Abstract—The project management architecture and mechanisms of distributed concurrent product design in a virtual enterprise are discussed. The process of project management and its functions are presented. First, aiming at the characteristics of distributed concurrent product design process, the architecture of project management of distributed cooperative product design in the virtual enterprise is presented to adapt to distributed concurrent development of complex products. The main advantages of the architecture are also discussed. As to product design project, it is impossible to establish a detail plan before the project implementation starts because project planning and implementation progress by turns. Task decomposition module dynamically establishes the task decomposition structure and the relationships among tasks. Adopting object oriented ideas and UML modeling tool, partner selection in the virtual enterprise is modeled. After the functions of partner selection are analyzed and determined, the multi-level partner selection architecture is constructed using Web technology and database technology. Based on gray relation analysis, partner selection is carried out based on the evaluation indices and weights extracted from the information provided by candidate enterprises. Finally, according to project schedule and actual resource status, process fusion module determines task flow based on task decomposition and distribution structure. Consequently, because task decomposition and distribution structure is a nesting one, process fusion is also a nesting one.

Index Terms—virtual enterprise, project management, architecture, mechanism, task decomposition, partner selection, process fusion

I. INTRODUCTION

A virtual enterprise is a provisional network organization that is composed of several independent enterprises that are connected by information technology for the purpose of seizing rapidly changing market opportunities [1][2]. Aiming at market demand, various resources of the enterprises in the virtual enterprise that mainly include design resources and manufacturing resources are optimized and deployed along the increment direction of value chain. Thus, each enterprise can take full advantage of its core competence and the virtual enterprise can be able to respond to market changes rapidly.

Project management starts with cybernetics and system theory. All the problems concerning how to make the best of existing resources to accomplish a mission in the shortest time span can be classified as project management [3]. Project management software is widely used in planning, scheduling, etc. A dynamic discrete affair, especially product design, software development, and so on can generate a large mount of dynamic information in project implementation. And uncertainties always lead to the changes of goal and constraints. Most actual software systems are not able to provide the functions of project supervision, effective project re-planning, resource scheduling, etc. As a result, it is difficult for project management to reflect and track the actual progress dynamically, modify original plan in real time, and control project implementation effectively.

In the paper, project management and coordination of distributed concurrent product design in a virtual enterprise is put forward [4]. The focus is concentrated on how to plan, manage, control and harmonize a project holistically and dynamically to ensure that right personnel make best use of various resources to accomplish tasks effectively and efficiently. Consequently, project goals can be achieved under given constraints.

II. THE ARCHITECTURE OF PROJECT MANAGEMENT OF DISTRIBUTED CONCURRENT PRODUCT DESIGN IN THE VIRTUAL ENTERPRISE

There does not exist fixed mode of project management. According to the characteristics of distributed concurrent product design process, the inherent rules and complex dependent relationships of product design activities are studied. The architecture of project management of distributed concurrent product design in the virtual enterprise is put forward to adapt to distribute concurrent complex product design, as shown in Fig. 1.

Project management of distributed concurrent product design in the virtual enterprise accomplishes macro management and control of the project to harmonize design activities dynamically.

The main functions of project programming module include project programming, task decomposition, process fusion, process optimization, etc. The project is decomposed into interdependent items of different granularity at different administrative levels that are
interrelated. Based on partner selection and resource matching, various resources are assigned to corresponding tasks dynamically. The cooperative relationships among people in teams depend on the logical and sequential relationships. Similarly, the organizational structure of personnel depends on the hierarchical architecture of task decomposition that determines its mechanism of control and cooperation to a certain extent.

Task decomposition, the attributes of tasks (such as input and output of tasks), and logical relationships between tasks constitute the whole hierarchy of project tasks. According to the granularity needed, the hierarchical architecture of items is established. Then, the cooperation among personnel, privilege grant, information share and so on at different administrative level have to be dealt with.

By adopting MAS-based organization and resource encapsulation based on agents, organizational flexibility is improved and people can make the best of their enthusiasm and creativity. Self-organization and agent autonomy can improve the level of decision-making and reinforce the management and control of complex product design project. The teams at the upper level of the organization are responsible for the organization and administration of items, while the teams at the lower level of the organization are responsible for implementation of the items.

III. THE CHARACTERISTICS OF THE ARCHITECTURE OF PROJECT MANAGEMENT OF DISTRIBUTED CONCURRENT PRODUCT DESIGN IN THE VIRTUAL ENTERPRISE

The main characteristics of the architecture of distributed concurrent product design project management in the virtual enterprise are as follows:

- Incremental project programming is support because project programming and implementation are carried out alternately.
- Whether project implementation is accordance with project schedule or not can be examined.
- The hierarchical architecture is adopted to control distributed developing activities.
- According to the complexity of product development in the virtual enterprise, the organization of the project teams can be changed, and the management pattern at different level of hierarchical organization can also be different. Administrate levels can increase or decrease to accommodate to different management requirements.
- Relatively self-governed design process at the lower level of the hierarchical administrative architecture corresponds to relatively self-governed design task in the task decomposition structure. As a result, robustness and flexibility of the system are improved.
- Task decomposition, resource matching, and process fusion mechanism are able to deal with resource shortage, task alteration and so on to reduce their influence on project implementation.
- Because the hierarchical organization is adopted to manage and control product development. The information granularity differs at different levels. With the progress of the project, the granularity becomes smaller and smaller along with the expansion of the architecture.

IV. TASK DECOMPOSITION AND DISTRIBUTION

As to product design project, it is impossible to establish a detail plan before the project implementation starts because project planning and implementation progress by turns. Task decomposition module establishes the task decomposition structure and the relationships among tasks.

Because the tasks are carried out by distributed teams in the virtual enterprise, the task decomposition and distribution manifest the following characteristics:

- The project is decomposed into items and tasks step by step and the task decomposition structure evolves dynamically.
- According to its goals defined at upper level, the task at the lower level accomplishes its mission autonomously.
- The task at lower level can be decomposed into sub-tasks again. And it manages and maintains the relationships among the sub-tasks.
- The rest may be deduced by analogy until the whole task decomposition structure is established.

The more the number of task decomposition levels is, the smaller administrative granularity is, the greater the complexity of project management is. Hence, the number of project decomposition levels and granularity of project decomposition rest with actual management demand.

Suppose that the project is decomposed into \( l \) level, and at this level the project is decomposed into \( n \) items. Each item is decomposed into \( m \) tasks again. Thus, there are \( \sum_{i=1}^{l} \sum_{j=1}^{m} T_{ij} \) tasks in all. Thereinto, \( T_{ij} \) is task \( j \) of item \( i \), \( n \) is the number of items, \( m \) is the number of tasks in each item.
\[ \sum_{i=1}^{n} \sum_{j=1}^{m} T_{ij} \] tasks are decomposed from above to below. Based on the relationships among \( \sum_{i=1}^{n} \sum_{j=1}^{m} T_{ij} \) tasks, the project can be modeled, programmed and optimized.

There are several methods of task assignment, such as task assignment by project manager or team leader, balanced task assignment based on task difficulty and team member’s capability, task assignment based on bidding strategy, etc. In the paper, the product design project involves different enterprises, institutes and departments located at different places so that task assignment based on bidding strategy is taken as main method of task assignment while the other methods are used as accessorial ones.

V. PARTNER SELECTION BASED ON GRAY RELATION ANALYSIS IN THE VIRTUAL ENTERPRISE

The core enterprise of the virtual enterprise is called an alliance leader that is responsible for managing the running and coordination of the whole virtual. Every enterprise that provides its core competence for the virtual enterprise is called an alliance leaguer. Confronted with a market opportunity, the alliance leader analyzes the opportunity and breaks a project down into smaller ones that are released on Internet. Then, after candidate partners balance their own capabilities and possible profit that can be achieved through cooperation in the virtual enterprise, they decide whether they bid for the projects. Finally, the alliance leader evaluates the bids according to predefined evaluation system and selects the optimal partners to form the virtual enterprise [5]. Adopting object oriented ideas and UML modeling tool, partner selection in the virtual enterprise is modeled, shown in Fig. 2.

The functional modules related to the system manager include alliance leader management, partner management, candidate enterprise management, system maintenance, bulletin board management, etc. The functional modules related to candidate enterprises include project browse, system registration, project bidding, enterprise information release, etc. The functional modules related to the alliance leader include exception handling, project management (project creation, modification, deletion, release, and so on), partner selection based on gray relation analysis that is carried out based on the evaluation indices and weights extracted from the information provided by candidate enterprises [6].

After the functions of partner selection system are analyzed and determined, the multi-level partner selection system architecture is constructed using Web technology and database technology, as shown in Fig. 3. It adopts B/W/D mode where client browser provides operation interface for users and Web server carries out data access, information decomposition, service transaction, etc based on database and XML files. The system is divided into four levels, namely user interface level, request receiving level, transaction level and data storage level.

VI. PROCESS FUSION

According to project schedule and actual resource status, process fusion module determines task flow based on task decomposition and distribution structure. Because task decomposition and distribution structure is a nesting one, process fusion is also a nesting one.

The resources that can be used in a project are limited. The time that a task needs to be accomplished depends close on the quantity and level of resources that the task can use. If the precondition of a task is satisfied, it can be implemented autonomously after it obtains the resources needed. Otherwise, the task still cannot be implemented. Corresponding personnel are responsible for the supervision of the task implementation. The accomplished tasks are not taken into account any more in succedent process fusion.

Figure 2. Partner selection USECASE chart of the virtual enterprise
Design environment is changing continually. When the state of resources changes, personnel absent, task period is misjudged, etc, process fusion module needs to adjust or reconfigure the design process. Current design programming methods, such as program review and so on, are unsuitable for design process that includes feedback information and iteration. Process programming is established through combining whole programming and local decision-making, which provides background and instruction for local decision-making. Whether taking resource optimization as the programming goal or taking time as the programming goal in local decision-making is determined by actual personnel in the virtual enterprise.

VII. CONCLUSIONS

The core of an virtual enterprise is how to produce high-grade products at right time and place and by right enterprises by reasonably choosing appropriate partners and optimizing resource utilization. The architecture of project management of distributed concurrent product design in the virtual enterprise is put forward. The focus is concentrated on how to plan, manage, control and harmonize a project holistically and dynamically to ensure that right personnel make best use of various resources to accomplish tasks effectively and efficiently. Consequently, project object can be achieved under given constraints. The main advantages of the architecture are also discussed. Based on the analysis of traditional project management, the mechanisms of project management of distributed cooperative product design in the virtual enterprise are presented to adapt to distributed concurrent development of complex products. The future researches are process fusion supervisory, resource allocation optimization, conflict and crisis disposal, and so on.

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