COORDINATION SCHEDULING BASED ON FUZZY CONCEPTS

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Abstract:
The decentralized and loosely coupled virtual enterprise’s appearance prompts a new form of project realization, i.e., the distributed and collaborated project realization, which challenges the research and application of the traditional project management. The imprecise data for scheduling and potential interest conflicts between the individual member enterprises and the whole project cause the difficulties and complexities of the global level scheduling in virtual enterprise. In this work, based on the fuzzy specification of the corresponding information, we present an approach, through the coordination between the manager and partners, to obtain the global predictive scheduling integrating the member enterprise selection and its sub-scheduling by which the time performance is optimized. Also the strategies of the resources allocation in the member enterprises are given.

Keyword:
Virtual enterprise, fuzzy concepts, coordination scheduling

1. Instruction

Steadily shortening product life cycles, globalization of markets and decreasing profit margins makes the realization of industrial projects face tighter time and resource constraints [1-2]. On the other hand, information and communication technologies enable cooperation between the enterprises in a distributed mode. Thus, pushed by the business and technical forces, corporations are increasing adopting a strategy of taking advantage of the global resource by which the resource constraints of the project implementation can be relaxed, then improvement of project cycle time becomes feasible.

The trend that transforming project realization manner from the central mode to the distributed mode has given rise to a new form of organizations, i.e., the virtual enterprise. Then, the project realized through the cooperation between the members located in distributed sites of virtual enterprise is called virtual project[1].

Although, in traditional operational research, many scheduling algorithms have been proposed, due to ignoring too much practical constraints and uncertainties, most of them can not integrate themselves into the commercial software of project management [3]. On the other hand, almost all the commercial project management software is centralized, which make them not fit for project management in the environment of loosely coupled virtual enterprise. We know that the distributed execution of project subtasks, imprecise information of enterprise states and potential conflict of interest between the whole project and individual member enterprises cause the difficulties of project scheduling in virtual enterprise. So the virtual project scheduling must emphasize the coordination between global level (whole project) and local level (individual member enterprise).
In this paper, a scheduling framework supporting coordination and collaboration between global and local levels are proposed. Also, the fuzzy set theory is employed to express uncertain or subjective information. In section 2, a framework of the coordinated project scheduling method and the global predictive scheduling process is proposed. Section 3 gives a conflict solution based on the fuzzy expression in the local schedule process. Section 4 makes conclusions.

2. Scheduling framework

From the point of scheduling process, the framework includes predictive scheduling and reactive scheduling. Predictive scheduling refers to global schedule generation, which is implemented through the coordination between the project manager enterprise and different potential member enterprises. Reactive scheduling happened in the process of global schedule generation and its execution, whose goal is to adjust the global predictive schedule according to the execution environment and exception handling. From the point of supervisor, it includes global scheduling and local scheduling. The global scheduling which is in the charge of the manager enterprise care about subtask partition, assignment of subtask to different potential member enterprise, time window that should be met, and the global exception handling. The local scheduling which is managed by the local member enterprise comprises the local realization of the global requirement in the process of predictive schedule generation, local schedule made, resource conflict solution, local disturbance handling by itself or coordinate with other member enterprises.

The project manager not only takes into account the complex precedence relations among the different subtasks, but also assigns an appropriate potential member enterprise for the implementation of each subtask. But the global level data about each potential member enterprise’s product capacity or processing duration are general aggregated, imprecise or estimated. To reduce the complexity of the decentralized predictive scheduling and assure the executability of the resulting schedule, the global level scheduling process is decomposed into a series of sub-processes with certain temporary dependency relation. For each subtask, a sub-process is carried out by the coordination between project manager enterprise and the potential member enterprises that have the capability to fulfill the subtask to decide its time windows.

The coordinated scheduling sub-process is described as below. For each subtask $T_i$, the project manager enterprise sends its earliest possible start time $ES_i$ to every potential member enterprise that has the capability to undertake the implementation of subtask $T_i$. Each potential member enterprise then enters its local predictive scheduling process, i.e., uses $ES_i$ to compute the earliest finish-time $EF_i$ of subtask $T_i$. In the local scheduling process, however, the load of the corresponding resources must be considered. If conflicts happen, the importance of different conflicting projects as well as the importance of the subtasks in their corresponding projects must be taken into account. After some scheduling strategies are used, each potential member enterprise obtains its own local schedule. Then the result earliest finish-time window $EF_i$ is sent back to the project manager. The project manager enterprise collects and compares all the $EF_i$ that are submitted by different member enterprises, and selects the proper one (for example the earliest one) as the subtask’s global predictive schedule. Also, the corresponding potential member enterprise now becomes the member enterprise of the virtual enterprise. Next, if the $T_i$’s successor $T_{i+1}$ has only one predecessor, the project manager enterprise can use $T_i$’s $EF_i$ as $T_{i+1}$’s earliest start time window. However, if $T_{i+1}$ has more than one predecessor, its earliest start
time window is the latest finished predecessor’s earliest finish-time window. The same cycle mention above can be applied to $T_{e1}$. Continuing this process until the final subtask is done. Now, the project manager has selected the corresponding member enterprise for all the subtasks, and the global predictive schedule has been obtained.

3. Local scheduling based on fuzzy concepts

To quantify the imprecise time information in the project scheduling, we use the trapezoidal possibility distribution to represent fuzzy time function. Some fuzzy operations and concepts are introduced as follows.

Let’s use $\{\pi_i(\tau)=h_i(\pi_{i1}, \pi_{i2}, \pi_{i3}, \pi_{i4}), \ i=1, 2, \ldots, n\}$ to represent fuzzy sets:

- Latest operation: $L(\pi(\tau), i=1, 2, \ldots, n) = \min\{h_i(\max(\pi_{i1}), \max(\pi_{i2}), \max(\pi_{i3}), \max(\pi_{i4}))\}$
- Earliest operation: $E(\pi(\tau), i=1, 2, \ldots, n) = \max\{h_i(\min(\pi_{i1}), \min(\pi_{i2}), \min(\pi_{i3}), \min(\pi_{i4}))\}$
- Fuzzy addition $\oplus: \pi(\tau) \oplus \pi(\tau) = \min\{h_1.h_2)(\pi_{i1}+\pi_{i2}, \pi_{i2}+\pi_{i3}, \pi_{i3}+\pi_{i4}, \pi_{i4}+\pi_{i5})\}$

As defined in [5], given two possibility distributions $\pi(\tau)$ and $\pi(\tau)$ of two fuzzy numbers $\alpha$ and $\beta$, which is showed in Figure 2, the possibility of fuzzy number $\alpha$ is greater than $\beta$ is: $p\{\pi(\tau) > \pi(\tau)\} = \text{the area of quadrangle cdef/the area of trapezoid cefg}.$

![Figure 2. The compare of two fuzzy numbers](image)

Now we discuss in detail about the local scheduling process. Assuming each potential member enterprise that is the candidate for one or more subtasks of the virtual project can fulfill its corresponding subtask independently. It means that they are independent performers from the point of view of the project manager. Under this assumption, we use the project $P_1$ in Figure 3 as an example to describe informally the integrated process of the member enterprise selection and global predictive schedule formation.

As show in Figure 3, project $P_1$ consists of five subtasks whose precedence relations are represented by the arcs that connect them. $T_0$ and $T_r$ are start and end subtasks respectively. Both of their fuzzy execution delays are $(0,0,0,0)$. The intermediate subtasks include $T_1$, $T_2$ and $T_3$. Assuming the manager know that the initial subtask $T_0$’s earliest start time window is $\pi_{00}(\tau) = (0,3,5,3.5)$, then the earliest start time window of subtask $T_1$ can be calculated as $\pi_{01}(\tau) = (0,0,0,0) \oplus (0,3,5,3.5) = (0,3,3,5)$. The project
manager enterprise sends the fuzzy time window \( \pi_{T1}(\tau) \) to the potential member enterprises \( A \) and \( B \) that have the capability to finish subtask \( T1 \). We use enterprise \( A \) as an example to show how it, considering its contracted subtasks and resource load, uses \( \pi_{T1}(\tau) \) to make its local schedule.

Let’s assume enterprise \( A \) has taken on the subtask that belongs to another virtual project and used sub-workflow 1 to realize the subtask. We also know activities \( A1 \) and \( A2 \) use resources \( R1 \) and \( R2 \); activity \( A3 \) uses resource \( R3 \). However, because enterprise \( A \) still has unused capability, it want to undertake the subtask \( T1 \) of project \( P1 \). If it uses sub-workflow 2 to realize \( T1 \) and activities \( A4 \) and \( A5 \) employ resource \( R3 \) and \( R1 \) respectively, then there are potential conflicts in \((A1, A2, A3)\) and \((A3, A4)\). If we assume that \( A2 \) in sub-workflow 1 is being executed and its completed time is \( \pi_{A2}(\tau) = (3,5,7) \), then the earliest fuzzy start time windows of activities \( A3 \) and \( A4 \) are \( \pi_{A3}(\tau) = \pi_{A2}(\tau) = (3,5,7) \) and \( \pi_{A4}(\tau) = \pi_{T1}(\tau) = (0,3,5) \) respectively. Because the executions of activities \( A3 \) and \( A4 \) both need the support of resource \( R3 \) and there is overlap in their possible start time windows, some strategies must be employed for enterprise \( A \) to deal with this resource conflict.

Our conflict solution strategy includes two levels. First, priority based strategy is used. However, if it is difficult to distinguish them by their priorities, fuzzy expressions are employed to provide additional information for decision-makers.

In order to balance the interests of both the alliance and individual members, the priority of each activity comprises two parts, i.e., \( p=\alpha+\beta \), in which \( \alpha \) denotes the importance of the project to the member enterprise, and \( \beta \) denotes the importance of the subtask to the project. Obviously, \( \alpha \) should be evaluated by the member enterprise and the project manager decided the value of \( \beta \). In addition, fuzzy concepts are employed to quantify the subjectively appointed priority. For simplicity, the triangular possibility distribution are used here, i.e., \( \alpha=(\alpha_1,\alpha_2,\alpha_3) \) and \( \beta=(\beta_1,\beta_2,\beta_3) \). Then, using the fuzzy addition operator, the priority of the subtask is obtained as \( p=(\alpha_1+\beta_1,\alpha_2+\beta_2,\alpha_3+\beta_3) \).

Using different subtasks’ degrees of profit as reference, enterprise \( A \) evaluates \( \alpha=(\alpha_1,\alpha_2,\alpha_3) \) of activities \( A3 \) and \( A4 \). Also, \( \beta=(\beta_1,\beta_2,\beta_3) \) of activities \( A3 \) and \( A4 \) can be obtained through the negotiation with project manager enterprise. Then, after computing \( p=\alpha\oplus\beta \) for activities \( A3 \) and \( A4 \) respectively, their priorities are obtained. According to the priorities of different activities, it is easy to determine their sequences, then the finish-time of the subtask can be calculated.

![Figure 3. Virtual Project Coordination Scheduling Sketch Map](image-url)
However, this method loses objectivity when there is only little difference between the priorities of different activities. We set a threshold $12 \alpha \in [0,1]$ if the $|p_{A4} - p_{A3}| < \alpha$ which means that it is difficult for enterprise $A$ to distinguish which one is more important, additional decision making information is required.

To deal with the temporal uncertainty in this situation, we use the fuzzy enabling time, fuzzy occurrence time, and fuzzy delay [4] of each activity to get the additional information.

Assuming resource $R_3$ is idle now, then it is available at time $\pi_{R3}(\tau) = (0,0,0,0)$. The job arriving times of activities $A_3$ and $A_4$ are $\pi_{A3}(\tau) = (3,5,5,7)$ and $\pi_{A4}(\tau) = (0,3,3,5)$ respectively, their fuzzy enabling times are:

$E_{A3}(\tau) = L(\pi_{R3}(\tau), \pi_{A3}(\tau)) = L((0,0,0,0), (3,3,5,5))$

$= (0,3,3,5)$

$E_{A4}(\tau) = L(\pi_{R3}(\tau), \pi_{A4}(\tau)) = L((0,0,0,0), (3,5,5,7))$

$= (3,5,5,7)$

Then the earliest operation on $E_{A4}$ and $E_{A3}$ is needed to obtain the possibility distribution of the time at which resource $R_3$ starts to be used.

$E(E_{A3}(\tau), E_{A4}(\tau)) = E((0,3,3,5),(3,5,5,7)) = (0,3,3,5)$

Next, to find the fuzzy occurrence times of the two conflicting activities, we perform the intersection (minimum operation in fuzzy arithmetic) of the two fuzzy enabling time functions mentioned above.

$O_{A3}(\tau) = \min(E_{A3}(\tau), E_{A4}(\tau))$

$= \min(E_{A3}(\tau), E_{A4}(\tau))$

$= \min((0,3,3,5), (3,5,5,7)) = 0.5(3,4,4,5)$

$O_{A4}(\tau) = \min(E_{A4}(\tau), E_{A4}(\tau))$

$= \min(E_{A4}(\tau), E_{A4}(\tau))$

$= \min((0,3,3,5), (0,3,3,5)) = (0,3,3,5)$

In the situation of resource conflict, there are two executing sequences of $A_3$ and $A_4$, but their possibilities are different. If we know the fuzzy delays of activities $A_3$ and $A_4$, their possible finish-time can be obtained. Let us assume $d_{A3}(\tau) = (3,4,5,6)$, $d_{A4}(\tau) = (4,5,7,9)$, using the fuzzy addition operation, the conflicting activities’ finish-times can be computed.

If activity $A_3$ starts first, the finish-time of $A_3$ is $\pi_{A3}(\tau) = O_{A3}(\tau) \oplus d_{A3}(\tau) = 0.5(6,8,9,11)$, and $A_4$’s finish-time is $\pi_{A4}(\tau) = L(\pi_{A3}(\tau), \pi_{A4}(\tau)) \oplus d_{A4}(\tau) = 0.5(10,13,16,20)$

If activity $A_4$ starts first, the finish-time of $A_4$ and $A_3$ are $\pi_{A4'}(\tau) = O_{A4}(\tau) \oplus d_{A4}(\tau) = (4,8,10,14)$, $\pi_{A3'(\tau)} = L(\pi_{A4}(\tau), \pi_{A4}(\tau)) \oplus d_{A3}(\tau) = (7,12,15,20)$ respectively.

Combining two situations, the finish-time of $A_3$ is $\pi_{A3}(\tau) = \max(\pi_{A3}(\tau), \pi_{A3'}(\tau))$, and the finish-time of $A_4$ is $\pi_{A4}(\tau) = \max(\pi_{A4}(\tau), \pi_{A4'}(\tau))$.

![Figure 4. Combined finish-times of $A_3$ and $A_4$](image-url)
computing complexity and improve the practical usability, we can use an approximate trapezoidal or triangular envelope function to replace the old one. For example, we can use $\pi_A(\tau) = (4, 8, 10, 20)$ to replace $\pi_A(\tau)$ in Figure 4. If we know $d_A(\tau) = (2, 3, 3, 4)$ (there is no resource conflict for the execution of activity $A_5$), enterprise $A$ can compute its finish-time of subtask $T_1$ as $\pi_{T_1}(\tau) = \pi_A(\tau) \oplus d_A(\tau) = (6, 11, 13, 24)$. However, as show in Figure 5, the possibility distribution can not get an approximate trapezoidal or triangular possibility distribution function. For this special case, the stochastic execution sequence makes the fuzzy finish-time information lose its application meaning. Then, according to the practical decision process, the information in the priority strategy mentioned above must be used again to choose one of the distribution areas such as $(3, 5, 6, 8)$, then the execution sequence is decided.

Repeating the process mentioned above until the final subtask $T_e$’s schedule is obtained. Now, assigning of different subtasks to different potential member enterprises and the global predictive scheduling are both completed.

4. Conclusion

Based on the fuzzy expression of the time window, a scheduling approach, which integrates the member enterprise selection and predictive global schedule generation, is proposed in this paper. Because the resulting schedule is obtained through the coordination between the project manager enterprise and its corresponding member enterprises, it must have the best executability. Also, the effort of rescheduling is reduced. For the future, intelligent agent and workflow technology should be used to realize the global and local scheduling system.

Reference


