Research on Optimization of Engineering Consulting Business Processes Based on Stochastic Petri Net Theory

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Abstract. Under the background of new era and new consulting, the business process is constantly changing, and the advantages and challenges of engineering consulting field coexist. This paper introduces stochastic Petri nets into the field of engineering consulting, models and simulates engineering consulting business processes, and combines the assignment and the equivalence of stochastic petri nets and Markov chains to evaluate and analyze the implementation effect of engineering consulting business processes, and verifies through examples that the method is applicable to business process modeling in the field of engineering consulting and can be used to analyze the relevant performance indexes of the model.

Keywords: stochastic petri nets; engineering consulting; optimization of processes

1 Introduction

Business process is an important carrier of enterprise value creation, the enterprise's understanding of process management is becoming more and more rational, and enterprises pay more and more attention on the application of the value of process management, however, Traditional business processes still have pain points such as redundancy, complexity, and fragmentation, Each one does as he pleases between the upstream and downstream of the business value chain, resulting in the enterprise's internal inefficiencies, the speed of development is constrained by the chaotic internal process system. Under the background of the digital economy, with the continuous development of the Internet of Things, artificial intelligence, big data, cloud computing and other technologies, as well as the implementation and transformation of Industry 4.0, more and more enterprises are beginning to accelerate the promotion of digital transformation, and the essence of digital transformation is the enterprise's business process reconstruction, Therefore, in order to solve the problems of process inefficiency and low synergy, enterprises need to reorganize and optimize the process, and design the business flow process from the perspective of the whole process and the whole scenario,

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quantitatively assess the effect of process change, and identify the breakpoints and blockages in the process.

Petri nets are commonly used tools for process modeling[1], with powerful analytical techniques and tools to analyze various characteristics of processes[2], it can be mapped to Markov chains for various quantitative analyses Petri. Ni[3] simulated the recycling business process of used smartphones with the help of Petri net model and reduced the process time to improve the process efficiency; Zhao[4] analyzed the operation process of unloading cars in railroad logistics centers based on Petri net model, and optimization measures were proposed to improve the operation efficiency; Xiao etc.[5] analyzed the time performance of the model based on Petri nets combined with probabilistic related theories.

This paper based on the above results, combined with Markov chain, analyzes the relevant performance metrics of the model by using relevant properties of Markov chain. Engineering consulting business integrates process, technology, economy, management, law, etc., which has certain complexity. With the advancement of the wave of digital transformation of the engineering consulting field, it is difficult for the process system of traditional engineering consulting to adapt to the new market environment, which is prone to cause problems such as low process efficiency and longtime of capital return. This paper introduces the stochastic Petri net model into the field of engineering consulting, takes the engineering consulting project as an example, combs its business process, and provides a basis for engineering consulting enterprises to carry out business process reengineering.

2 Introduction to the relevant theories

2.1 Stochastic Petri net theory

Petri net theory was originally proposed by Carl Adam Petri [6]， petri net is a relational grid that describes events and conditions , it is one of the commonly used methods for process modeling， Petri nets provide a powerful way of describing and studying information processing systems characterized by parallelism, asynchrony, and stochasticity[7], Stochastic Petri net model can provide modeling and performance analysis for systems with stochastic processes [8], therefore, it is well suited for process modeling of the consulting engineering business.

Petri net model contains four modeling elements, which are Place, Transition, Connection and token. Among them, the Place describes the state and location of the system, the Transition describes the consumption, using and generation of resources in the system, the Connection denotes the relationship between the system states, which is usually represented by a directional line segment, and the Token is included in the Place and can move between two Places, which is usually represented by a black dot. The definitions are as follows[9]:

Petri net is a quaternion, $PN = (S, T, F, M_0)$, among them:

S is a finite set of Places， $S = \{s_1, s_2, \ldots, s_m\}$;

T is a finite set of Transitions， $T = \{t_1, t_2, \ldots, t_n\}$， and $S \cap T = \emptyset, S \cup T \neq \emptyset$, that is, the set of Places and the set of Transitions do not intersect and the two sets are not simultaneously empty set;

$F = (S \times T) \cup (T \times S)$, which is the set of directed Connections between the set of Places and the set of Transitions, i.e., F exists only between the set of Places and the set of Transitions;

$M_0: S \rightarrow N$， $N = \{1,2，3 \ldots\}$, which is the initial identity, a mapping of the set of Places to the natural numbers, i.e., the distribution of tokens in the petri net;

$F: S \rightarrow N$, which indicates the capacity function of the Place set, which represents the maximum number of resources that can be stored in each Place;

$K: W \rightarrow N$, which is a weight function, which represents the consumption or generation of resources;

$\lambda = \{\lambda_1，\lambda_2，\lambda_3，\ldots, \lambda_n\}$, which is the set of average implementation rates of Transitions. λ_i is the average implementation rate of Transitions, denoting the number of implementations per unit of time. $\gamma_i = 1/\lambda_i$, which is the reciprocal of the average implementation rate and denotes the average implementation delay or average implementation time for the Transition λ_i.

2.2 Performance analysis of stochastic Petri net model

The performance analysis of stochastic Petri net model is generally divided into the following steps[10]:

(1) Constructing a Petri net model of the system process and verifying the reliability of the model;

(2) Setting the implementation time of Transitions. Based on the established petri net model of the system, associate an implementation time or delay to all Transitions that matches the actual situation.

(3) Constructing a Markov chain which isomorphic to the petri net model of the system. On the basis of the known stochastic Petri net model, the Markov chain is obtained isomorphically based on the distribution of tokens (resources) in the model Place as well as the triggering rules of the Transitions in the model.

(4) Solving the Markov chain. Based on the obtained Markov chain, the transfer rate matrix of the Markov process is constructed and the steady state probability is obtained by solving the matrix equation.

Assuming that a Markov chain which is isomorphic to the d Petri net model already exists, and that there are n states in this Markov chain, the transfer rate matrix Q can be defined as:

$$Q = \lfloor q_{i,j} \rfloor, 1 \leq i, j \leq n \tag{1}$$

Where the value of the element $q_{i,j}$ of the transfer rate matrix is: if $q_{i,j}$ is an element on the diagonal of the matric, the number of $q_{i,j}$ is equal to the sum of the rates labels in the Connections that are exported from the state M_i to all other state M_j; if $q_{i,j}$ is not an element on the diagonal of the matrix, it is determined whether the state identifiers

M_i and M_j are connected by Connection, if so, the value of $q_{i,j}$ is equal to the marked value of the Connection, if not, then 0.

Assuming the steady-state probability of n states in a Markov chain be a row vector $X = (x_1, x_2, \ldots, x_n)$, according to the properties of Markov chain, the system of equations can be obtained as.

$$\begin{cases} XQ = 0 \\ \sum_I x_i = 1, \ 1 \le i \le n \end{cases} \tag{2}$$

Solving this system of equations gives the steady state probability of each state $P[M_i] = x_i, \ 1 \le i \le n$.

(5) Analyzing model performance indicators. Based on the steady-state probabilities of the individual states M_i, the final performance of the system can be determined by calculating the corresponding performance indicators. The performance indicators are as follows:

①The average number of Tokens of Place s_i.

$$\overline{u_{s_i}} = \sum_j j \times P[(s_i) = j] \tag{3}$$

Where j denotes the number of Tokens.

The average number of Tokens can be used to indicate the busy and idle status of the Place.

②The average number of Tokens of the system $U(t)$.

$$U(t) = \sum_{M \in S} P(M) \tag{4}$$

③According to the principle that the inflow rate of the system is equal to the outflow rate, the labeled flow rate of the system Transition $R(t, s)$ can be derived.

$$R(t, s) = U(t) \times \lambda \tag{5}$$

The average execution time of the system can be obtained from the labeled flow rate of the system Transition and the average number of Tokens of the system.

3 Stochastic Petri net-based business process model for engineering consulting

3.1 Building the model

A process model based on stochastic petri net is established according to the basic process of engineering consulting services. In order to ensure the reliability of the process, the model should satisfy the following conditions in its structure:

(1) The initial Token must be able to reach the end Token through the series of Transitions shown in Fig. 1;

(2) When the initial Token reaches the end after a series of Transitions, the output Place must contain at least one Token;

(3) The process model does not contain dead changes.

The established business process model based on petri net theory for engineering consulting is shown in Fig. 1, and the meanings of each Place and Transition in the figure are shown in Table 1.

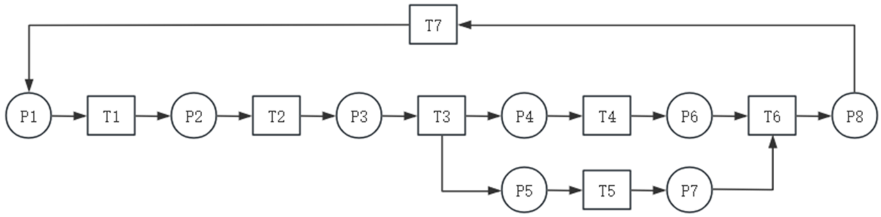

Fig. 1. A business process model for engineering consulting based on petri net

Table 1. Meaning of each Place and Transition in petri net model

Place	Meaning	Transition	Meaning
P1	Client submits project requirements	T1	Project Commissioning
P2	Acceptance of project entrustment by the entrusted party	T2	Signing of operational contracts
P3	Work docking	T3	Clarification of responsibilities and content of tasks by both parties
P4	Client builds project team	T4	Task division by the client team
P5	Entrusted party builds the project team	T5	Task division by the Entrusted party team
P6	Preparation of project-related information by the client	T6	Project implementation
P7	Project schedule proposal by the entrusted party	T7	Project results
P8	Project delivery		

Analyzing the performance indicators of this business process model assuming that resource is constrained[11], since engineering consulting services require a certain amount of manpower and material resources, under the constraint of resources, if the service cycle is long and the manpower is insufficient, it is prone to inefficiency and ineffectiveness of services, and it is necessary to carry out engineering consulting services for the next client only when the service resources are in an available state.

3.2 Setting the time for implementation of Transitions

Based on relevant work experience and other research results, the implementation time is set for each Transition of the business process model, as shown in Table 2

Table 2. Assignment of time for Transition implementation

Transitions	Assign-ment(workday)	Rate	1/workday
T1	0.1	λ_1	10
T2	0.1	λ_2	10
T3	0.5	λ_3	2
T4	0.2	λ_4	5
T5	4	λ_5	0.25
T6	10	λ_6	0.1
T7	1	λ_7	1

3.3 Isomorphic Markov chains

Based on the petri net model shown in Fig. 1 and the assignments in Table 2, the resulting isomorphic Markov chain for the model of Fig. 1 is shown in Fig. 2.

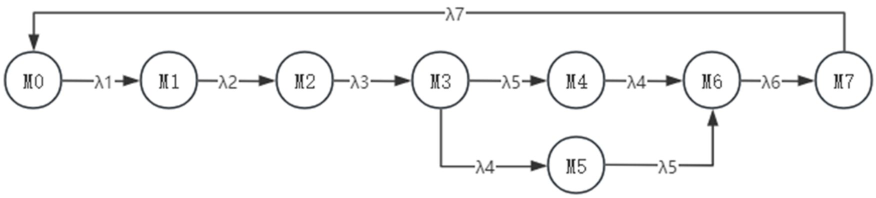

Fig. 2. Isomorphic Markov chains to the petri net models

Based on the petri net model shown in Fig. 1 and the isomorphic Markov chain shown in Fig. 2, the links in the isomorphic Markov chain and the Places they contain are obtained as shown in Table 3.

Table 3. The state of the isomorphic Markov chain and the Places it contains

Links in the isomorphic Markov Chain	M0	M1	M2	M3	M4	M5	M6	M7
Place	P1	P2	P3	P4/P5	P4/P7	P5/P6	P6/P7	P8

3.4 Solving the Markov chain

The transfer rate matrix of the isomorphic Markov chain is:

$$Q = \begin{bmatrix} -\lambda_1 & \lambda_1 & & & & & & \\ & -\lambda_2 & \lambda_2 & & & & & \\ & & -\lambda_3 & \lambda_3 & & & & \\ & & & -(\lambda_4 + \lambda_5) & \lambda_5 & \lambda_4 & & \\ & & & & -\lambda_4 & & \lambda_4 & \\ & & & & & -\lambda_5 & \lambda_5 & \\ & & & & & & -\lambda_6 & \lambda_6 \\ \lambda_7 & & & & & & & -\lambda_7 \end{bmatrix} \quad (6)$$

Solving for Eq. (2) yields the steady state probabilities for each state as shown in Table 4.

Table 4. Steady state probabilities for each state of a iosmorphic Markov chain

Links in the isomorphic Markov Chain	M_0	M_1	M_2	M_3	M_4	M_5	M_6	M_7
$P[M_i]$	0.00637	0.00637	0.03183	0.01212	0.00061	0.2424	0.63656	0.06365

3.5 Analyzing model performance indicators

According to Eq. (3) and Eq. (4), the average number of Token of the system can be obtained as 1.8916, and the labeled flow rate of the system Transition is 0.06365, according to the principle of equal rate of inflow and outflow of the system and the Eq. (5), the average execution time of the system can be obtained as 29.6954 workdays.

4 Conclusion

This paper introduces the theory of petri net into the process modeling field, introduces the related theory of stochastic petri net model, and introduces it into the field of engineering consulting, utilizes the mathematical model simulation ability of petri net model as well as its characteristics of graphical modeling, establishes an intuitive and easy-to-understand business process model of engineering consulting. This paper also assimilates the stochastic petri net model into a Markov chain, and analyzes its performance according to the relevant characteristics of the Markov chain to solve the characteristics of the system process and analyze its performance. This paper fully verifies the usability of the stochastic petri net model in the field of engineering consulting, but further research is still needed, such as how to precisely change and optimize the process according to the performance indicators results after the process performance evaluation.

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