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A Time Petri Net Representation for Scientific Research Project Management*

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Abstract: An efficient and convenience model of business process plays a crucial role in scientific project management. Existing Petri net models lack the ability to cope with the time constrain of the business process. Thus the time factor was introduced to Petri net in this paper. The formal definitions of time Petri net were presented in details. The techniques to model the business process of scientific project management system with the time Petri net were discussed as well. A time Petri net model for an instance of scientific project management system was setup and study. The research results indicate the time Petri net is an efficient method to represent the scientific project management system.

1. Introduction

Nowadays with the rapid increase of scientific research investment in China, scientific project management (SPM) takes an important place in related governments, institutes and enterprises. SPM is a complex business process, covering information processing, discrete event modeling and decision-making strategy. Usually, the process of SPM includes several phases and may last for a long time. In every phase, a series of tasks should be carried out in sequence or parallel. Some binding rules must obey in the tasks and a lot of related documents may be produced as the results [1][2]. Many managers will participate in the whole program and multi decision makers will co-operate to get final decisions. The information resource should be shared among the different managers. All the management events must be organized in a proper way to avoid resource collision and ensure the efficient schedule. Besides, time constrains are crucial issue in the process of SPM. Almost every task should be completed on time to guarantee the valid results. Thus a unified model or representation tools should be adopted to guide this kind of multi-operator multi-phases project management.

Petri nets (PN) is a well-known mathematical tool to model and analyze complex discrete event systems which can be characterized as synchronous, parallel, simultaneous, distributed, resource sharing [3]. Petri nets were already applied to workflow management and decision support system [3-5], which are relevant areas with SPM because SPM can be regarded as a workflow management system to some extent. Naturally PN is used as formal method for modeling and analyzing SPM systems. Reference [1] introduced PN and workflow conception to SPM and verified the integrity of the proposed model. Reference [2] adopted colored Petri net to model the SPM business and mainly focused on optimizing the model structure. These work observably advanced the research progress. But the time constrain of the business process was not intentionally considered in these models. Therefore a time extended Petri net is proposed and formally defined for modeling the business process of SPM systems in this paper.

2. Formal definition of Time Petri Net

2.1 Formal Definition of TPN

Petri nets have been studied for many years and formally defined in mathematics. But classical Petri net ignored time constrains. Many efforts were made to extend Petri net with time factors. And several formal definitions of Petri net incorporating timing aspect have been proposed, such as timed Petri nets, delay Petri nets, and stochastic Petri nets. These extended Petri net is perfect in theory but somewhat complex for ordinary users. Thus we try to formally define a practical time extended Petri net for the special application of SPM.

Definition 1 Time Petri net is a tuple $TPN=(P, T, F, W, D, M_0)$

Where,

$P=\{p_1, p_2, \ldots, p_n\}$, denotes a finite nonempty set of places, represents fuzzy propositions;

$T=\{t_1, t_2, \ldots, t_k\}$, denotes a finite nonempty set of transitions，$T \cap P=\Phi$;

$F \subseteq (P\times T)\bigcup(T\times P)$ is the relation between places and transactions;

$W: F\rightarrow \in I^+$ is the weight function of a relation, the weighted value is an integer. The default weight of a relation is 1.

$D : T\rightarrow \in R^+ \cup \{0\}$ is the time function of a transaction, denotes the maximum time consumption of a firing transaction and the default value is 0.

$M(p)$ is the marking of the place p, represented by token. M_0 is initial marking for places.

Definition 2 TPN is a time Petri net， $\forall x \in P\bigcup T$,

$$\bullet x = \{y | y \in P\bigcup T \wedge (y,x)\in F\}$$

$$x\bullet = \{y | y \in P\bigcup T \wedge (x,y)\in F\}$$

$\bullet x$ is the pre-sets of x，$x\bullet$ is the post-sets of x.

Definition 3 If TPN holds two special places: one start place p_s and one end place p_e , that is, $\bullet p_s =\Phi$ and $p_e \bullet=\Phi$, it can be regarded as an extended time Petri net (eTPN). Besides, if a new transaction t_i is added to this eTPN, then $\bullet t_i =\{p_e\}$ and $t_i\bullet =\{p_s\}$, namely the net is strongly connected.

Petri net model could be presented by graphic symbols, which could describe the static structure and dynamic behaviors of discrete event system. Graphical representation of eTPN for SPM is set up by the following symbols: *places* –by circles, *transitions* – by rectangles, and *relations* – by pointers between transitions and locations or locations and transitions, tokens – by black dots or an integer, the weight of relations and time delay of transaction are close to their hosts. See an example in figure 1, where place p_s has 1 token, time delay of transaction t_1 is 5 days, the weights of relation (p_s,t_1) are 2, and all other elements hold the default value. By the way, if a new transaction t_2 is added to the example, the connectivity of model should be guaranteed, showed in figure 2.

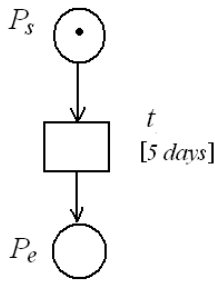


Fig.1 Graphic symbols for eTPN

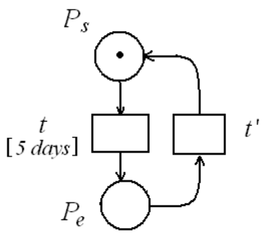


Fig. 2 Add a transaction to eTPN

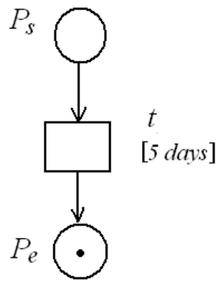


Fig.3 Results of transaction fired

2.2 Firing Rules of eTPN

Dynamic behaviors of eTPN can be defined by transition firing, which describe the system state transfer.

Theorem 1 $\exists t \in T, \forall p \in \bullet t$, if $M(p) \geq W(p,t)$, t is said to be enabled.

Theorem 2 An enabled transition t can fire before the deadline —time constrain of t, and a overtime transaction will lose the right of firing.

Theorem 3 If the present marking is M, when enabled transition t fires, the new marking M' is expressed as

$$M'(p)=\begin{cases} M(p)-W(p,t), & p \in \bullet t - t\bullet \\ M(p)+W(t,p), & p \in t\bullet - \bullet t \\ M(p)-W(p,t)+W(t,p), & p \in \bullet t \bigcap t\bullet \\ M(p), & other\ cases \end{cases}$$

Speaking of the example in figure 1, t_1 satisfy the enable conditions, which can fire in 5 days. If it fired, the marking might change. The result is shown in figure 3, where the token moves to p_e.

3. eTPN Representation for Basic Business Process of SPM

There are many kinds of scientific projects supported by different fund councils, government agents, and other organizations in the real world. Usually the projects selection, evaluation and process management defers from each other. But three basic business processes are typical process of the SPM systems.

3.1 Sequential business process

Sequential business process is the basic structure in SPM. An example of the sequential process is showed in figure 4(a), which describes the early phase of project collection. And the corresponding eTPN model is showed in figure 4(b). In the eTPN model, p_1 represents the project guide document, has 1 token, transaction t_1 represents the operation of issue the guide, p_2 represents the project application documents, transaction t_2 represents the operation of collecting the applied projects, time constrain is 30 days. Place p_1 and p_3 can be regarded as the start place and end place. From the eTPN model, the time consumption of the business process can be calculated by summing up the fire time of all transaction on the path from p_1 to p_3. went with out saying, the time sum is the maximum delay to complete the process.

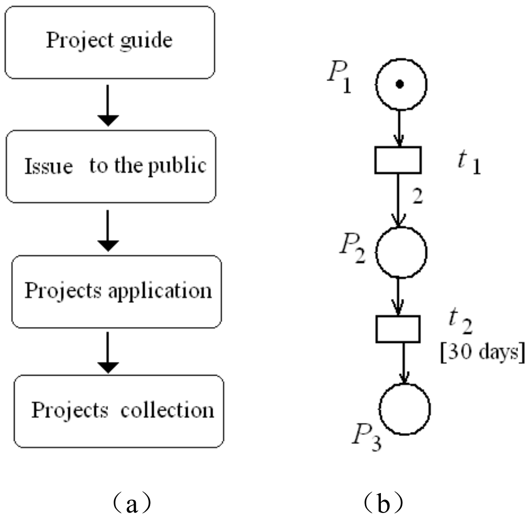


Fig.4 Sequential model

3.2. Parallel business process

Parallel tasks are common practices in SPM business process. An example of the parallel process is showed in figure 5(a), which describes the phase of project selection. The candidate projects will be assigned to committee of experts for evaluation. And different experts can evaluate the projects in parallel. The corresponding eTPN model is showed in figure 5(b). In the eTPN model, p_1 represents the candidate project, has 1 token, transaction t_1 represents the operation of assign the projects to experts, p_2 and p_3 represents the projects assigned to expert 1# and expert 2#. Transaction t_2 and t_3 represents the parallel tasks of expert evaluation, time constrains of t_2 and t_3 are 15 days and 20 days. Place p_4 and p_5 represent the result of experts evaluation. Transaction t_4 represents the task of integral evaluation and finial results are represented by p_6. It is clearly there are 2 paths from the start place p_1 to the end place p_6. Of cause the time consumption of the business process is 25 days, the maximum time delay among the paths.

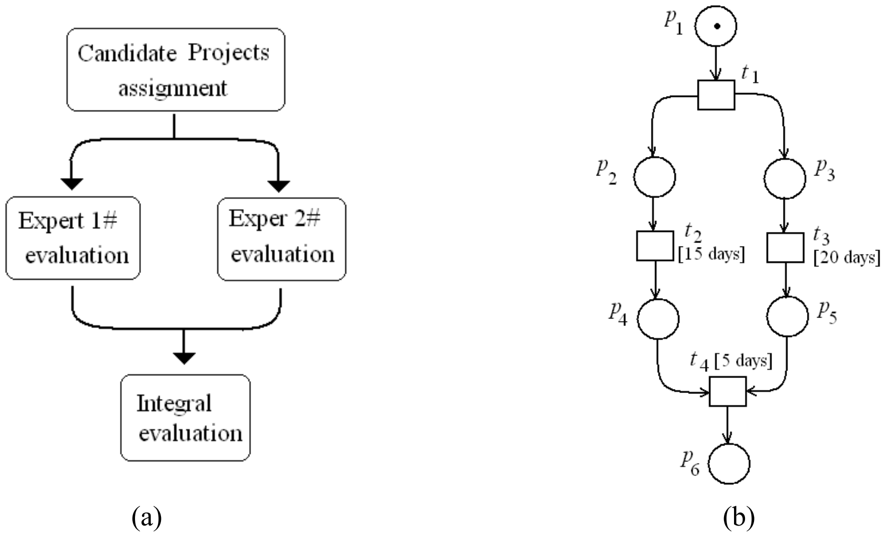


Fig. 5 Parallel process

3.3 Loop business pocess

Loop tasks also appear in SPM systems. For example, when projects finish, they will be sent to the committee for go-around. This process is showed in figure 6 (a). The corresponding eTPN model is showed in figure 6(b). In the eTPN model, p_1 represents the finished project, has 1 token, transaction t_1 represents the operation of jury comment, p_2 and p_3 represents the passed projects and not passed ones. Transaction t_2 represents the task of archiving the project reports. Transaction t_3

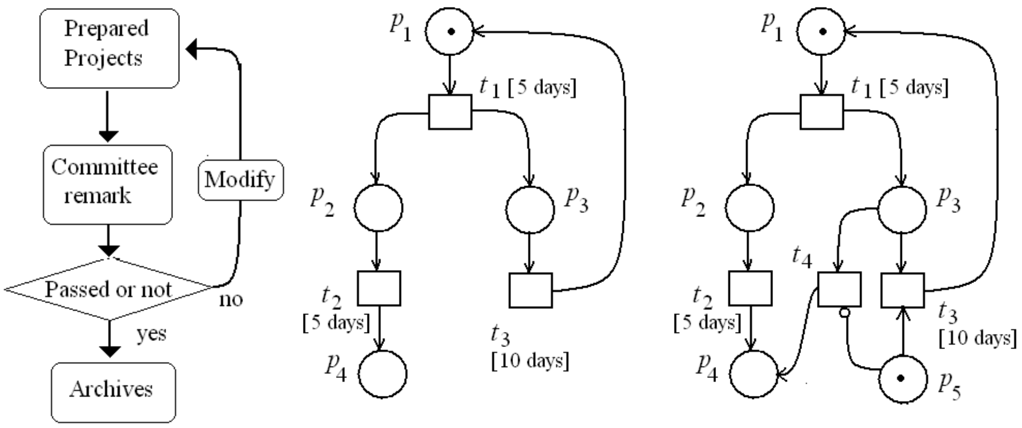
represents the modification task of the un-passed projects. Place p_4 represents the archived projects. The model of loop process exist hazard if there are endless loops, as in the example. In the real world loop tasks can repeat under a maximum number. This condition is easy to realize by adding inhibit arc to eTPN.

Lemma 1 Inhibit arc is a special relation of $P \rightarrow T$, if transaction t satisfy the following conditions, t is said to be enabled. $\forall p \in \bullet t$, if (p,t) is an inhibit arc, then $M(p) = 0$, if (p,t) is not an inhibit arc, then $M(p) \geq W(p,t)$.

Lemma 2 If (p,t) is an inhibit arc, when transaction t fires, the marking of p_i do not change. That means the weight of inhibit arc is 0 as default.

Under the conception of inhibit arc, place p_5 is added to the model, which works as a loop controller, seeing figure 6(c). p_5 holds one token, meaning the un-passed projects can be modified only once. An inhibit arc (p_5, t_4) was used to insure the logic rationality whose graphic symbol is an arc with a circle end. Transaction t_4 represented the operation of tagging un-passed projects.

With the help of inhibit arc and condition place, the time cost of loop process can be calculated by the eTPN model. As in figure 6(c), maximum time cost is 20 days to finish the workflow.



(a) (b) (c)

Fig. 6 Loop process

4.Integrality of eTPN model for SPM

4.1 Integrality Verification Techniques

The integrality of eTPN model insures the correct of the business process and no structural conflicts. Reference [6] [7] proposed a series of reduction rules to verify the integrality of workflow and theoretically proved the method. We adopt some of the reduction rule to verify the integrality of eTPN model for SPM systems.

Definition 4 There are two kinds of node in the eTPN, one is called place nodes and an other is called transactions nodes.

Rule 1 In the sequential structure, if a node has exactly one input node and one output node, it can be removed from the graph and its input node and output node can merge together.

Rule 2 In the parallel structure, Nodes that have exactly one input node or one output node, and where the input node or output node is of the same type. These nodes can merge together.

Rule 3 An inhibit arc (p_h,t_h) can be removed, meanwhile, p_h , t_h and all arcs connected to them can be removed as well. That means the condition played by inhibit arc is always satisfied as testing the net integrality.

Rule 4 In the loop structure, if node N_i is the input of node N_k and node N_k is the input of node N_i. The 2 nodes can replace by one node and then merge with adjacent same type node.

Applying above rules, if an eTPN model could be reduced into the basic structure and start place p_s and end place p_e would merge into one place in the end, the model is said integrality and has no structure confliction.

4.2 An Instance eTPM Model Verification

An instance eTPN model for SPM system is setup by combining the models in figure 4, figure 5 and figure 6, showed in figure 7 (a). Apply rule 1and rule 3, the model can be reduced as figure 7(b). Continue using rule 1 and rule 2, the model can be reduced as figure 7(c). Using rule 1, the model can be reduced as figure 7(d). Using rule 4 , the model can be reduced as figure 7(e). Using rule 1 once more, the model will turn into one place as figure 7(f). That means the original model is integrality and valid.

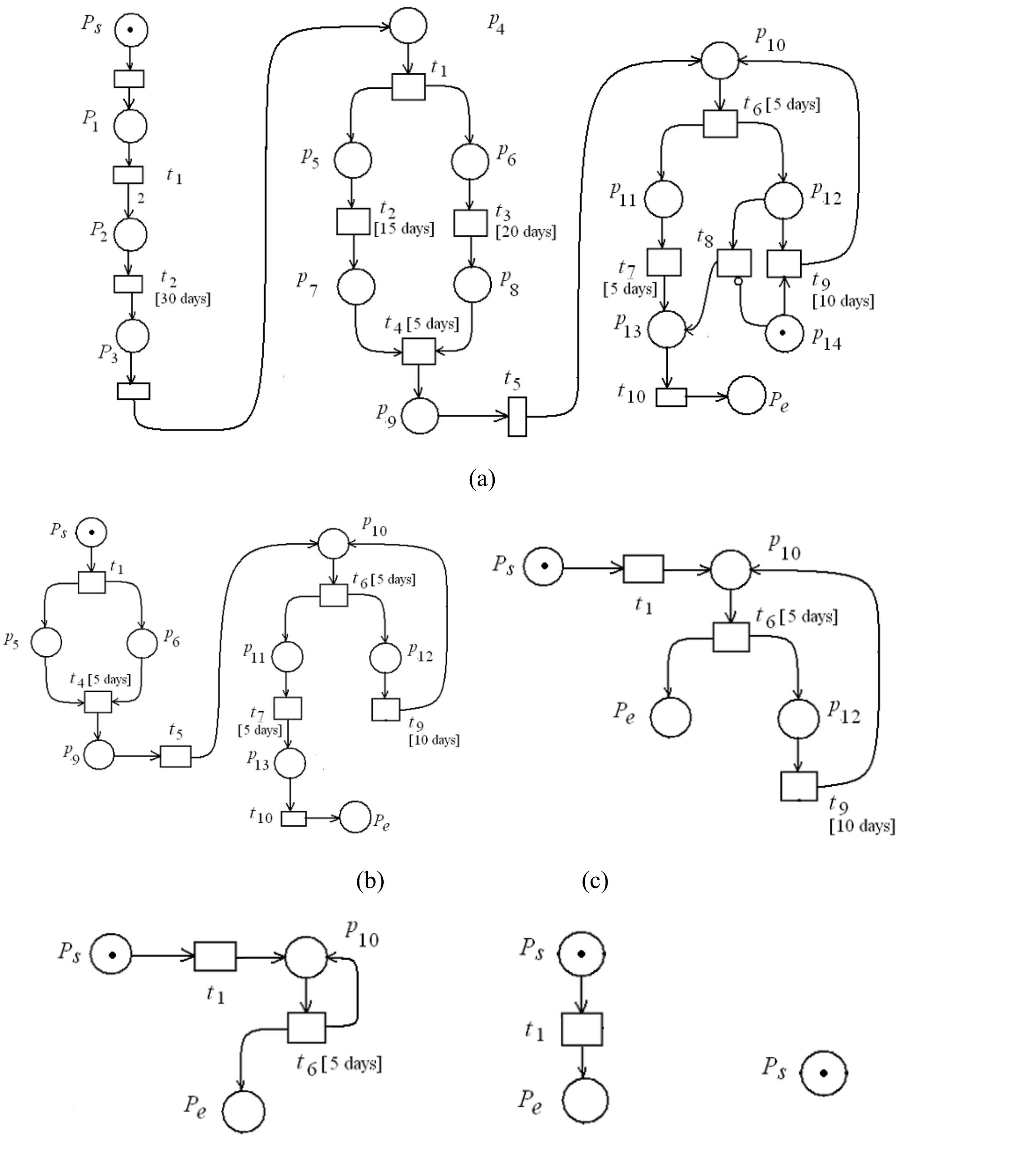


Fig. 7 eTPN model reduction

5. Conclusions

An extended time Petri net was proposed for modeling SPM systems. Compared with existing models, the proposed eTPN model has the ability to analyze time characteristics of the business process and easy to structure. Considering most SPM operators are unprofessional with formal method or mathematics theory, the model adopts simple graphic symbols and no abstract concept and parameters are introduced. But it is still practical and acceptable to analyze and optimize the business process of SPM. The proposed model is proved valid for SPM systems by applying reduction rules to verify its integrality.

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