment is an expansion of the application of QFD. It can be used for reliability analysis of the construction equipment system. QFD is an effective quality management techniques and methodology which is widespread application in the world. QFD makes use of a House of Quality (HOQ) to convert the needs information as engineering characteristic. It’s a methodology that can analyze the relationship between the engineering needs and the measures with a series of matrix. HOQ includes a great deal of information, it can carry out qualitative analysis and quantitative analysis, and intuitive easy to understand. Quality and reliability are closely related and

complementary to each other. Reliability Function Deployment (RFD) makes use of QFD methodology get the technical requirements from the expected reliability need with HOQ at the early development of systems or products. Thus the reliability is designed into the system or the products. Or, do RFD by FMEA or FAT with QFD combination. At this time, the HOQ for reliability analysis can be called the "House Of Reliability (HOR)". Reliability Function Deployment of the process shown in Figure 3.1.

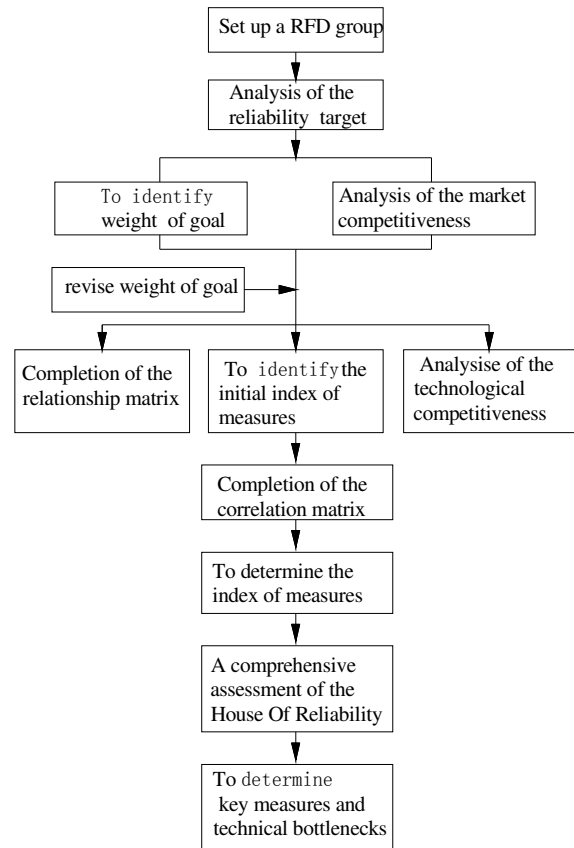


Figure 3.1 Reliability Function Deployment of the flow chart

3.2 RFD of marine construction equipment system

The main objectives of construction project include the quality target, the progress target, the costs target, the security target, the environment target and so on. The reliability to achieve these targets depends on many factors. The construction equipment system is a major factor in the mechanized construction conditions. In order to identify the key sub-systems of equipment, we can make use of methodology of RFD. Figure 3.2 is a HOR which takes the Yangshan Deepwater Port project as an example. It works to take the reliability of achieving the project targets as the “objective”, and to take the reliability of the construction equipment system as the “measure”.

On this figure, weight of the “objective” k_i ($i = 1, 2, \dots, m$) is divided into five grades, that is “1”, “2”, “3”, “4”

and “5”. The “1” mean the most of no account, and the “5” mean the most important. Relationship-count of the j item of the “measure” with the i item of the “objective” is the r_{ij} , calculating the importance of the sub-systems reliability in the “measure” row according to the Formula

$$(3.2-1)^{[3]}: \quad h_j = \sum_{i=1}^m k_i r_{ij} \quad (3.2-1)$$

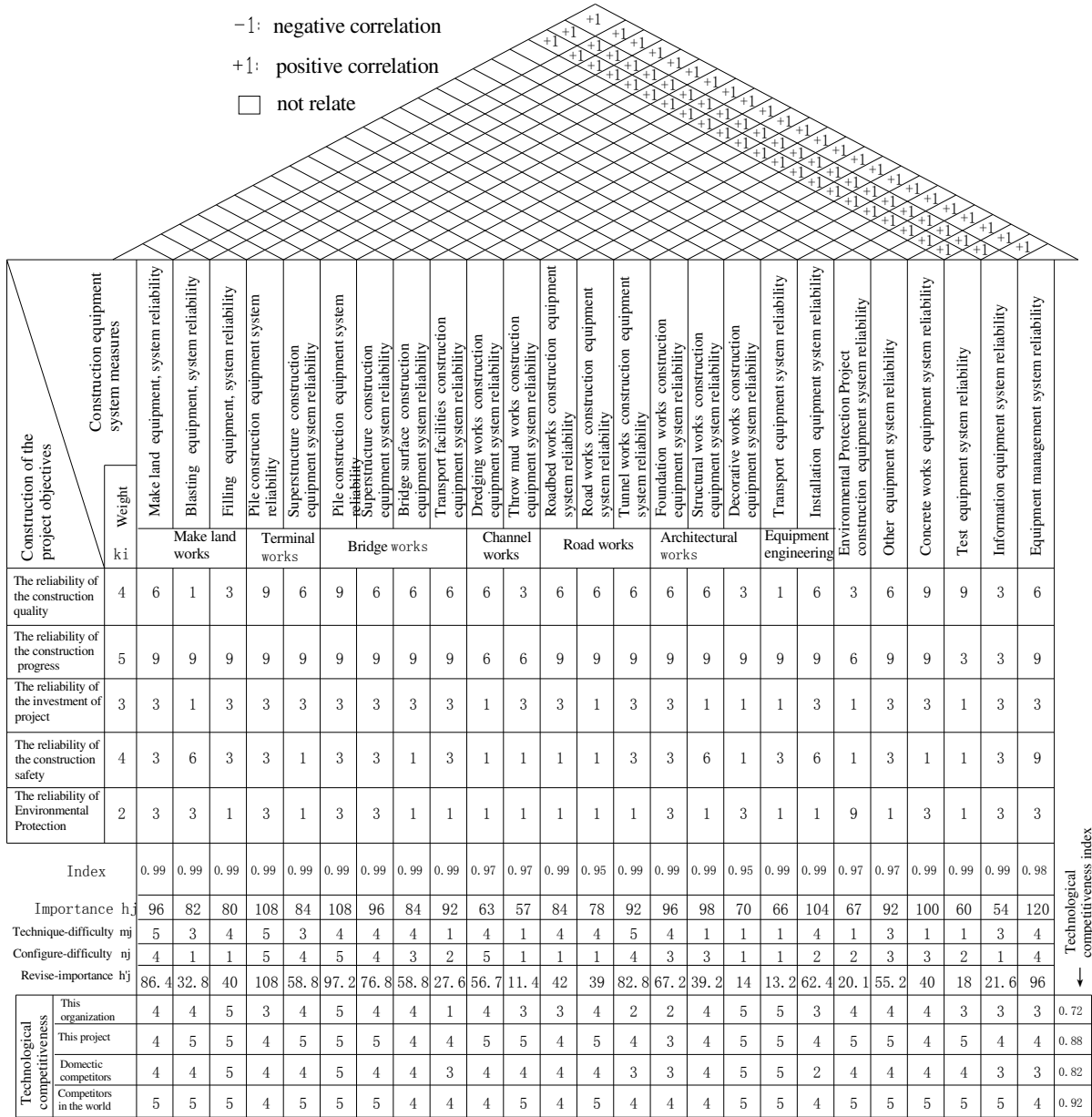


Figure 3.2 A Reliability Function Development sample of Yangshan deep-water port construction equipment system

We can assess the technical ability to compete in the House Of Reliability (HOR). The HOR’s “basement” that is technical ability to compete assessment matrix. In this matrix, the “technical-competitiveness” of T_j ($j = 1, 2, 3, \dots, n$) can be given to the five value “1”, “2”, “3”, “4” and “5”. Said that “5” of the most competitive. Technical-Competitiveness-Index of the “ T ” is calculated according to the following Formula (3.2-2) [6]:

$$T = \sum_{j=1}^n h_j T_j / (5 \sum_{j=1}^n h_j) \quad (3.2-2)$$

On the Figure 3.2, the “technical-difficulty” of the “measures” m_j ($j = 1, 2, \dots, n$) was divided into five level “1”, “2”, “3”, “4” and “5”. The “5” is the most difficult techniques. In this paper, the HOR is different from common HOR (or HOQ) that set up “the configure-difficulty” item and the “revise-importance” item in order to consider the “configure-difficulty” and the “technical-difficulty” as an important factor while carrying on equipments ABC classification. The “configure-difficulty” of n_j ($j = 1, 2, \dots, n$) is also divided into five level “1”, “2”, “3”, “4” and “5”. The “5” is the most difficult configure. And the “revise-importance” of

h'_i is calculated according to the following Formula (3.2-3)^[6]:

$$h'_{ji} = (m_j + n_j) / 10 \times \sum_{i=1}^m k_i r_{ij} \quad (3.2-3)$$

The Formula 3.2-3 expresses that if the technique-difficulty and the configure-difficulty of a measure is bigger, its revise-importance value is also bigger. This measure item needs to be valued. If the technique-difficulty and the configure-difficulty of a measure are smaller, even the value of its measure-importance is bigger, its revise-importance value will be revised and become smaller. For example, in the Figure 3.2, the bridge construction equipments system's importance is 84, the communication construction equipments system's importance is 92. But taking into account their technique-difficulty and configure-difficulty, the order of the size of the original revise-importance has been the opposite. If according to their importance, both all should be included in the category-A equipment, but according to their revise-importance demarcation they are all no longer belong to the category-A equipments.

While we divide the equipments (or process) into ABC class, the equipment and process of the systems which revise-importance is greater than 1.25 times the average are included in class A and the rest classified as class B or C. It can be seen from Figure 3.2, that the filling works construction equipments system, wharf pile foundation construction equipments system and bridge pile foundation construction equipments are critical sub-systems. Their equipment and process can be designated as class A. Because the configure-difficulty of equipments system will take place variety at different times and different circumstances, the ABC demarcation should be dynamic. The RFD should be adjusted in time in accordance with the actual situation in order to seize key points in time. The data of the scale bigger RFD is larger. If it is calculated by hand, we are error-prone. However, if we create RFD in the Microsoft Excel, when the data was adjusted, as long as the formulas are set up, the software can automatically calculate immediate such as the importance, the revise-importance and the competitiveness-index, etc. About Quality Function Deployment of the details can be found in the reference [6].

4 Maintenance strategy of the construction equipment system

4.1 The dynamic ABC classification based on project

At present, most of company manage the equipments that are transferred to construction projects still according to their classification of ABC in company. However, the position of a set of equipment in the project is different from in the company. Equipment in the company is the category-A equipment, but its role in a particular project may not be very critical; or there are more of such equipment for replacement, and its influence to the objectives of the project is not too great. Again such as, a set equipment in the company is not important, but if it is

only one, there is no alternative, and the serve of its parts are very difficult and once broke down it has a significant impact to the quality of construction works, the construction progress and the cost of the project. So this equipment is utmost importance to achieve the objectives of the project. So the important degree of construction equipment system has to be assess depend on its importance and reliability in carrying out a project objective. When the equipment system carries on ABC demarcation, we must be based on the project. It is necessary that makes sure the classification of equipments and processes to depend on their position, function and the role of the project. Figure 3.2 set up the "configure-difficulty-index" and "technique-difficulty-index" in response to the equipment system's special circumstances in a project.

Current the equipment's ABC category unchanged for a long time once designated. If a set of equipment is classified as category-A, it will be treated in accordance with category-A equipment no matter in which project; regardless of the role what play in the project, and no emphasis on the specific process of equipment system. In fact, equipment's role and influence is different for the project's objective in different projects. Even within the same project, equipment's role and impact is also a different for the project under different circumstances and different periods of time. And its importance is changing. From an engineering practice, the quality of the process influence very greatly for the achievement of the project's objectives. Dynamic classification of ABC management should consider two issues: First, in different projects, the equipment and the process should be divided into its categories based on the specific situation of the project. Second, in the same projects, the classification of the equipment and the process should be adjusted according to the project progress and changes in a timely manner, in order to ensure that the management and control are strengthened for the critical equipment and processes. In addition, after the "bucket theory" of "short-board" is taken long, a new "short-board" will appear. We should focus to the new "short-board" in time. These changes can be reflected by the "configure-difficulty" and the "technical-difficulty" in Figure 3.2.

4.2 Maintenance strategy of the construction equipment system

Category-A of process and equipment are a small number, but the role and impact is larger to the project. They accounted for 20% of the total number to 30%, but the work accounts for 70% to 80%. They are the key and bottleneck in the course of the project construction. The equipments and processes in the event of a failure will cause a significant loss and impact on the project. Therefore, in the course of operation, require such equipment and the process has a very high reliability. This category of process and equipments should be the focus of maintenance and should be adopted the RCM (Reliability-Centered Maintenance) maintenance of way, so as to enable both the maintenance workload and maintenance costs reduce, less investment to achieve more output. On the B and C categories, respectively can be used the "plan maintain" and the "failure maintain"

Reliability Function Development table.

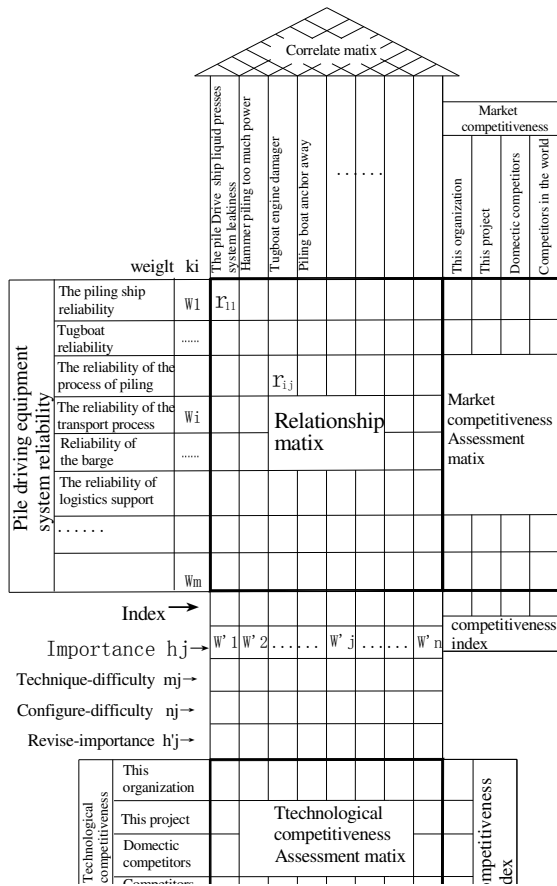


Figure 4.4 Reliability Function Deployment for terminal works piling equipment

5 Conclusion

Ocean engineering construction mechanization degree is high. The higher the construction mechanization degree is, the higher the degree of dependence on equipment is. Therefore, the performance and the reliability of the construction equipment system are very essential to the project. The project's general contractor should carry out Business Process Reengineering (BPR), and build up an orchestration management mechanism for construction equipment, in order to improve the current decentralized management situation that the equipments are manage by entirely sub-contractor own.

The maintenance strategy of construction equipment system for construction project is different from the enterprise. The ABC classification of construction equipment system should emphasis their importance for the project, and based on the project. RFD methodology can be used not only for ABC classification of process and equipment by the technical-difficulty, the configure-difficulty and the revise-importance, but also more in-depth quantitative and qualitative analysis. With Chinese the reform of project procurement model, the general contracting model is the way to gradually extend. The Market-competitiveness-index, the technological-competitiveness- index and so on in the Reliability Function Deployment matrix can provide strategic decision-making information for the general contractor.

The category-A equipment and process should adopt the RCM (Reliability-Centered Maintenance) maintenance of way, and the B and C categories respectively can use the "plan maintain " and the "failure maintain" method. The ABC classification of construction equipment system should be dynamic. The category should be adjusted in a timely manner with the construction progress in order to seize the equipment and processes that play a key role or in bottleneck location in the project.

The sub-project in the project is constructed by different sub-contractors in general with their own construction equipment. Because the ownership of the equipment belongs to different organizations, their own management is decentralized. The general contractor of the project can not unified dispatch equipment such as army command military equipment. Therefore, it is need to research further how to establish an orchestration management mechanism for the entire system of construction equipment in order to enhance its reliability and efficiency,

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***contact:** ccwww.cc@163.com; phone 0518-82382543; fax0518-82331425; <http://www.ccwww.cc>;

Lianyungang ConstructionWeb E-business Science &
Technology Co. Ltd.; 25-1-1001 Jiuhexincheng Kaifaqu
Lianyungang, Jiangsu, 222042, China.