Organization and Management of Construction for big Science Projects

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Abstract. Big Science projects are usually jointly funded and led by governments or intergovernmental organizations through cooperation. Big Science projects are effective methods for solving complex environmental problems such as climate change, fusion power generation, and breakthroughs in core industrial technologies. The International Thermonuclear Experimental Reactor (ITER) project is a typical international Big scientific project. The construction of these big science projects possesses all the characteristics of traditional construction projects. However, due to the extensive use of new technologies, they are characterized by special equipment components, immature process, complex processes, and lack of standards. At the same time, they also have research and development attributes, which lead to a high probability of problems during the construction process and difficulties in controlling progress and costs. This article proposes adopting an organizational design with a technical leader system, utilizing agile management as the core control method, and leveraging advanced management techniques such as BIM during the construction process. These measures can effectively improve technical preparation and construction control, enhance personnel efficiency, and reduce risks during the construction process.

Keywords: Big science project, Technical Leader System, Agile Management, BIM，ITER

1 Introduction

Big science engineering projects refer to the construction of large-scale scientific research facilities or experimental equipment with breakthrough scientific exploration as the core goal. Big science project jointly led and invested by countries, international organizations or multiple countries. Normally Big science project integrate cutting-edge technology, interdisciplinary knowledge and global collaborative resources, and carried out in extremely complex and uncertain environments.

Big science is a concept coined by physicist Alvin Weiberg in 1960s to describe large-scale scientific projects designed to solve the world's biggest problems. Typical big science projects include the International Space Station (ISS), the International Thermonuclear Experimental Reactor (ITER). Big science projects are difficult and costly to build, the equipment and construction cost usually up to hundreds of millions

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or even billions of dollars. There for ,it is difficult for a single scientist or group of scientists to afford. But big science projects are generally considered to be efficient ways for solving complex industrial problems. Therefore big science projects are usually invested by governments or jointly invested by different intergovernmental organizations [1]. The construction of big science project simultaneously represents a country's comprehensive strength, It is also an important driven for nation's innovation development, which could provides important support for major scientific and technological achievement outputs. As the world population grows, issues such as climate change, food safety, biohazard prevention and control are becoming more and more complex, the problem solving requires multidisciplinary collaboration and the investment of large amounts of resources [2]. At present, more and more big science projects are planned to enter the construction stage, but the construction of big science projects is difficult to manage due to many differences compared with traditional industrial projects(shown in table 1), so the difficulties on managing the special project and make sure the construction of big science project implemented in a smooth way is gradually becoming a bottleneck in the development of science and technology [3].

Table 1. Distinction between Big Science projects and traditional large-scale infrastructure projects

No.	Comparison Dimension	Big Science Projects	Traditional Large Industrial Projects
1	**Project Objective**	Focuses on advancing scientific questions (non-commercial purposes),	Aims for industrial applications, e.g.,power plants
2	**Technical Characteristics**	Uses cutting-edge materials, technologies, and processes	Relies on mature, standardized technologies
		Complex equipment	Market-available or modular equipment
		Immature technologies requiring iterative R&D	Stable technology lifecycle with slower iteration.
3	**Funding & Investment**	High capital expenditure (billions to trillions)	Moderate-scale investments
		By national governments or international organizations (e.g., ITER).	Diversified funding sources
4	**Management & Experience**	Led by scientist-dominated teams with limited engineering expertise	Managed by professional engineering teams (e.g., EPC contractors)
		First Of A Kind，no similar experience	Similar experience could be found
5	**Construction Organization**	Non-linear workflows	Linear workflows
		Requires solutions for extreme conditions	Follows conventional code and standed
6	**Risk**	High technical risks (unproven solutions)	Risks tied to market fluctuations or supply chain

2 Project Characteristics of Big Science Projects

Big science construction projects often have large investment, long cycle and complex process. In essence, the construction of big science projects has all the characteristics of traditional construction projects and has not been separated from the scope of construction engineering, but at the same time, due to the characteristics of the originality and R&D attributes of the big science project, which leads to a much lower degree of technological maturity than that of the general engineering projects, the main characteristics of which are as follows:

2.1 Widely use of New Technologies

Big projects are at the forefront of technology, and their device designs represent the highest level of current technology. Many devices need to be used in extremely harsh environments. Taking the ITER project as an example, its devices need to integrate various factors that challenge physical limits, such as ultra-high temperature, ultra-low temperature, strong magnetic field, ultra-high vacuum, and ultra-high current, into one device. Therefore, the technical requirements for devices and materials are generally high, and traditional industrial designs often cannot meet the requirements of application scenarios. Therefore, the new technologies such as new materials, new technologies, new processes, and new equipment need to be widely used. Therefore, the proportion of the new technologies is generally high than traditional industrial project, even far higher than that of mature industrial projects.

2.2 Lack of Standards to Rely on

Based on the characteristics of the widespread use of the new technologies in the above-mentioned big scientific projects, many construction methods and acceptance criteria do not have a standard system to rely on, and are mostly executed according to similar standards. Even if corresponding standards are developed, the applicability of the standards is poor, resulting in frequent disputes or inability to execute during the construction and quality acceptance process. For example, the design of the PCR ring (a type of restraint device) protective cover in ITER international fusion engineering project is a simple temporary hard protection measure. Due to the lack of similar design experience, designers refer to the design standards of safety helmets, which makes the protective cover too bulky and adds considerable trouble to the introduction, lifting, and welding of them.

2.3 Generally High Technical Requirements.

Due to its specific scenario requirements, the technical requirements of big science project are higher than the average technical level. At the same time, the personnel who design such devices are mostly scientific researchers, lacking engineering and technical experience. In addition, the design requirements of designers are generally high, and some even exceed the current technical ability, especially in construction accuracy, welding requirements, and other aspects. For example, during the welding process of the foundation support of a ITER CTB(a component of feeder), it is required that the embedded plate of the foundation be preheated up to 60 °C, while the reference standard only requires a conventional temperature. Due to the difficulty of preheating the pre embedded plate, the welding difficulty, efficiency, and cost increase to triple times.

2.4 Processes and Methods are Immature or not Verified.

The immaturity of technology in big science projects is a common problem. Generally speaking, in the research and development stage, new technologies and processes adopted need to be validated in advance before implementation. However, most of them are validated and developed for key processes. During the project construction process, insufficient process validation and omissions still occur. At this time, in order to ensure the effective progress of the project, contractors have to undertake some work such as process validation, certification, and further technology development, whether for their own interests or to promote the project. However, there is a certain probability of failure in process validation, which inevitably leads to work stoppages, delays, and increased costs. During the construction of ITER, such verification work almost happened at first installation of all components (FOAK work), which not only puts higher requirements on construction technicians, but also causes operational difficulties for contractors.

2.5 Special Equipment Components.

Many equipment and components in big science projects are quite unique, many of which are one-of-a-kind. Some components also have characteristics such as large size, heavy weight, and easy deformation, making it difficult for engineers to find similar construction experience to draw on. The development of construction method, measurement, lifting, welding and other procedures has brought difficulties, requiring engineers and technicians have be high qualified, need them to have solid skills and rich experience in order to implement them.

2.6 Many Risk Factors.

Combining the characteristics of the above-mentioned big science project, the risk factors of project construction have increased exponentially, especially some technical and procurement risks, many of which have unforeseeable characteristics, leading to increased coordination and management difficulties in project schedule management, cost control, etc., and the widespread occurrence of project delays and cost overruns; For example, the International Thermonuclear Experimental Reactor (ITER) project had an initial budget of 5 billion Euros in 2006 and an expected construction period of 10 years. After adjusting the budget in 2016, the project budget has reached 20 billion Euros. In 2024, ITER announced that the estimated cost of implementing a new baseline when the budget has exceeded 25 billion Euros. Although it has been implemented for nearly 18 years, the actual completion period still requires 9 years [4].

2.7 The Effect of R&D Attributes

The construction process of big science facilities itself has research and development attributes. The R&D attributes of big science project are reflected in the characteristics of its first reactor or first set of equipment assembly, which are often using Three-Phase Concurrent Engineering (TPCE) model, though time-saving, but increase risks due to the lack of sequential verification. Some R&D work is gradually improved with the progress of the project, or problems are discovered only at specific stages of the project, resulting in the need for simultaneous construction and R&D, increasing the uncertainty of the project.

3 Major Problems in the Organization and Implementation of Big Science Projects

As mentioned earlier, the construction of big science projects has all the characteristics of traditional industrial projects, that is, the safety, quality, construction coordination and other issues encountered in traditional industrial projects are reflected in big science project. However, based on the characteristics of new technology, high standards, special equipment, and research and development attributes of the aforementioned big science project, the problems that arise during project construction are also quite prominent.

3.1 Frequent Technical Issues.

The smooth implementation of the project relies on the full cooperation amount the owner, supervisor, and construction party, as well as the collaborative work of various disciplines such as project quality, safety, technology, and business. The lack of any link will trigger the "barrel effect" and lead to difficulties in project implementation. The above situation is mainly reflected in the outbreak of quality problems, but the underlying reasons are more complex, such as inaccessible installation, immature technology, and substandard welding quality. Once a problem occurs, it is inevitable that a series of operations such as project suspension, problem analysis, solution, and implementation of the plan will be required, resulting in delays in the project schedule, increased costs, difficulties in resource coordination, and finally increase the management burden. Due to the high proportion of the new technologies in big science project, the overall maturity of the project is low, and the frequency of construction problems has significantly increased. Excessive frequency will inevitably lead to a series of problems such as stumbling and fragmented construction progress in project construction.

3.2 Poor Procurement Efficiency

Due to the inability to accurately predict future demand, procurement activities are characterized by small batches, diverse types, high requirements, and high procurement difficulty. On one hand, this is due to the use of many new materials, which often have a low degree of commercialization, few suppliers, or insufficient supply capacity. The procurement duration is long or uncontrollable, and if the corresponding item requirements cannot be effectively identified earlier, it is easy to encounter situations where waiting for materials; On the other hand, adopting new processes can easily lead to construction logic problems. take the machining work for a certain project as a case, this work requires the pre construction components to be in place first, and then the machining work can be started through processes such as site measurement,3D modeling, reverse engineering, and finally machining. Which means, pre work needs to progress to a certain extent before the subsequent work can begin, and cannot be carried out in advance. What else, the machining duration is relatively long, which inevitably becomes a critical path, leading to temporary suspension of on-site work.

3.3 Progress Cannot be Effectively Controlled

Due to the fact that most big science projects are implemented for the first time and have limited reference experience, there are varying degrees of poor plan feasibility during the schedule planning stage; Secondly, the increase in uncontrollable factors during the implementation process has also made dynamic management of the project more difficult, resulting in frequent process adjustments and resource reallocation, which has increased the difficulty of dynamic adjustment optimization;

3.4 Costs are Difficult to Control.

It is inevitable that there will be issues with project progress and expenses exceeding expectations. This is manifested in the fragmentation of construction work and a decrease in labor efficiency due to numerous technical issues; The delay in the project has led to an increase in personnel idle time; The difficulty of project management coordination has increased, leading to an increase in engineers and technicians, resulting in a high proportion of indirect costs. Although some of the costs of the above work can be compensated through change and claims, some management oversights and repeated construction due to substandard construction quality (such as insufficient adjustment accuracy resulting in repeated adjustments) cannot be compensated. In fact, it is obvious that once the project is delayed, an increase in costs is inevitable.

3.5 The Owners Lack of Experience.

In most cases the owners of big science projects are from scientific research institutions or international organizations, who often suffer from a lack of project management talent and experience. Although the owner can introduce advanced management experience and leverage the power of external consulting firms, the core of project management lies in human experience. Coupled with the fact that big science project is a one-time work, experience accumulation and feedback cannot be formed, which will have an undeniable impact in the early stages of project management.

4 Key Implementation Recommendations

4.1 Technical Based Construction Management System

From the above analysis, it can be seen that technical management is the core of the construction of big science projects. The adequacy of technical preparation will directly affect the implementation effect of the project. Undoubtedly, from the perspective of project organization and management, technical will be the driven of a big science project. There for, there should be a management organization with technical leaders as the core, and coordinate all links of people, machines, materials, and environment. The key to establishing a management organization with technical management as its core is the technical leader system, also known as the "virtual project manager", which divides the construction of big science facilities into multiple work packages based on subsystems or equipment, and assigns a technical leader to each package. The leader will lead and be responsible for the technical preparation work of the corresponding work package in the early stage of construction, including the preparation of installation procedures, measurement documents, safety documents, etc. Coordinate various requirements such as procurement, business, and manpower with various sectors, such as proposing work environment requirements to the construction sectors, etc. Provide technical briefing, construction technical guidance, handling of technical issues during construction, quality acceptance, etc. During the construction phase, the leader will lead the completion delivery and experience summary during the completion phase. To a certain extent, the technical leader system is equivalent to establishing a virtual project organization for each work package, and the technical leader is equivalent to the "project manager" of that work package. In this way, with the technical leader as the core node, various stakeholders such as the owner and supervisor can be coordinated externally, and various resources can be organized internally to flexibly and efficiently promote the work of related work packages.

In terms of organizational form, the functional organizational structure and decision-making system of the project can remain unchanged. In terms of work arrangement, a technical leader can be responsible for managing multiple work packages based on the construction plan or logical relationship, achieving flow management for the leader. At the same time, a leader work group can be established for managing work packages with relatively large workloads. The above-mentioned technical leader system, which does not involve organizational restructuring, has the characteristics of being short, flat, and fast, and can be flexibly adjusted and optimized to match the technical characteristics of large scientific engineering projects. The specific working mode is shown in Figure 1.

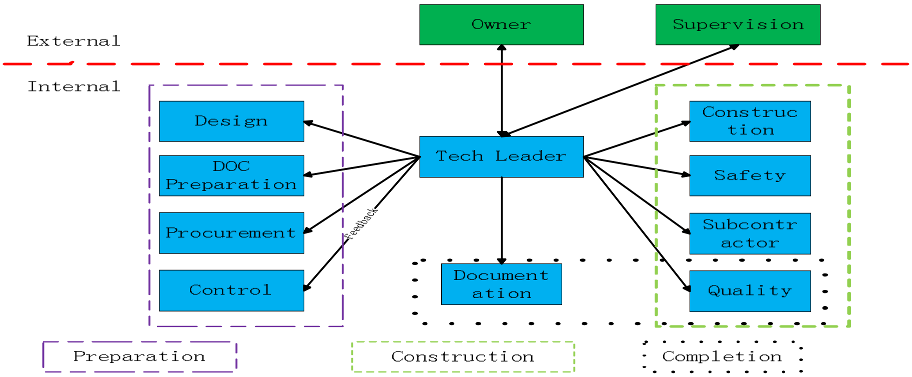

Fig. 1. Technical leader system

4.2 Agile Management Based Control System

Plan Management System Driven by Agile Management. The poor controllability of scheduling is a typical characteristic of construction in big science projects, which is caused by the overall lack of coordination in various aspects such as upstream design, midstream construction, and downstream equipment supply. Agile project management (APM) is suitable for complex projects with unpredictable requirements and immature technical solutions. It has the characteristics of flexibility, variability, and continuous iteration, and the schedule management of big science projects clearly conforms to this feature [5]. During the implementation process, the control engineer can serve as the lead and agile coach. Based on a three week rolling plan, construction coordinators, technical leaders, procurement engineer, and owner can be included in the team to form an agile management team for project schedule management. Through weekly planning meetings, daily station meetings, and other forms, resource constraints such as manpower, technical, items, and work interfaces can be analyzed to optimize and adjust the weekly work plan and as well as the three week rolling plan. The direct connection between various professions, owners, and other demanders has been achieved, solving the characteristics of long processes and low information transmission efficiency in traditional waterfall management methods [6]. Assisted by monthly, annual, and overall plans, achieve iterative and spiral progress in plan control management. Adopting agile management can also maximize the digestion of problems at the grassroots and initial stages of events, reduce the workload of project management coordination, and lower the load of project management. The iterative approach of agile management is shown in Figure2.

A practical application case of APM is the Machine assembly work of the ITER project. Due to the high complexity of engineering technology and the long international cooperation chain, traditional "rigid plan management" faces challenges such as upstream component delivery delays, frequent quality defects caused by differences in standards, and deviations in the installation accuracy of superconducting magnets. The contractor utilizes the concept of agile management to establish a multi-level planning system on the schedule management system, including "daily plan, weekly plan, three week rolling plan, and half year baseline plan". Short term plan (daily/weekly) focuses on specific tasks (detailed to personnel, equipment, materials); Dynamically incorporating a three week rolling plan into the risk buffer; The half year baseline plan maintains stable strategic objectives. In terms of iteration mechanism, daily work arrangements and progress review are carried out through stand meetings（a short meeting started every morning with all workers）, and the three week plan is adjusted through weekly review meetings. For example, when there is a delay in the installation of thermal shield due to quality defects, the team immediately transfers the originally planned manpower to the assembly of the superconducting feeder system (originally planned to start 2 weeks later) to avoid idleness. In terms of implementation methods, the project team try to train workers to have multiple skills by organizing skill training, then the project could achieve flexible cross job configuration. In terms of risk prevention mechanism, the planned construction tasks are classified and managed, with priority given to tasks with higher priority to ensure the stability of the critical path plan. At the same time, a task buffer pool is set up to exceed the previous plan and reserve a certain amount of work load in the plan(ie 120%), ensuring that resources can be immediately transferred to reserve tasks in case of set interruptions partly, thus ensuring work efficiency. Through the application of APM approach mentioned above, the achievement rate of the ITER project machine assemble plan has increased from less than 50% in the initial stage to around 79%.

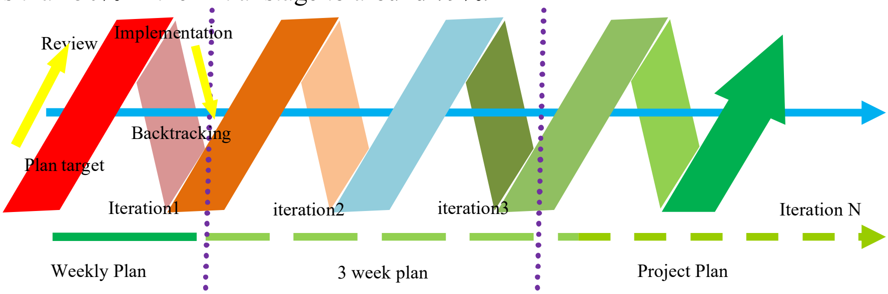

Fig. 2. Modeling of Agile management on Planning

Efficiency Optimization and Human Resource Mobilization Management Driven by Working Hour Management. Based on the above characteristics of big science project, there are the following manifestations in specific installation projects: the work content rarely involves large-scale single tasks, and the work content presents a discrete characteristic of low quantity demand and multiple types. At the same time, the skill requirements for various types of work are high, which leads to low work efficiency in some specific works. In addition, frequent unforeseeable interruptions further reduce work efficiency. The demand for human resource presents an irregular fluctuation curve, rather than the normal distribution curve in traditional construction projects (see figure3). Therefore, in practical work, control engineers should adjust the work schedule, optimize the construction logic, to make the project manpower curve as smooth as possible, in order to facilitate the orderly progress of project construction. This requires more refined management of construction operations and the establishment of a work hour management system. On the basis of achieving reasonable classification and effective collection of working hours, combining working hour data with earned value management, using contract data as the budget value, and converting actual working hour data into value as the actual value, a earned value curve can be generated, supplemented by pie charts, which can effectively monitor the work efficiency of each construction site and dynamically optimize and adjust according to the work efficiency situation to solve the problem of insufficient efficiency. From a long term perspective, combining working hour data with construction plans can develop a long term human resource mobilization plan and update it on a rolling basis. This can achieve dynamic adjustments in human resource mobilization and demobilization, avoiding the occurrence of sudden increases and decreases in short-term human resource demand.

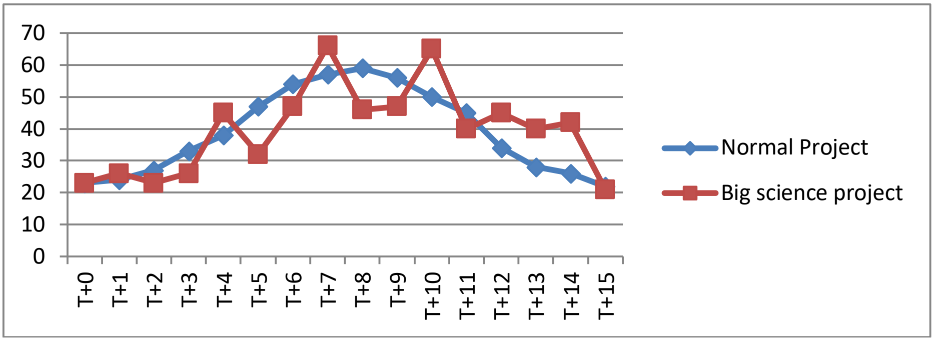

Fig. 3. Human resource Waving on Big science project

Risk Management Driven by TOP 10. Risk management is an important part on project management in any situation, and it is an activity covers all stakeholders. Risk factors in big science projects exhibit characteristics of small, scattered, and numerous. However, the cumulative effect of risks cannot be ignored, and some risks also have unpredictability. The importance of risk management should be fully recognized from the perspective of project management. By using TOP10 management and other means, a multi-level project management system and risk analysis and judgment mechanism from departments level to projects level should be established, and a risk management checklist should be formed to strengthen the prediction and early disposal of risks. Dynamic risk management can be achieved through risk management meetings and other forms to control the impact of risks to a certain extent. Risk control engineers should regularly collect project risk influencing factors and rank them according to the probability and degree of risk occurrence. At the project level, regular risk management meetings should be held to discuss risk solutions and the completion status of risk action items, in order to avoid uncontrollable situations caused by risk expansion.

4.3 Make full use of Information Technology and New Project Management Technology Tools

The application of information technology has been widely used in the field of construction area, especially BIM technology has formed many mature application scenarios in drawing review, 3D collaborative design, collision management, visual disclosure and other aspects in many construction fields [7]. The installation of big science project involves many structural components, which have the characteristics of special and complex structure, tedious process, and high skill requirements. During personnel qualification and training, as well as on-site construction, it is easy to encounter quality problems caused by unskilled operation. Make full use of BIM technology, with the technical leader leading the preparation of visual BIM models or 3D animated demonstrations, embedding construction points such as quality control and schedule requirements into the models. During training and certification, construction disclosure, and on-site construction stages, a combination of two-dimensional and three-dimensional modes is used, combined with lightweight platforms, VR devices, and mobile clients application software to enable workers to quickly grasp construction points and difficulties, in order to improve workers' work efficiency and proficiency[8].

The application of BIM technology in complex special process construction has unique advantages. Taking the joint assembly process of the superconducting feeder system in the ITER project as an example, the core work of the nuclear fusion device magnet system involves more than 20 steps such as personnel training and certification, joint assembly, insulation curing, vacuum discharge experiments, etc. During the personnel qualification stage, BIM technology can be used to decompose the superconducting joint structure through virtual processes based on BIM models (Figure 4). Key parameters such as assembly process, insulation layer winding direction, and heating temperature curve can be demonstrated through animation, avoiding the understanding deviation of traditional text manuals and achieving 3D visualization training, allowing operators to actually understand each operation step and key point; During the on-site implementation phase, workers are allowed to scan the joint components through their mobile phones/tablets. The BIM model could automatically overlays AR animations, highlighting details such as tool selection and parameter value settings for the current step to achieve dynamic guidance of the process（see figure 5）. In addition, BIM technology can be combined with project control to provide real-time statistics on the number of completed joints. Which could automatically generate progress reports, and achieve automatic and accurate progress measurement and deviation analysis. The above methods can significantly reduce the training duration for workers, lower the probability of misoperation, and thus improve the quality of the process.

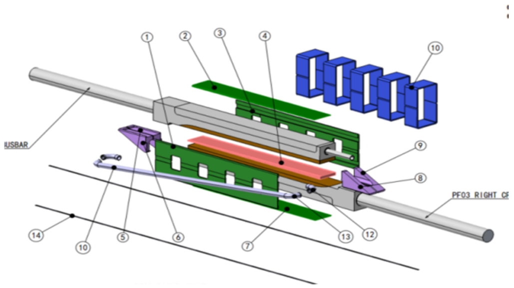

Fig. 4. Feeder Joint 3D model

Fig. 5. Joint assembly on site[9]

5 Challenges and Shortcomings

Although adopting the suggestions in the chapter 4 above has to some extent solved the problems of difficult management and delayed planning in big science project, the implementation of the above methods still faces some challenges and shortcomings, mainly including the following integral aspects:

5.1 Human Resource Demand Issues.

Firstly, adopting a management model of technical leader system is equivalent to assigning a technical leader to each work package, which improves the level of precision in management. This also means that the project needs to have a large team of technical leaders. Taking the ITER TAC1 contract as an example, there are over 500 work packages in total. Although the work assignments take 5-10 years to complete, and considering that similar packages can be handled by the same technical leader, it also means that the project requires 20-25 technical leaders, which is equivalent to nearly 30% of the project organization. Secondly, the technical leader is equivalent to a small project manager, who will have to manage all the issues related to the package, in other words the technical leader be qualified with both technical and management abilities. It is relatively difficult to find technical leaders who are competent for the job.

5.2 Cost Increase

Whether adopting the technical leader system or agile management methods, their essence is to increase the level of refinement in management. The result is an increase in the workload of management and the number of management personnel. When compared with traditional industrial projects, its indirect costs (management costs) will appear relatively high.

5.3 Internal Competition for Managing Resources

The technical leader system is a way to achieve refined management of work packages through a virtual project department without breaking the traditional linear management structure of the project organization. In the actual implementation process, different technical leaders only focus on the progress of their own work packages, which may lead to competition for project resources among leaders to a certain extent. For example, the number of workers is limited, and managers may compete for worker resources for their own goals. This will have an impact on project management to some extent.

6 Summary

The unique characteristics of construction in big science projects make the technical preparation and technical guidance during construction stage particularly important. Compared to traditional projects, the investment in technical management of big science project is more complex , which requires innovative organizational and project control methods to adapt to the characteristics of it. From a organizational point of view, a technical driven organizational should be established, for each component or subsystem a virtual project team should be formed .By this means the problem could be solved at the embryonic stage ,and can effectively avoid interruptions such as work stoppages and delays caused by technical problems during the construction process. At the same time, strong technical capabilities can also provide strong support when short-term technical development is needed. The construction goals of big science project are often inconsistent with the implementation goals of the engineering project. The use of control methods such as agile management can timely grasp the needs of various stakeholders. They allow flexible adjustments on the short-term, medium-term, and long-term goals of the project, which also creats iteration cycles for on-site construction organization, construction coordination, and planning management. This keeps the project in a continuous spiral of optimization, improves the flexibility of resource utilization, and reduces the risk of personnel idling and project delays.

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