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# Improving Business Process Efficiency for Supply Chain Finance: Empirical Analysis and Optimization Based on Stochastic Petri Net

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**ABSTRACT** Efficient business process is important to the operations of supply chain finance (SCF). Many deficiencies exist in the processes of SCF such as complicated workflows and high time-consuming steps. However, few studies have paid attention to evaluate and improve the performance of SCF processes. We empirically model and investigate the processes of supply chain finance by constructing a Stochastic Petri Net based on the field survey of a focal firm. Two critical indices, place busy rate and transition utilization rate, are evaluated. The results demonstrate that some places (transitions) of the Petri Net have high busy rates (utilization rates). By integrating the Petri Net and dependency graph, several key places and transitions in the Petri Net of SCF processes are identified for further optimization. To improve the performance of SCF processes, we propose three optional adjusting schemes on the basis of information sharing perspective (for the first half of the Petri Net) and risk sharing perspective (for the second half of the Petri Net). The proposed optimization strategies have further been proven to reduce the place busy rates, shorten the process, and improve the process efficiency of the supply chain finance.

**INDEX TERMS** Supply chain finance, process improvement, stochastic Petri Net, information sharing, risk sharing.

## I. INTRODUCTION

Supply chain finance (SCF) is becoming more and more popular and important in the field of supply chain management. In 2016, it was reported that 68 percent of the firms in China had overdue payments, while 15.9 percent of the firms experienced overdue payments with the delay over 150 days [1]. There would be more severe payment delay when it comes to small and medium-sized enterprises (SMEs) [2]. Due to the weak risk resistibility, insufficient finance source and high financing cost, most SMEs have trouble in obtaining the external funds. The shortage of capital may incur the poor performance and low efficiency of a supply chain. SCF aims to align financial flows with product and information flows in

the supply chain, and to improve the cash flow management level from a supply chain's perspective [3]. By involving financial institutions [4] or technology providers [5], and alleviating the unforeseeable risks of an individual company into the one shared in the supply chain, SCF managers and operators would be able to control the potential risks more effectively [6], [7].

To better ameliorate the potential risks and enhance the workflow performance of SCF, an efficient process is necessary and important. Elaborately designed processes will significantly reduce the time-consuming periods and increase the benefits of SCF. On the contrary, an inferior operation process would weaken the performance of SCF. Thus, it is untrivial to investigate the performance of SCF in theory and practice, and to identify the deficiencies and key steps that are potential to improve the SCF process.

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In prior literature, many topics in SCF research field are widely studied including characteristics of SCF [8], interaction of the SCF three entities (the bank, focal firm and financing applicant) in game theory [9], decision optimization by mathematical model [10], and corresponding computational technologies [11] *et al.* However, there are few studies involving the process optimization in the domain of SCF. How to improve and optimize SCF processes is still a big challenge for scholars and practitioners. To fill the research gap, we investigate the SCF process performance based on the Petri Net and propose the improving strategies considering the perspectives of information sharing and risk sharing.

Our work focuses on the supply chain of a national high-tech enterprise named as Company J which specializes in the production of heat exchanger equipment. A powerful modeling method, Stochastic Petri Net (SPN) embedded with time delay, is adopted to analyze the performance of the SCF process. Stochastic Petri Net, which describes data flow, control flow and status transition, is a graphic tool for simulation modeling and analysis of complex systems [12], [13]. As an extended Petri Net, the Stochastic Petri Net (SPN) is applicable for both static and dynamic analysis with stochastic processes. Hence, SPN can be a useful tool to investigate the process of supply chain finance. In the Stochastic Petri Net, the place busy rates and transition utilization rates are calculated to identify the weak parts of the process that need to be improved. However, few studies have ever used Stochastic Petri Net to evaluate and optimize the process of supply chain finance. In addition, dependency graph is also used to identify and verify the places and transitions in SPN that should be potential for adjustment.

The simulation results demonstrate that some places (transitions) at the first and second half of SPN have higher place busy rates (transition utilization rates). Specifically, those parts closely related to the two activities in the process, i.e. “the inspection on Downstream firms”, and “the repayment of Downstream firms”, are the significant parts for process improving. The identification of key events in the dependency graph echoes to the SPN evaluation. At the first half of the process, according to the information sharing in the theory of SCF, we suggest to integrate (the “I” in ESIA principal, i.e. Eliminate, Simplify, Integrate and Automate) the inspection of Company J and the Bank on the financing applicants (Downstream firms in our context). When it comes to the repayment of Downstream firms, Company J (the focal firm) is involved into the repayment to share the risk with the bank, so that there would be sufficient funds in the account of financing applicant to fulfill the repayment. As a result, three optional improving schemes are proposed: information sharing, risk sharing, information & risk sharing. The metrics including time-consumption, place busy rates and transition utilization rates are expected to decline.

This study contributes to the literature of supply chain finance twofold: (1) A research procedure is proposed to improve the process optimization in SCF by combining the Stochastic Petri Net modeling tool and ESIA principle.

(2) Three improving strategies from the information and risk sharing perspectives, which not only are feasible in our context, but also may be generalized to other supply chains and industries, would enrich the theory of process management and optimization.

The rest of this paper is organized as follows: Section II reviews the related literature on supply chain finance process management and Petri Net applications. Section III constructs the Petri Net of SCF process. Section IV evaluates the performance of SCF process based on the Stochastic Petri Net with analysis of place busy rates and transition utilization rates. In this section, we also use the dependency graph to analyze the causality of process events in the Petri Net and analyze the critical events. Section V selects the potentially adjustable places and transitions and proposes three adjusting schemes to improve the process. Section VI concludes our study with findings, theoretical and practical implications and opportunities for future work.

## II. LITERATURE REVIEW

### A. SUPPLY CHAIN FINANCE AND BUSINESS PROCESS

Supply chain finance refers to a set of solutions to finance specific products as they move along the supply chain [11]. By integrating the financing into supply chains, there would be more effective control over the capital flow, information flow, and logistics; thus, the risks of the chain would be mitigated [14]. Supply chain finance has become an efficient means to solve the funds shortage, which is one of the major problems of SMEs [15]. The primary financing patterns can be categorized into three types: financing for accounts receivable, financing for prepayment and financing for stock [16].

Supply chain finance has attracted a lot of scholars' attention and interest over the past decade. Many scholars find that potential risks in dynamic and turbulent supply chain finance systems will be even more complicated. Furthermore, information asymmetry in supply chain finance process will lead to the greater potential risks. Without controlling the risks properly, the capital chain may break [17]. Some researchers [1], [18] analyze the risk of supply chain financing by introducing the basic model of supply chain finance for SMEs, and propose the corresponding solutions. Some other scholars [6], [19] discuss the classification of credit risk in commercial bank supply chain finance business and the principles of risk management. Generally speaking, there are five key types of risks in supply chain finance: credit risk, market risk, legal risk, operational risk and regulatory risk [20].

There exist unneglectable risks in the business processes of supply chain finance, e.g. overstaffing in organizations [21], poor communications [22] and among others. Business process consists of several activities that are run by different entities [23]. The process becomes complicated due to some uncorrelated activities and different kinds of coordination mechanisms [24]. The high complexity may render high challenges to manage the process effectively [25]. Moreover, inefficient workflows may lead to low work efficiency and

business process flexibility [24]. Thus, improvement of business processes is essential for an organizational survival and business success [25]–[27].

However, few studies have spent effort on the process of supply chain finance. The existing literature mainly concentrates on the risk management of supply chain finance and financing theoretical models. As mentioned in [28], there is great potential for us to reschedule the business process to reduce cost, enhance efficiency, improve customer satisfaction, and even to promote social welfare of the supply chain.

### B. MODELING TOOL: PETRI NET

Petri Net is a well-known representational language to model business process [29], which can be used to represent parallel or concurrent activities in a system and can enable users to investigate the whole system visually [30]. A Petri Net consists of four elements: place, transition, directed arc and token. A place not only represents a location, but also presents the resource depository. Tokens are represented by small black dots in the place, which are dynamic objects that can be moved from one place to another. Events are generally characterized by “transitions”. There is a directed arc between the place and the transitions [31], [32].

Petri Net has been proven to be a powerful simulation system that is applicable to various research fields such as work flow [33], performance evaluation [34], software design [35], food systems [36], web service discovery [12], emergency healthcare systems [13], property preservation [37], multithreaded software [38], and resource allocation systems [39] *et al.* Some types of Petri Nets have been developed, including Timed Petri Net (TPN) [40], Colored Petri Net (CTPN) [41], Generalized Stochastic Petri Net (GSPN) [42], and so forth.

In the complicated system, Petri Net is able to evaluate the performance of the system accurately [30]. Additionally, Petri Net can adjust flexibly as the rule varies, which empowers it to be an ideal modeling approach to simulate the business process. Thus, Petri Net is widely adopted to the study of process management. For instance, a model [5] integrating Timed and Colored Petri Net with correlation graphs is built to study several performance indicators of supply chain events. Zhu *et al.* [29] build a location-aware Petri Net to adjust business process. In the context of cross-organizations, Zeng *et al.* [43] use Petri Net to analyze the data from the operational logs of each system server and model the process.

However, to the best of our knowledge, no study has applied Petri Net to analyze the business process of supply chain finance. In our study, Stochastic Petri Net embedded with time parameters is utilized to assess the business process of supply finance and identify the key places and transitions that would be optional to optimize the SCF process.

### C. ESIA PRINCIPLE

ESIA principle is widely applied to systematically improve the existing process and customer satisfaction. On the basis

of analysis and understanding of the exist process, we are able to create the new process using ESIA principle [44]. Specifically, the basic content of ESIA consists of four tasks [45]: Eliminate (Eliminating unnecessary steps in the original process), Simplify (Simplification of the remaining process based on the previous step), Integrate (Integrating the decentralized steps to form a smooth flow) and Automate (Using modern information technology to realize automatic operation of process).

ESIA principle is fairly practical and popular in the business process management. As stated by Gasparski [46], “ESIA allows one to analyze individual business process and interactions between them, identifying the potential for specific improvements. Interestingly, this approach is similar to Kotarbiński’s economization measures, described in this paper, but more simplistic, disregarding some of the potentially useful improvement techniques that had been identified by Kotarbiński”. Indramawan and Yadrifil [47] apply ESIA to construct As-Is and To-Be processes in project procurement and show that the processing time can be shortened up to forty percent. Also, a modified version of the ESIA framework is used for further process improvement [48]. Thus, the ESIA method has been proven to be a suitable analysis tool for business process reengineering in many application areas, such as multimedia audio-visual process improvement [49] *et al.* In our study, the principle of ESIA, combined with the theory of supply chain finance, is applied to improve the process of SCF.

## III. PETRI NET OF COMPANY J’S SUPPLY CHAIN FINANCIAL BUSINESS PROCESS

### A. PETRI NET CONSTRUCTION

Company J is a national high-tech enterprise that specializes in the production of air-conditioning heat exchanger equipment, high-speed precision stamping equipment, and micro-channel heat exchanger equipment *et al.* As one of the largest suppliers in the air-conditioning heat exchanger industry, the firm produces these products that are popular in both the domestic market and abroad (exported to over 40 countries around the world). The high unit-price (value) of the products may exert heavy capital loads on its Downstream firms and may even cause the loss of sales. As the focal firm of the supply chain, Company J tends to offer guarantee support for its Downstream firms so that the banks are willing to grant Downstream firms the loans (i.e. supply chain finance). There will be a complex financing process in the supply chain to control the risks when the banks are involved. However, to balance the risk control and workflow complexity, the process of SCF should be evaluated and optimized.

Company J’s business processes of SCF are collected by means of field research [50], as shown in Figure 6 (Appendix A). The investigation design and key process contents of the field research are described in detail in Appendix A. To be specific, we started the investigation from the manufacture departments, by interviewing the



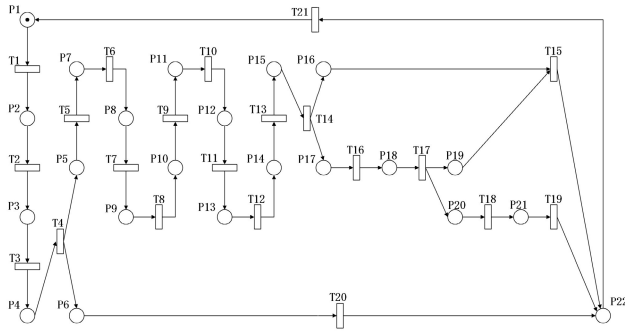


FIGURE 1. The Petri Net of company J's SCF business process.

$R(M_0)$  as vertices, and an arc set representing the direct reachability relationship between labels. By exploring the network system's state change and transition occurrence sequence, the relevant properties of the network system can be obtained. In this section, we analyze the basic properties of the Petri Net as shown in Figure 1 to verify the correctness using the reachable marking graph.

In the reachable marking graph, the corresponding identity of each vertex is combined into a vector. The Petri Net place set has  $m$  elements,  $P = \{P_1, P_2, \dots, P_m\}$ ; Thus, an identifier  $M$  of this net can be expressed as an  $m$ -dimensional vector  $M = [M(P_1), M(P_2), \dots, M(P_m)]$ .

Definition. Let  $q_{i,j} = d(1 - e^{-\lambda_k \tau})/d\tau|_{\tau=0} = \lambda_k$  denotes a bounded Petri net. The reachable marking graph of  $\Sigma$  is defined as a triple  $RG(\Sigma) = (R(M_0), E, P)$ , where:

$$E = \{(M_i, M_j) | M_i, M_j \in R(M_0), \exists t_k \in T : M_i[t_k > M_j]\}$$

$$P : E \rightarrow T, P(M_i, M_j) = t_k, \text{ if and only if } M_i[t_k > M_j$$

Let  $R(M_0)$  be the vertex set of  $RG(\Sigma)$  and  $E$  be the arc set of  $RG(\Sigma)$ ; if  $P(M_i, M_j) = t_k$ , then name  $t_k$  as a subscript of the arc  $(M_i, M_j)$ .

The reachable marking graph is a useful tool for analyzing the properties of the bounded Petri Net, which can help to identify those unfavorable situations in the Petri Net, e.g., conflicts and dead chains (see Figure 7 in Appendix A). All the markings in the Petri Net are reachable starting from  $M_0$ . There is constantly a transition sequence that enables the transition  $T$ , i.e.,  $T$  meets the condition of liveness.

#### IV. EVALUATION OF PROCESS PERFORMANCE BASED ON A STOCHASTIC PETRI NET

The time delay of the transition is introduced to construct the Stochastic Petri Net (SPN). The performance of the system can be quantitatively evaluated using the isomorphism of its state space and Markov chain. In terms of the occurrence of an event in the system, the Petri Net usually consumes a certain amount of time. Denote  $\lambda \in \{\lambda_1, \lambda_2, \dots, \lambda_n\}$  as the firing rate for each transition, where  $\lambda$  is assumed to follow a certain probability distribution to construct a Stochastic Petri Net.

There are three steps involved in the evaluation procedure:

- 1) Establishing a Stochastic Petri Net of the system.

- 2) Constructing a Markov chain that is isomorphic to the Stochastic Petri Net.

- 3) Evaluating the required system performance based on the stable state probability of the Markov chain.

In the third step, the  $n \times n$  transfer matrix is denoted as  $Q = [q_{i,j}]$ ,  $1 \leq i, j \leq n$ ,

i) when  $i \neq j$

If  $\exists t_k \in T : M_i[t_k > M_j]$  then

$$q_{i,j} = d(1 - e^{-\lambda_k \tau})/d\tau|_{\tau=0} = \lambda_k \tag{1}$$

else  $q_{i,j} = 0$

ii) when  $i = j$

$$q_{i,i} = d \prod_k (1 - (1 - e^{-\lambda_k \tau})) / d\tau|_{\tau=0}$$

$$= de^{-\tau} \sum_k \lambda_k / d\tau|_{\tau=0}$$

$$= - \sum_k \lambda_k \tag{2}$$

where  $k \neq i$  and  $\exists M' \in [M_0 > , \exists t_k \in T : M_i[t_k > M']$ ,  $\lambda_k$  is the rate of  $t_k$ .

Denoting a row vector  $X = (x_1, x_2, \dots, x_n)$  as the steady state probability of  $n$  states in a Markov chain, the linear equations according to the Markov chain process is derived as follows:

$$\begin{cases} XQ = 0 \\ \sum_i x_i = 1 \end{cases} \quad 1 \leq i \leq n, \tag{3}$$

where  $Q$  is the state transfer matrix. Denoting  $x_i = P[M_{i-1}]$ , i.e.,  $x_1 = P[M_0]$ .

The performance is measured in terms of place busy rate and transition utilization rate. In the steady state, the probability density function of the mark indicates the probability of the number of tokens contained in each place (node).

**Place busy rate:** The token probability function of the place  $P_i$  is obtained by using the stable probability of the reachable marking ( $\forall P_i \in P, \forall i \in N, :$ )

$$P[M(P) = i] = \sum_j P[M_j] \tag{4}$$

where  $M_j \in [M_0 > \text{ and } M_j(P) = i$

**Transition utilization rate:** The utilization rate  $U(t)$  ( $\forall t \in T$ ) is the sum of all the stable probabilities, which belongs to markings that enable  $t$  to be implemented:

$$U(t) = \sum_{M \in E} P[M], \tag{5}$$

where  $E$  is the set of all reachable markings that enable  $t$  to be implementable.

#### A. BUSY RATE OF PLACES

As shown in Appendix B, we firstly calculate the steady-state probabilities of each marking obtained by formula (3). Afterward, the place busy rates are derived leveraging the formula (4) as shown in Table 2.

Obviously,  $P_6$  (The Bank rejects the requirements of Downstream firms) has the highest busy rate, while  $P_{22}$  (End of this round of financing process) and  $P_5$  (The Bank's

**TABLE 2.** The busy rate of places.

Place	Busy rate	Place	Busy rate
<i>P1</i>	<b>0.1322</b>	<i>P12</i>	0.0283
<i>P2</i>	<b>0.0881</b>	<i>P13</i>	0.0057
<i>P3</i>	<b>0.0881</b>	<i>P14</i>	0.0378
<i>P4</i>	0.0110	<i>P15</i>	0.0283
<i>P5</i>	<b>0.1888</b>	<i>P16</i>	<b>0.1180</b>
<i>P6</i>	<b>0.5296</b>	<i>P17</i>	0.0755
<i>P7</i>	0.0378	<i>P18</i>	0.0142
<i>P8</i>	0.0566	<i>P19</i>	<b>0.0850</b>
<i>P9</i>	0.0566	<i>P20</i>	0.0094
<i>P10</i>	0.0283	<i>P21</i>	0.0189
<i>P11</i>	0.0378	<i>P22</i>	<b>0.2643</b>

approval of the application) follow. In addition, the busy rates of *P1* (Downstream firms submit financing requirements to company J), *P2* (Company J investigates Downstream firms), *P3* (Company J contacts Cooperative bank), *P16* (Downstream firms have sufficient fund in the account) and *P19* (Sufficient fund in the account of Downstream firms with the cooperation of company J) are as well at high levels.

Place busy rate presents the probability that a place is busy during the process of supply chain finance. The greater the probability is, the busier the place would be. Based on the results of Table 2, there are some critical places that are potential to further improve the performance of SCF process. *P1*, *P2* and *P3* are the preliminary stages of the process, which are busy and time-consuming. *P5* denotes the busy processing on the bank's approval of application. In the case that the bank rejects the financing application, there would be information block at *P6* with the highest place busy rate. The reason for the high busy rate of *P22* (End of a round of financing process) pertains to the factors that terminate the financing abnormally, i.e., the Bank rejects the requirements of Downstream firms or Downstream firms have insufficient fund in the account, which piles up the information at place *P22*. The Downstream firms' repayment states phased to the bank will result in the status of the Downstream firms' funds in the bank account to be sufficient or not. This is critical to whether the financing can be operated properly in the late stages of the process. Therefore, we should as well pay attention to *P16* to improve the process. In addition, if Downstream firms' account has sufficient funds with the cooperation of company J, the SCF process can be proceeded more smoothly, implying that *P19* should also been taken into consideration. In general, the places of *P1*, *P2*, *P3*, *P5*, *P6*, *P16*, *P19* and *P22* are the key places for improvement.

### B. UTILIZATION RATE OF TRANSITIONS

The utilization rate of a transition in the process refers to the sum of the stable probability of all state markings when the transition is performed. From the calculation formula (5) mentioned earlier, we can get TABLE 3.

From calculating the transition utilization rates, we can get which transitions are relatively important in the process

**TABLE 3.** The utilization rate of transitions.

Transition	Utilization rate	Transition	Utilization rate
<i>U(T1)</i>	<b>0.1322</b>	<i>U(T12)</i>	0.0057
<i>U(T2)</i>	<b>0.0881</b>	<i>U(T13)</i>	0.0378
<i>U(T3)</i>	<b>0.0881</b>	<i>U(T14)</i>	0.0283
<i>U(T4)</i>	0.0110	<i>U(T15)</i>	0.0189
<i>U(T5)</i>	0.0378	<i>U(T16)</i>	<b>0.0566</b>
<i>U(T6)</i>	0.0378	<i>U(T17)</i>	0.0142
<i>U(T7)</i>	<b>0.0566</b>	<i>U(T18)</i>	0.0094
<i>U(T8)</i>	<b>0.0566</b>	<i>U(T19)</i>	0.0189
<i>U(T9)</i>	0.0283	<i>U(T20)</i>	<b>0.0566</b>
<i>U(T10)</i>	0.0378	<i>U(T21)</i>	<b>0.2643</b>
<i>U(T11)</i>	0.0283		

of SCF. The greater the transition utilization rate is, the more important the transition would be. The results in the Table 3 demonstrate that transition *T1*, *T2*, *T3* at the first half and transition *T16*, *T20*, *T21* at the second half of financing process have relatively high utilization rates. In other words, "The financing requirement of Downstream firms and the engagement intention of the bank at the beginning" and "The Bank's reminder for the Downstream to repay and the termination of financing at the second half of process" are potential options to improve the efficiency of SCF process. Moreover, transitions *T7* and *T8*, indicating the flow of funds among Downstream firms, banks, and company J, also have higher utilization rates and are important. In summary, the transitions of *T1*, *T2*, *T3*, *T7*, *T8*, *T16*, *T20*, and *T21* are important transitions

## V. IMPROVEMENT OF SCF PROCESS

In this section, the results of Section IV are testified by dependency graphs to filter the potential places and transitions which may enhance the performance of SCF process to the most extent. Based on the dependency graph analysis, we develop some improvement strategies to optimize the business process.

### A. CAUSAL RELATIONSHIP OF EVENTS BASED ON DEPENDENCY GRAPHS

The dependency graph is widely used to characterize causality relationship and search for the key events. Based on the Petri Net in Figure 1, the relationship between the input and output of events is investigated to show the causality and sequence of events and the transitions that occur when events are transferred. Thus, twenty-two events are defined as shown in TABLE 4.

The dependency graph in Figure 2 illustrates the causal relationship between events. The event that initiates the current one can be traced by the "arrow-based reverse tracking" in the directed graph. As we can see, the termination event *E22* is directly incurred by either *E6*, *E16*, *E19* or *E21*. After a detailed analysis of the causal relationships on these events, we figure out that *E4*, *E15* and *E18* are the key events (Appendix C).

TABLE 4. Description of the events.

Event	Description	Transition	Place
E1	Downstream firms submit financing requirements to company J	-	P1
E2	Company J investigates Downstream firms	T1	P2
E3	Company J seek out the interested Bank	T2	P3
E4	Downstream firms submit financing applications to bank	T3	P4
E5	The Bank approves the application	T4	P5
E6	The Bank rejects the application	T4	P6
E7	The Bank requires Company J for repurchase agreement	T5	P7
E8	Downstream firms pay deposit to Company J	T6	P8
E9	Bank supplements the insufficient part of the fund for the equipment procurement	T7	P9
E10	Company J manufactures the equipment	T8	P10
E11	The Bank pays company J for delivery	T9	P11
E12	Company J delivers the equipment to Downstream firms	T10	P12
E13	Company J install and test the equipment	T11	P13
E14	The Bank pay Company J for the arrival	T12	P14
E15	Downstream firms repay the bank by stages	T13	P15
E16	Downstream firms have sufficient fund for repayment	T14	P16
E17	Downstream firms have insufficient fund for repayment	T14	P17
E18	Downstream firms repay the load within the expiration	T16	P18
E19	Downstream firms have sufficient fund for repayment	T17	P19
E20	Downstream firms still don't have sufficient fund for repayment	T17	P20
E21	Company J repurchase equipment according to the agreement	T18	P21
E22	End of this financing process	T15, T19, T20	P22

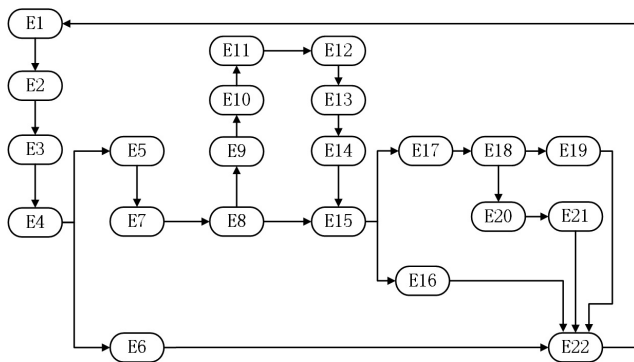


FIGURE 2. Dependence graph of the Petri Net of J company's supply chain finance business process.

B. PLACE AND TRANSITION SELECTION FOR IMPROVEMENT

We have dug out the busy places (P1, P2, P3, P5, P6, P16, P19, P22), the busy and important transitions (T1, T2, T3, T7, T8, T16, T20, T21), and key events (E4, E15, E18) in the SCF process. However, some of them may be indispensable in the process and not suitable for adjustment. In this section,

we attempt to further filter the places and transitions for process improvement by excluding irrational options.

Some of the places and transitions should be excluded from the consideration set. For instance, T7 (Company J receives deposits from Downstream companies) and T8 (Company J receives funds from the Bank) are indispensable places in the Petri Net. It is difficult to integrate these two places as well. Thus, T7 and T8 are ruled out. T20 happens when the banks reject the financing requirement. It is infeasible to employ ESIA principle. T21 is essentially the transition when the financing cooperation agreements expire. No matter whether the bank offers the financing, the process will constantly terminate after T21. Hence, T21 is nonadjustable. P5 and P6 are unmodifiable because they are key places that cannot be eliminated. P22, which refers to the end of this financing process, is also undeletable. Overall, the transitions T7, T8, T20, and T21 and places P22 are eliminated from the candidate set. As a result, our optimization will concentrate on {(P1, P2, P3, P16, P19), (T1, T2, T3, T16)} as potential places and transitions for improvement.

C. IMPROVING THE SCF PROCESS

We propose the process improvement strategy on the basis of theories commonly accepted in the realm of SCF and the selected places and transitions. The ESIA theory [49] of process optimization is applied in this section.

Two major issues in supply chain are considered: information and risk. Information, which is an important component in supply chains, plays a critical role in supply chain finance [51]–[57]. The process complexity in SCF is heavily attributed to asymmetric information on the financing parties, e.g., the capability of repayment, the market status, etc. This may lead to moral hazard and adverse selection in the pledge loan credit contract [51], [58]. Besides, risk assessment and control [51], [59], [60] are also the key activities in the process of SCF. The information asymmetry increases the uncertainty of the banks to select the safe credit side (Downstream firms). The banks suffer potential risks that the money may not be returned. This is even more serious when the Downstream firms collude with the focal firm.

It seems to be functional to adjust the process by enhancing the information sharing [56] or risk sharing [60] between the focal firm (Company J) and the banks. The relationship between the focal firm and financing applicant (Downstream firms in our study) renders the focal firm to have richer information. However, it is difficult for the Bank to accurately understand the Downstream firm. Sharing information or risk tends to lower the process complexity that is designed to reduce the uncertainty in SCF.

1) INFORMATION SHARING

As identified in the previous section, the places {P1, P2, P3} are the most time-consuming, while the transitions {T1, T2, T3} are of the greatest importance to the process. They are all included in the segments of “P1-P3”, where two consecutive key activities are involved: “the inspection

of Company J on Downstream firms”, and its follow-up “Company J’s inquiry for the engagement intention of the Bank”. Generally, Company J has more information about Downstream firms. If Company J and the banks can cooperate and share information with each other, it is expected to simplify the process considerably. In the Petri Net, this can be achieved by integrating the two places (the “I” in ESIA method) and parallelly undergoing the inspection procedure. As a result, the time-consuming delay of transition *T4* (from *P4* to *P5*) in the process are reduced.

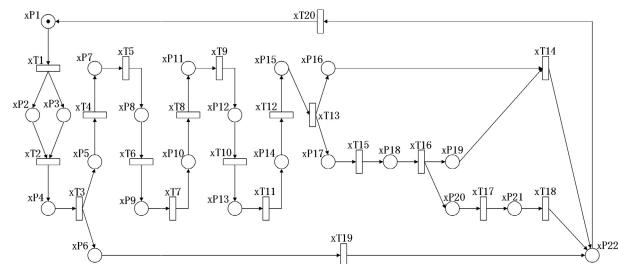


FIGURE 3. New Petri Net of SCF process improved by information sharing.

Figure 3 illustrates the optimized process considering information sharing and stage integration. In the adjusted process, Company J and the banks carry on the inspection simultaneously. By involving the banks into the starting stages of SCF, the load in *P1*, *P2*, *P3* and *P5* of the initial process (Figure 1) may be relieved, while the efficiency (time-consuming) of inspection is enhanced (decreased). The places in the new process as shown in Figure 3 are labeled as “*xP*”, while all the transitions in the new process are labeled by “*xT*” (the details of place and transition descriptions are shown in Table 15 of Appendix D).

TABLE 5. The busy rate of places.

Place	Busy rate	Place	Busy rate
<i>xP1</i>	<b>0.1070</b>	<i>xP12</i>	0.0535
<i>xP2</i>	<b>0.0713</b>	<i>xP13</i>	0.0107
<i>xP3</i>	<b>0.0713</b>	<i>xP14</i>	0.0713
<i>xP4</i>	<b>0.0089</b>	<i>xP15</i>	0.0535
<i>xP5</i>	<b>0.0713</b>	<i>xP16</i>	0.1025
<i>xP6</i>	0.7995	<i>xP17</i>	0.0624
<i>xP7</i>	0.0713	<i>xP18</i>	0.0000
<i>xP8</i>	0.1070	<i>xP19</i>	0.0668
<i>xP9</i>	0.1070	<i>xP20</i>	0.0178
<i>xP10</i>	0.0535	<i>xP21</i>	0.0357
<i>xP11</i>	0.0713	<i>xP22</i>	0.0535

The busy rates of places in the optimized process are re-evaluated following the calculation in Section IV. As shown in Table 5, the improvement significantly reduces the burden of the five places (*xP1*, *xP2*, *xP3*, *xP4* and *xP5*, which are identical to *P1*, *P2*, *P3*, *P4*, *P5* in the original process). In contrast to those in Table 2, busy rates of them are 0.1070 (vs. 0.1322 in the original process), 0.0713 (vs. 0.0881 in the preliminary process),

0.0713 (vs. 0.0881 in the preliminary process), 0.0089 (vs. 0.0110 in the initial process), and 0.0713 (vs. 0.0881 in the process of Figure 1), respectively. Besides, it is surprise that the busy rates of *P22* also declines significantly.

TABLE 6. The utilization rate of transitions.

Transition	Utilization rate	Transition	Utilization rate
<i>U(xT1)</i>	0.1070	<i>U(xT11)</i>	0.0107
<i>U(xT2)</i>	0.0713	<i>U(xT12)</i>	0.0713
<i>U(xT3)</i>	0.0089	<i>U(xT13)</i>	0.0535
<i>U(xT4)</i>	0.0713	<i>U(xT14)</i>	0.0357
<i>U(xT5)</i>	0.0713	<i>U(xT15)</i>	0.0357
<i>U(xT6)</i>	0.1070	<i>U(xT16)</i>	0.0000
<i>U(xT7)</i>	0.1070	<i>U(xT17)</i>	0.0178
<i>U(xT8)</i>	0.0535	<i>U(xT18)</i>	0.0357
<i>U(xT9)</i>	0.0713	<i>U(xT19)</i>	0.0134
<i>U(xT10)</i>	0.0535	<i>U(xT20)</i>	0.0535

As shown in Table 6, there is no remarkable increase in the utilization rates of transitions in the shortened process. Usually, we may suppose that eliminating some steps (places) of the process would incur higher utilization rates of some transitions. However, the results of the new process represent the similar level. That is to say, we are able to adjust the process without expanding time-consumption. Thus, the results of Table 5 and VI imply that the optimization of process works properly in general.

## 2) RISK SHARING

The places {*P16*, *P19*} and transition {*T16*}, essentially, are closely related to the activity of Downstream firms’ repayment, and especially related to the scenario that Downstream firms are unwilling or incapable to repay the loan. Thus, company J is introduced into the repayment process to share the risk assumed by the bank. This may ensure that the fund of Downstream firms’ bank account is enough for repayment, enabling the financing business process to proceed more smoothly. It is expectable that not only the busy rates of place *P16* and *P19*, but also the time-consumption of transition *T16* is reduced.

The process in Figure 1 is rescheduled to the new one shown in Figure 4. By eliminating (The “*E*” in ESIA) two places and transitions, {(*P19*, *P20*), (*T18*, *T19*)}, we attempt to shorten the process and reduce the time-consumption. The description of the places and transitions (labeled as “*yP*” and “*yT*”) are listed in Table 16 (Appendix D). All the transitions in the new process are included in the original process (as shown in Table 1).

As shown in Table 7, risk sharing between the focal firm and the banks may promote the Downstream firms to keep sufficient fund in the account of Downstream firms. The process is shortened in the modified process with only 20 places, at the expense of busy rate of *yP16* (*P16* in Figure 1) raising from 0.1180 (Table 2) to 0.1383.



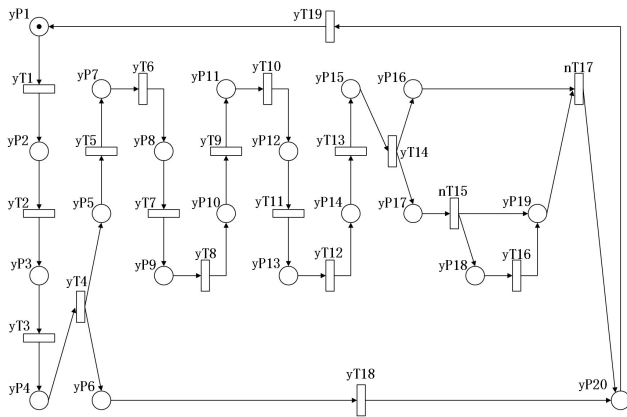


FIGURE 4. New Petri Net of SCF process improved by risk sharing.

TABLE 7. The busy rate of places.

Place	Busy rate	Place	Busy rate
yP1	0.1303	yP11	0.0372
yP2	0.0869	yP12	0.0279
yP3	0.0869	yP13	0.0056
yP4	0.0109	yP14	0.0372
yP5	0.1862	yP15	0.0279
yP6	0.5361	yP16	0.1383
yP7	0.0372	yP17	0.0372
yP8	0.0558	yP18	0.016
yP9	0.0558	yP19	0.0372
yP10	0.0279	yP20	0.2606

After optimization by sharing risks between the focal firm and the bank, fewer transitions are required in the adjusted process, which means low time-consumption and resource consumption for the supply chain financing. Generally, there are fine decreases in the utilization rates of transitions (Table 8).

TABLE 8. The utilization rate of transitions.

Transition	Utilization rate	Transition	Utilization rate
$U(yT1)$	0.1303	$U(yT11)$	0.0279
$U(yT2)$	0.0869	$U(yT12)$	0.0056
$U(yT3)$	0.0869	$U(yT13)$	0.0372
$U(yT4)$	0.0109	$U(yT14)$	0.0279
$U(yT5)$	0.0372	$U(yT15)$	0.0372
$U(yT6)$	0.0372	$U(yT16)$	0.0160
$U(yT7)$	0.0558	$U(yT17)$	0.0373
$U(yT8)$	0.0558	$U(yT18)$	0.0372
$U(yT9)$	0.0279	$U(yT19)$	0.2606
$U(yT10)$	0.0372		

### 3) INFORMATION & RISK SHARING

The process may be further improved if both information sharing and risk sharing are taken into consideration. The rationale behind is the fact that there is no conflict between

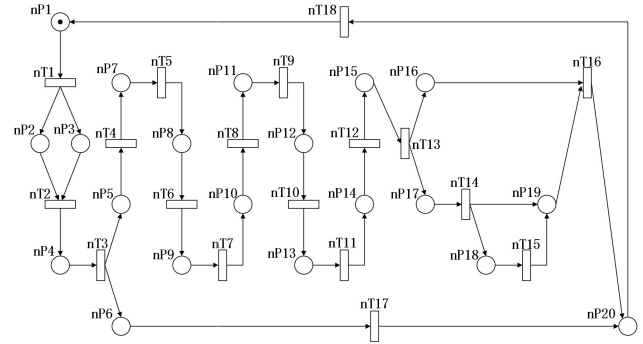


FIGURE 5. New Petri Net of SCF process improved by information & risk sharing.

these two optimization strategies. Figure 5 demonstrates the procedure combination. The description of the places and transitions (labeled as “nP” and “nT”) are listed in Table 17 (Appendix D).

By means of information sharing, there will be process simplification and reduction of place busy rate (time-consuming) in the first part of SCF process. Risk sharing tends to shorten the process, particularly for the repayment of Downstream firms, and lower the risk of contract violation which would terminate the process abnormally. As a result, the new process has saved two places and three transitions.

In the case that the strategies of information and risk sharing are simultaneously adopted to improve the process, the effect of process optimization stacks. The place P19 of the process in Figure 1 is removed. The busy rates of nP3 and nP16 are lower than those in the original process, i.e., 0.0116 vs. 0.0881 and 0.1139 vs. 0.1180, respectively (as shown in Table 9).

TABLE 9. The busy rate of places.

Place	Busy rate	Place	Busy rate
nP1	0.1387	nP11	0.0396
nP2	0.0925	nP12	0.0297
nP3	<b>0.0116</b>	nP13	0.0059
nP4	0.0925	nP14	0.0396
nP5	0.2501	nP15	0.0297
nP6	0.5987	nP16	<b>0.1139</b>
nP7	0.0396	nP17	0.0793
nP8	0.0594	nP18	0.0149
nP9	0.0594	nP19	0.0347
nP10	0.0297	nP20	0.2774

Analogously, as shown in Table 10, the utilization rate of transition nT3 (0.0116) is significantly lower than that of T3 in the original process (0.0881). In the second half of the process, the transition nT16 suffers a smaller busy rate of 0.0396, in contrast to T16 in Table 3. Hence, the proposed optimization works well on some specific steps of the SCF process.

**TABLE 10.** The utilization rate of transitions.

Transition	Utilization rate	Transition	Utilization rate
$U(nT1)$	0.1387	$U(nT10)$	0.0297
$U(nT2)$	0.0925	$U(nT11)$	0.0059
$U(nT3)$	<b>0.0116</b>	$U(nT12)$	0.0396
$U(nT4)$	0.0925	$U(nT13)$	0.0297
$U(nT5)$	0.0396	$U(nT14)$	0.0198
$U(nT6)$	0.0594	$U(nT15)$	0.0149
$U(nT7)$	0.0594	$U(nT16)$	<b>0.0396</b>
$U(nT8)$	0.0297	$U(nT17)$	0.0925
$U(nT9)$	0.0396	$U(nT18)$	0.2773

## VI. CONCLUSIONS

### A. FINDINGS

This paper aims to improve the efficiency of business process in supply chain finance which is operated among different entities including a focal firm (Company J), financing applicants (Downstream firms) and banks. A Stochastic Petri Net with the time delay of the transition is constructed to estimate the performance of the process. The relevant data of business flow chart is collected through an empirical investigation of Company J.

We figure out that, in the Petri Net, there are places with high busy rates and transitions with high utilization rates at both the first half and second half of the financing process. We further analyze the causal relationship of the events in the Petri Net by dependency graph to identify key events, i.e., the corresponding key places and transitions. By excluding those are infeasible, several potential places and transitions are selected for process adjustment. Generally, there are two important parts identified in the Petri Net: inspection of focal firm (Company J) and the banks on the financing applicants, and re-payment of the financing applicants.

Three different strategies involving information sharing or/and risk sharing are proposed in our study to improve the process of supply chain finance. By integrating the place about examination of focal firm on the applicants and place about Company J's inquiry for the engagement intention of the Bank, the adjustment not only reduces the time-consuming period, but also enhances the understanding of the applicants. Sharing the risk between the bank and focal firm in the repayment stage, in terms of involving the focal firm if the applicants are incapable to repay, will also shorten the process, reduce the busy rates of places and increase the efficiency of SCF process.

### B. THEORETICAL AND PRACTICAL IMPLICATIONS

In this study, the theory of Stochastic Petri Net (SPN) is applied to analyze the process of supply chain finance. Few studies have ever touched on this research field. Our work not only extends the theoretical research on SCF process management but also expands the theoretical application of SPN. Although prior literature uses Petri Net to analyze the supply chain process, for example, Ma *et al.* [33] used

Petri Net to the model and analyzed the cross-organizational workflow systems in the context of lean supply chain (LSC), there are still many challenges in the research field of supply chain process management. Our work focuses on the process improvement of supply chain finance field based on Petri Net, which is yet theoretically unexplored.

We also offer theoretical support for the process management and improvement, by leveraging the concept of information and risk sharing. Traditionally, the process designers tend to adjust the steps (places) in the process without sufficient theoretical support. However, our work suggests that the strategies of information sharing or/and risk sharing can be an insightful guidance for process management. It is noteworthy that this may be applicable to other fields besides supply chain finance.

Practically, our results of the research will be of interest to business process managers and designers in supply chain finance field. The key process steps can be identified and optimized to guarantee the process to work smoothly. For example, during the process of SCF, it is important that the banks and core enterprises should collaborate more closely with each other. Thus, fully information sharing between the banks and the focal firms will benefit from the risk control of the financing. Besides, risk sharing between the banks and focal firms will in turn motivate the focal firm to filter the downstream firms and share information with the banks. As a result, if the downstream firms realize that only when they are exceptionally reliable that the focal firm would be willing to offer financing support, the uncertainty of the banks may correspondingly decrease. In summary, through analysis on the process and optimization on the key process places and transitions, the performance of SCF process can be eventually improved.

### C. LIMITATIONS AND FUTRURE WORKS

The research introduces a firm case for process improvement, which may limit the external validity. In the future, the research could be further improved by incorporating more sample firms and making the comparisons between results from the different sample firms. Greater attention could be paid to the process of supply chain finance in other industries for proposing the general principle of improving the SCF process performance. For instance, Do the places in the earlier and end stages of the process generally suffer high busy rates, disregarding the types of industry? Do information sharing and risk sharing strategies of SCF process improvement work in other industries?

## APPENDIX A

### INVESTIGATION DESIGN

#### 1. Purpose of Investigation

- (1) The departments involved in the current operation of supply chain finance in the firm
- (2) Acquiring the process of supply chain finance and corresponding organizational activities in the firm that faces middle and small-sized enterprises

- (3) Investigating the problems existing in the current supply chain finance business of the enterprise

**2. The process of investigation**

- (1) Collecting information of the investigated firm
- (2) Analyzing and finding the potential problems
- (3) Brainstorming the possible solutions
- (4) Thinking of the data collections
- (5) Survey and consolidation on data

**3. Investigation Method**

- (1) Interview
- (2) Collection of files and data provided by the enterprise

**4. Investigation Content**

- (1) Profile and organizational structure of the enterprise
- (2) The department (launching the business process) that is responsible for the operation of supply chain finance
- (3) The departments that are related to supply chain finance, e.g. logistics department, inventory, procurement department, the financial department, manufacture departments, etc.
- (4) The organizations involved in supply chain finance, e.g. the banks

**5. Data Collection**

- (1) Up-streams
- (2) Resources imported into the Small and medium-sized enterprises (SMES)
- (3) Financing of SMES
- (4) The bank’s needs of dealing with the financing process
- (5) The coordinate activities of focal firm
- (6) Logistics, logistics service of third-party provider
- (7) The time duration of each activity
- (8) The exchange of information, etc.

Notes: A. Agreement of sales; B. Financing requirement; C. Agreement on repurchase; D. Financing agreement; E. Security deposit; F. Replenishment the remaining fund; G. Delivery notification; H. Delivery; I. Repay funds by installments; J. Repayment on time/ buy-back of the equipment.

We have decomposed the above business flow chart into the following events:

- (1) Downstream firms submit financing application to Company J. After conformation of Downstream firms’ financing requirements, Company J inspects the Downstream firms. If the inspection is approved, Company J signs a sales agreement with the Downstream firms with a Bank as fund source. Otherwise, financing terminates.
- (2) The Downstream firms and Company J submit a financing requirement and repurchase agreement to the bank, respectively. Afterward, the bank inspects the status of Downstream firms and assess company J’s capability of repurchase simultaneously.
- (3) The bank signs repurchase agreements with Company J.
- (4) The bank signs financing agreements with Downstream firms.

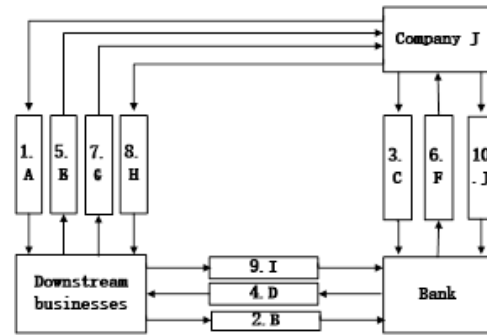


FIGURE 6. The business process of company J’s supply chain financing.

- (5) Downstream firms pay company J the security deposit.
- (6) Company J submits the requirement of funds to the bank when Downstream firms do not have enough funds (60% of equipment funds). The Bank pays the required funds. Company J receives the bank’s funds and start the manufacture. Company J notifies Downstream firms when the production is complete.
- (7) Downstream firms request for equipment delivery. Company J ships the equipment to Downstream firms.
- (8) Company J finishes equipment installment and debug for the Downstream firms. Downstream firms confirm receipt after testing the status of equipment.
- (9) The bank pays Company J 30% of equipment’s price. Downstream firms carry out the production and repay the loan by stage.
- (10) The bank verifies whether the funds in the Downstream firms’ account are sufficient. If not, the bank informs company J to repurchase the equipment. Financing process continues if there is sufficient fund in the account.

As stated in the sales agreement, Downstream companies should pay 60% of the price of equipment before the settlement of the equipment. However, because of the high price level and long production cycle of the equipment, Downstream enterprises, especially SMEs, usually confront financial difficulties. Spontaneously, Downstream firms resort to the banks. To smooth the transactions, the equipment repurchase of Company J is proposed as a guarantee to the Bank. However, there are yet no standard operation processes in supply chain finance, which is a relatively newly emerging business with hidden risks. We conduct an in-depth investigation of the business processes to identify the key events that would affect the operation of the process and then offer improving strategies.

**APPENDIX B**

**THE PROCEDURE OF PERFORMANCE EVALUATION**

**A. BUILD A RANDOM PETRI NET**

Given the definition of the P/T system, we are able to yield a corresponding SPN by adding a set of average firing rates. As shown in Figure 8, we construct the corresponding Markov chain, with the arc between each marking (state) representing the corresponding transition.

The state set of Markov chain is described in TABLE 11.

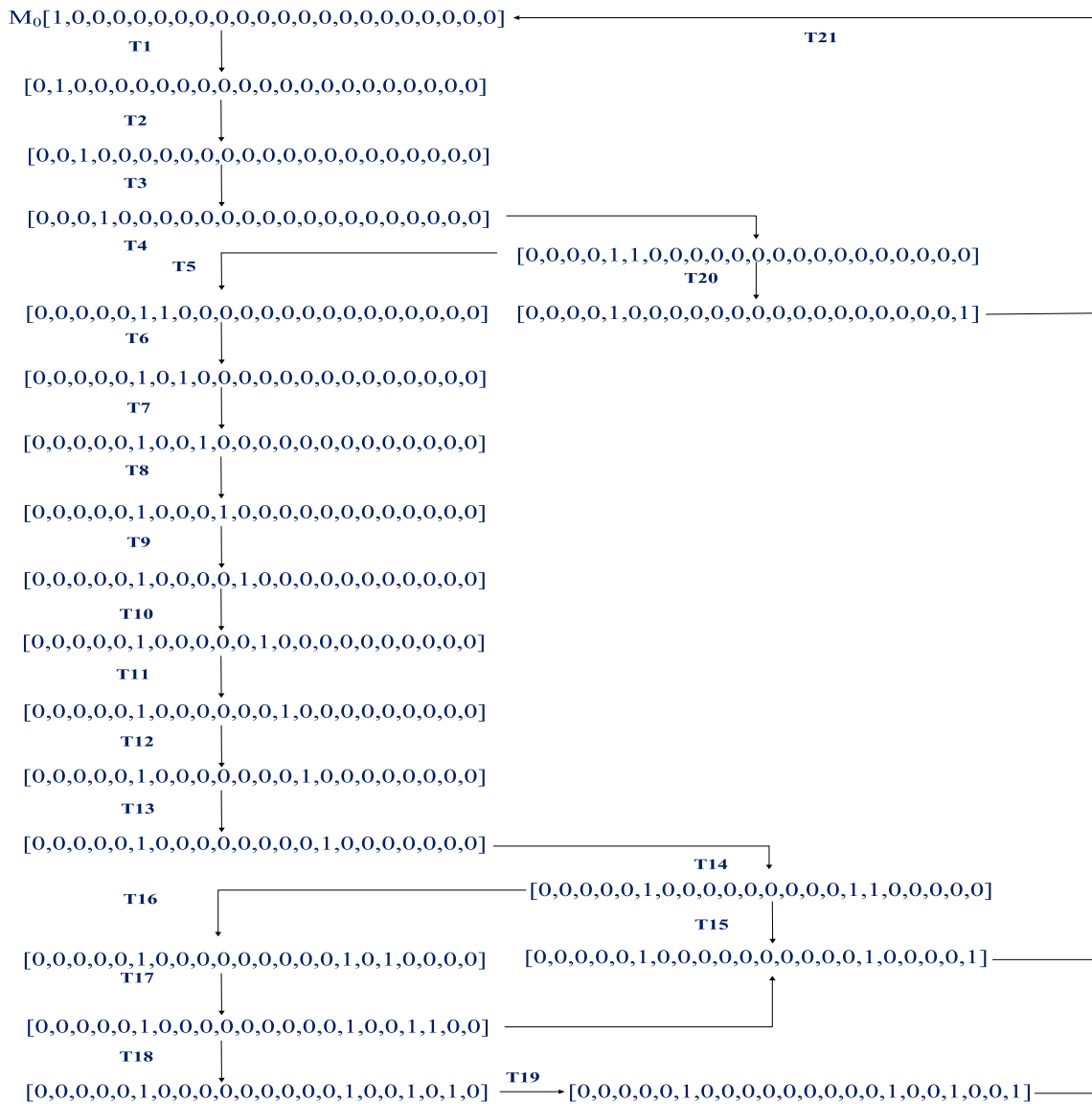


FIGURE 7. The reachable marking graph of Petri Net.

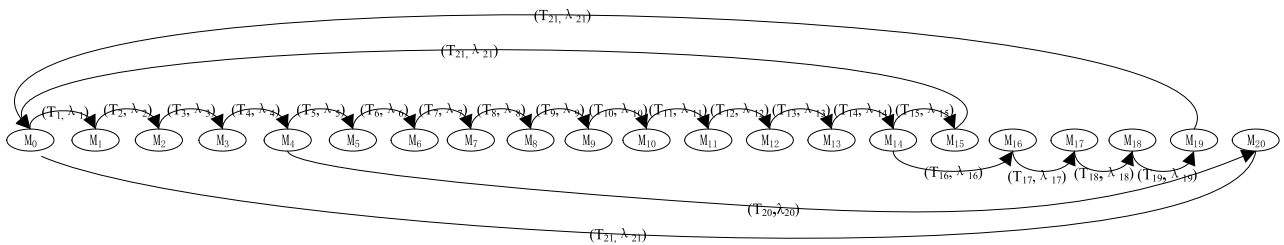


FIGURE 8. Markov chain isomorphic to the Petri Net model.

**B. CALCULATION OF PERFORMANCE MEASURES FOR STOCHASTIC PETRI NET**

**1) THE STEADY-STATE PROBABILITY OF MARKETER**

The transition probabilities of markings are assumed to follow the negative exponential distribution. In our study,

we used the average firing rates  $\lambda$  to calculate the transition probabilities. The average firing rates are the reciprocal of the time delay of transitions, i.e.  $\lambda_i = 1/\tau_i, i \in \{1, \dots, 21\}$ . The time variables of the transitions, which are gathered from Company J, represent the time period between the time that

TABLE 11. Markov chain state sets isomorphic to Petri Nets.

	$P_1$	$P_2$	$P_3$	$P_4$	$P_5$	$P_6$	$P_7$	$P_8$	$P_9$	$P_{10}$	$P_{11}$	$P_{12}$	$P_{13}$	$P_{14}$	$P_{15}$	$P_{16}$	$P_{17}$	$P_{18}$	$P_{19}$	$P_{20}$	$P_{21}$	$P_{22}$
$M_0$	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$M_1$	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$M_2$	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$M_3$	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$M_4$	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$M_5$	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$M_6$	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$M_7$	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
$M_8$	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
$M_9$	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
$M_{10}$	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
$M_{11}$	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
$M_{12}$	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
$M_{13}$	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
$M_{14}$	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
$M_{15}$	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
$M_{16}$	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
$M_{17}$	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
$M_{18}$	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0
$M_{19}$	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1
$M_{20}$	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

TABLE 12. Average rate of transition.

The rate of transition	Time unit	The rate of transition	Time unit
$\lambda_1$	2	$\lambda_{12}$	20
$\lambda_2$	3	$\lambda_{13}$	3
$\lambda_3$	3	$\lambda_{14}$	4
$\lambda_4$	24	$\lambda_{15}$	3
$\lambda_5$	3	$\lambda_{16}$	3
$\lambda_6$	3	$\lambda_{17}$	4
$\lambda_7$	2	$\lambda_{18}$	6
$\lambda_8$	2	$\lambda_{19}$	3
$\lambda_9$	4	$\lambda_{20}$	4
$\lambda_{10}$	3	$\lambda_{21}$	1
$\lambda_{11}$	4		

transition is available and the time the transition is indeed implemented. The values of the transition rate  $\lambda$  is given in TABLE 12.

Based on the values of the transition rate  $\lambda$  obtained above, the state transfer matrix in the Stochastic Petri Net can be calculated, as shown in Table 13.

The steady-state probabilities of each marking obtained by formula (3) are shown in TABLE 14.

2) PLACE (NODE) BUSY RATE

According to formula (4), the place busy rates are derived as follows:

$$P[M(P1) = 1] = P(M0) = 0.1322$$

$$P[M(P2) = 1] = P(M1) = 0.0881$$

$$P[M(P3) = 1] = P(M2) = 0.0881$$

$$P[M(P4) = 1] = P(M3) = 0.0110$$

$$P[M(P5) = 1] = P(M4) + P(M20) = 0.1888$$

$$P[M(P6) = 1] = P(M4) + P(M5) + P(M6) + P(M7)$$

$$+ P(M8) + P(M9) + P(M10) + P(M11) + P(M12)$$

$$+ P(M13) + P(M14) + P(M15) + P(M16) + P(M17)$$

$$+ P(M18) + P(M19) = 0.5296$$

$$P[M(P7) = 1] = P(M5) = 0.0378$$

$$P[M(P8) = 1] = P(M6) = 0.0566$$

$$P[M(P9) = 1] = P(M7) = 0.0566$$

$$P[M(P10) = 1] = P(M8) = 0.0283$$

**TABLE 13.** The state transfer matrix.

$M_0$	$M_1$	$M_2$	$M_3$	$M_4$	$M_5$	$M_6$	$M_7$	$M_8$	$M_9$	$M_{10}$	$M_{11}$	$M_{12}$	$M_{13}$	$M_{14}$	$M_{15}$	$M_{16}$	$M_{17}$	$M_{18}$	$M_{19}$	$M_{20}$
$-\lambda_1$	$\lambda_1$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	$-\lambda_2$	$\lambda_2$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	$-\lambda_3$	$\lambda_3$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	$-\lambda_4$	$\lambda_4$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	$-\lambda_5-\lambda_{20}$	$\lambda_5$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$\lambda_{20}$
0	0	0	0	0	$-\lambda_6$	$\lambda_6$	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	$-\lambda_7$	$\lambda_7$	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	$-\lambda_8$	$\lambda_8$	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	$-\lambda_9$	$\lambda_9$	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	$-\lambda_{10}$	$\lambda_{10}$	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	$-\lambda_{11}$	$\lambda_{11}$	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	$-\lambda_{12}$	$\lambda_{12}$	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	$-\lambda_{13}$	$\lambda_{13}$	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	$-\lambda_{14}$	$\lambda_{14}$	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	$-\lambda_{15}-\lambda_{16}$	$\lambda_{15}$	$\lambda_{16}$	0	0	0	0
$\lambda_{21}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$-\lambda_{21}$	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$-\lambda_{17}$	$\lambda_{17}$	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$-\lambda_{18}$	$\lambda_{18}$	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$-\lambda_{19}$	$\lambda_{19}$	0
$\lambda_{21}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$-\lambda_{21}$
$\lambda_{21}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	$-\lambda_{21}$

**TABLE 14.** The steady-state probability of markings.

Marking	Steady-State Probabilities	Marking	Steady-State Probabilities
$P[M_0]$	0.1322	$P[M_{11}]$	0.0057
$P[M_1]$	0.0881	$P[M_{12}]$	0.0378
$P[M_2]$	0.0881	$P[M_{13}]$	0.0283
$P[M_3]$	0.0110	$P[M_{14}]$	0.0189
$P[M_4]$	0.0378	$P[M_{15}]$	0.0566
$P[M_5]$	0.0378	$P[M_{16}]$	0.0142
$P[M_6]$	0.0566	$P[M_{17}]$	0.0094
$P[M_7]$	0.0566	$P[M_{18}]$	0.0189
$P[M_8]$	0.0283	$P[M_{19}]$	0.0566
$P[M_9]$	0.0378	$P[M_{20}]$	0.1510
$P[M_{10}]$	0.0283		

$$\begin{aligned}
 P[M(P11) = 1] &= P(M9) = 0.0378 & P[M(P17) = 1] &= P(M14) + P(M15) = 0.0755 \\
 P[M(P12) = 1] &= P(M10) = 0.0283 & P[M(P18) = 1] &= P(M16) = 0.0142 \\
 P[M(P13) = 1] &= P(M11) = 0.0057 & P[M(P19) = 1] &= P(M17) + P(M18) + P(M19) = 0.0850 \\
 P[M(P14) = 1] &= P(M12) = 0.0378 & P[M(P20) = 1] &= P(M17) = 0.0094 \\
 P[M(P15) = 1] &= P(M13) = 0.0283 & P[M(P21) = 1] &= P(M18) = 0.0189 \\
 P[M(P16) = 1] &= P(M14) + P(M16) + P(M17) & P[M(P22) = 1] &= P(M15) + P(M19) + P(M20) = 0.2643 \\
 &+ P(M18) + P(M19) = 0.1180 & &
 \end{aligned}$$

**TABLE 15. Description of place and transition in the Petri Net of Figure 3.**

Place	Description
<i>xP1</i>	Financing requirement that Downstream firms submitted to Company J
<i>xP2</i>	Company J's investigation on Downstream firms
<i>xP3</i>	Company J's inquiry for the engagement intention of the Bank
<i>xP4</i>	Financing application submitted by Downstream firms to the Bank
<i>xP5</i>	The Bank's approval of the application
<i>xP6</i>	The Bank's rejection of the application
<i>xP7</i>	Guarantee offered by Company J for repurchasing the equipment
<i>xP8</i>	Security deposit that Downstream firms paid Company J
<i>xP9</i>	The fund required by company J for supplements in the sales agreement
<i>xP10</i>	The equipment manufacturing of Company J
<i>xP11</i>	Payment from the banks to company J
<i>xP12</i>	Equipment delivery of Company J to Downstream firms
<i>xP13</i>	Equipment installment and testing
<i>xP14</i>	Arrival payment from the Bank to Company J
<i>xP15</i>	Repayment of Downstream firms to the Bank by stages
<i>xP16</i>	Sufficient fund in the account of Downstream firms
<i>xP17</i>	Insufficient fund in the account of Downstream firms
<i>xP18</i>	Repayment of Downstream firms to the Bank within the agreed expiration
<i>xP19</i>	Sufficient fund in the account of Downstream firms with the cooperation of company J
<i>xP20</i>	Insufficient fund in the account of Downstream firms
<i>xP21</i>	Repurchase of the equipment by Company J
<i>xP22</i>	End of this financing process
Transition	Description
<i>xT1</i>	Company J receive financing requirement
<i>xT2</i>	Company J signed a sales agreement with Downstream firms and confirms the engagement cooperation intention of the bank
<i>xT3</i>	The Bank inspects Downstream firms
<i>xT4</i>	The Bank signs cooperation agreement with Downstream firms
<i>xT5</i>	Company J signs repurchase agreement with the Bank
<i>xT6</i>	Company J receives deposits from Downstream companies
<i>xT7</i>	Company J receives funds from the Bank
<i>xT8</i>	Downstream company informs J company the issues about equipment delivery
<i>xT9</i>	Company J receives payment for equipment delivery from the Bank
<i>xT10</i>	Downstream firms receive equipment
<i>xT11</i>	Downstream firms confirm that equipment is qualified and operate under good conditions
<i>xT12</i>	Company J receives the banks funds
<i>xT13</i>	The Bank investigates whether the fund repaid by Downstream firms are available
<i>xT14</i>	The bank informs Company J to maintain production
<i>xT15</i>	The Bank reminds the Downstream to repay within the agreement expiration
<i>xT16</i>	The Bank investigates availability of the funds from the Downstream firms again
<i>xT17</i>	The Bank informs Company J to repurchase the equipment
<i>xT18</i>	The Bank receives funds from Company J
<i>xT19</i>	The Bank terminates financing of Downstream firms
<i>xT20</i>	Failure of the financing cooperation agreements

**APPENDIX C  
ANALYSIS OF THE CAUSAL RELATIONSHIPS**

*E4* (Downstream firms submit a financing application to bank)

- *E6*(Bank's check fails)
- *E22* (End of a financing process)

We can see that *E4* (Downstream firm submits financing application to the bank) is an event of decision and will trigger

*E5* and *E6* events. The event *E6* leads to *E22*, implying that the entire financing business process terminates. Hence, *E4* is essentially a key event.

- E15* (Downstream firms repay the bank in phases)
- *E16* (Downstream firms have sufficient bank account funds)
- *E22* (End of a round of financing process)
- E15* (Downstream firms repay the bank in phases)

TABLE 16. Description of place and transition in the Petri Net of Figure 4.

Place	Description
<i>yP1</i>	Financing requirement that Downstream firms submitted to Company J
<i>yP2</i>	Company J's investigation on Downstream firms
<i>yP3</i>	Company J's inquiry for the engagement intention of the Bank
<i>yP4</i>	Financing application submitted by Downstream firms to the Bank
<i>yP5</i>	The Bank's approval of the application
<i>yP6</i>	The Bank's rejection of the application
<i>yP7</i>	Guarantee offered by Company J for repurchasing the equipment
<i>yP8</i>	Security deposit that Downstream firms paid Company J
<i>yP9</i>	The fund required by company J for supplements in the sales agreement
<i>yP10</i>	The equipment manufacturing of Company J
<i>yP11</i>	Payment from the banks to company J
<i>yP12</i>	Equipment delivery of Company J to Downstream firms
<i>yP13</i>	Equipment installment and testing
<i>yP14</i>	Arrival payment from the Bank to Company J
<i>yP15</i>	Repayment of Downstream firms to the Bank by stages
<i>yP16</i>	Sufficient fund in the account of Downstream firms
<i>yP17</i>	Insufficient fund in the account of Downstream firms
<i>yP18</i>	Sufficient fund in the account of Downstream firms with the cooperation of company J
<i>yP19</i>	Repayment of Downstream firms to the Bank within the agreed expiration
<i>yP20</i>	End of this financing process
Transition	Description
<i>yT1</i>	Company J receive financing requirement
<i>yT2</i>	Company J signed a sales agreement with Downstream firms and confirms the engagement cooperation intention of the bank
<i>yT3</i>	The Bank delivers the engagement intention
<i>yT4</i>	The Bank inspects Downstream firms
<i>yT5</i>	The Bank signs cooperation agreement with Downstream firms
<i>yT6</i>	Company J signs repurchase agreement with the Bank
<i>yT7</i>	Company J receives deposits from Downstream companies
<i>yT8</i>	Company J receives funds from the Bank
<i>yT9</i>	Downstream company informs J company the issues about equipment delivery
<i>yT10</i>	Company J receives payment for equipment delivery from the Bank
<i>yT11</i>	Downstream firms receive equipment
<i>yT12</i>	Downstream firms confirm that equipment is qualified and operate under good conditions
<i>yT13</i>	Company J receives the banks funds
<i>yT14</i>	The Bank investigates whether the fund repaid by Downstream firms are available
<i>yT15</i>	The Bank reminds the Downstream to repay within the agreement expiration
<i>yT16</i>	The Bank investigates availability of the funds from the Downstream firms again
<i>yT17</i>	The Bank informs J Company to continue cooperation in production
<i>yT18</i>	The Bank informs Company J to repurchase the equipment
<i>yT19</i>	Expiration of the financing cooperation agreements

→ *E17* (Downstream company has insufficient bank account funds)  
 → *E18* (Downstream firms pays back to banks during agreed time)  
 → *E20* (The bank account funds of Downstream firms are still insufficient)  
 → *E21* (Company J repurchase equipment according to the agreement)  
 → *E22* (End of a round of financing process)  
*E15* (Downstream firms repay the bank in phases)  
 → *E17* (Downstream company has insufficient bank account funds)

→ *E18* (Downstream firms pays back to banks during agreed time)  
 → *E19* (Downstream company has sufficient bank account funds)  
 → *E22* (End of a round of financing process)  
 From Figure 2, it can be seen that the event *E15* (Downstream firms repay the bank in phases) belongs to the second half of the business process It will trigger the events *E16* and *E17* and decide whether the financing is completed successfully, or Downstream company will breach the contract, or Company J will need to buy back equipment. Thus, *E15* is of key significance for the process to terminate successfully.



**TABLE 17. Description of place and transition in the Petri Net of Figure 5.**

Place	Description
<i>nP1</i>	Financing requirement that Downstream firms submitted to Company J
<i>nP2</i>	Company J's investigation on Downstream firms
<i>nP3</i>	Company J's inquiry for the engagement intention of the Bank
<i>nP4</i>	Financing application submitted by Downstream firms to the Bank
<i>nP5</i>	The Bank's approval of the application
<i>nP6</i>	The Bank's rejection of the application
<i>nP7</i>	Guarantee offered by Company J for repurchasing the equipment
<i>nP8</i>	Security deposit that Downstream firms paid Company J
<i>nP9</i>	The fund required by company J for supplements in the sales agreement
<i>nP10</i>	The equipment manufacturing of Company J
<i>nP11</i>	Payment from the banks to company J
<i>nP12</i>	Equipment delivery of Company J to Downstream firms
<i>nP13</i>	Equipment installment and testing
<i>nP14</i>	Arrival payment from the Bank to Company J
<i>nP15</i>	Repayment of Downstream firms to the Bank by stages
<i>nP16</i>	Sufficient fund in the account of Downstream firms
<i>nP17</i>	Insufficient fund in the account of Downstream firms
<i>nP18</i>	Sufficient fund in the account of Downstream firms with the cooperation of company J
<i>nP19</i>	Repayment of Downstream firms to the Bank within the agreed expiration
<i>nP20</i>	End of this financing process
Transition	Description
<i>nT1</i>	Company J receive financing requirement
<i>nT2</i>	Company J signed a sales agreement with Downstream firms and confirms the engagement cooperation intention of the bank
<i>nT3</i>	The Bank inspects Downstream firms
<i>nT4</i>	The Bank signs cooperation agreement with Downstream firms
<i>nT5</i>	Company J signs repurchase agreement with the Bank
<i>nT6</i>	Company J receives deposits from Downstream companies
<i>nT7</i>	Company J receives funds from the Bank
<i>nT8</i>	Downstream company informs J company the issues about equipment delivery
<i>nT9</i>	Company J receives payment for equipment delivery from the Bank
<i>nT10</i>	Downstream firms receive equipment
<i>nT11</i>	Downstream firms confirm that equipment is qualified and operate under good conditions
<i>nT12</i>	Company J receives the banks funds
<i>nT13</i>	The Bank investigates whether the fund repaid by Downstream firms are available
<i>nT14</i>	The Bank reminds the Downstream to repay within the agreement expiration
<i>nT15</i>	The Bank investigates availability of the funds from the Downstream firms again
<i>nT16</i>	The Bank informs J Company to continue cooperation in production
<i>nT17</i>	The Bank informs Company J to repurchase the equipment
<i>nT18</i>	Expiration of the financing cooperation agreements

*E18* (Downstream firms pays back to banks during agreed time)

→ *E20* (The bank account funds of Downstream firms are still insufficient)

→ *E21* (Company J repurchase equipment according to the agreement)

→ *E22* (End of a round of financing process)

*E18* (Downstream firms pays back to banks during agreed time)

→ *E19* (Downstream company has sufficient bank account funds)

→ *E22* (End of a round of financing process)

*E18* (Downstream firms pays back to banks during agreed time) relates to whether the loans are repaid in time. This is

also a key event and will lead to two results: the first is the smooth progress and completion of the financing business process that we are looking forward to; the second is a risky point, the breach of contract by Downstream financing companies which will cause problems in the capital chain, such that the financing model does not work properly.

**APPENDIX D**

See Tables 15, 16, and 17.

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