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Computer Supported Delivery Time Decision in Collaborative Product Development

Hongxin Li Yushun Fan
Department of Automation, Tsinghua University, Beijing, P. R. China

ABSTRACT: In this paper, the delivery of an order in collaborative product development process is treated as the accomplishment of a project. The delivery time is determined based on estimating project duration with PERT network activity model. A computer-supported procedure for estimating the expected activity flow time of the PERT model is proposed, which uses the history information on performing the activities under respective conditions. The delivery time is the results of trade-off between the estimated project duration and the incurred cost.

Key Words: PERT, delivery time, collaborative product development

1 INTRODUCTION

Collaborative product development is becoming a growing trend in many industrial sectors such as cars and house appliances. The forces that drive the formation of this trend come from following aspects: firstly, companies seek worldwide opportunities to extend their market; secondly, the collaboration of small and medium enterprises naturally concentrate on core competence; last but not least, the manufacturers have shifted their market competition strategy from cost and quality to speed, which is know as time-based competition. Agile manufacturing is one of the pursued manufacturing paradigms in this competition environment.

For all the collaboration relationships, OEM-supplier relationship is very common between distributed enterprises, or between enterprises from matured markets and premature markets. The OEM has the idea of developing a new product, but prefers to outsource some or all of the engineering tasks to other companies for the following considerations:

- To reduce market risks
- To concentrate on core competences
- To manufacture the products in the region where they are sold

The OEM plays the role of integrating the outsourced parts or components into a whole product and possesses the trademark or patent right of the final product. Generally, the establishment of OEM-supplier collaboration undergoes two stages. In the first stages, the OEM finds the potential suppliers and select one as collaboration partner. In the second stage the OEM and the selected supplier partner perform the collaborative product development.

In partner selection stages, once an OEM determined the potential suppliers that will be responsible for the development of one part or component being outsourced, the next step is to evaluate the biddings of all these potential suppliers. In the time-based competition environments, the OEM mostly concerns the response time of the potential suppliers in bidding the delivery time and the reliability of the bidden delivery time. As far as the response time is concerned, the OEM usually specifies an expiring date for receiving the returned bidding. The biddings that are submitted after the expiring date will not be take into consideration any more.

The potential supplier that intends to be selected by the OEM has to submit the bidding before the expiring date. From the supplier's perspective, on the one hand, it has to make a preponderant bid over other potential suppliers for the outsourced engineering task. On the other hand, the bidden delivery time should be robust enough so that the possibility of incurring the penalty of deferred delivery is reduced to a desired level. Deferred delivery also ruin the reputation of the supplier in the trade for breaking the contract. Therefore, there is a great demand of an effective method for supporting the product/service provider making decision in the collaboration establishment stage. In this paper, the delivery time is determined based on estimating project duration with PERT network activity model. A computer-supported procedure for estimating the expected activity flow time of the

PERT model is proposed, which uses the history information on performing the activities under respective conditions. In section 2, the PERT network activity model is reviewed and the way of how to implement the information management system on executed activities is proposed. The computer supported activity flow time estimation is dealt with in section 3. The determination of the project duration and the trade-off between the delivery time and incurred cost are discussed in section 4 and 5 respectively. Finally, conclusions are given in section 6.

2 THE MODEL FOR ESTIMATING THE DELIVERY TIME

Since the supplier plays the role of Make-to-Order or Engineering-to-Order, the way of fulfilling of an order is unlikely to be repeated in exactly the same way of fulfilling another order at a future time. Therefore, each order should be treated as a project. The problem of bidding the delivery time of an order becomes that of estimating the duration of the corresponding project.

2.1 *PERT network activity model*

Programme evaluation and review technique (PERT) is widely used in estimating the durations and planning the schedules of projects, especially for those have high uncertainty in the durations involved. A well-defined network activity model must be built first for each project to be analysed with PERT. The first step in using PERT is to estimate the activity duration or activity flow time for each activity in the network activity model. Suppose a project P consists of a set of activities:

$$P = \{A_1, A_2, \dots A_n\} \qquad (1)$$

PERT requires three estimates for each activity A_i: an optimistic time t_i^o, a most likely time t_i^m, and a pessimistic time t_i^p, $i = 1, 2, \dots n$. The expected flow time of activity A_i is given by:

$$t_i^e = \frac{t_i^o + 4t_i^m + t_i^p}{6}, \; i = 1, 2, \dots n \qquad (2)$$

The PERT method also gives the reliability by the variance of t_i:

$$D[t_i] = (\frac{t_i^p - t_i^o}{6})^2, \; i = 1, 2, \dots n \qquad (3)$$

The optimistic time t_i^o is estimated under the most favourable conditions of executing activity A_i, while the pessimistic time t_i^p is estimated under the most unfavourable conditions.

However, it is difficult or time-consuming to judge which conditions are the most favourable and which are the most unfavourable to perform an activity. The activity flow times is usually estimated by a rule of thumb. With the support of modern information technology and information management system, it is possible to record the information on actually performing an activity. The data concerning the execution of a type of activity can be used as samples to estimate the flow time of this type of activity under certain situations. After the expected flow time of each activity in the PERT model is obtained, the expected project duration can be calculated by adding the expected time of all the activities along the critical path of the PERT model. Therefore, the delivery time decision of a supplier in collaboration establishment with OEM can be supported with such an information management system.

2.2 *The information management system on executed activities*

The questions in managing the information concerning the execution of an activity may be:

- What information concerning the execution of an activity should be recorded?
- How are these information used in the estimation of activity flow time?

These questions are heavily project dependent. For the purpose of estimating the expected flow time of an activity in PERT network, the recorded information should be concentrated on the knowledge about the task, the availability of the required resource and the proficiency of the actor of an activity.

For facilitating the retrieve and query the history information on executing an activity, the recorded information about an activity should be highly structured and well organised. Taking a supplier of car engine for example, the PERT network activity model of a project is illustrated in Figure 1, which corresponds to develop a certain type of engine to an OEM of car. PERT model is usually an activities-on-arc network, i.e. arrow representing the activity of project. But the length of an arrow does not represent the duration of the activity.

The example project covers three main stages:

- Product design
- Product engineering
- Production

Only part of the PERT network is sketched for simplifying the illustration. As results of pursuing the paradigm of concurrent engineering, these stages are overlapped.

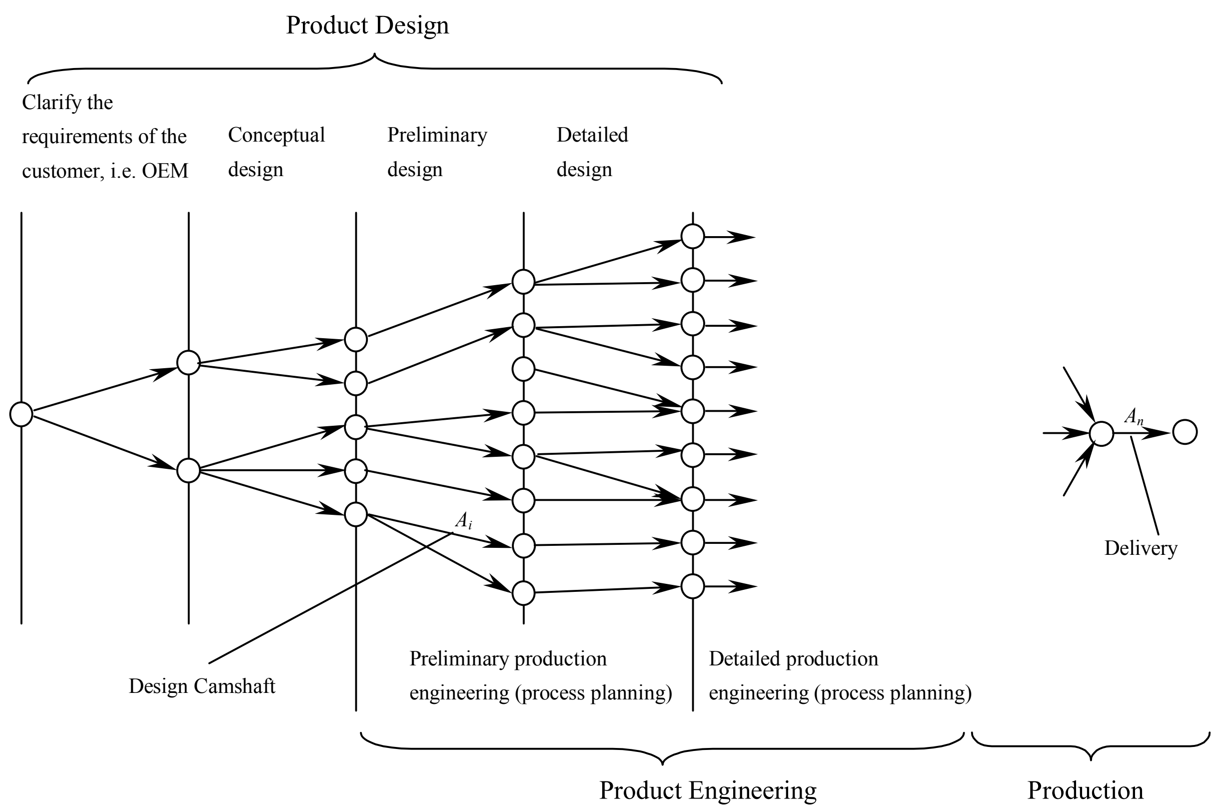

Figure 1. An illustration of PERT network activity model of developing an engine

For an activity named *Design Camshaft* that belongs to the product design stage of this project, the information that should be recorded concerning the execution of this activity is shown in Figure 2.

The information recorded under the entry of *Design Camshaft* is constructed as a tree, with the activity itself being the root element. The root element has a set of attributes and contains other elements, which

Design Camshaft

- Duration
- Index of creativeness
- Index of Re-usable product specification
- Human Resource
  - Availability
  - Designer
    - Proficiency
    - Years of experience
- Hardware
- Software
  - Operating system
  - CAD system
- Cost
  - Indirect Cost
  - Direct Cost

Figure 2. Information on performing Design Camshaft activity

can also have their attributes and contain lower level elements until the attributes and elements of lowest level are reached. Thus structured information can easily be mapped to XML schema, which defines the semantics of an XML data file. It can also be mapped to forms of relational database.

For the *Design Camshaft* activity in this example, the attribute *Duration* is an integer representing workdays, i.e. the time consumed to produce final product specification, including the engineering change time in design process. The attribute *Index of creativeness* is a real number between 0 and 1, representing the degree of unknown knowledge (technical, functional characteristics) about the part to be designed, with 0 meaning completely unknown. The attribute *Index of Re-usable product specification* is also a real number between 0 and 1, representing the percentage of product specifications of previously designed camshafts that can be re-used, which are stored in the geometric Modelling database.

The *Human Resource* is a complex type elements contained by the root element, which has an attribute *Availability* and contains another element *Designer*. *Availability* describes the time the design task has to wait before a designer is available, while the *Proficiency* is an enumerative attribute of *Designer* taking the value or *Novice* or *Expert*. The attribute *Years of experience* is a real number representing the number of years the designer devoted to this engineering area.

The *Design Camshaft* activity can also have other attribute or element such as *Hardware* and *Software*. The cost information incurred in performing this activity can be recorded too as results of activity-based costing. These information can be input into the information management system manually. For a supplier with high level of applying information technology, some of them can also be imported from other application system such as ERP systems.

3 COMPUTER SUPPORTED ACTIVITY FLOW TIME ESTIMATION

When estimating the duration of a project with PERT, the expected times of all activities in the network activity model of the project has to be estimated first. Taking the *Design Camshaft* activity as an example, the procedure for estimating the expected flow time spending in the design of a concrete camshaft in a project is described as following steps.

Step 1. Define the criteria for qualifying the most favourable conditions
The criteria for judging what are the most favourable conditions of performing *Design Camshaft* activity should be defined first. Based on the information model concerning the conditions to perform *Design Camshaft* activity described in section 2.2, it is also possible to define a set of criteria for judging if a concrete design camshaft activity is performed under the most favourable conditions. An example of such criteria may be:

- More than 80% of the knowledge about the design of the required camshaft is known
- More than 50% of the product specification of previously designed camshaft can be re-used;
- The availability of the humane resource should be less than 2 days after the design order is issued;
- The designer is an expert with more the 10 years of experience in this engineering area etc.

Step 2. Search the executed activities that satisfy the defined criteria
With the criteria defined in step 1, the history records concerning the execution of *Design Camshaft* activities are matched. The outcome of the matching process is the *Design Camshaft* activities that are executed under the most favourable conditions.

Step 3. Estimate the optimistic time of Design Camshaft *activity*
The flow time of the matched out activities are the samples for estimating the optimistic time. Suppose the size of the matched out samples is *m*, the flow time of the *Design Camshaft* activities in this sample set can be represented as:

$$t_{i,1}^{o},\ t_{i,2}^{o},\ \ldots,\ t_{i,m}^{o} \tag{4}$$

The estimation of the optimistic time will be given by:

$$t_i^o = \frac{1}{m}\sum_{k=1}^{m} t_{i,k}^{o} \tag{5}$$

Step 4. Estimating the pessimistic time of Design Camshaft activity
Similarly, the criteria for judging *Design Camshaft* activities performed under the most unfavourable conditions are defined, and the pessimistic time of *Design Camshaft* activities, t_i^p, is estimated.

Step 5. Estimate the most likely time of designing a camshaft
In partner selection stage, the OEM usually specifies a start time or a desired working period for the outsourced engineering task as results of pursuing Just-in-Time (JIT) delivery. The supplier will roughly estimate the situation of performing the *Design Camshaft* activity in that time, and search for the *Design Camshaft* activities that are executed under similar conditions. Thus, the most likely time of accomplishing this activity, t_i^m, is estimated.

Step 6. Estimate the expected time of design a camshaft
With the three estimations obtained in previous steps, the expected time t_i^e and its reliability of designing a camshaft are given by equation (2) and (3), respectively.
As soon as the criteria are defined, these steps can be automatically executed by the information management system. Nevertheless, computer supported activity flow time estimation has little effect or could not be applied to any more in the following cases:

- The information management system is newly built. Therefore, the volume of history records is not large enough for statistical method
- The activity is of a new type and there is no record in the information management system.

In such cases, the rule of thumb is still needed.

4 THE ESTIMATION OF PROJECT DURATION

After the expected flow times of all activities of a project are estimated, the next step is to calculate the project duration. Suppose the project *P* defined by set (1) has the PERT network activity model shown in Figure 1. The number of the PERT-paths is *l*. For a given PERT-path p_j, the expected time of p_j is equal to the sum of all activities along it, i.e.

$$T_j^e = \sum_{A_i \in p_j} t_i^e \quad j = 1, 2, \ldots, l \tag{6}$$

The expected project duration is the expected time of the critical path of the PERT network, i.e.

$$T^e = \max\{T_j^e, j = 1, \ldots l\} \tag{7}$$

For a PERT with considerable activities, it is a tedious task to find the critical path. Under the support of computer systems, the critical path can be found by comparing the expected time of all paths. More effective algorithms are proposed and implemented with project management tools in the application of PERT method.

5 DECISION-MAKING ON DELIVERY TIME

The delivery time will be decided mainly referring to the expected project duration T^e, considering the incurred cost and the probability of accomplishing the project within the determined project duration.

5.1 *Direct and indirect cost of a project*

The activity flow time is considerably influenced by the availability of the resources required to perform this activity, including the human resources. Since the allocation of resources can be coordinated by the invested cost, the supplier has to trade-off between the project duration and the cost for developing the parts or components when bidding the delivery time. With the activity-based costing, it is possible to analyse the direct cost of an activity incurred in its execution, such as manpower, equipment, electricity, water, and other resources. Typically, the direct cost of an activity is increased as its duration is reduced since additional manpower or equipment are required, as is illustrated on the left side of Figure 3.

The indirect costs include those that are incurred in the management efforts, rentals, fixed expense allocation and other overhead items. The delivery performance clause specified in the contract between supplier and OEM also implies other form of indirect costs, such as the cost penalties for delayed delivery. It is also possible to allocate the overall indirect cost of a project to each activities using activity-based costing. Indirect cost of an activity is proportional to activity duration since the management efforts and overhead costs will be reduced as activity duration decreases, as shown on the right side of Figure 3.

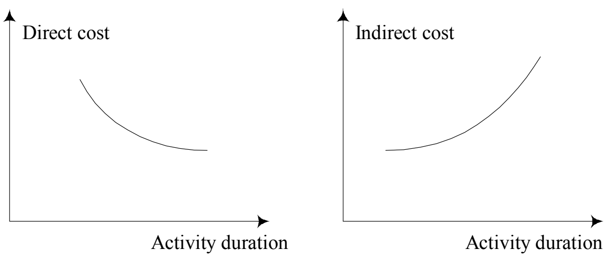

Figure 3. Illustration of direct cost and indirect cost vs. activity duration

Having known the function of the direct and indirect costs vs. the flow time of each activity in the PERT network, the direct and indirect costs vs. the project duration can be obtained. The trade-off between the cost and project duration can be performed through adjusting the project duration and reviewing the increase or decrease of the cost. It should be point out that following constrains should be met:

$$t_i^o < t_i < t_i^p, \; i = 1, 2, \ldots, n \tag{8}$$

$$\sum_{A_i \in Critical\_path} t_i^o \le T \le \sum_{A_i \in Critical\_path} t_i^p \tag{9}$$

It means that the duration of activity A_i, as well as the project duration, should not be reduced to that less than its optimistic time, and should not be extended to that longer than its pessimistic time.

In the trade-off process, reducing project duration may reduce project cost. However, if the project duration is reduced to certain extent the project cost will increase again since the increase of direct cost will overwhelm the decrease of indirect cost.

5.2 *The probability of finishing a project*

Reducing project duration will increase the risk of delaying delivery. This consists with intuition. The underlying reason is that the actual project duration is a stochastic variable. Given a determined project duration, T, the probability of finishing the project within T will be given by the following integration:

$$P\{t < T\} = \int_{-\infty}^{T} f(t)dt \tag{10}$$

Where $f(t)$ is the probability function of the project duration. If the determined project duration T is reduced, the probability of finishing the project within T will be reduced too.

The OEM and each of its potential suppliers will negotiate on the cost, duration and other delivery terms. Finally, the OEM selects one from the potential suppliers. The bidden delivery time, d, is the time of placing the order, t, plus the determined project duration T, i.e.

$$d = t + T \tag{11}$$

6 CONCLUSIONS

This paper deals with the decision-making problem of a supplier in making a bid for the outsourced engineering task of an OEM. The efforts are concentrated on determining the delivery time, which is transformed into the problem of estimating the project duration with PERT network activity model. In contrast to traditional PERT method, the expected flow time of an activity is estimated with statistical method using the history information of the executed activities of the same type. The way of how to select and construct the information to be recorded is given through concrete examples. This paper also gives the way for performing the trade-off between the project duration and incurred cost. Meanwhile, the risk in the trade-off is pointed out. With the volume of the maintained history information increased, more reliable delivery time will be obtained with the proposed method.

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