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A Business Process Network Efficiency Model for Handling Conflicting Information

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Abstract

In today's big data era, where a significant volume of business data is generated daily, managing conflicting information within business process networks is crucial for maintaining operational efficiency. This paper addresses this challenge by proposing an efficiency model for business process networks tailored to handle conflict information, drawing on queuing theory and evidence theory. Firstly, we introduce a novel approach for measuring conflict information based on evidence theory and Pignistic probability transformation theory. Next, we tailor efficiency models for the four fundamental structures found in business process networks: sequential, selective, parallel, and loop structures, using queuing theory to manage conflict information effectively in each scenario. We further extend this approach by conceptualizing virtual business activities, allowing us to view the entire business process network as a sequential structure of virtual business activities, facilitating efficiency measurement across the network. Utilizing these measurements, we formulate the queuing service of the business process network as a nonlinear programming problem aimed at minimizing time, thus determining the optimal service rate for business process activities. Finally, we demonstrate the applicability and effectiveness of our proposed model through an experimental analysis focused on the railway intermodal transportation business process. The experimental results indicate that our model significantly reduces the impact of conflicting information, leading to a measurable improvement in the efficiency of the business process network. Specifically, the model achieves a notable enhancement in the coordination and execution of intermodal transportation activities, thereby streamlining operations and reducing decision-making uncertainties. This structured approach not only addresses the challenge of managing conflicting information within business process networks but also provides a clear framework for understanding and optimizing network efficiency.

KEYWORDS

Business process, conflict information, evidence theory, queuing theory, synergy efficiency

1. INTRODUCTION

The business process effectiveness model has always been the core of modern organizations, which affects the operation of business processes and needs to continuously adapt to the needs of business process development.[1] Additionally, business process networks play a crucial role in the business environment, generating significant volumes of business data and information daily. However, conflicts among these pieces of information pose challenges to the collaborative operation efficiency of business process networks. To address this issue, this paper proposes a novel efficiency model for business process networks based on queuing theory and evidence theory, aiming to handle conflict information and enhance network efficiency.

The collaborative operation of business process networks is paramount for organizational success. Yet, in such networks, information may originate from multiple sources, potentially leading to inconsistencies or conflicts. To minimize the impact of these conflicting pieces of information on business efficiency, a comprehensive solution is needed. Queuing theory and evidence theory serve as the foundation of this study, providing robust support to address these challenges.

Queuing theory helps us understand and optimize waiting and processing times within business processes, thereby minimizing delays caused by conflicting information. Evidence theory, on the other hand, offers an effective approach to handling inconsistencies and conflicts, enabling us to integrate information from diverse sources and make sound decisions.

Against this backdrop, to address the increasing volume of data and information and the resulting conflicts in modern business environments, this paper primarily relies on evidence theory, queuing theory, and business process theory to investigate the impact of conflict information on the efficiency of business process networks. We propose a novel efficiency model for business process networks based on the fusion of conflict information.

Through this study, we aim not only to propose a theoretical framework but also to validate its applicability and effectiveness through experimentation in real-world scenarios. Ultimately, our goal is to provide organizations with a viable approach to cope with the increasingly complex business environment and ensure the smooth operation of their business process networks.

This remainder of the paper is organized as follows. Section 2 discusses the related work concerning this study. In Section 3, some necessary assumptions are summarized. Section 4 presents the new business process network efficiency model, including the measurement of conflict information and the efficiency models for four typical business process network structures respectively. The algorithm of queuing service for business process is proposed in Section 5. Section 6 presents the experiment and analysis of the approach. The conclusions are drawn in Section 7.

2. RELATED WORK

In this section, wen review previous works related to business process network in two aspects:(1) business process effectiveness model, and (2) the handling of conflict information.

1) Literature review through the last few years has shown that the industry is paying more and more attention to the efficiency of business processes, including workflow modeling, scheduling optimization, and process reengineering. For example, Liu *et al.*[2] proposed a workflow model that measures the average value and probability density function of waiting time and processing time based on queuing theory and multi-dimensional workflow network. In addition, Ou-Yang and Winarjo[3] proposed a Petri-Net (PN) integration method that supports multi-agent process mining. Zeng *et al.*[4] defined four coordination models based on workflow integration and proposed a process integration method based on various organizational models and inter-organizational coordination models of cross-organizational workflow models. Bae *et al.*[5] added process semantics and selection paths to the business process structure, thereby realizing the evaluation of process time, completion time, and delay time. Hsu *et al.*[6] used the k-nearest neighbor method to detect the activity duration of the business process instance by analyzing the instances in the execution process of the business process, considering the execution, transmission, queue and delay of the activity. In addition, considering

resource scheduling, Xiao *et al.*[7] designed a collaborative optimization algorithm based on role professional ability evaluation model to solve the problem that role ability, authority and responsibility do not match in business process collaborative mode. For the consistency analysis of business process, Yang *et al.*[8] measured the consistency degree of business process according to the value of Petri net behavior compatibility, and put forward a business process consistency analysis method of Petri net based on probability and time factors. Li *et al.* [9] applied stochastic Petri nets for process modeling and evaluated it through Markov chain equivalence, which was then applied in the field of engineering consulting for business process modeling. Xu *et al.*[10] proposed a method for predicting remaining time in business processes, combining bidirectional gated recurrent neural networks and attention mechanisms. They improved prediction accuracy through iterative strategies. Li *et al.* [11] introduced a collaborative mechanism for business processes considering strategy priorities. They optimized coordination strategies to better match the value requirements of both collaborating parties. In addition to the above work, it can be seen from the literature review that the current business process efficiency research lacks attention to the impact of data/information flow on the efficiency of business process collaboration.

2) When merging uncertain information from different sources, it is inevitable to deal with conflicting information, that is, inconsistent information. The mathematical model commonly used for fusion are evidence theory and Bayesian theory. Since information processing based on Bayesian theory requires a lot of prior knowledge considerations,[12] information processing is more difficult, while evidence theory is more widely applied to represent and handle conflict and incomplete information from multiple sources.[13] In addition, the current research on conflict information mainly focuses on the conflict measurement, along with its application in information fusion and intelligent decision-making. Common conflict measurement methods include Jousselme distance,[14] evidence similarity measurement based on Tanimoto measure,[15] and Pignistic probability distance.[16] Based on the Dempster-Shafer (DS) combination rules of evidence theory, Altieri *et al.*[17] used the analytic hierarchy process to construct a hierarchical multi-attribute information fusion and decision-making method. In addition, Deng *et al.*[18] studied and analyzed how to deal with conflicts between data involved in DS combination rules of evidence theory and proposed a multi-source information fusion method based on Hellinger distance and trust entropy. Yan *et al.*[19] established a fusion factor based on probability distribution function and evidence trust and proposed a new evidence fusion rule. Therefore, the current research on conflict information mainly focuses on information fusion based on evidence

theory, so as to consider how to deal with conflict information as much as possible.

As mentioned above, in the modern information age, data/information flow has an important impact on the efficiency of business process collaboration. In particular, conflicting information is often generated in the networked operation of business processes. How to deal with the conflicting information of business process operations plays an important role in investigating and improving the efficiency of business process collaboration.

However, there is little research that combines business processes with evidence theory to improve the efficiency of business process networks. Furthermore, there has been scant research in the field of using queuing theory and evidence theory to handle conflicting information.

For this purpose, based on evidence theory, queuing theory and business process theory, this paper mainly studies the impact of conflict information on business process network efficiency and proposes a new business process network efficiency model based on conflict information fusion.

3. SOME ASSEMPTIONS

For the purpose of measuring the conflict information occurs in the execution of activities, without loss of generality, the business process activity is regarded as an independent M/M/1 queuing system. Some basic assumptions about activities in business processes are defined as follows:

1) In the processing procedure of business process activity A_i, queuing rules serve as first-come-first-served.

2) The business process instance's arrival process is independent and random, and modelled as an exponential distribution with the parameter λ.

3) The queue capacity of a business process activity A_i has no limit, so is enough to accommodate all arriving business process instances.

4) In business process activity A_i, the resource of service desk processes only one business process instance at a time, and the service time is modelled as an exponential distribution with the parameter μ_i.

4. BUSINESS PROCESS NETWORK EFFICIENCY MODEL

In this section, evidence theory and Pignistic probability transformation are used to measures conflicting information. Combining the conflict information measurement and M/M/1 queuing theory, the efficiency models of business process networks under four typical structures are then analysed and established.

4.1 Measurement of conflict information

Different measurements of conflict information can be derived according to different scenarios,[20] which are summarized below.

Scenario 1: assume that a hypothesis is represented by a subset of the frame of discernment $\Theta = \{A_1, A_2, \dots, A_n\}$, and $P_{m_1}(A_i)$ and $P_{m_2}(A_i)$ are the probability transformation functions corresponding to evidence m_1 and m_2 respectively. It is said that evidence m_t (t=1, 2) supports A_i if $P_{m_t}(A_i)$ is the maximum one ($i \in \{1, \dots, n\}$). If both m_1 and m_2 support the same proposition, then their conflict coefficient $k \in [0, 0.5]$ and is calculated as:

$$k = \frac{n}{4n-4} \sum_{A_i \in \Theta} \left| P_{m_1}(A_i) - P_{m_2}(A_i) \right|, i = 1,2,\dots,n \tag{1}$$

Scenario 2: assume that a hypothesis is represented by a subset of the frame of discernment $\Theta = \{A_1, A_2, \dots, A_n\}$, and $P_{m_1}(A_i)$ and $P_{m_2}(A_i)$ are the probability transformation functions corresponding to evidence m_1 and m_2 respectively. If m_1 and m_2 support different propositions, then their conflict coefficient $k \in [0.5, 1]$ and is calculated as :

$$k = \frac{1}{4} \sum_{A_i \in \Theta} \left| P_{m_1}(A_i) - P_{m_2}(A_i) \right| + \frac{1}{2}, i = 1,2,\dots,n \tag{2}$$

Scenario 3: assume that a hypothesis is represented by a subset of the frame of discernment $\Theta = \{A_1, A_2, \dots, A_n\}$, and $P_{m_1}(A_i)$ and $P_{m_2}(A_i)$ are the probability transformation functions corresponding to evidence m_1 and m_2 respectively. Due to the fact that different propositions may correspond to the same maximal value, that means m_1 and m_2 may support either the same proposition or different propositions, in this case, their conflict coefficient k is calculated as:

$$\begin{cases} y_1 = \frac{n}{4n-4} \sum_{A_i \in \Theta} \left| P_{m_1}(A_i) - P_{m_2}(A_i) \right| \\ y_2 = \frac{1}{4} \sum_{A_i \in \Theta} \left| P_{m_1}(A_i) - P_{m_2}(A_i) \right| + \frac{1}{2} \\ k = \alpha y_1 + (1-\alpha) y_2 \end{cases} \tag{3}$$

Here,

$$\alpha = \sum_{A_i \in \Theta} min\{P_{m_1}(A_i), P_{m_2}(A_i)\} \tag{4}$$

α indicates the degree of information consistency of evidence m_1 and evidence m_2.

Example 4.1. Assume a hypothesis with the frame of discernment $\Theta = \{A_1, A_2, A_3\}$, there are two evidences m_1 and m_2. $P_{m_1}(A_i)$ and $P_{m_2}(A_i)$ (i=1, 2, 3) are the probability transformation functions corresponding to m_1 and m_2 respectively with the following results:

$$m_1: P_{m_1}(\{A_1\}) = 0.49,\ P_{m_1}(\{A_2\}) = 0.17,\ P_{m_1}(\{A_3\}) = 0.34$$
$$m_2: P_{m_2}(\{A_1\}) = 0.52,\ P_{m_2}(\{A_2\}) = 0.24,\ P_{m_2}(\{A_3\}) = 0.24$$

For the evidence m_1, the maximum value of the probability transformation function is 0.49, which supports the proposition A_1. For the evidence m_2, the maximum value of the probability transformation function is 0.52, which supports the proposition A_1. Therefore, evidences m_1 and m_2 support the same proposition, so their conflict coefficient k is calculated using Equation (1):

$$k = \frac{3}{4*3-4} * [|0.49 - 0.52| + |0.17 - 0.24| + |0.34 - 0.24|] = 0.075.$$

4.2 Efficiency of network structure model

Although the overall business process is complex, it is essentially a nesting of various process structures, which can be decomposed into four basic process control structures: sequence, selective, parallel and loop structure.[21] Based on the existing research[20] about the efficiency of single business activities, the process efficiency of the whole business process under the influence of conflict information can be calculated.

4.2.1 Sequence structure

As is shown in Fig. 1, a part of the sub-structure in the whole business process is sequence structure, which consists of several independent key business activities operating in sequence.

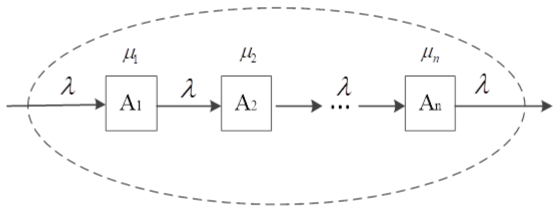

Fig. 1 Sequence structure in business process

As a result, the whole business process time is the sum of the key business activities' time in the sequence structure. Each business activity consists of waiting time, execution time, and transportation time. If the number of business activities is n in the subsystem, the efficiency index formula of each process is given as follows:

$$T(A_i) = W_q(A_i) + W_p(A_i) + C(A_i) = \frac{(1+k)}{\mu_i - \lambda - k\lambda} + C(A_i), i = 1,2,\ldots,n \quad (5)$$

$$PT = \sum_{i=1}^{n} T(A_i) \quad (6)$$

Here, $C(A_i)$ is the oper ation time between business activities, $T(A_i)$ is the activity cycling time of key business process activities, $W_q(A_i)$ is the waiting time of the business process instance in business process activities, $W_P(A_i)$ is the execution time of the business process instance in business process activities, and PT is the business process time of sub-sequential structure.

Example 4.2. Assume that there are three business activities in the sequence structure, with its conflict coefficient k =0.15, and we also have the service rate of each activity below:

$$\mu_1 = 6;\ \mu_2 = 7;\ \mu_3 = 6.$$

Meanwhile, the process instances arrive at this activity with an exponential distribution (4 times per hour), that is $\lambda = 4$. So the business process time of this sequence structure is:

$$PT = \sum_{i=1}^{3} T(A_i) = \frac{(1+k)}{\mu_1-\lambda-k\lambda} + C(A_1) + \frac{(1+k)}{\mu_2-\lambda-k\lambda} + C(A_2) + \frac{(1+k)}{\mu_3-\lambda-k\lambda} + C(A_3)$$

$$= \frac{1+0.15}{6-4-0.15*4} + C\left(A_1\right) + \frac{1+0.15}{7-4-0.15*4} + C\left(A_2\right) + \frac{1+0.15}{6-4-0.15*4} + C\left(A_3\right)$$

$$= 0.8214 + C(A_1) + 0.4792 + C(A_2) + 0.8214 + C(A_3) = 2.122 + C(A)$$

Here, $C(A) = C(A_1) + C(A_2) + C(A_3)$.

4.2.2 Selective structure

As is shown in Fig. 2 below, in the selective structure of business process, when branching, it can only select one of the paths in $\{A_1, A_{21}, A_{31}, A_4\}$, $\{A_1, A_{22}, A_{32}, A_4\}$, …, $\{A_1, A_{2n}, A_{3n}, A_4\}$.

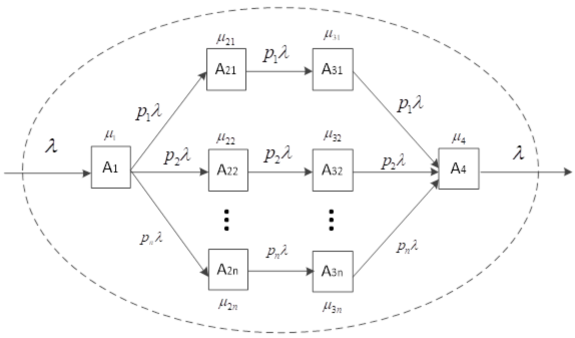

Fig. 2 Selective structure in the business process

Then the efficiency index formula of each process is given as follows:

$$T(A_1) = W_q(A_1) + W_p(A_1) + C(A_1) = \frac{(1+k)}{\mu_1-\lambda-k\lambda} + C(A_1)$$

$$T(A_4) = W_q(A_4) + W_p(A_4) + C(A_4) = \frac{k+1}{\mu_4-(k+1)*max\{p_1\lambda, p_2\lambda, \ldots, p_n\lambda\}} + C(A_4)$$

$$\begin{cases} T(A_{2n}) = \frac{(1+k)}{\mu_{2n}-\lambda p_n(1+k)} + C(A_{2n}) \\ T(A_{3n}) = \frac{(1+k)}{\mu_{3n}-\lambda p_n(1+k)} + C(A_{3n}) \end{cases}$$

$$\sum_{j=1}^{n} p_j = 1$$

$$C_n = C(A_1) + C(A_{2n}) + C(A_{3n}) + C(A_4)$$

$$PT = min\begin{cases} T(A_1) + T(A_{21}) + T(A_{31}) + T(A_4) \\ T(A_1) + T(A_{22}) + T(A_{32}) + T(A_4) \\ \dots \\ T(A_1) + T(A_{2n}) + T(A_{3n}) + T(A_4) \end{cases}$$

For the selective structure, the process time PT is the minimum value of the sum of time in all branch execution paths. That is,

$$PT = min\begin{cases} (1+k)[\frac{1}{\mu_1-\lambda(1+k)} + \frac{1}{\mu_{21}-\lambda p_1(1+k)} + \frac{1}{\mu_{31}-\lambda p_1(1+k)} + \frac{1}{\mu_4-(k+1)*max\{p_1\lambda,p_2\lambda,\dots,p_n\lambda\}}] + C_1 \\ (1+k)[\frac{1}{\mu_1-\lambda-k\lambda} + \frac{1}{\mu_{22}-\lambda p_2(1+k)} + \frac{1}{\mu_{32}-\lambda p_2(1+k)} + \frac{1}{\mu_4-(k+1)*max\{p_1\lambda,p_2\lambda,\dots,p_n\lambda\}}] + C_2 \\ \dots \\ (1+k)[\frac{1}{\mu_1-\lambda-k\lambda} + \frac{1}{\mu_{2n}-\lambda p_n(1+k)} + \frac{1}{\mu_{3n}-\lambda p_n(1+k)} + \frac{1}{\mu_4-(k+1)*max\{p_1\lambda,p_2\lambda,\dots,p_n\lambda\}}] + C_n \end{cases} \quad (7)$$

Example 4.3. If we have two paths for selection in the selective structure, that is n =2, and the probability of each path that includes four business activities is $p_1 = 0.4$ and $p_2 = 0.6$ respectively.

With the conflict coefficient k=0.15, and the flow instance reaches the index distribution 4 times per hour ($\lambda = 4$), also known that the service rate of each activity:

$$\mu_1 = 6;\ \mu_{21} = 6.5;\ \mu_{31} = 6.8;\ \mu_{22} = 6.2;\ \mu_{32} = 7.1;\ \mu_4 = 6.6$$

We can calculate the business process time of this example as follows:

$$PT = min\begin{cases} (1+k)[\frac{1}{\mu_1-\lambda(1+k)} + \frac{1}{\mu_{21}-\lambda p_1(1+k)} + \frac{1}{\mu_{31}-\lambda p_1(1+k)} + \frac{1}{\mu_4-(k+1)*max\{p_1\lambda,p_2\lambda,\dots,p_n\lambda\}}] + C_1 \\ (1+k)[\frac{1}{\mu_1-\lambda-k\lambda} + \frac{1}{\mu_{22}-\lambda p_2(1+k)} + \frac{1}{\mu_{32}-\lambda p_2(1+k)} + \frac{1}{\mu_4-(k+1)*max\{p_1\lambda,p_2\lambda,\dots,p_n\lambda\}}] + C_2 \end{cases}$$
$$= min\begin{cases} (1+0.15)[\frac{1}{6-4(1+0.15)} + \frac{1}{6.5-4*0.4(1+0.15)} + \frac{1}{6.8-4*0.4(1+0.15)} + \frac{1}{6.6-(0.15+1)*\max\{0.4*4,0.6*4\}}] + C_1 \\ (1+0.15)[\frac{1}{6-4-0.15*4} + \frac{1}{6.2-4*0.6(1+0.15)} + \frac{1}{7.1-4*0.6(1+0.15)} + \frac{1}{6.6-(0.15+1)*\max\{0.4*4,0.6*4\}}] + C_2 \end{cases}$$
$$= min\begin{cases} 1.5995 + C_1 \\ 1.7202 + C_2 \end{cases}$$

Here,

$$C_1 = C(A_1) + C(A_{21}) + C(A_{31}) + C(A_4);\ C_2 = C(A_1) + C(A_{22}) + C(A_{32}) + C(A_4)$$

Now, the business process time depends on the operation time between business activities $C(A_i)$, if $C_1 = C_2 = C$, then we get the minimum time for this example, that is $PT = 1.5995 + C$, so the selected path is $\{A_1, A_{21}, A_{31}, A_4\}$.

4.2.3 Parallel structure

In the parallel structure of business process, based on the same business process instance, the policy of executive path is to execute multiple branch paths simultaneously (see Fig. 3 below).

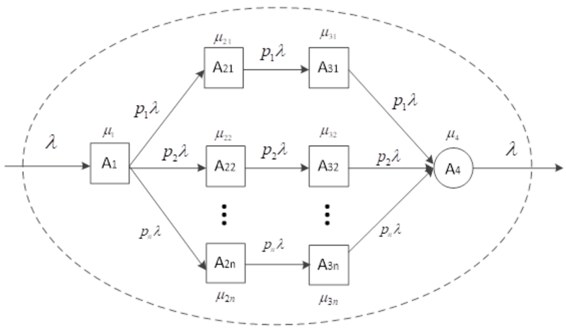

Fig. 3 Parallel structure in business process

Its business process efficiency indicators are calculated as follows:

$$T(A_4) = W_q(A_4) + W_p(A_4) + C(A_4) = \frac{k+1}{\mu_4 - (k+1)\lambda \sum_{j=1}^{n} p_j} + C(A_4).$$

Note that $\sum_{j=1}^{n} p_j = 1$, so we have

$$T(A_4) = \frac{k+1}{\mu_4 - (k+1)\lambda} + C(A_4).$$

For the parallel structure, the process time *PT* is the maximum value of the sum of active time in all branch execution paths. The efficiency of this structure is given by the Equation (8):

$$PT = max \begin{cases} (1+k)[\frac{1}{\mu_1 - \lambda(1+k)} + \frac{1}{\mu_{21} - \lambda p_1(1+k)} + \frac{1}{\mu_{31} - \lambda p_1(1+k)} + \frac{1}{\mu_4 - (k+1)\lambda}] + C_1 \\ (1+k)[\frac{1}{\mu_1 - \lambda(1+k)} + \frac{1}{\mu_{22} - \lambda p_2(1+k)} + \frac{1}{\mu_{32} - \lambda p_2(1+k)} + \frac{1}{\mu_4 - (k+1)\lambda}] + C_2 \\ \cdots \\ (1+k)[\frac{1}{\mu_1 - \lambda(1+k)} + \frac{1}{\mu_{2n} - \lambda p_n(1+k)} + \frac{1}{\mu_{3n} - \lambda p_n(1+k)} + \frac{1}{\mu_4 - (k+1)\lambda}] + C_n \end{cases} \quad (8)$$

Example 4.4. Assume there are two branches and each branch has four business activities in the parallel structure, $p_1 = 0.3$ and $p_2 = 0.7$ are the probabilities of the process executes the two branches respectively. Also given that the conflict coefficient *k*=0.15, and each activity's service rate is known as:

$$\mu_1 = 7.3;\ \mu_{21} = 6.9;\ \mu_{31} = 7.1;\ \mu_{22} = 7.2;\ \mu_{32} = 7.1;\ \mu_4 = 7.2.$$

Based on the analysis of the historical data, it is concluded that the flow instance reaches the index distribution, 4 times per hour, that is $\lambda = 4/h$.

So the business process time of this example is calculated based on the Equation (8):

$$PT = max \begin{cases} (1+k)[\frac{1}{\mu_1 - \lambda(1+k)} + \frac{1}{\mu_{21} - \lambda p_1(1+k)} + \frac{1}{\mu_{31} - \lambda p_1(1+k)} + \frac{1}{\mu_4 - (k+1)\lambda}] + C_1 \\ (1+k)[\frac{1}{\mu_1 - \lambda(1+k)} + \frac{1}{\mu_{22} - \lambda p_2(1+k)} + \frac{1}{\mu_{32} - \lambda p_2(1+k)} + \frac{1}{\mu_4 - (k+1)\lambda}] + C_2 \end{cases}$$

$$= max \begin{cases} (1+0.15)[\frac{1}{7.3 - 4(1+0.15)} + \frac{1}{6.9 - 4*0.3(1+0.15)} + \frac{1}{7.1 - 4*0.3(1+0.15)} + \frac{1}{7.2 - (0.15+1)*4}] + C_1 \\ (1+0.15)[\frac{1}{7.3 - 4(1+0.15)} + \frac{1}{7.2 - 4*0.7(1+0.15)} + \frac{1}{7.1 - 4*0.7(1+0.15)} + \frac{1}{7.2 - (0.15+1)*4}] + C_2 \end{cases}$$

$$= max \begin{cases} 1.2776 + C_1 \\ 1.4536 + C_2 \end{cases}$$

Here,

$$C_1 = C(A_1) + C(A_{21}) + C(A_{31}) + C(A_4);\ C_2 = C(A_1) + C(A_{22}) + C(A_{32}) + C(A_4)$$

Similarly, the business process time depends on the operation time between business activities $C(A_i)$, if $C_1 = C_2 = C$, then we get the maximum time of this instance, that is the parallel structure's process time $PT = 1.4536 + C$.

4.2.4 Loop structure

In the loop structure of business process, for some reasons, the business process activity may execute the same business process twice or more. As is shown in the following Fig. 4 , the loop structure is composed of several key business activities of loop structure, then the business process efficiency is the sum of each cycled activity time.

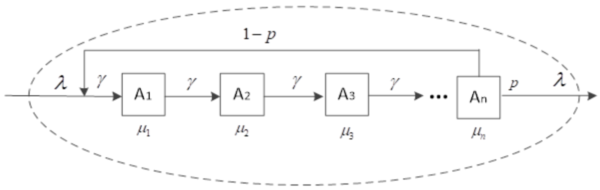

Fig. 4 Loop structure in business process

If the business process example has cycled R times in the loop structure, the efficiency index formula is given as follows:

$$T(A_i) = \frac{(k+1)p}{p\mu_i - (k+1)\lambda} + C(A_i) \tag{9}$$

$$PT = R * \sum_{i=1}^{n} T(A_i) \tag{10}$$

Example 4.5. If there are three business activities in the loop structure, and each activity will execute the same business process twice, that is R=2. Assume we have the following parameter values:

The conflict coefficient: k=0.15;

The service rate of each activity: $\mu_1 = 8;\ \mu_2 = 8;\ \mu_3 = 9;$

The probability of the process does not enter the loop structure: p=0.6;

The process instances arrive at this activity with an exponential distribution (4 times per hour): $\lambda = 4$.

So the business process time of this loop structure is:

$$PT = 2 * \sum_{i=1}^{3} T(A_i) = 2 * [\frac{(k+1)p}{p\mu_1 - (k+1)\lambda} + C(A_1) + \frac{(k+1)p}{p\mu_2 - (k+1)\lambda} + C(A_2) + \frac{(k+1)p}{p\mu_3 - (k+1)\lambda} + C(A_3)]$$

$$= 2 * [\frac{(0.15+1)*0.6}{0.6*8-(0.15+1)*4} + C\left(A_1\right) + \frac{(0.15+1)*0.6}{0.6*8-(0.15+1)*4} + C\left(A_2\right) + \frac{(0.15+1)*0.6}{0.6*9-(0.15+1)*4} + C\left(A_3\right)]$$

$$= 2 * [3.45 + C\left(A_1\right) + 3.45 + C\left(A_2\right) + 0.8625 + C\left(A_3\right)] = 15.525 + 2C(A)$$

Here, $C(A) = C(A_1) + C(A_2) + C(A_3)$.

We can notice that each sub-structure can be regarded as a virtual business process activity. Subsequently, the whole business process network is essentially a sequence structure of virtual activity. The virtual business activity is composed of actual activities.

$$PT_{network} = \sum PT_{sequence}^{virtual} = PT_{sequence}^{actual} + PT_{selection} + PT_{parallel} + PT_{loop} \tag{11}$$

Example 4.6. Assume that we have the model of whole business process network (see Fig. 5 below), which consists of sequence structure, selective structure, parallel structure and loop structure. To be specific, PT_1 is the loop sub-structure, PT_2 is the parallel sub-structure, PT_3 is the selective sub-structure, PT_4 is the sequence sub-structure.

Now, we take the sub-structures PT_1, PT_2 and PT_3 as virtual business process activities, so the whole business process network is essentially a sequence structure of virtual activity.

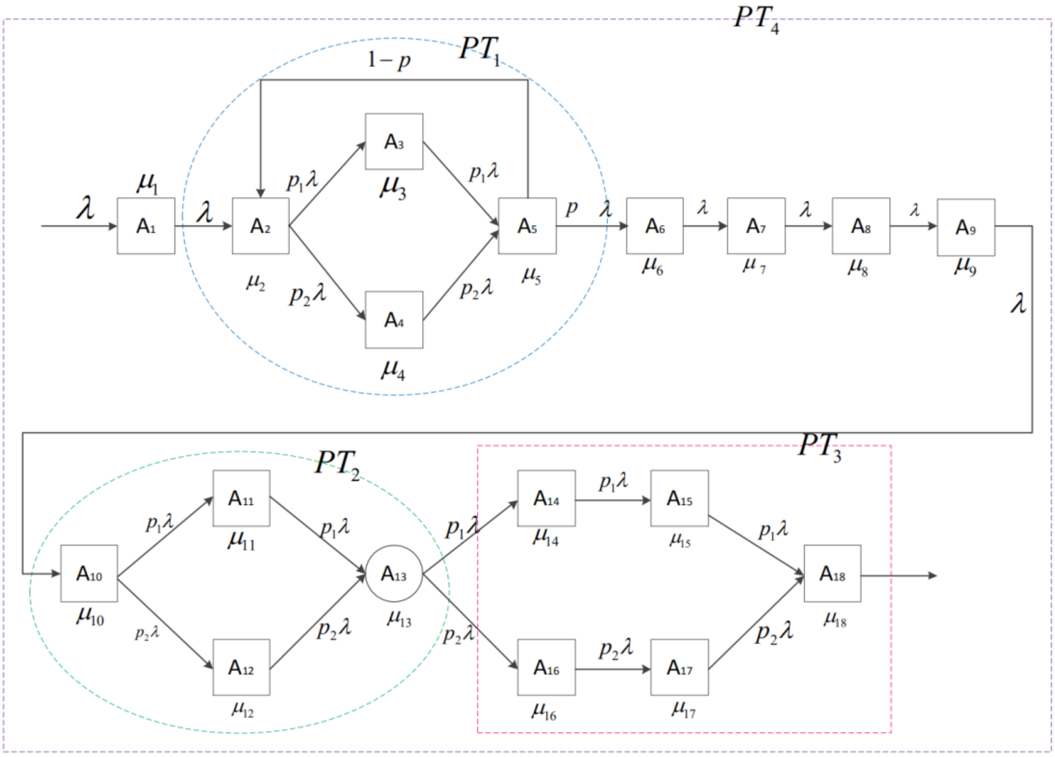

Fig. 5 An example model of whole business process network

The efficiency of the whole business process network is calculated by the Equation (11):

$$PT = \sum PT_{sequence}^{virtual} = PT_{sequence}^{actual} + PT_{selection} + PT_{parallel} + PT_{loop}$$

$$= PT_4 = [T(A_1) + \sum_{i=6}^{9} T(A_i)] + PT_1 + PT_2 + PT_3$$

Due to the fact that $\begin{cases} p_1\lambda = (1-p)p_1\lambda + \lambda \\ p_2\lambda = (1-p)p_2\lambda + \lambda \end{cases}$, it follows that $p_1\lambda = p_2\lambda = \frac{\lambda}{p}$.

$$PT_1 = min\begin{cases} R * [\frac{(k+1)p}{p\mu_2-(k+1)\lambda} + \frac{(k+1)p}{p\mu_3-(k+1)\lambda} + \frac{(k+1)p}{p\mu_5-(k+1)\lambda} + C_1] \\ R * [\frac{(k+1)p}{p\mu_2-(k+1)\lambda} + \frac{(k+1)p}{p\mu_4-(k+1)\lambda} + \frac{(k+1)p}{p\mu_5-(k+1)\lambda} + C_2] \end{cases}$$

$$PT_2 = max\begin{cases} (1+k)[\frac{1}{\mu_{10}-\lambda(1+k)} + \frac{1}{\mu_{11}-\lambda p_1(1+k)} + \frac{1}{\mu_{13}-(k+1)\lambda}] + C_3 \\ (1+k)[\frac{1}{\mu_{10}-\lambda(1+k)} + \frac{1}{\mu_{12}-\lambda p_2(1+k)} + \frac{1}{\mu_{13}-(k+1)\lambda}] + C_4 \end{cases}$$

$$PT_3 = min\begin{cases} (1+k)[\frac{1}{\mu_{14}-\lambda p_1(1+k)} + \frac{1}{\mu_{15}-\lambda p_1(1+k)} + \frac{1}{\mu_{18}-(k+1)*\max\{p_1\lambda, p_2\lambda\}}] + C_5 \\ (1+k)[\frac{1}{\mu_{16}-\lambda p_2(1+k)} + \frac{1}{\mu_{17}-\lambda p_2(1+k)} + \frac{1}{\mu_{18}-(k+1)*\max\{p_1\lambda, p_2\lambda\}}] + C_6 \end{cases}$$

In the formula,

$$C_1 = C(A_2) + C(A_3) + C(A_5); \quad C_2 = C(A_2) + C(A_4) + C(A_5);$$

$$C_3 = C(A_{10}) + C(A_{11}) + C(A_{13}); \quad C_4 = C(A_{10}) + C(A_{12}) + C(A_{13});$$

$$C_5 = C(A_{14}) + C(A_{15}) + C(A_{18}); \quad C_6 = C(A_{16}) + C(A_{17}) + C(A_{18});$$

Therefore, if the executive path of the whole business process network is:

$$\{A_1, A_2, A_4, A_5, A_6, A_7, A_8, A_9, A_{10}, A_{11}, A_{12}, A_{13}, A_{14}, A_{15}, A_{18}\}$$

Then, the efficiency of the whole business process network is:

$$PT = PT_4 = [T(A_1) + \sum_{i=6}^{9} T(A_i)] + PT_1\{A_2, A_4, A_5\} + PT_2 + PT_3\{A_{14}, A_{15}, A_{18}\}$$
$$= \left[\frac{(1+k)}{\mu_1-\lambda(1+k)} + C(A_1)\right] + \sum_{i=6}^{9}\left[\frac{(1+k)}{\mu_i-\lambda-k\lambda} + C(A_i)\right] + PT_1\{A_2, A_4, A_5\} + PT_2$$
$$+PT_3\{A_{14}, A_{15}, A_{18}\}.$$

The above section discussed the measurement of conflict information and introduced the efficiency models for four typical business process network structures respectively with example illustrations.

5. ALGORITHM OF QUEUING SERVICE FOR BUSINESS PROCESS

The whole business process goal is to improve the efficiency of process operation, that is, the queuing optimization problem to minimize the time. Therefore, the objective function of business process network along with its constraints are expressed as follows:

$$min\ PT = \sum_{h=1}^{w} T(W_h) = \sum_{h=1}^{w}\sum_{i=1}^{z}[Y_{hi} * \frac{\left(\frac{\mu_{hi}}{1+k}\right)}{\overset{\wedge}{\mu_h}} * (\frac{1+k}{\mu_{hi}-\lambda(1+k)} + C(A_{hi}))]$$
$$= \sum_{h=1}^{w}\sum_{i=1}^{z}[Y_{hi} * \frac{\mu_{hi}}{\overset{\wedge}{\mu_h}(1+k)} * (\frac{1+k}{\mu_{hi}-\lambda(1+k)} + C(A_{hi}))] \quad (12)$$

s.t.

$$\sum_{i=1}^{z}[\mu_{hi} * \frac{1}{1+k}\frac{\lambda * Y_{hi} * p_{hi}}{\sum_{i=1}^{z}(\lambda * Y_{hi} * p_{hi})}] = \overset{\wedge}{\mu_h}$$

Here,

w: The number of virtual activities in a business process network.

W_h: The hth virtual activity of business process network.

$\hat{\mu}_h$: The service rate of virtual business activity in the business process network.

μ_{hi}: The service rate of real business activity A_i without the impact of conflict information in the virtual activity.

z: The number of actual business activities contained in a virtual business activity.

p_{hi}: The execution probability of actual business activity A_i in the virtual business activity, $0 \leq p_{hi} \leq 1$.

Y_{hi}: Indicate whether the actual business activity in the virtual business activity participates in the execution of the business process instance or not. $Y_{hi} = 1$ means 'execution'; while $Y_{hi} = 0$ means 'not involved in execution'.

The above optimization problem can be regarded as a form of quadratic nonlinear programming problem with linear constraints. Accordingly, the gradient method is used to find the direction of descent direction of the function, the dichotomy method is used to reduce the range of the function solution, it is summarized in a compact form as follows:

$$\begin{gathered} min\, f\,(X) \\ s.t. \\ AX = b \end{gathered} \tag{13}$$

Here,

$$f(X) = PT; \quad X = [\mu_{h1}, \mu_{h2}, \ldots, \mu_{hz}]^T;$$

$$A = [\frac{\lambda * Y_1 * p_1}{(1+k)\sum_{i=1}^{z}(\lambda * Y_i * p_i)}, \ldots, \frac{\lambda * Y_z * p_z}{(1+k)\sum_{i=1}^{z}(\lambda * Y_i * p_i)}]; \quad b = [\mu];$$

The algorithm for queue service about the business process is designed to solve this optimization problem, which is summarized below:

TABLE 1 The algorithm of queuing service for business processes

Input: business process instance PI_s; the arrival rate λ of the business process instance; deviation $\varepsilon = 1 \times 10^{-6}$;
Output: the service rate μ_i of business process activity;
Procedure: **Step 1 Matrix segmentation** The coefficient matrix A is m row and n column, and dividing the coefficient matrix:

$$P_{m\times m}=\begin{bmatrix} a_{1p_1} & a_{1p_2} & \cdots & a_{1p_m} \\ a_{2p_1} & a_{2p_2} & \cdots & a_{2p_m} \\ \vdots & \vdots & \vdots & \vdots \\ a_{mp_1} & a_{mp_2} & \cdots & a_{mp_m} \end{bmatrix} \qquad B_{m\times s}=\begin{bmatrix} a_{1b_1} & a_{1b_2} & a_{1b_3} & \cdots & a_{1b_s} \\ a_{2b1} & a_{2b_2} & a_{2b_3} & \cdots & a_{2b_s} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{mb_1} & a_{mb_2} & a_{mb_3} & \cdots & a_{mp_s} \end{bmatrix}$$

$$A_{m\times n}=[P,B]_{m\times n}=\begin{bmatrix} a_{1p_1} & a_{1p_2} & \cdots & a_{1p_m} & a_{1b_1} & a_{1b_2} & a_{1b_3} & \cdots & a_{1b_s} \\ a_{2p_1} & a_{2p_2} & \cdots & a_{2p_m} & a_{2b1} & a_{2b_2} & a_{2b_3} & \cdots & a_{2b_s} \\ \vdots & \vdots & \vdots & & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{mp_1} & a_{mp_2} & \cdots & a_{mp_m} & a_{mb_1} & a_{mb_2} & a_{mb_3} & \cdots & a_{mp_s} \end{bmatrix}_{m\times n}$$

Similarly, the solution vector is divided into

$$X^T=[(X_P)^T,(X_B)^T]$$

Step 2 The conversion of a function condition

$$AX=b \Leftrightarrow [P,B]*[X_P,X_B]=b$$

According to the matrix multiplication theorem, it follows that:

$$P*X_P+B*X_B=b$$

multiply the inverse matrix, it is obtained:

$$X_P+P^{-1}B*X_B=P^{-1}b$$
$$X_P=P^{-1}b-P^{-1}B*X_B$$

Step 3 The initial point

With a nonzero vector v, existing $v^T=[(v_P)^T,(v_B)^T]$, which is satisfied $\nabla f(X)^T*v<0$, $v_P=(-P^{-1}B)v_B$, if the element values of the gradient $\nabla f(X)$ and vector v_B are opposite to each other, then the v is the initial feasible solution and dimensionality reduction direction of the function, marked as X^0.

Step 4 The gradient step

Initial point X^0, the derivative of the initial point $\nabla f(X^0)$

The vector of step $\delta=[\delta_1,\delta_2,\delta_3,...,\delta_z], i=1,2,\ldots,z$

Along the direction of the initial point, the gradient method is adopted to transform into an unconstrained nonlinear programming: $\max_{\delta}\psi(\delta)=f(X^t+\delta*(-\nabla f(X^t)))$

According to the gradient method, there is

$$X_i^{t+1}=X_i^t+\delta_i*\left(-\nabla f(X_i^t)\right)\geq 0,\ t=0,1,2,...$$

Due to the fact that $X_i^{t+1}=X_i^t+\delta_i*(-\nabla f(X_i^t))\geq 0$, it follows that:

$$\delta_i^{max}=\frac{X_i^t}{\nabla f(X_i^t)}$$

Step 5 Bisection method

If $f(\frac{X_i^{t+1}+X_i^t}{2})<0$, then $X_i^t=\frac{X_i^{t+1}+X_i^t}{2}$;

If $f(\frac{X_i^{t+1}+X_i^t}{2})>0$, then $X_i^{t+1}=\frac{X_i^{t+1}+X_i^t}{2}$;

Step 6 Judge feasible solution

If $f(X_i^{t+1})>f(X_i^t)$, then we will move to Step 5. Bisection method is implemented in the gradient descent direction to produce a new feasible solution.

If $f(X_i^{t+1})<f(X_i^t)$, then we will transfer to Step 7.

Step 7 judge the optimal feasible solution

If it satisfies $\begin{cases} |f(X^{t+1}) - f(X^t)| \le \varepsilon \\ \left| f(\frac{X^t + X^{t+1}}{2}) - f(X^t) \right| \le \varepsilon \end{cases}$, the optimal feasible solution is X^{t+1}.

Otherwise, *t*=*t*+1, and jump to Step 5.

Step 8 The end of algorithm, returning the optimal solution X^{t+1}.

Below provide the step and justification to determine the initial point X^0:

1) Partial derivatives of X_P and X_B

$$\begin{cases} \frac{\partial f(X)}{\partial X_P} = [\frac{\partial f(X)}{\partial x_{p_1}}, \frac{\partial f(X)}{\partial x_{p_2}}, \frac{\partial f(X)}{\partial x_{p_3}}, \dots, \frac{\partial f(X)}{\partial x_{p_m}}]^T \\ \frac{\partial f(X)}{\partial X_B} = [\frac{\partial f(X)}{\partial x_{b_1}}, \frac{\partial f(X)}{\partial x_{b_2}}, \frac{\partial f(X)}{\partial x_{b_3}}, \dots, \frac{\partial f(X)}{\partial x_{b_s}}]^T \end{cases}$$

$$\begin{aligned} \nabla f(X) &= \nabla f(X_P, X_B) = \nabla f(P^{-1}b - P^{-1}B * X_B, X_B) \\ &= -(P^{-1}B)^T \frac{\partial f(X)}{\partial X_P} + \frac{\partial f(X)}{\partial X_B} \end{aligned}$$

Marked as, $Q_B = \nabla f(X) = -(P^{-1}B)^T \frac{\partial f(X)}{\partial X_P} + \frac{\partial f(X)}{\partial X_B}$

2)

$$\nabla f(X)^T * v = [\frac{\partial f(X)}{\partial X_P}, \frac{\partial f(X)}{\partial X_B}]^T * [v_P, v_B] = \left(\frac{\partial f(X)}{\partial X_P}\right)^T v_P + \left(\frac{\partial f(X)}{\partial X_B}\right)^T v_B$$

3) According to $v_P = (-P^{-1}B)v_B$, then

$$\begin{aligned} \nabla f(X)^T * v &= \left(\frac{\partial f(X)}{\partial X_P}\right)^T v_P + \left(\frac{\partial f(X)}{\partial X_B}\right)^T v_B \\ &= \left(\frac{\partial f(X)}{\partial X_P}\right)^T (-P^{-1}B)v_B + \left(\frac{\partial f(X)}{\partial X_B}\right)^T v_B \\ &= \left(-\left(\frac{\partial f(X)}{\partial X_P}\right)^T * (P^{-1}B) + \left(\frac{\partial f(X)}{\partial X_B}\right)^T\right) * v_B \\ &= {Q_B}^T * v_B \end{aligned}$$

4) The values of the vector *X* and vector *Y* are negative, therefore:

$$v_e = \{-Q_e | e = b_1, b_2, \dots, b_s\}$$

5) Matrix multiplication, we have:

$$\nabla f(X)^T * v = (Q_B)^T * v_B = \sum_{l=b_1}^{b_s} (Q_l * v_l) = -\sum_{l=b_1}^{b_s} (Q_l)^2 < 0$$

Consequently, v is the initial feasible point of the function, which is also marked as X^0.

6. EXPERIMENTS AND ANALYSIS

We use the road and rail transportation business process (see Fig. 6) as a case study. The implementation of the activities in this process requires the integration of information from multiple participants such as railway bureaus, road and rail transport operators, and road transport companies. Especially in the process of integrating different types of information, conflicting information will cause hesitation in the execution of business activities and affect the efficiency of the entire road-rail combined transport operation.

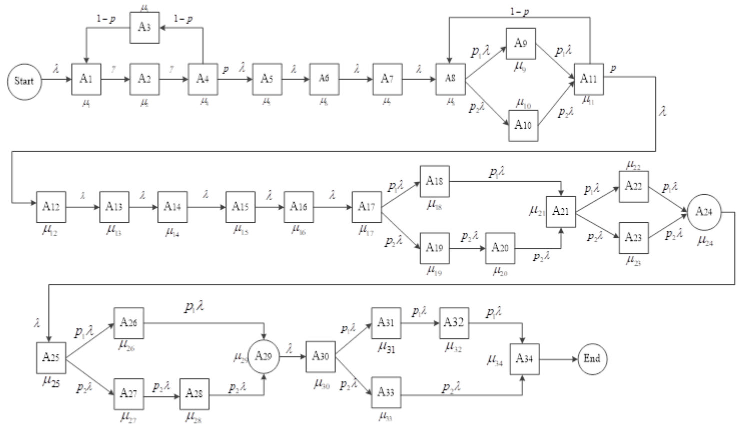

Fig. 6 The rail-road intermodal transport business process

Road and railway operators, road transportation companies, customers, cargo owners and railway bureaus share information throughout the entire business process of multimodal transportation. In the modeling process, we define the information type of the road-rail intermodal transportation business process operation as the identification frame element, which constitutes the identification frame. According to different information types, the evidence space is constructed and the result of the probability transformation function is calculated. Table 2 below shows the meanings of activities in the rail-road intermodal transport business process.

TABLE 2 The meaning of business process activity

Activity	Meaning
Start	The start activity of road-railway intermodal transport
A_1	The consignee sends the order to the shipper
A_2	The shipper accepts the order online
A_3	Contract modification
A_4	Negotiate the sales contract
A_5	The consignee and the consignee sign the sales contract
A_6	The shipper applies for transportation
A_7	Acceptance by road-railway intermodal transport operator
A_8	Formulate transportation plan
A_9	Inform shipper of transportation plan
A_{10}	Draw up contract of carriage
A_{11}	Confirm the terms of the carriage contract

A_{12}	Sign the carriage contract
A_{13}	Submit container application to railway bureau
A_{14}	Railway bureau allocates the empty containers
A_{15}	Inform container information to the oproperator
A_{16}	Inform the container information to the shipper and the road transport company
A_{17}	Sign the multimodal transport contract
A_{18}	The shipper prepares the goods for packing
A_{19}	Obtain empty containers
A_{20}	Transport by road carrier
A_{21}	The loading
A_{22}	The shipper informs delivery information to consignee
A_{23}	The heavy boxes are transported by the road carrier
A_{24}	The goods is reloaded at Terminal A
A_{25}	The railway transport
A_{26}	The goods is reloaded at Terminal B
A_{27}	Inform the arrival of the goods to operator
A_{28}	Schedule of railway transport costs
A_{29}	Road transport
A_{30}	The consignee takes the goods with documents
A_{31}	Empty containers transportation
A_{32}	Empty containers are delivered to the freight station
A_{33}	Schedule of road transport charges
A_{34}	Collect the documents of road-railway intermodal transport
End	The end activity of road-railway intermodal transport

Assume that evidence space is given as below:

m_1:

$$m_1(\{\theta_1\}) = 0.1, m_1(\{\theta_4\}) = 0.1, m_1(\{\theta_5\}) = 0.1, m_1(\{\theta_1, \theta_3, \theta_5\}) = 0.1,$$

$$m_1(\{\theta_2\}) = 0.1, m_1(\{\theta_3\}) = 0.2, m_1(\{\theta_1, \theta_2, \theta_3, \theta_4, \theta_5\}) = 0.3$$

m_2:

$$m_2(\{\theta_1\}) = 0.1, m_2(\{\theta_2\}) = 0.15, m_2(\{\theta_3\}) = 0.05, m_2(\{\theta_4\}) = 0.05,$$

$$m_2(\{\theta_4, \theta_5\}) = 0.2, m_2(\{\theta_5\}) = 0.15, m_2(\{\theta_1, \theta_2, \theta_3\}) = 0.3$$

m_3:

$$m_3(\{\theta_2\}) = 0.1, m_3(\{\theta_1\}) = 0.1, m_3(\{\theta_3\} = 0.05, m_3(\{\theta_2, \theta_3, \theta_4\}) = 0.2,$$

$$m_3(\{\theta_5\}) = 0.05, m_3(\{\theta_4\}) = 0.1, m_3(\{\theta_1, \theta_2, \theta_3, \theta_4, \theta_5\}) = 0.4$$

m_4:

$$m_4(\{\theta_1\}) = 0.1, m_4(\{\theta_2\}) = 0.1, m_4(\{\theta_3\}) = 0.1, m_4(\{\theta_4\} = 0.15,$$

$$m_4(\{\theta_5\}) = 0.05, m_4(\{\theta_1, \theta_3, \theta_5\}) = 0.2, m_4(\{\theta_2, \theta_4, \theta_5\}) = 0.3$$

m_5:

$m_5(\{\theta_1\}) = 0.1, m_5(\{\theta_4\}) = 0.15, m_5(\{\theta_5\} = 0.1, m_5(\{\theta_2\}) = 0.1,$

$m_5(\{\theta_3\}) = 0.1, m_5(\{\theta_2, \theta_4\}) = 0.15, m_5(\{\theta_1, \theta_2, \theta_3, \theta_4, \theta_5\}) = 0.3$

Here, θ_1 represents the order information, θ_2 represents the business activity information, θ_3 represents the vehicle information, θ_4 is the logistics equipment information, and θ_5 represents the role of information. In addition, m_1 represents the information source of railway bureau, m_2 represents the information source of road transport company, m_3 represents the information source of road-railway intermodal transport operator, m_4 represents the information source of shipper and m_5 is the information source of consignee.

The detailed steps are summarized below:

1) Conflict measurement

Pignistic probability conversion and the results of probability transformation function:

m_1: $P_{m_1}(\{\theta_1\}) = 0.209464$ $P_{m_1}(\{\theta_2\}) = 0.140714$ $P_{m_1}(\{\theta_3\}) = 0.318928$

$P_{m_1}(\{\theta_4\}) = 0.155114$ $P_{m_1}(\{\theta_5\}) = 0.171964$

m_2: $P_{m_2}(\{\theta_1\}) = 0.2$ $P_{m_2}(\{\theta_2\}) = 0.28125$ $P_{m_2}(\{\theta_3\}) = 0.11875$

$P_{m_2}(\{\theta_4\}) = 0.11665$ $P_{m_2}(\{\theta_5\}) = 0.28335$

m_3: $P_{m_3}(\{\theta_1\}) = 0.161449$ $P_{m_3}(\{\theta_2\}) = 0.248338$ $P_{m_3}(\{\theta_3\}) = 0.162599$

$P_{m_3}(\{\theta_4\}) = 0.248338$ $P_{m_3}(\{\theta_5\}) = 0.094638$

m_4: $P_{m_4}(\{\theta_1\}) = 0.166087$ $P_{m_4}(\{\theta_2\}) = 0.192857$ $P_{m_4}(\{\theta_3\}) = 0.166087$

$P_{m_4}(\{\theta_4\}) = 0.273215$ $P_{m_4}(\{\theta_5\}) = 0.201755$

m_5: $P_{m_5}(\{\theta_1\}) = 0.141276$ $P_{m_5}(\{\theta_2\}) = 0.213198$ $P_{m_5}(\{\theta_3\}) = 0.141276$

$P_{m_5}(\{\theta_4\}) = 0.296632$ $P_{m_5}(\{\theta_5\}) = 0.141276$

According to the measurement method of conflict information in different situations, the conflict coefficients between $\mathrm{m}_1, m_2, m_3, m_4, m_5$ are calculated and the conflict matrix is obtained:

$$K = \begin{bmatrix} 0 & 0.625007 & 0.6206295 & 0.599063 & 0.622633 \\ 0.625007 & 0 & 0.608928 & 0.601951 & 0.61784 \\ 0.6206295 & 0.608928 & 0 & 0.568192 & 0.542892 \\ 0.599063 & 0.601951 & 0.568192 & 0 & 0.048081 \\ 0.622633 & 0.61784 & 0.542892 & 0.048081 & 0 \end{bmatrix}$$

According to the idea of normalization,[22] the weight coefficient of each subject in the evidence space is calculated, and the following results are obtained: $\eta_1 = 0.2378972$, $\eta_2 = 0.2364108$, $\eta_3 = 0.2217582$, $\eta_4 = 0.1514245$, and $\eta_5 = 0.1525093$.

Therefore the integrated level of conflict k is calculated:

$$k = \sum_{i=1}^{5}[\eta_i * \frac{\sum_{j=1}^{5} K_{ij}}{5}] = 0.44812192$$

2) Service rates for rail-road intermodal transport operations under conflict information

According to the historical data, the flow instance reaches the index distribution, 4 times per hour, that is $\lambda = 4/h$. At the same time, according to the business process model of root shown in Fig. 6, the set of virtual business activity is composed of business process structure:

$W_1=\{A_1, A_2, A_3, A_4\}$, $W_2=\{A_5\}$, $W_3=\{A_6\}$, $W_4=\{A_7\}$, $W_5=\{A_8, A_9, A_{10}, A_{11}\}$, $W_6=\{A_{12}\}$, $W_7=\{A_{13}\}$, $W_8=\{A_{14}\}$, $W_9=\{A_{15}\}$, $W_{10}=\{A_{16}\}$, $W_{11}=\{A_{17}, A_{18}, A_{19}, A_{20}, A_{21}\}$, $W_{12}=\{A_{22}, A_{23}, A_{24}\}$, $W_{13}=\{A_{25}, A_{26}, A_{27}, A_{28}, A_{29}\}$, $W_{14}=\{A_{30}, A_{31}, A_{32}, A_{33}, A_{34}\}$.

The executive efficiency of the integrated road-rail transport business process $PT = \sum_{i=1}^{14} T(W_i)$. Calling the queue service algorithm for rail-road intermodal transport business process, the service rate can be obtained as follows with the MATLAB software:

$$A = [0.2302, 0.2302, 0, 0.2302, 0.2302\ , 0.2302, 0.2302, 0.2626,0.2140,0,0.2140, 0.1381, 0.1381, 0.1381, 0.1381, 0.1381, 0.1381, 0.3297, 0, 0.0311, 0.0311, 0.2987, 0.0438, 0.3014, 0.3453,0.1154,0.1054, 0.01, 0.01, 0.1154, 0.1154, 0.073, 0.073, 0, 0.073]$$

$$[\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}] = [8.092, 8.092, 7, 8.092, 8.092, 8.092, 8.092, 8.092, 7.8897,7, 7.8897, 8.092, 8.092, 8.092, 8.092, 8.092, 8.092, 7, 7.1029, 7.1029,7.9891, 7.1387,7.9533, 8.092,8.092, 7.9974,7.0946, 7.0946, 8.092, 8.092, 7.6905, 7.6905, 7, 7.6905]$$

3) Efficiency of integrated rail-road intermodal transport business process

In this example, from the service rate of rail-road intermodal transport business activities, the executive path of rail-road intermodal transport business process is given as follows:

$$\{A_1, A_2, A_4, A_5, A_6, A_7, A_8, A_9, A_{11}, A_{12}, A_{13}, A_{14}, A_{15}, A_{16}, A_{17}, A_{19}, A_{20}, A_{21}, A_{22}, A_{23}, A_{24}, A_{25}, A_{26}, A_{27}, A_{28}, A_{29}, A_{30}, A_{31}, A_{32}, A_{34}\}$$

The whole executive efficiency of rail-road intermodal transport business process is calculated as follows:

$$PT = \sum_{\substack{i=1 \\ i \neq 3}}^{7} T(A_i) + PT_{selection}\{A_8, A_9, A_{11}\} + \sum_{i=12}^{16} T(A_i) + PT_{selection}\{A_{17}, A_{19}, A_{20}, A_{21}\} + PT_{parallel}\{A_{22}, A_{23}, A_{24}\}$$

$$+PT_{parallel}\{A_{25},A_{26},A_{27},A_{28},A_{29}\}+PT_{selection}\{A_{30},A_{31},A_{32},A_{34}\}$$

$$\begin{cases} p_1=0.6324, p_2=0.3676, for\ PT_{selection}\{A_8,A_9,A_{11}\}; \\ p_1=0.1997, p_2=0.8003, for\ PT_{selection}\{A_{17},A_{19},A_{20},A_{21}\}; \\ p_1=0.4218, p_2=0.5782, for\ PT_{parallel}\{A_{22},A_{23},A_{24}\}; \\ p_1=0.3443, p_2=0.6557, for\ PT_{parallel}\{A_{25},A_{26},A_{27},A_{28},A_{29}\}; \\ p_1=0.7922, p_2=0.2078, for\ PT_{selection}\{A_{30},A_{31},A_{32},A_{34}\}; \end{cases}$$

It follows that:

$$PT=[3.77851053+C_1]+[1.31500497676+C_2]$$
$$+[3.1487587768+C_3]+[2.235504627+C_4]$$
$$+[0.944281646+C_5]+[2.13809409+C_6]$$
$$+[2.030395916+C_7]=(15.59055056+C)/h$$

Here, the constant C or C_i represents the flexible transit time in the actual integrated rail-road intermodal transport business. In addition, the waiting time of the process node concerned in the perspective of customers (or goods) can also be calculated by calculating the efficiency of the single rail-road intermodal transport business process, so as to find out the nodes with large time occupation and optimize the process.

Next, we consider more factors in this case, and then measure its whole executive efficiency in different conditions.

1) Executive probability of actual business activity

Different customers have different requirements for rail-road intermodal transport, which varies the probability of each activity in the business process. Now, assume that there are two customers.

When the first customer participates in the rail-road intermodal transport, the executive probabilities of actual business activities are as follows:

$$\begin{cases} p_1=0.4218, p_2=0.5782, for\ PT_{selection}\{A_8,A_9,A_{11}\}; \\ p_1=0.9157, p_2=0.0843, for\ PT_{selection}\{A_{17},A_{19},A_{20},A_{21}\}; \\ p_1=0.7922, p_2=0.2078, for\ PT_{parallel}\{A_{22},A_{23},A_{24}\}; \\ p_1=0.9595, p_2=0.0405, for\ PT_{parallel}\{A_{25},A_{26},A_{27},A_{28},A_{29}\}; \\ p_1=0.6557, p_2=0.3443, for\ PT_{selection}\{A_{30},A_{31},A_{32},A_{34}\}; \end{cases}$$

With the executive probabilities, we can get the service rates as follows with the MATLAB software:

$$[\mu_1,\mu_2,\mu_3,\mu_4,\mu_5,\mu_6,\mu_7,\mu_8,\mu_9,\mu_{10},\mu_{11},\mu_{12},\mu_{13},\mu_{14},\mu_{15},\mu_{16},\mu_{17},\mu_{18},$$
$$\mu_{19},\mu_{20},\mu_{21},\mu_{22},\mu_{23},\mu_{24},\mu_{25},\mu_{26},\mu_{27},\mu_{28},\mu_{29},\mu_{30},\mu_{31},\mu_{32},\mu_{33},\mu_{34}]$$
$$=[8.0531,8.0531,7,8.0531,8.0531,8.0531,8.0531,8.0531,7.4441,7,7.6089,8.0531,$$
$$8.0531,8.0531,8.0531,8.0531,8.0531,7,7.0887,7.0887,7.9643,7.8343,7.2188,$$

$8.0531, 8.0531, 8.0104, 7.0427, 7.0427, 8.0531, 8.0531, 7.6905, 7.6905, 7, 7.6905]$

From the service rates, we see that the executive path does not change. So, the whole executive efficiency of rail-road intermodal transport business process is calculated by the same formula, and the result is:

$$PT_1 = [3.8435 + C_1] + [1.2701 + C_2] + [3.2029 + C_3] + [1.6238 + C_4] + [1.0868 + C_5] + [1.8716 + C_6] + [1.7567 + C_7] = (14.6555 + C)/h$$

While the second customer has different requirement for rail-road intermodal transport, so the executive probabilities of actual business activities are different:

$$\begin{cases} p_1 = 0.7922, p_2 = 0.2078, for\ PT_{selection}\{A_8, A_9, A_{11}\}; \\ p_1 = 0.9595, p_2 = 0.0405, for\ PT_{selection}\{A_{17}, A_{19}, A_{20}, A_{21}\}; \\ p_1 = 0.6557, p_2 = 0.3443, for\ PT_{parallel}\{A_{22}, A_{23}, A_{24}\}; \\ p_1 = 0.0357, p_2 = 0.9643, for\ PT_{parallel}\{A_{25}, A_{26}, A_{27}, A_{28}, A_{29}\}; \\ p_1 = 0.8491, p_2 = 0.1509, for\ PT_{selection}\{A_{30}, A_{31}, A_{32}, A_{34}\}; \end{cases}$$

Similarly, the service rates can be obtained as follows with the MATLAB software:

$$[\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}]$$
$$= [7.8132, 7.8132, 7, 7.8132, 7.8132, 7.8132, 7.8132, 7.8132, 7.6443, 7, 7.6443, 7.8132, 7.8132, 7.8132, 7.8132, 7.8132, 7.8132, 7, 7.0329, 7.0329, 7.7803, 7.5333, 7.2800, 7.8132, 7.8132, 7.0290, 7.7842, 7.7842, 7.8132, 7.8132, 7.6905, 7.6905, 7, 7.6905]$$

With the different executive probabilities and different service rates, the whole executive efficiency of rail-road intermodal transport business process is calculated:

$$PT_2 = [4.2998 + C_1] + [1.6645 + C_2] + [3.5832 + C_3] + [1.7943 + C_4] + [1.1043 + C_5] + [2.7506 + C_6] + [2.2838 + C_7] = (17.4806 + C)/h$$

From the above calculation results, it can be seen that even under the same conflict information and the same instance arrival rate, the execution efficiency of the rail-road intermodal business process is different from different customers. In other words, the execution probability of business activities has an impact on the efficiency of business processes.

2) Conflict information

Due to the different participants in the railway-road intermodal transport business, the information shared in the operating network is also different. For example, when participants first joined the railway-road intermodal transport business, they were not familiar with the process and rules of information sharing, but as the number of participants increased, the proficiency of participants was strengthened, and the quality of shared information was gradually guaranteed. Therefore, conflicting information will fluctuate by 10% depending on the participant. Taking 5% as the calculation length, we can get the execution efficiency of the business process under different conflict coefficients.

First, suppose that the conflict is reduced by 10%, that is, $k_1 = k*(1\text{-}10\%) = 0.403309728$. We can calculate the service rate through MATLAB software, and calculate the overall execution efficiency of the railway intermodal business process:

$$[\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}]$$
$$= [7.8995, 7.8995, 7, 7.8995, 7.8995, 7.8995, 7.8995, 7.8995, 7.5689, 7, 7.5689, 7.8995, 7.8995, 7.8995, 7.8995, 7.8995, 7.8995, 7, 7.7199, 7.7199, 7.7199, 7.3794, 7.5201, 7.8995, 7.8995, 7.3097, 7.5898, 7.5898, 7.8995, 7.8995, 7.7126, 7.7126, 7, 7.7126]$$

$$PT_1 = [3.6828 + C_1] + [1.3121 + C_2] + [3.0690 + C_3] + [1.9181 + C_4] + [0.9421 + C_5] + [1.9456 + C_6] + [1.9029 + C_7] = (14.7726 + C)/h$$

Second, the conflict is reduced by 5%, that is $k_2 = k * (1 - 5\%) = 0.425715824$. Similarly, the service rates and the calculated result are as follows:

$$[\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}]$$
$$= [7.8854, 7.8854, 7, 7.8854, 7.8854, 7.8854, 7.8854, 7.8854, 7.5599, 7, 7.5599, 7.8854, 7.8854, 7.8854, 7.8854, 7.8854, 7.8854, 7, 7.7086, 7.7086, 7.7086, 7.3735, 7.5119, 7.8854, 7.8854, 7.3048, 7.5805, 7.5805, 7.8854, 7.8854, 7.7014, 7.7014, 7, 7.7014]$$

$$PT_2 = [3.9194 + C_1] + [1.3745 + C_2] + [3.2662 + C_3] + [2.0134 + C_4] + [0.9915 + C_5] + [2.0488 + C_6] + [1.9967 + C_7] = (15.6106 + C)/h$$

Third, the conflict is increased by 5%, that is $k_3 = k * (1 + 5\%) = 0.470528016$. With the new conflict coefficient, the service rates has changed:

$$[\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}]$$
$$= [7.8584, 7.8584, 7, 7.8584, 7.8584, 7.8584, 7.8584, 7.8584, 7.5429, 7, 7.5429, 7.8584, 7.8584, 7.8584, 7.8584, 7.8584, 7.8584, 7, 7.6870, 7.6870, 7.6870, 7.3621, 7.4963, 7.8584, 7.8584, 7.2955, 7.5629, 7.5629, 7.8584, 7.8584, 7.6800, 7.6800, 7, 7.6800]$$

And the calculated result of the whole executive efficiency is as follows:

$$PT_3 = [4.4645 + C_1] + [1.5134 + C_2] + [3.7204 + C_3] + [2.2247 + C_4] + [1.1032 + C_5]$$

$$+[2.2818 + C_6] + [2.2048 + C_7] = (17.5127 + C)/h$$

Fourth, the conflict is increased by 10%, that is $k_4 = k * (1 + 10\%) = 0.492934112$. We can get the service rates with the MATLAB software and calculate the whole executive efficiency:

$$[\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}]$$

$$= [7.8455, 7.8455, 7, 7.8455, 7.8455, 7.8455, 7.8455, 7.8455, 7.5347, 7, 7.5347, 7.8455, 7.8455, 7.8455, 7.8455, 7.8455, 7.8455, 7, 7.6767, 7.6767, 7.6767, 7.3566, 7.4889, 7.8455, 7.8455, 7.2911, 7.5544, 7.5544, 7.8455, 7.8455, 7.6698, 7.6698, 7, 7.6698]$$

$$PT_4 = [4.7805 + C_1] + [1.5913 + C_2] + [3.9838 + C_3] + [2.3425 + C_4] + [1.1667 + C_5] + [2.4141 + C_6] + [2.3207 + C_7] = (18.5995 + C)/h$$

According to the calculation results, as the conflict coefficient increases, the *PT* gradually increases, that is, the execution efficiency of the rail-road intermodal transport business process gradually decreases. Therefore, this case study shows that we can optimize the execution efficiency of the business process from the perspective of reducing conflicting information, such as providing guidance for information sharing to new participants and speeding up their proficiency.

In addition, with the gradual standardization of the form of business process information sharing and the gradual proficiency of participants in the information sharing process, sometimes there will be no conflicting information in the railway-road intermodal transport business process, that is, k_5=0. So how is the execution efficiency of the business process in this case?

Similarly, getting the service rates with the MATLAB software as follows:

$$[\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}]$$

$$= [8.2623, 8.2623, 7, 8.2623, 8.2623, 8.2623, 8.2623, 8.2623, 7.7983, 7, 7.7983, 8.2623, 8.2623, 8.2623, 8.2623, 8.2623, 8.2623, 7, 8.0102, 8.0102, 8.0102, 7.5324, 7.7299, 8.2623, 8.2623, 7.4346, 7.8277, 7.8277, 8.2623, 8.2623, 8.0000, 8.0000, 7, 8.0000]$$

Then, calculating the whole executive efficiency of the case which does not have conflict information:

$$PT_5 = [1.4077 + C_1] + [0.6142 + C_2] + [1.1731 + C_3] + [0.8584 + C_4] + [0.4192 + C_5] + [0.8535 + C_6] + [0.8556 + C_7] = (6.1817 + C)/h$$

When there is no conflict between the shared information, the result of the entire execution time is $PT_5 = (6.1817 + C)/h$, while the previous result is $PT = (15.59055056 + C)/h$, and the conflict coefficient k of the conflict information is 0.44812192. After simple calculations, we can conclude that the latter is almost 2.5 times than the former, which means that the existence of conflicting information will have a major impact on the efficiency of business process execution.

3) Arrival rate

In daily traffic activities, there are always peak periods and off-peak periods. When the traffic demand reaches the peak, the arrival rate of the process instance is 5 times per hour, and it is 2 times per hour during the off-peak period. Therefore, the value range of λ is 2, 3, 4, 5.

When $\lambda_1 = 2$, the service rates is obtained with the MATLAB software:

$$[\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}]$$
$$= [7.8717, 7.8717, 7, 7.8717, 7.8717, 7.8717, 7.8717, 7.8717, 7.5513, 7, 7.5513, 7.8717, 7.8717, 7.8717, 7.8717, 7.8717, 7.8717, 7, 7.6976, 7.6976, 7.6976, 7.3677, 7.5040, 7.8717, 7.8717, 7.3001, 7.5716, 7.5716, 7.8717, 7.8717, 7.6905, 7.6905, 7, 7.6905]$$

And the whole executive efficiency of rail-road intermodal transport business process is calculated:

$$PT_1 = [1.7463 + C_1] + [0.7974 + C_2] + [1.4553 + C_3] + [1.0986 + C_4] + [0.5395 + C_5] + [1.0927 + C_6] + [1.0961 + C_7] = (7.8259 + C)/h$$

When $\lambda_2 = 3$, using the MATLAB software to get the service rates and calculating the executive efficiency of the experiment:

$$[\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}]$$
$$= [7.8717, 7.8717, 7, 7.8717, 7.8717, 7.8717, 7.8717, 7.8717, 7.5513, 7, 7.5513, 7.8717, 7.8717, 7.8717, 7.8717, 7.8717, 7.8717, 7, 7.6976, 7.6976, 7.6976, 7.3677, 7.5040, 7.8717, 7.8717, 7.3001, 7.5716, 7.5716, 7.8717, 7.8717, 7.6905, 7.6905, 7, 7.6905]$$

$$PT_2 = [2.4633 + C_1] + [1.0134 + C_2] + [2.0527 + C_3] + [1.4398 + C_4] + [0.7006 + C_5] + [1.4343 + C_6] + [1.4330 + C_7] = (10.5372 + C)/h$$

When $\lambda_3 = 5$, the service rates are as follows:

$$[\mu_1, \mu_2, \mu_3, \mu_4, \mu_5, \mu_6, \mu_7, \mu_8, \mu_9, \mu_{10}, \mu_{11}, \mu_{12}, \mu_{13}, \mu_{14}, \mu_{15}, \mu_{16}, \mu_{17}, \mu_{18}, \mu_{19}, \mu_{20}, \mu_{21}, \mu_{22}, \mu_{23}, \mu_{24}, \mu_{25}, \mu_{26}, \mu_{27}, \mu_{28}, \mu_{29}, \mu_{30}, \mu_{31}, \mu_{32}, \mu_{33}, \mu_{34}]$$

$$= [7.8717, 7.8717, 7, 7.8717, 7.8717, 7.8717, 7.8717, 7.8717, 7.5513, 7, 7.5513, 7.8717,$$
$$7.8717, 7.8717, 7.8717, 7.8717, 7.8717, 7, 7.6976, 7.6976, 7.6976, 7.3677, 7.5040,$$
$$7.8717, 7.8717, 7.3001, 7.5716, 7.5716, 7.8717, 7.8717, 7.6905, 7.6905, 7, 7.6905]$$

Then, the whole executive efficiency is:

$$PT_3 = [13.7678 + C_1] + [3.2690 + C_2] + [11.4732 + C_3] + [4.5776 + C_4] + [2.7311 + C_5]$$
$$+[5.6149 + C_6] + [4.5174 + C_7] = (45.9510 + C)/h$$

From the results above, we can see that the instance's arrival rate has no effect on the service rate. But with the acceleration of the flow instance's arrival speed, the *PT* increases gradually.

7. CONCLUSIONS

This article proposes a business process network efficiency model based on queuing theory and evidence theory to minimize the impact of conflicting information on the operation efficiency of the business process network.

1) By applying evidence theory and Pignistic probability transformation to measure conflicting information, and integrating the measurement of conflicting information with M/M/1 queuing theory, four typical structural efficiency models of business process networks are analyzed and established.

2) To minimize time, the proposed model is transformed into a nonlinear programming model, and a business process queueing service algorithm is established.

3) Using the road-rail intermodal transportation business process as an example, the application of the proposed model is demonstrated and evaluated. It is concluded that the execution probability of actual business activities and conflicting information affect the efficiency of the business process network, while the arrival rate of individual cases during the transportation process does not affect the service rate of individual activities.

This article first proposes the idea of applying queuing theory to analyze and study the collaborative operation efficiency of business process networks with conflicting information from the customer's perspective. This research provides a solid theoretical and practical foundation for improving the efficiency of business process network execution in the context of big data.

The limitations of this article are primarily manifested in several key aspects. Initially, while the research establishes a theoretical and practical foundation for enhancing the operational efficiency of business process networks within the context of big data, it does not thoroughly investigate the application of big data analytics tools and technologies that could potentially enhance the performance of the model. Secondly, the study lacks an in-depth examination of the model's generalizability across diverse business process networks, which is critical for its broader applicability. Furthermore, the absence of direct quantitative comparisons with alternative methods restricts the assessment of the model's comparative advantages. These shortcomings highlight areas for future research and refinement, aimed at ensuring the model's capability to address the challenges posed by big data and the complexities inherent in contemporary business operations.

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