Collaborative Project Management with Supplier Involvement in Complex Product Development

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Abstract
In Complex Product Development (CPD) project, enterprises gather suppliers distributed in time, space under the thought of lean product development. However, increasing number of globally distributed project teams bring with great challenges for virtual projects to arrive at high levels of collaboration. This paper presents a Collaborative Project Management (CPM) framework that aims at improving suppliers’ integration in the process of project management by enhancing collaboration among a multi-tier supplier network. Related concepts, implementation steps and supporting tools in this framework are introduced. Two aspects of CPM: project management teams and project planning are then discussed in detail. Finally, a prototype system was developed to provide enterprise an interface to collaborate with supplier network by means of efficient information.

Keywords: Collaborative Project Management; Supplier Involved; Product Lifecycle Management; Project Lifecycle Management; Complex Product Development

1. Introduction
Successful project means its goals are accomplished within its budget and scheduled time frame. Unlike manufacturing and assembly, where activities can sometimes be outsourced in an arms-length transfer of prices and quantities, CPD is an uncertain and long-lead-time activity with advance investments and joint work between firms that requires coordination about product features and qualities. Project management paradigm has been changed from managing inputs and outputs of project located at a single location [1] to management of project process [2] within virtual enterprise. Suppliers widely distribute across different industries, and it brings with great challenges for knowledge sharing and consistence of project data. We assert that there is a need for a new CPM solution that will help enterprises make project plan and allocate resources across enterprises. And a CPM system is required for integrating project partners seamlessly. The focus of this paper is on collaborative solution for effectively managing CPD project. In a wider perspective, this paper also intends to contribute to the theories of project management with supplier involvement, including the project management processes, detailed methods and IT infrastructure for project lifecycle collaboration.

This article is organized as follows. Section 2 includes related studies reviews and gap analysis. Section 3 presents the new collaborative solutions, including some significant definitions and the process/methods in MtSiCPM. Section 4 introduces the detailed methods and process for project planning and controlling.
Our Supplier involved Collaborative Project Management System (SiCPMS) is developed in section 5. Finally, section 6 summarizes this study and presents future research directions.

2. State-of-the-Art Review

Nowadays suppliers involve more extensively and earlier in product development project. Traditional project management scenarios of single locations can not satisfy the collaboration requirements in virtual project. To effectively tackle these challenges in virtual enterprise environment, new solutions are required for achieving successful project management and competitive advantages. These solutions should integrate suppliers into the process of collaborative project management and provide different project members a virtual project space for exchanging information and coordination.

To satisfy these emerging challenges, tremendous efforts have been paid in research and development of models supporting collaborative work in virtual enterprise. Wynstra et al. [3] established an activity-based framework that identified roughly 20 managerial activities, which distinguished between the strategic management arena and the operational arena. A Synchronization Point model was presented [4] to support cooperative process management and coordination. Grefen [5] gave a process framework of three levels to manage the data and processes across different organizations, he also applied E-contract to supervise and control suppliers’ task [6]. Blake [7] showed great interests in services-based cross-organizational workflow and defined different domains in out-sourced environments. Chen et al. [8] compared traditional project with distributed project and then proposed collaborative project management architecture to satisfy different collaboration levels. Romano, Chen and Nunamaker [9] explained different collaboration levels and designed collaborative project management software to support “concerted-level” collaboration. Evaristo [10] discussed the concept of collaborative IT infrastructure and proposed a framework for the implementation of such infrastructure. These achievements mentioned above provided conceptual frameworks or tools to achieve collaborative project management. Although many of the internal processes associated with project management are well defined, comparatively little information exists on how to integrate suppliers into the process [11]. Most research on the management of projects is relatively young and still suffers from a scanty theoretical basis and a lack of concepts [12].

3. Solutions of MtSiCPM

MtSiCPM provides a comprehensive framework for enterprise to collaborate with suppliers throughout project lifecycle. By combing the advantages of supplier management and project management, we provide methods and processes integrating suppliers to project management, and develop IT tools to support timely collaboration with suppliers.

3.1. Concepts of MtSiCPM

Suppliers involved Collaborative Project refers to complex product development project, e.g. aeronautic manufacturing project, in which OEM collaborates with globally distributed suppliers to accomplish project goals. MtSiCPM is the collaborative project management tools/processes allowing enterprise to realize collaboration and interaction with suppliers in project management and product development. Through organizing suppliers in a hierarchical relationship and utilizing the advantage of IT technology, we provide the processes of this new scenario, and develop CPM system for managing CPD project spanning multiple organizations.

Definition 1. MtSiCP is a 7-tuple:

\[ MtSiCP = \{\{\text{TASKS}\}, \{\text{RELS}\}, \{\text{RES}\}, \text{CE}, \{\text{SUPPLIERS}\}, \{\text{TIERS}\}, \{\text{CON}\}\} \]  

Where TASKS is Task Set, RELS is Relationships Set, i.e. there exists a directional constraint between two tasks. RES is Resource Set required for tasks, CE is Core Enterprise, and SUPPLIERS is Suppliers Set. TIERS is tier set representing supplier’s organizational hierarchy in project, CON is project constraints.
According to their organizational hierarchies in virtual enterprise, suppliers assume different tasks in product development and project management. Within dynamic alliance, CE is responsible for project and worked as the project leader. And suppliers are divided into multi-tier suppliers based on the levels of their tasks in Product Breakdown Structure (PBS). CE is the ultimate supplier for customer, who also can be viewed as a zero tier supplier. And the tiers of other suppliers increase sequentially. Fig.1 shows the relationship between product hierarchy and Multi-tier Suppliers in MtSiCPM.

**Definition 2. Collaborative Task (CT)**

Tasks that can be broken down into subtasks carried out by lower suppliers. A collaborative task $CT^a_i$ can be written as:

$$CT^a_i = \{\text{Supplier}_{\text{ParentT}}, \{\text{CT}^a_j\}, \{\text{UT}^a_k\}, \text{ParentT}|(a,i,j,k \in Z)\}$$

Where $i$ is task number, $a$ is task level, $\text{Supplier}$ is the supplier, who will lead lower tier suppliers to complete task together. $\text{ParentT}$ is the parent task.

**Definition 3. Unit Task (UT)**

Compared with CT, UT refers to the tasks that cannot be broken down into lower subtasks; it is the minimum element of multi-level plan. A unit task can be written as:

$$UT^a_i = \{\text{Supplier}, \text{ParentT}, \text{Resource}, \text{Duration}|(a,i \in Z)\}$$

Where $i$ is task number, $a$ is task level, $\text{Supplier}$ is supplier for this task, who will finish their task independently. $\text{ParentT}$ is the parent task, $\text{Resource}$ is resource set for this task, $\text{Duration}$ is task duration.

### 3.2 Collaborative Solution of MtSiCPM

Project lifecycle has four basic stages: initiation, planning, controlling and closure. Compared with lifecycle of traditional project management, MtSiCPM has more stages. Fig.2 illustrated the main process of MtSiCPM, which not only describes the inputs/outputs of each step, but also explains methods for some key steps, related business objects and supporting tools. In this paper we focus on three stages: initiation, planning and controlling.

Initiation analyzes project requirements and determines project scope. The initiation stage should include two areas: project definition and supplier selection. Project definition analyzes business requirements and gets project goals based on understanding of the business environment. Supplier Selection in collaborative
product development has more features than traditional development projects, which needs additional concerns about suppliers’ collaborative development capabilities, information technology and enterprise background factors. In this step, a new approach of supplier selection based on fuzzy AHP theory is employed.

The planning stage consists of: WBS, sorting task, estimating task and project duration, networking the activities in their logical sequence and optimizing resource. WBS is identifying deliverables and creating work breakdown structure according the feature of product structure and firm strategy. In this step, a process integrating suppliers into WBS decomposition is developed. Networking tasks is building the network diagram in logical sequence. Estimating the durations for activities in CPD project has more factors needed to be taken into concern. For projects with many organizations and little historical data, duration estimation is apt to be hindered by large number of uncertainty factors. Within this step, Grey System theory is adopted. Through looking into internal laws of development of things, Gray System theory [13] can predict future condition of things. Making preliminary plan is to develop the schedule after estimating the costs and resource requirements for each activity. MtSiCPM treats external suppliers as internal resources. Therefore Optimizing resources need to optimize two types of resources: enterprise resource and supplier resource. Resource optimization is a critical step for global optimization in virtual enterprise. In this step, a Genetic Algorithm considering supplier resource is employed.

Project controlling consists of those processes integrating suppliers into monitoring, indentifying the potential problems, and making necessary corrective actions. Monitoring ongoing activities is to collect task execution data from suppliers. Identifying variables is to measure the project variables (resources, cost, progress, etc.) against the project plan at different levels. In this step, many tools, such as Critical Chain Theory, Progress Vanguard line and variable analysis methods are used in integration. Schedule adjustment is to make reasonable corrective actions for addressing risks and issues properly.
In addition to above methods, a Supplier involved Collaborative Project Management System (SiCPMS) is also needed to support above functions. Additionally a variety of methods and tools are adopted, such as supplier/project management, and collaborative protocol. Collaborative protocol includes different levels of collaboration alignment, such as goal, process, ontology, method, target, trigger, information and media, which will enable virtual enterprise work efficiently. A detailed explanation of all the contents is beyond the scope of this short paper, so we will only further discuss some core components.

4. Core Components of MtSiCPM

4.1. Project Management Teams

A reasonable hierarchy of organisational structure must be established before project starts. WBS and Organization Breakdown Structure (OBS) are essential precondition for corrective planning. The correlation between PBS/WBS/OBS and project teams is showed in Fig.3. The level of PBS determines the level of WBS and OBS. WBS and OBS define a Work Package (WP) together at the lowest level. Upper level supplier leads lower level suppliers to establish Integrated Product Teams (IPTs).

Project management teams are responsible for managing tasks at different levels, i.e. their responsibilities include creating detailed project plan, monitoring execution of plan and collaborating with other teams. The Product Management Team (PMT) composed of core enterprise and first tier suppliers is responsible for project management at level 0, and the output of their work is the objective product. First tier supplier and second tier supplier form System Management Team (SMT), which is set up for managing tasks at level 1, and the output of SMT is the system of this product. Component Management Team (CMT) made up of second and third tier supplier manages tasks at level 2, and the output of CMT is the components of each system. Third tier suppliers establish Party Design and Build Team (PDBT) within
their organizations to develop the parts. The first three IPTs (from level 0 to level 2) are oriented at management and integration, the IPT at the lowest level (level 3) is established for design and manufacturing. In addition to above mentioned IPTs (PMT, SMT, CMT, PDBT, etc), there needs a Portfolio Management Team (PoMT) for coordination between different projects.

4.2. Multi-tier Supplier Collaborative Planning

As shown in Fig.4, WBS decomposition in MtSiCPM is realized through collaborative work of suppliers at different levels. Arrows indicate collaborative relations between suppliers. The granularity of WBS at the lowest level must guarantee that all the tasks are assigned to a single supplier. Suppliers will finish UT, and transfer CT to lower suppliers as a Sub-Project, which will be managed and finished by lower suppliers. As we can see once a CT is broken down into WBS at lower levels, a more detailed plan mapping with that task will be generated subsequently. Both WBS decomposition and plan generation are executed by suppliers at corresponding levels.

5. Supplier involved Collaborative Project Management System

5.1. Design of SiCPM

Fig.5 illustrates the system architecture at conceptual level. This system can be integrated with other information systems that need to be employed within virtual enterprise. SiCPMS consists of three layers to satisfy the function requirements of MtSiCPM: Supplier Collaborative Business Layer (SCB), Supplier Collaborative Process Layer (SCP) and Supplier Collaborative Operation Layer (SCO). SCB Layer analyzes project constrains and project objectives, and then defines function scope and responsibilities for customers, enterprise and suppliers. SCP Layer summarizes supplier collaborative process models based on characteristics of these processes. Collaborative processes are decomposed into measurable and controllable details in SCO Layer. Collaborative Application layer mainly works for system maintenance and provides applications for upper layer operations. The Collaboration Service Bus integrates the information system needs to be employed. It includes following types of service: Protocol Service (PS) for changing information into standard collaboration protocol, Interface Service (IS) for enterprise application integration, Transfer Service (TS) for data transaction, Computing Service (CS) for computing and analyzing tasks, and Search Engine (SE) for searching information.
5.2. Collaboration in SiCPM

Explicit and precise information is essential for distributed projects. Clear specification and unanimous agreement on critical information such as schedule/goal/roles/responsibilities are main goals for collaborative project management. In addition, information collaboration should support automatic notification of changes, such as updated schedule, task status and response message to any collaborative request. These functions need supports of information system both from enterprise and suppliers. Fig. 6 is the information model which can provide frequent and essential information flow between suppliers and enterprise. "ProcessExecution" will be initiated once it received an event. And there are four events to be listened: the temporal events (task deadlines, for instance), user events (submitting or delivering event), state change (task state) and exceptions.

6. Conclusion

The goal of this article intends to give an overview of collaborative project management in CPD project and provide a new approach for CPM with supplier involvement. The discussion focused on two categories: the theories/methods of CPM with supplier involvement and information system. In this paper, we present a framework of CPM, which can effectively support cross organisational collaboration as well as project management within virtual enterprise. The framework was proposed to address challenges in CPD project. This new scenario can integrate suppliers into project management tightly. The new project management paradigm requires more collaborative methodologies and supporting tools. In this framework, suppliers are responsible for WBS decomposition, making project plan and collaborating with other enterprises to facilitate project controlling. Our framework provides a foundation for the steps/approaches/tools needed for involving suppliers into CPM. The core components depict the correlations of PBS/WBS/OBS/project teams, and process of collaborative planning. Finally, our proposed system architecture gives components, functions and function relationships needed to build a CPM information system. The system built on this architecture will provide tools lacked in current project management software. The collaborative model enables information collaboration and avoids creation of information islands which easily happened in distributed project. This research provides frontier foundation for functions and components needed to be developed in collaborative project management.

Future researches should focus on exploration of the mathematical models for supplier selection and resource optimization. More efforts should be paid on expanding the system to an applicable system. There still needs a case study to analyze the effectiveness of the solution proposed in this study both from quantitative and qualitative perspective. We believe this framework will provide collaboration support beyond what current project management scenarios achieved, and will facilitate high level collaboration in CPD project.

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References


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**Supplier collaborative project management system**

- **User layer**
  - Administrator
  - Core enterprise
  - Supplier

- **Supplier CPM layer**
  - Supplier selection
  - Schedule mgt
  - Resource mgt
  - Cost mgt
  - Risk analysis
  - Experiments

- **SCO layer**
  - Process matrices contents
  - Detail collaboration process deployment
  - Collaborative process selection from matrix
  - Collaborative strategy selection/VE establishment

- **SCP layer**
  - Collaboration service bus

- **SCB layer**
  - Budgets
  - Resources
  - Goals
  - Specification
  - Details
  - Strategy
  - User mgt
  - Secure access
  - Workflow mgt
  - Data transfer
  - Calendar mgt
  - Contract mgt
  - Scope mgt
  - Computing

- **Database layer**
  - Supplier DB
  - Collaboration DB
  - Project DB
  - Product DB

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**Fig.5 System Architecture of SiCPMS**
Fig. 6 Information Collaboration