Resource management modelling and simulating of construction project based on Petri net

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Abstract

This paper establishes a model to exactly express the resource configuration, task duration and information transmission during the project execution phase. Based on the resources' properties in the projection execution phase and the hierarchical timed coloured Petri net (HTCPN), this hierarchical model exactly express the information required for project resource management, such as the task dependencies, resource demands and the task durations by defining a non-empty colour set as coloured tokens to represent the classes and combinations of the resources. This model is then simulated and analysed on the model structure, resource conflicts and run time using CPN Tools to verify the correctness and effectiveness of the HTCPN modelling of the project resources in the project execution phase.

Keywords: Construction Project, Petri Net, Resource, Modelling, Simulation

1 Introduction

The execution of a project has various constraints such as the time, resources and information, in which the resources are the key constraint having direct influence on the project cycle and economics [1]. There are three existing methods of scheduling and optimizing the project resources: peak shaving and least variance methods to optimize resources configuration. (They do not consider the random factors that may occur in the project execution and the consequence); mathematically modelling based on resource demands to optimize resources configuration using the heuristic algorithm or the meta-heuristic algorithm to seek a globally optimized solution. (The application of this method is limited due to the modelling difficulty); simulation method to optimize the resources configuration. CYCLONE (Cycle Operation Network) is the first simulation technique wildly used in project execution [2]. It integrates the queuing theory and the simulation technique into the network scheduling to consider the random factors that may occur in a cycle operation. However, this method cannot characterize the synchronous, asynchronous, parallel, and resource-sharing properties between tasks so well.

The Petri net is a modelling tool with the properties of strict formal expression, matured mathematical analysis and visual graphic representation [3]. A model established for project management using the Petri net not only has the advantage of the one by CYCLONE to characterize the random in system but also visually and in more detail depicts the parallel, synchronous and resource sharing properties between tasks. By defining, a non-empty colour set as coloured tokens to represent the classes and combinations of the resources, this paper establishes a resource management model for a project in execution phase based on the hierarchical timed coloured Petri net. It conveniently and exactly expresses the information needed for resource management, such as the task dependencies, resource demands and task durations. This resource management model is then simulated and analysed on the model structure, resource conflicts and run time using CPN Tools.

2 Resource Properties of a Construction Project in Execution Phase

In execution phase, a construction project involves a large number of resources, in which the human resource, materials and machines are the key resources. The resources can be divided into consumable resources (e.g. the materials) and non-consumable resources (e.g. human resource and machines). This paper discusses the management of the non-consumable resources. In the construction project execution phase, the non-consumable resources have the following properties [4].

a) Reusability. Subject to certain constraints, the non-consumable resources can be reused. In contrast, the consumable resources are not reusable.

b) Shareability. Subject to certain constraints, resources of one class can be shared by various tasks.

c) Exclusivity. Under certain conditions, a resource can only be used by one task. In a finite set of resources,

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the reusability and exclusivity of one resource may bring to resource conflict.

3 Definition of a Hierarchical Timed Coloured Petri Net

HTCPN=(S,SN,SA,PN,PT,PA,FS,FT,PP) [5][6], where S is a finite set of pages, belonging to which each page s ($s\in S$) is a non- hierarchical timed coloured Petri net, TCPN=(P,T,A,C,W,M,G,I,I_0) [7] and $\forall s_1,s_2\in S{:}s_1\neq s_2 \Rightarrow (P_{s1}\cup T_{s1}\cup A_{s1})\cap(P_{s2}\cup T_{s2}\cup A_{s2})=\varnothing$.

SN is a set of substitution nodes ($SN\subseteq T$).

SA is the page assignment function, through which SN maps to S.

PN is a set of port nodes ($PN\subseteq P$). The inter-page message flow functions via these port nodes.

PT is a port type function, through which PN maps to {in,out,i/o,general}.

PA is the port assignment function that is a binary relation to SN and subject to the following constrains.

$\forall t\in SN$: $PA(t)\subseteq X(t)\times PN_{SA(t)}$

$\forall t\in SN$, $\forall(p1,p2)\in PA(t)$:

$[PT(p_2)\neq general \Rightarrow ST(p1,t)=PT(p2)]$

$\forall t\in SN,\forall(p1,p2)\in PA(t)$: □$[C(p_1)=C(p_2)\wedge I(p_1)=I(p_2)]$

FS is a finite set of unit type, each element of it has the same colour and initial expression, i.e.

$\forall fs\in FS,\forall p_1,p_2\in fs$: $[C(p_1)=C(p_2)\wedge I(p_1)=I(p_2)]$

FT is a unit type function. It maps FS to [global, page, instance]. The set of page union nodes and the set of local nodes are included in the same page, i.e.

$\forall fs\in FS$: □$[FT(fs)\neq global \Rightarrow \exists s\in S{:}\ fs\subseteq Ps]$

PP is a multi-set defined in the root page, which is the top-most page.

4 Modelling of Resources in Construction Project Execution Phase

4.1 DEFINING THE NON-EMPTY COLOR SETS

C is the non-empty coloured set of the HTCPN. Before modelling the resources, it is required to define a number of data types, that is to say, define coloured tokens to represent the classes and combinations of various resources. In this paper, the definition of coloured tokens is focused on the non-consumable resources.

The colour sets are defined through CPN ML. For modelling of the resources of the project execution phase, the following colour sets are defined.

a) colset Pro = int timed; Timed Project.

b) colset P = int timed; Timed Partial Project (Task).

c) colset S = bool; Acceptance Criteria of Project. Its token in place is of Boolean type.

d) colest res = int; Resource Classes, e.g. 1 represents the civil work engineers, 2 the piping engineers and 3 the electrical engineers.

e) colset ress = list res; List of Resources.

f) colset req = record n:INT*m:INT*tim:INT*rn1:INT*rn2:INT*rn3:INT Resource Request,

where

n is the number of the project item that sends the resource request.

m is the number of the project sub-item that sends the resource request.

tim is the time when the request is sent.

rn1, rn2, rn3 are the requested amount of the three classes of resource respectively.

g) colset reqs = list req; List of Resource Requests.

h) colset mtres = record m: INT*t:INT*r: ress; List of Resources that the Project Sub-item m Received at the Time t.

i) fun FuzzyTime (a,b,c); Function Declaration. It is the fuzzy time when the task completes, where a is the minimal duration, b the most possible duration and c the maximal duration, of the task.

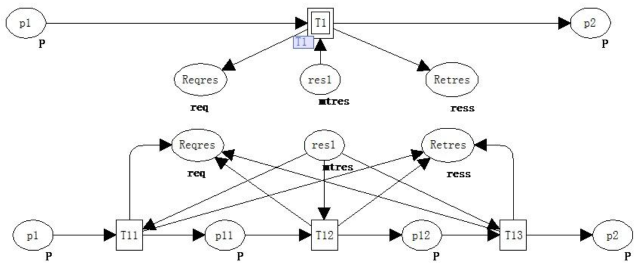


FIGURE 1 Hierarchical characterization of resource management through the substitution transitions

4.2 MODELING THE RESOURCE MANAGEMENT IN HIERARCHY

A project consists of a number of project items that are to be performed in sequence, in parallel or synchronously. As soon as a project item starts, it inevitably requests the resources, receives them and returns the (non-consumable) resources when the task ends. A project item divides into several sub-items. As project items, the sub-items are processes to consume resources (consumable resources) or to use non-consumable resources. That is to say, requests, assignment and return of resources of a project item are finally those of the divided sub-items. Figure 1 shows the hierarchy of the resource management. Through the substitution transitions, the resource management is characterized in a hierarchical net. T1 is start transition of the project item. It requests, receives and returns resources from the places Reqres, res1 and Retres. T1 is a substitution transition, which belongs to the page of its parent net. The net (page) in the dotted box is the subnets of T1. The start transitions of several project sub-items, T11, T12 and T13 request resources from the place Reqres and one sub-item starts when it receives the resources from the place res1 and returns the resources to the place Retres when it completes. In spite of the transitions of parent net and its subnet(s) relates to the same set of places, the hierarchical characterization simplified the net model. Furthermore, sub-items may be modelled as common models, which can be repeatedly used in modelling of different projects to enhance the modelling efficiency.

4.3 MODELING OF RESOURCE ASSIGNMENT AND RETURN FOR RESOURCE MANAGEMENT

Figure 2 shows a basic model of resource assignment and return. All the request tokens for resources sent by the tasks go into the place Reqres. When the amount of resources in the places pool1, pool2 and pool3 satisfies the requests from the place Reqres, the transition R1 assigns the requested resources to the resource output places res1, res2, res3, res4 for the tasks respectively. If the amount of resources does not satisfy the requests from the place Reqres, resources confliction occurs.

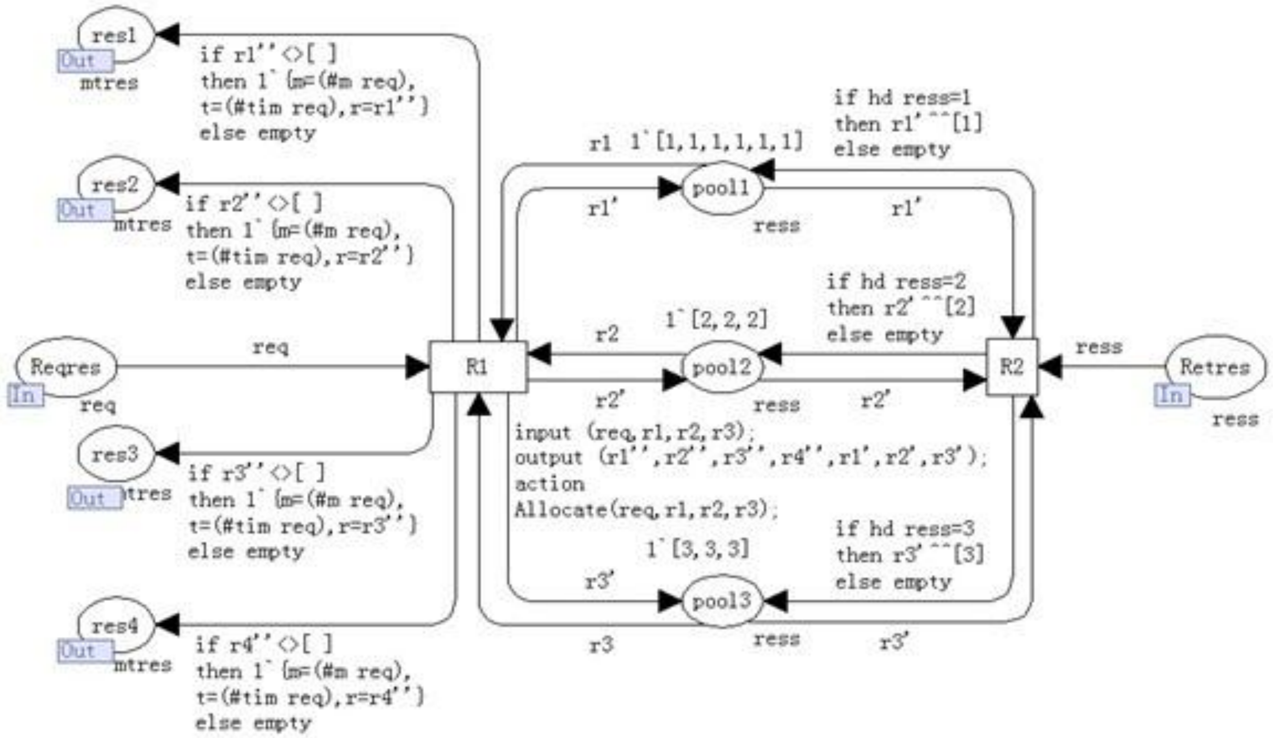


FIGURE 2 The basic model of resource assignment and return

5 Examples of Modelling and Simulation

In this paper, a project is taken as an example to model the source management for simulation. The CPN tools from Aarhus University are used as the modelling and simulation platform.

5.1 MODELLING

The example project consists of the construction word p1, installation work p2 and the furnishing work p3. To perform the works in parallel, the work p1 is divided into two phases, t1 and t3. t4 is the execution of p2 and t5 the execution of p3. They are partially parallel with t1 and t3 through multi-dependencies. t1 and t3 are substitution transitions, which represent the construction work of the underground foundation and the structure under the Floor 1, and the structure of and above Floor 1, respectively. Also, t4 and t5 are substitution transitions. t1, t3, t4 and t5 send resource requests, receive the resources assigned to them and return the resources at the tasks' ends. The substation transition Res globally controls the resource movement of t1, t3, t4 and t5, as shown in Figure 3. Of t1, t3, t4 and t5, the sub-item works have their own subnets for characterizing the resource movement. Figure 4 shows the subnets of t1. For simplification, other subnets are not shown. Figure 5 shows the subnets of Res, which are modelled base on the basic model of resource assignment and return (as shown in Figure 2) and added the timer transition TIMER to generate the time list poolt for assigning the resource(s) under any confliction condition. It sequentially assigns the resources in the order of request time. In the event that a request waits for one resource for some time, the time stamp of the resource will be changed at the time of assigning this resource. When the resource is returned, the time stamp of the resource is changed to the value the waiting time adding the task duration, as shown in Figure 5. For simplification, the definition of variables and functions and the description of transitions and places are not discussed in this paper.

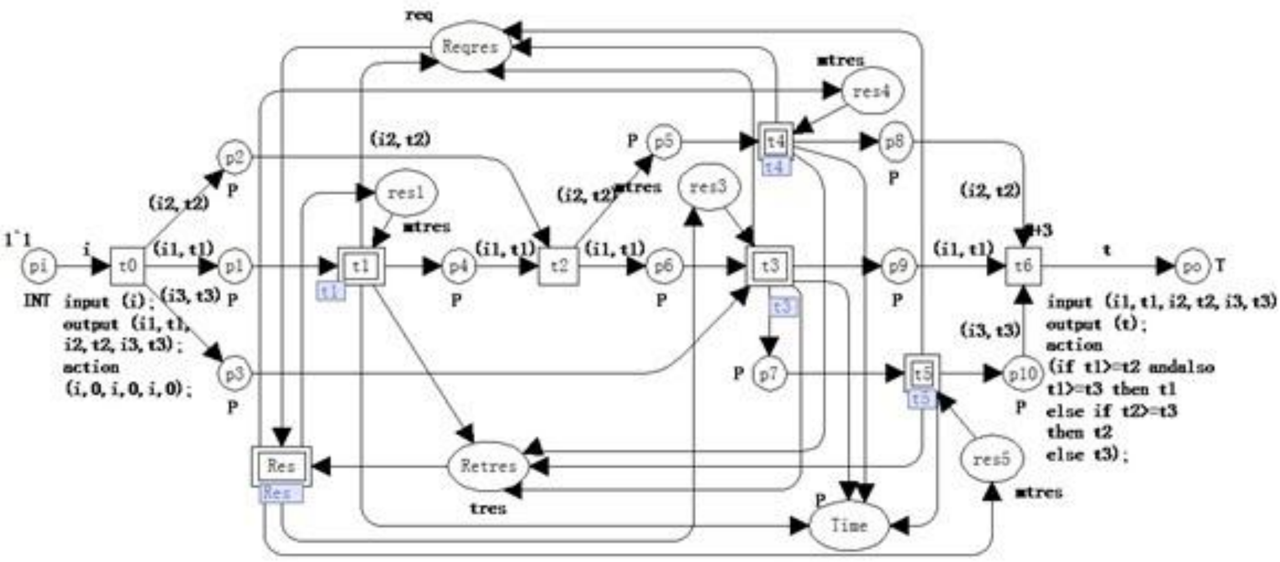


FIGURE 3 Resource management model (top)

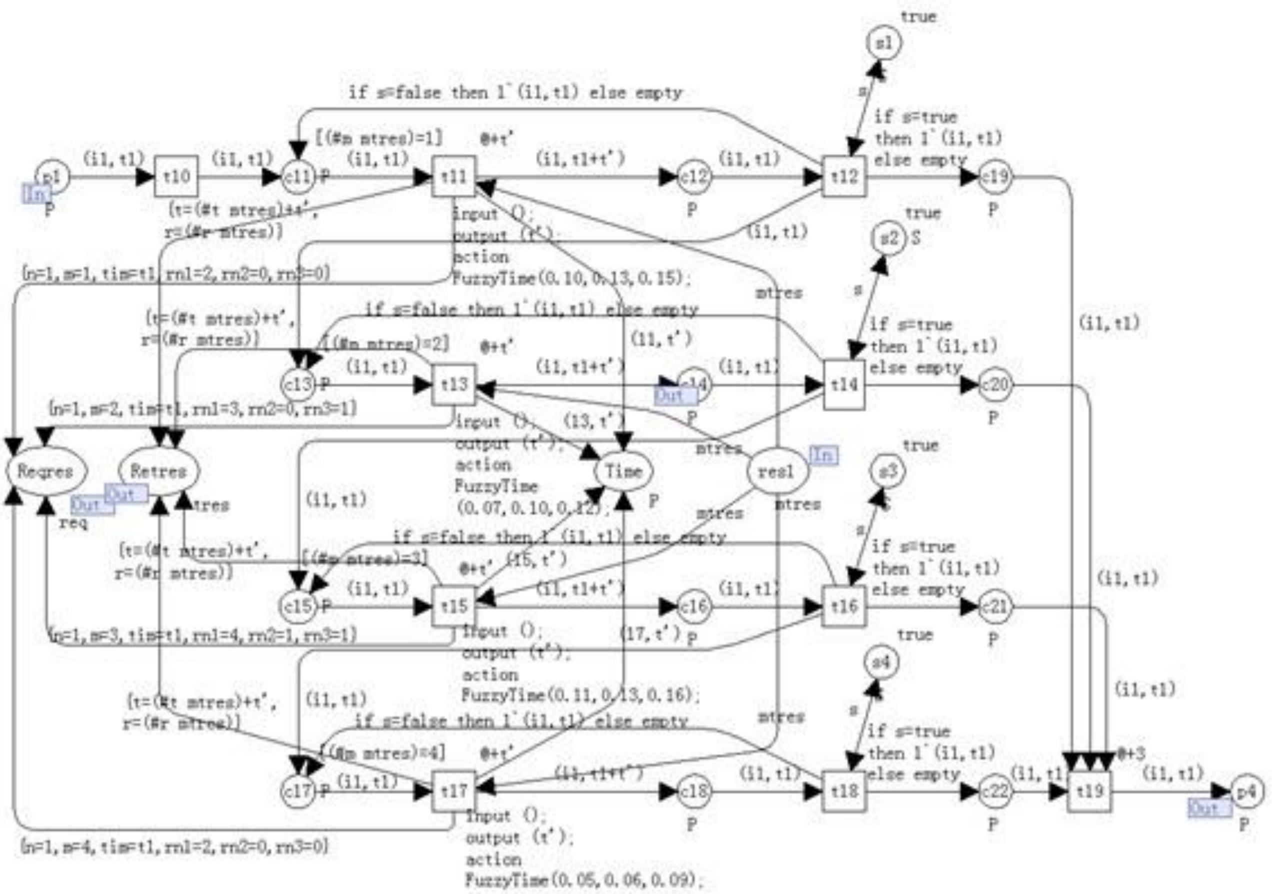


FIGURE 4 Resource management model (the subnets oft1)

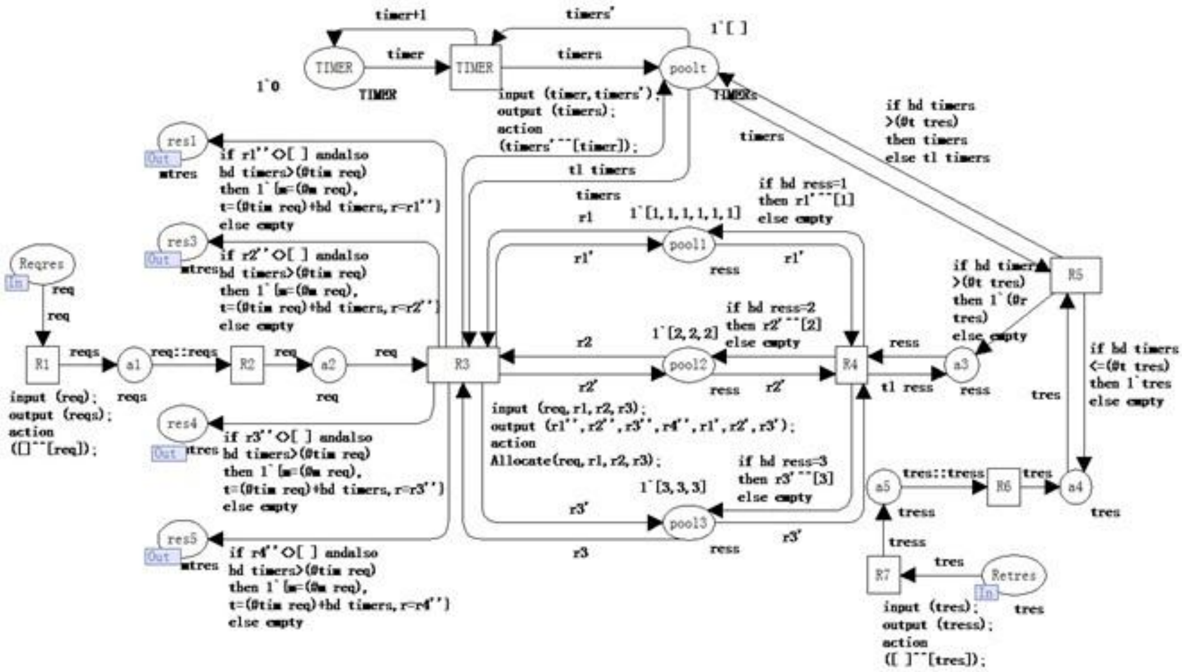


FIGURE 5 Resource management model (Resource Layer)

5.2 SIMULATION

5.2.1 Setting the Parameters

Table 1 shows the basic parameter settings for the model simulation, in which r1, r2, r3 represent construction engineers, piping engineers and electrical engineers respectively. In Table 1, the individual quantities of the three types of engineers, the quantities of engineers that various tasks requires and the fuzzy duration of the tasks are also shown.

TABLE 1 Resource list of tasks in the execution phase

	r1	**r2**	**r3**	**Time Required (d)**
	4	2	2	
t11	2	0	0	@+(FuzzyTime(10,13,15))
t13	3	0	1	@+(FuzzyTime (7,10,12))
t15	4	1	1	@+(FuzzyTime (11,13,16))
t17	2	0	0	@+(FuzzyTime (5,6,9))
t31	4	1	1	@+(FuzzyTime (90,110,120))
t33	3	1	1	@+(FuzzyTime (35,40,45))
t35	2	1	1	@+(FuzzyTime (15,20,29))
t41	1	2	2	@+(FuzzyTime (110,120,130))
t43	0	2	2	@+(FuzzyTime (25,30,35))
t51	2	1	1	@+(FuzzyTime (55,60,65))
t53	2	0	0	@+(FuzzyTime (50,60,90))

5.2.2 Simulating the Model

a) General Analysis of the Petri Net Established.

The feature of State Space of CPN Tools is used for checking the syntax and analysing the structure of the resource management model established to get the state space report, which shows the reachability, boundedness and liveness properties of the established model. By these properties, the model can be justified.

b) Conflictions

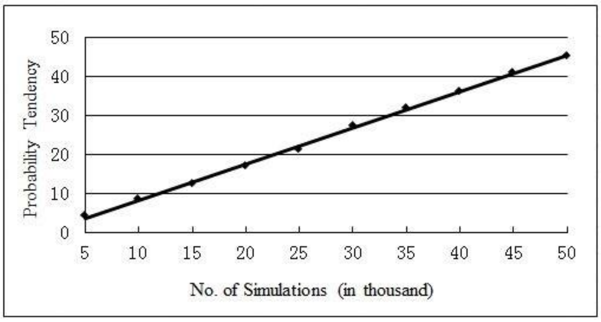
Due to the tasks performed in parallel and the exclusive property of the engineers, a confliction occurs when an engineer is requested by more than one task. To the model, a confliction occurs when the finite quantity of the coloured tokens in the resource place is short to fire two or more transitions (tasks) at one time. The real firing time of the task that lacks of resources will be delayed due to waiting for the resources and the time stamps of the tokens in the resource places are changed.

c) Analysis of Run Time

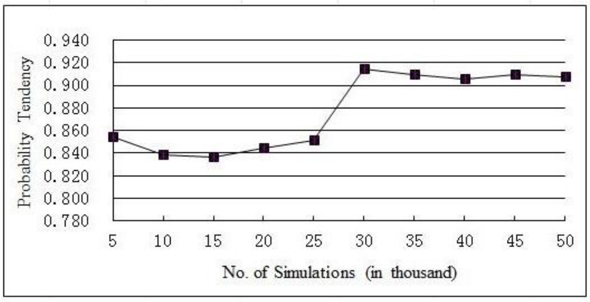
Under the resource constraints shown in Table 1, 5,000 times of simulation are made to the resource model using CPN Tools Simulation for the probability of the construction project ending in 280 days, as shown in Table 2. As the simulation progresses, the probability of this industrial and civil construction project ending in 280 days tends to 91%, as shown in Figure 6. The resources configured in the places r1, r2 and r3 satisfy the need of project schedule.

TABLE 2 Data sheet of resource management model simulation

No. of Simulations	**No. of Successful Simulations**	**Probability Tendency**
5000	4270	0.854
10000	8386	0.839
15000	12546	0.836
20000	16893	0.845
25000	21276	0.851
30000	27427	0.914
35000	31823	0.909
40000	36225	0.906
45000	40931	0.91
50000	45381	0.908



a) No. of Successful Simulations



b) Probability Tendency

FIGURE 6 Simulation for the Probability of Project Ending in 280 days: a) No. of Successful Simulations, b) Probability Tendency

6 Conclusions

This paper discussed the resource properties of the project in execution phase and established a model for resource management. CPN Tools are used for modelling the instance and simulation to check the model structure, find out any resource conflictions and analyse the run time so as to justify the model and verify its correctness. The model can be used to assess various project schedules through setting and adjusting the resource input and select one from them that has high resource utilization rate while keep the optimized project duration.

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