A Simulation Approach based Project Schedule Assessment

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Abstract: Traditional program evaluation and review technique lacks of complex task relation models. To tackle this, this paper proposes a project schedule risk assessment model based on extended Petri net, in which the characteristics of task duration, task overlap and sub-tasks are modelled. Based on the characteristics of concurrent iteration in product development schedule, the influence of each sub-task relationship on the simulation uncertainty is considered. In this case, several mathematical distributions are used to simulate the schedule of the subtask based on its own characteristics and the relationship between them. Based on the above modelling, the key path of the project schedule is selected, and the transition mechanism of state change in the simulation is designed. Finally, simulation results show that the proposed project schedule risk assessment method can provide specific reference for the development plan of the whole project and its sub-projects. In addition, the model can also be used to evaluate the cost of the project and establish the cost standard of the project according to the evaluation.

1 INTRODUCTION

Along with the high-speed progress of science and technology, complex product development has greater project scale and more task types in civilian and military applications. This makes the project schedule risk assessment a challenging problem. In most cases, the development schedule of complex product can be divided into several independent sub-systems, which often have complex constraints on their finish-start relations. These task correlations among subsystems increase the risk of product development.

Traditional program evaluation and review technique lacks of complex task relation modelling. For instance, Tian (Tian et al., 2008) established the project schedule risk model on the basis of multiple risk attribute analysis. Meantime, the distribution function of task progress assessment method is given, and various risk factors for time delay were summarized. But the start-finish relations of tasks are not considered and evaluated. Huang (Huang et al., 2005) tried to simulate and analyse the whole project progress by establishing a random network schedule model with Monta Carlo simulation. These works are useful, but the resource constraint relation between tasks is neglected. This might lead to its project schedule inaccuracies.

To tackle this problem, we will design a petri net based modelling method to describe project schedules and evaluate its timespan.

The paper is structured as follows. Section 2 will establish the formal descriptions of extended petri net. In Section 3, detailed project model is given. Section 4 presents the simulation process and Section 5 gives a case study.

2 PROGRESS MODELING BASED ON EXTENDED PETRI NET

Petri net is the network structure information flow model proposed by C.A.Petri in 1962 in his doctoral dissertation for the first time (Browning and Eppinger, 2002). The basic Petri net is defined as a

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triple net; The extended Petri net (Mok et al., 2001) defined in this paper is as follows:

$$exPN = (P, T, F, L, C, Ptri) \quad (1)$$

The meanings of each symbol are as follows:

$P = (P_1, P_2, P_3, \dots P_n)$ is finite set of places;

$T = (t_1, t_2, t_3, \dots t_n)$ is a finite set of transition nodes; $P \cap T = \emptyset$. Also, P and T can't be zero at the same time. $F \subseteq (P \times T) \cup (T \times P)$, F is the flow relationship on the PN, and its elements are called arcs. And $\mathrm{dom}(F) \cup \mathrm{cod}(F) = P \cup F$, among them $\mathrm{dom}(F) = \{x|\exists y: (x, y) \in F\}$, $\mathrm{cod}(F) = \{x|\exists y: (y, x) \in F\}$.

L is a hierarchical relation set of hierarchical Petri nets. Each of these elements contains information such as the level of the Petri net model in which it is located and its parent level.

C is a set of colors in a colored Petri net, corresponding to the resources in project management (Fehling, 1991). The attributes of each color include quantity, unit value in a certain period of time, and other information.

Petri is the priority set of Petri net transitions. The priority here does not play a role in the normal transition. When the transition is deadlocked, it will play a role in breaking the deadlock.

3 EXTENDED PETRI NET SCHEDULE MODELING

3.1 Project Schedule Management and High-level Petri Net Modeling

(1) Petri net modeling of task duration (Barad, 2016):

The duration of complex product development tasks can't be specifically determined during the development of schedules. Therefore, this paper assumes that the duration of the development of complex products is subject to the distribution of certain parameters or a certain value. Taking into account the characteristics of time-delay Petri nets and random networks, it will be used to describe the task duration in project management.

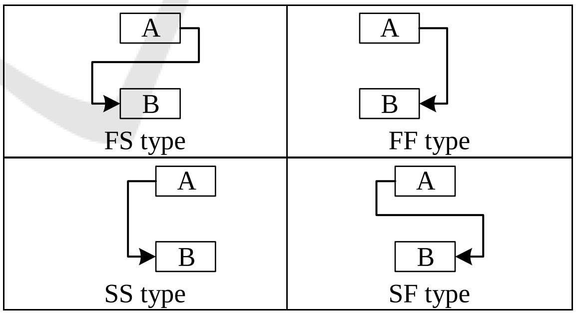
(2) Petri net modeling of summary tasks:

In view of the close relationship between certain tasks in the development of complex products and the large number of tasks, these tasks are often regarded as a task body. Another "virtual task" is abstracted to contain the task body (Hussin, 1992). Project managers only need to model abstract virtual tasks (also known as summary tasks) in the first level of task planning (Zaitsev and Shmeleva, 2011). The detailed task information under this virtual task can find the corresponding detailed task plan diagram at the second level, and the hierarchical relationship of this task can be extended down as needed. In view of the close relationship between certain tasks in the development of complex products and the large number of tasks, these tasks are often regarded as a task body. Another "virtual task" is abstracted to contain the task body. Project managers need to model only abstract virtual tasks, also known as summary tasks, in the first level of task planning. The detailed task information under this virtual task can find the corresponding detailed task plan diagram at the second level, and the hierarchical relationship of this task can be extended down as needed. Due to the hierarchical network in the structure and the demand of project management is very close, so this paper put the virtual task of the project management corresponds to the node, task relationship under virtual tasks correspond to a hierarchical subnet.

(3) Petri net modeling of task overlapping relation:

In real project management, there is often a time-constrained relationship among tasks (Rickert and Schreckenberg, 2013). Generally, it is the lap network plan: finish-start (FS), finish- finish (FF), start- start (SS) and start-finish(SF). The four overlapping relationships are defined as follows (Neumann and Burks, 2012):

Table 1: Four task relation types.



1) FS type: This type indicates that the B task cannot be started until the A task is completed.

2) FF type: It Indicates that B can only be finished after A has been finished.

3) SS type. SS indicates that B can only start after A task starts.

4) SF type. SF indicates that task B can only be finished after task A starts.

3.2 Project Progress Assessment Method

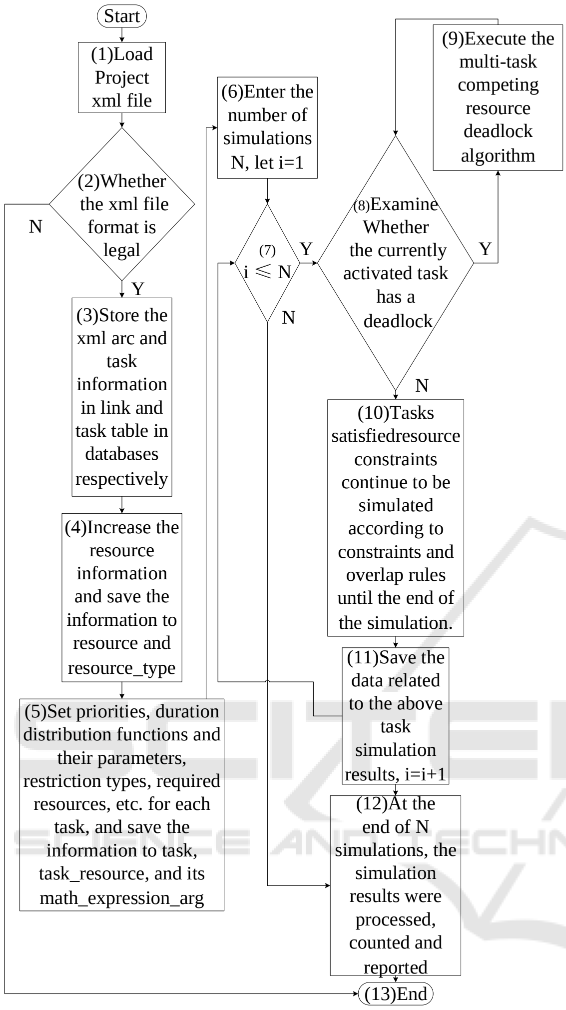


Figure 1: Project progress simulation flow.

(1) Load the project task relationship and structure diagram files into memory;

(2) Check whether the task relationship and attributes of the XML file are legal (including whether or not there is a deadlock check caused by the task associative relationship). If step 3 is performed legally, go to step 2.

(3) Parse the arc information, task information and other informations in the XML file, and store them in the database link table, task table and other related tables in the background. Then perform the step 4.

(4) In the resource management interface, the number of resources required for the task, resource type, and other information are added, and saved in the resource tables and the resource type tables. Then go to step 5.

(5) Setting the priority of task, the distribution function types, parameters of the time limit and other related information for a project in the task management interface, and save to the task table, task_resource table, math_expression_type table and so on. Perform step 6.

(6) Input the times of simulation, and set i =1. Perform step 7.

(7) Judge i≤N, if the condition is true, execute step 8, or else execute step 11.

(8) Check whether the currently active task set S has a deadlock due to resources. If it exists, execute the "multitasking competitive resource deadlock" algorithm (while saving related information to the database), and perform step 9.

(9) Execute "transition node state transition" algorithm for activated tasks.

(10) Save the relevant data of the above simulation results, let i=i+1; go to step 7.

(11) When simulation is completed, the simulation results are processed, counted, and reported. Perform step 12.

(12) End of simulation.

The above process is shown in figure 1.

4 PROGRESS RISK ANALYSIS BASED ON SIMULATION RESULTS

In order to calculate the probability of schedule risk in the development of complex products, the correlation of schedule risk is now analyzed as follows (Song and Gong, 2015):

Considering the simulation is run N times, the simulation result shows that the production cycle p is repeated np times (Song et al., 2018). Then the probability of occurrence of the project duration $P(D = p)$ (Ma et al., 2016) is:

$$P(D=p)=\frac{n_p}{N} \tag{2}$$

The risk probability $P(D \neq p)$ of the project's simulation duration is not p (Song et al., 2013):

$$P(D \neq p) = 1 - P(D = p) \tag{3}$$

In the N simulations, the simulation result set with the simulation duration less than or equal to p is $\{p_1, p_2, ..., p_r\}$, and the frequency set of the corresponding simulation result is $\{c_1, c_2, ..., c_r\}$, and $\sum_{s=1}^{r} c_s \leq N$, so the project duration is less than or equal to p of the probability (Shi et al., 2015) is:

$$P(D \neq p) = 1 - P(D = p) \tag{4}$$

The probability that the project duration is greater than p is:

$$P(D > p) = 1 - P(D \leq p) \tag{5}$$

The risk probability of the project duration between $[p_a, p_b)$ (Song et al., 2010) is $P_f(p_a \leq D < p_b)$:

$$P_f(p_a \leq D < p_b) = P(D < p_b) - P(D < p_a) \tag{6}$$

According to the specific shape of the project period (frequency) scatter plot obtained by N simulations, the law of the scatter plots is searched, and the cumulative probability distribution function relationship of the complex product development period can be obtained by using curve fitting, and the hypothesis is $F(x)$ (Suhariyanto et al., 2017). x is the simulation period, then the corresponding product development schedule risk probability distribution function $F_f(x)$ is:

$$F_f(x) = 1 - F(x) \tag{7}$$

Based on the schedule risk probability distribution function, the risk trend can be seen intuitively, and the schedule risk duration of the complex product development period being less than a certain period of time or a certain period of time interval can be calculated, thereby verifying the designated project progress for the project manager. The rationality of the plan provides the basis and also provides a reference for the further decision-making of the project schedule (Luz and Francisco, 2018).

5 SIMULATION AND ANALYSIS OF CASE RESULTS

There are a total of 30 tasks in the selected project, including six summary tasks. The remaining 24 task durations are described below:

Table 2: Project task duration information. Task duration is often stochastic in practice. Here we use triangular and normal distribution to describe it.

ID	Task name	Task duration distribution	Task paras	Estimated duration of task (day)
2	The design of the product	Triangular distribution	(30,45,60)	45
3	Product documentation preparation	Triangular distribution	(41,45,61)	49
4	Material preparation	Triangular distribution	(23,36,43)	33
5	Finalizing of gland	Normal distribution	(37,2)	37
7	Gland curing	Normal distribution	(41,3)	41
8	Gland polishing	Normal distribution	(43,2)	43
9	The setting and curing of filter	Normal distribution	(43,4)	43
10	Clean the gland surface	Normal distribution	(39,1)	39
11	Gland assembly	Normal distribution	(37,2)	37
13	Welding ring test assembly	Triangular distribution	(90,100,140)	110
12	Welding ring curing	Triangular distribution	(110,130,150)	130
15	Skeleton test and protection	Normal distribution	(37,2)	37
17	Skeleton shell blowing sand	Normal distribution	(30,2)	30
18	Skeleton shell set, curing	Normal distribution	(38,4)	38
19	Skeleton detection	Normal distribution	(33,3)	33
20	End face of skeleton shell	Normal distribution	(36,2)	36
21	Skeleton punching	Normal distribution	(33,1)	33
22	Skeleton shell paint	Normal distribution	(34,3)	34
23	Pilot cone production	Normal distribution	(41,4)	41
25	Outlet nozzle	Normal distribution	(37,2)	37
26	Filter assembly	Triangular distribution	(44,56,62)	54
27	Filter test	Triangular distribution	(35,45,52)	44
29	Physical acceptance of filter	Triangular distribution	(24,46,50)	40
30	The Acceptance review of filter	Triangular distribution	(25,45,53)	41

Throughout the investigation of the real-world data in this community, we find the relevant parameters of the auto vehicle driving behavior at the intersection of the cell structure, as shown in the following figure. These data are our model input parameters.

The following figure shows the relationship diagram of 30 tasks. A round-cornered box represents a task body. The virtual circle in the task represents a summary task id. Due to the complicated lapped relationship, no detailed description is given here.

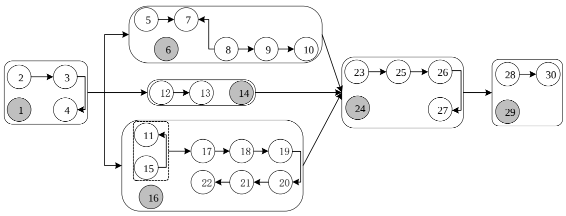


Figure 2: Mapping of product structure and development project.

For FS type, it is widely used in practice. After the previous task is finished generating specific resource, the latter task can then begin.

Tasks 11 and 15 are FF type. Task 15 restricts the completion time of Task 11. Task 11 can be completed after Task 15 is completed.

Task 7 and Task 8 are SF type, which requires Task 7 to be completed after Task8 begins. Since Task 8 lasts longer than Task 7, Task 8 can be divided into two subtasks named Task8.1 and Task8.2, Task 8.1 has the same time limit with Task 7, and the remaining time is used to complete the task 8.2. This task type can be transformed into FF type. that is, when task 8.1 is completed, task 7 can also be completed.

We can calculate the critical path from figure2:

According to the above analysis, the total planned duration of Task 8 and Task 7 is 43 days, and the planned duration of Task 11 and Task 15 is 39 days.

Path 1 (including task 5/7/8/9/10), the expected completion time of the task is: 162 days.

Path 2 (including task 12/13), the expected completion time of the task is: 240 days.

Path 3 (including task 11/15/17/18/19/20/21/22), the expected completion time of the task is: 243 days

By analyzing the total duration of the three paths above, the critical path of the project can be drawn as:

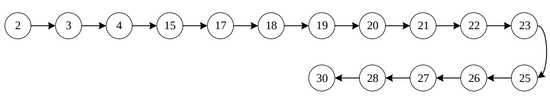


Figure 3: The critical path of the project.

According to the calculation, the construction period of the critical path of the project is 625 days.

Figure 4 shows the statistics of the number of times each task becomes a critical task within 2000 simulations, so it can be more intuitive to see which tasks have a greater impact on the whole construction period. And we can determine the critical path in Figure 5 from this figure.

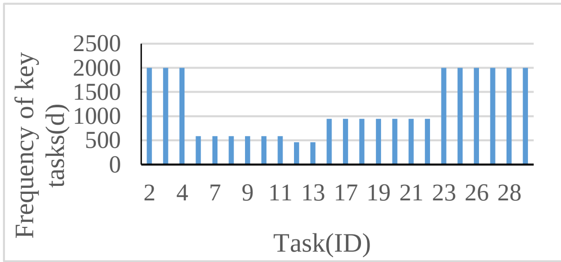


Figure 4: Simulation results of critical tasks' frequencies within 2000 simulation.

Horizontal axis is the sequence number of the task. Vertical axis is the number of a task observed to be a critical task.

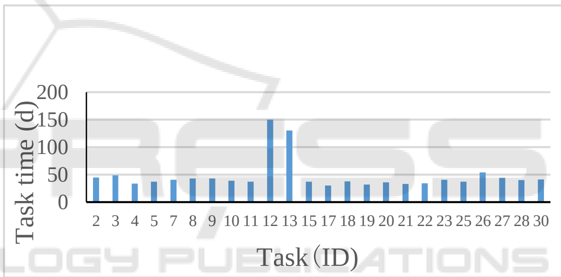


Figure 5: Average duration of the subtask simulation.

The figure 5 shows the average duration of each subtask with 3000 simulations. It can be seen that the task duration is very close to the expected value.

The figure 6 shows the frequency diagram of the simulation period. It can be seen from the figure that the distribution of the duration of the task presents a middle concentration and the two ends gradually decrease.

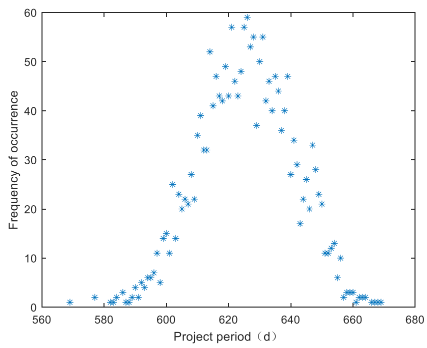


Figure 6: Frequency distribution of project duration.

Figure 7 shows the probability of the project construction period simulation. We can see that it is most appropriate to set the project construction period at around 620 days.

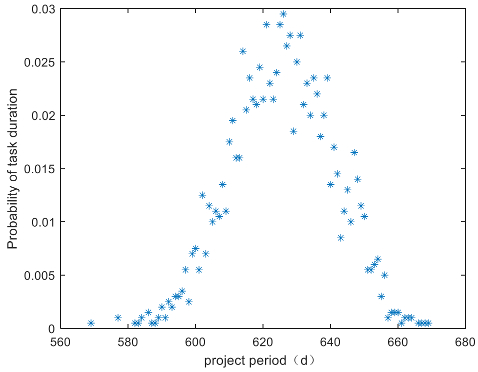


Figure 7: Probability distribution of project duration.

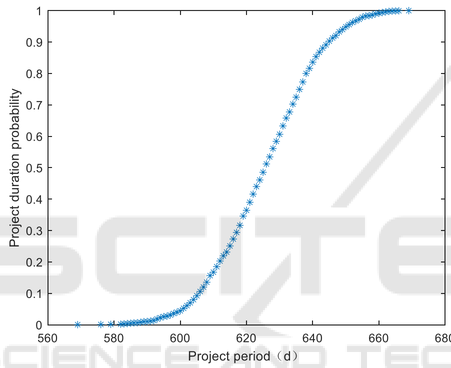


Figure 8: Probability of project duration cumulative.

Figure 8 shows the project simulation duration accumulation probability. It can be concluded that the maximum duration of the project development is about 660 days, and the probability of the project period is less than 640 days is more than 80%.

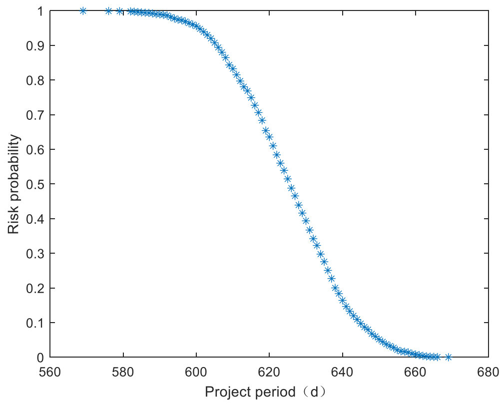


Figure 9: Project duration risk probability.

As can be seen from Figure 9, when the project duration is set within 580 days, the project can't be completed on time.

6 CONCLUSIONS

A schedule risk assessment method based on extended Petri nets is proposed. Based on the high-level Petri nets (layered Petri nets, stochastic Petri nets, colored Petri nets), Petri nets are modeled for the task duration, mission affiliation, and task restriction types in project management, which extends Petri nets' changes. At the same time, the scheduling simulation algorithm based on extended Petri net is proposed. Based on the analysis of the simulation results, a method for estimating the progress risk of the development of complex products is presented.

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