Retraction note

On January 4, 2022, the editors were asked by the authors to suspend publication because an important issue has been overlooked and the article needed to be revised.

Accordingly, the article **RESEARCH ON EMERGENCY LOGISTICS MODEL OF AGRICULTURAL PRODUCTS BASED ON COUPLING OF PETRI NET AND BLOCKCHAIN** has been retracted at the request of the authors.

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HUIMIN GE, Prof.[1]
(Corresponding author)
E-mail: hmge@ujs.edu.cn
HAISHENG LIU[1]
E-mail: lhs_jxsc@163.com
RUI WANG[1]
E-mail: wanghahaq@163.com
SHUAI ZHU[1]
E-mail: ZhuShuai918@163.com
LINBEI SHAO[1]
E-mail: shao_linbei@163.com
[1] Jiangsu University
Automotive and Traffic Engineering
Zhenjiang, Jiangsu 202013, China

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RESEARCH ON EMERGENCY LOGISTICS MODEL OF AGRICULTURAL PRODUCTS BASED ON COUPLING OF PETRI NET AND BLOCKCHAIN

ABSTRACT

In this COVID-19 epidemic, due to insufficient awareness of the impact of sudden public health emergencies on agricultural logistics at this stage, agricultural products were left unsold, stocks were backlogged, and losses were severe. In the process of distribution, we should not only ensure a short time cycle and avoid the contamination of agricultural products by foreign bacteria, but also pay attention to the waste of human, material, and financial resources. Therefore, this study mainly adopts the combination of the petrochemical network and block chain to build an agricultural products emergency logistics model. This paper first shows the operation mechanism of the petri dish network and blockchain coupling in the form of a graph and then uses the culture network modelling and simulation tool PIPE to directly verify the construction model. It is proved that the structure and overall business process of the agricultural products logistics system constructed by combining the Petri net and block chain are reasonable, reliable, and feasible in practical application and development. It is hoped that this study can provide a reference direction for agricultural emergency logistics.

KEYWORDS

Petri net; blockchain; coupling model; agricultural emergency logistics.

1. INTRODUCTION

Agricultural logistics enterprises, logistics distribution centres, and wholesale markets should be organised to strengthen cooperation with production bases, leading enterprises and farmers' cooperatives to improve the efficiency of logistics and distribution. In the absence of data transparency and trust mechanisms, the development of logistics industry has gradually fallen into a trust dilemma [1]. The use of blockchain technology and Petri network coupling mechanism to achieve information sharing and information symmetry has solved the problem of low transparency of logistics information as well as the problem of obstructed transportation, saving transportation time, and reducing losses.

In the field of block chain application: domestic scholars have done a relatively in-depth research on the application of block chain technology. Block chain technology is applied to logistics information traceability system, food safety traceability system, etc. effectively solving the traditional agricultural products logistics quality and safety, circulation rate, agricultural products information asymmetry, and other problems. On the other hand, foreign scholars' research on block chain technology is mainly applied in commercial finance, and their research on logistics are mostly in general commodity logistics. The application of blockchain technology in supply chain and logistics has also achieved good results. In addition, blockchain technology has also been studied in intelligent logistics. Ye et al. [2] designed and developed a supply chain prototype system, which effectively solved such thorny issues as low trust among participants in the supply chain, difficult government regulation, and difficult balance between information sharing and privacy protection. Li [3] proposed GSCTM, a modelling method for grain supply chain. Liu [4] developed an information platform for retail supply chain participants. Khiat et al. [5] pointed out that as an integration technology, blockchain is an emerging concept, which allows the scattered and unchanging storage of verified data. Bagloee et al. [6] introduced the potential application of blockchain in the transportation, logistics, and supply chain industries, whereby the concept of transactibility and mobility was introduced.

In Petri net research areas: domestic and foreign research of the Petri net is mainly focused on the use of Petri net modelling to solve practical problems, especially in the area of logistics services and emergency management, effectively improving the efficiency of the model, providing a strong professional and formal description ability, convenient for hierarchical modelling and the stages of independent verification and validation. Jiang [7] introduced the Petri net modelling method to build a set of relatively perfect logistics product supply chain security traceability systems. Ge et al. [8] established the workflow model of emergency management and verified the rationality of the model. Sun and Li [9] used stochastic Petri nets to establish a cross-organisational emergency coordination process and isomorphised its corresponding Markov chain according to the possible state sets. The application of generalised stochastic Petri nets has also been studied deeply by domestic scholars. Zhang et al. [10] first applied the generalised stochastic Petri net model to quantitatively analyse the performance and operational efficiency of general emergency management workflow. Liu and Lu [11] modelled the emergency management process of energy emergencies and put forward suggestions on optimising the process. Liu [12] established the e-commerce cold chain logistics process model and put forward suggestions on improving the e-commerce cold chain logistics process and improving the stability and efficiency of e-commerce cold chain logistics. Clempner [13] mainly used the decision-based Petri net model for modelling, proving that the best trajectory problem has a solution, which also means that the Petri net model is feasible for modelling. Sutanas [14] built a Petri net model for a flood emergency management process. Zhong et al. [15] studied the urban emergency response system using the Petri net model and demonstrated the effectiveness of the model.

2. PETRI NET AND BLOCKCHAIN COUPLING MECHANISM

2.1 Operating mechanism of the Petri net

Petri nets are mathematical representations of discrete parallel systems and are suitable for describing asynchronous and concurrent computer system models. The place in the Petri net is the issuer of all "tasks", that is, the "causes" of all asynchronous concurrent operations, and the "changes" correspond to the "results" generated by the corresponding asynchronous concurrent operations. In addition, the prototype Petri net introduces a token in use to represent the dynamic state generated after the "change", that is, the token in the system. The introduction of tokens can well describe the local "dynamic" situation of the system after asynchronous concurrent operations. It is a system model suitable for describing asynchrony and finding phenomena. It has both strict mathematical definitions and intuitive graphical representations. Therefore, it is often used as the main modelling tool for discrete event systems. At present, the Petri net theory has formed an independent branch of discipline and has made certain research results in many other disciplines and technical fields.

The emergency logistics system is different from the ordinary logistics system; it is a typical discrete event system, a dynamic system driven by the event system process. The time interval of the event and the location are uncertain, and it is difficult to determine a timely distribution. There are emergency resource management difficulties, rescue demand information and feedback are difficult to obtain in real-time. These series of problems are challenging for the entire emergency logistics system. Therefore, the Petri net must be expanded and improved according to the emergency logistics system [16].

The Petri net includes four basic elements: repository, transition, directed arc, and token, and two common elements: condition and event. The classical Petri net model is shown in *Figure 1*. The sufficient conditions of the Petri net are as follows:

$$P \cap T = \emptyset \tag{1}$$

$$P \cup T \neq \emptyset \tag{2}$$

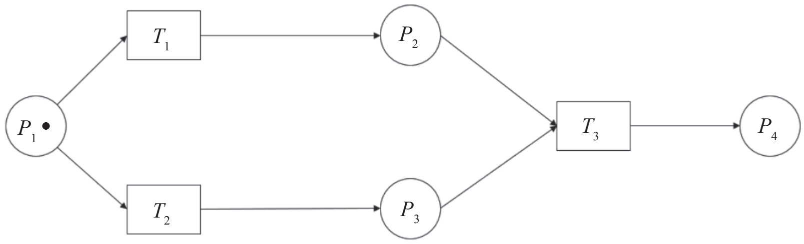

Figure 1 – Classic Petri net model

$$F \subseteq (P \times T) \cup (T \times P) \tag{3}$$

$$\mathrm{dom}(F)\,\mathrm{cod}(F) = P \cup T \tag{4}$$

where:

P – the library set of the network;

F – an ordered pair set consisting of a pair of P and T, which is called the flow relationship of the network;

$\mathrm{dom}(F) = \{x \mid \exists y{:}(x,y) \in F\}$ – the first element set of the ordered even set of F;

$\mathrm{cod}(F) = \{x \mid \exists y{:}(y,x) \in F\}$ – the second element set of the ordered even set of F;

$X = P \cup T$ – the set of elements of the network [17, 18].

According to the characteristics of the emergency logistics of agricultural products, the operation mechanism of modelling was analysed by using the Petri net. The Petri net modelling algorithm of the agricultural products emergency logistics process is as follows:

1) P or T is used to represent the events in the process, and the directed arc is used to represent the relationship between the events;
2) There is only one repository at the beginning and the end of the process;
3) The control structure is used to represent the path selection, and the control structure connects the corresponding P and T.
4) Change can be achieved through control structure.
5) Repeat 3 and 4 until all control processes of the emergency logistics process of agricultural products are realised [18].

The discrete stochastic model of the agricultural product emergency logistics system is transformed into an approximate model with continuous determination, so as to make better use of the Petri net in order to analyse the discrete event dynamic system. The Petri net provides a unified graphical representation method graph analysis technology for the agricultural product emergency logistics system to describe the characteristics of the system.

2.2 Operating mechanism of blockchain

Due to the sudden and uncertain occurrence of agricultural product emergency logistics, the command centre cannot get accurate information in time, which seriously affects the decision-makers' judgment who then make wrong decisions, resulting in a large area of logistics paralysis. The decentralised technology of blockchain can solve this kind of problem effectively. Decentralisation makes the rights of the participants in the logistics system equal, and the information provider and decision-maker are not unique, which makes the information diversified and greatly improves the accuracy and timeliness of information. Decentralisation also makes the generation of transactions, verification transactions, recording transactions, and processing transactions based on the distributed network. The separation processing method can deal with more data problems in a short time and improve the operation efficiency.

The smart contract of blockchain technology is a group of scenarios. The parties who sign the contract agree on the content of the contract and deploy it on the blockchain in the form of smart contract, which can automatically execute the contract on behalf of the signers without relying on any central organisation [19]. In the process of the emergency logistics of agricultural products, we can use smart contract to restrict the contract parties in the intermediate process, ensure the fairness and reliability of the intermediate process in a certain sense, and promote the operation efficiency of the agricultural emergency logistics system.

2.3 Coupling mechanism of the blockchain and Petri net

From the above analysis, it can be seen that there are great similarities between the blockchain and Petri nets in the agricultural logistics process.

1) The Petri net has a precise semantics and graphical description. Once the model is established, it is simple and easy to read. The Petri net model is

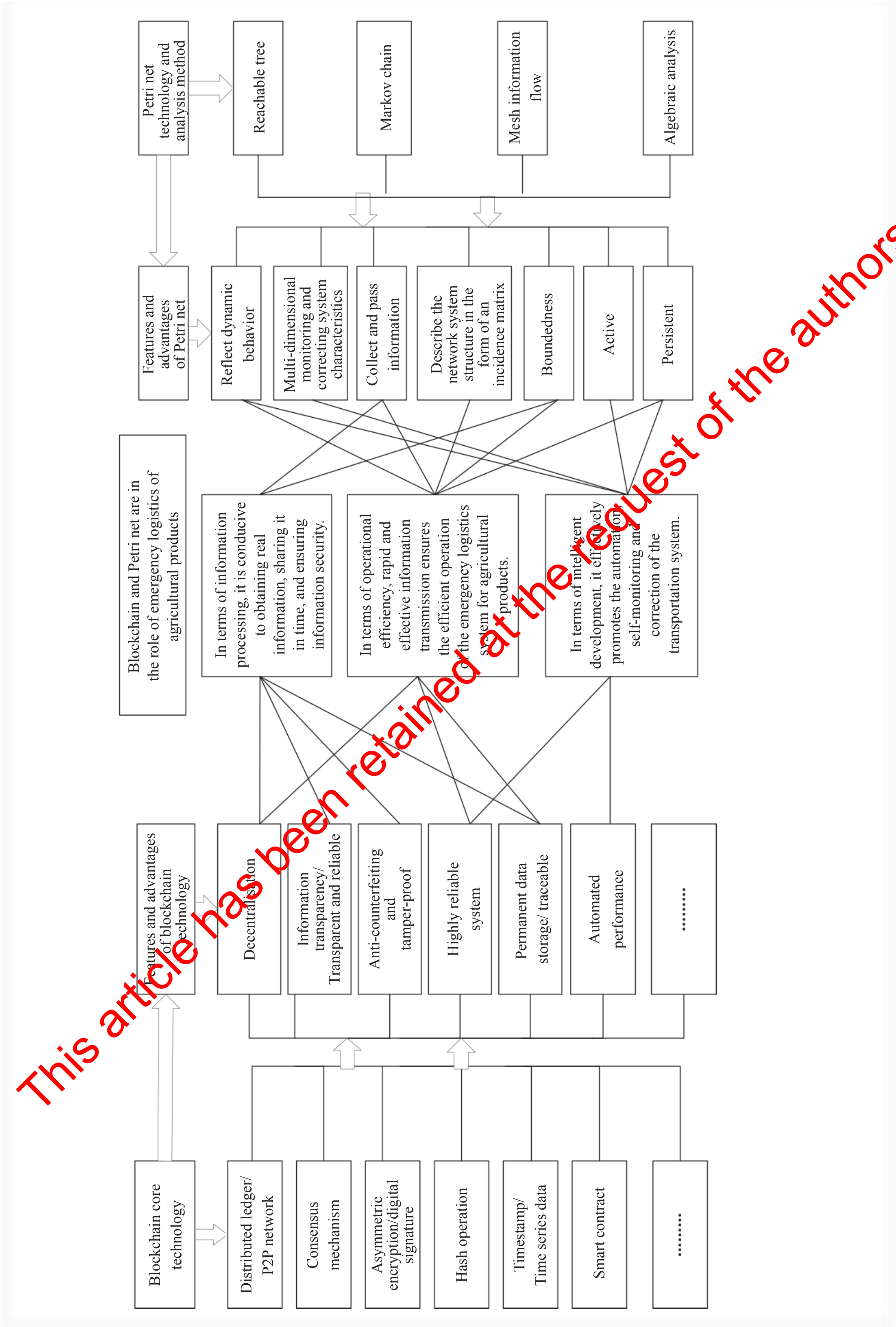

Figure 2 – Coupling mechanism between blockchain and Petri nets

constructed for each step by refining the Petri net modelling elements for each major event at each step.

2) After the model is established, the discrete nature of the blockchain speeds up the transfer of information between subjects and improves efficiency; information is made open and transparent through sharing mechanisms and smart contract technology.
3) Coupling the blockchain consensus mechanism, smart contract, and other technologies with the Petri net's Markov chain, reachability tree, and other analysis methods, sharing information in time, ensuring information security, effectively promoting the automation of the transportation system, and ensuring the emergency logistics system of agricultural products operate efficiently.

The specific manifestation is shown in *Figure 2*.

3. EMERGENCY LOGISTICS MODEL

After analysing each initial triggerable event in the production, processing, sales, and other processes of agricultural products, the distribution of the number of tokens in the initial state is determined and the emergency logistics model of agricultural products coupled with the blockchain and Petri net $\sum 1$ is established, as shown in *Figure 3*.

The meaning of each element in the Petri net is as follows:

- $p=(p_1,p_2,p_3,...,p_m)$ represents the set of all the places in the Petri net. It is a non-empty finite set, which can be represented as input signals such as resources, conditions, status, and input data.
- $t = t_t \cup t_i\,(t_t \cap t_i = \emptyset)$ is expressed as a Petri net as a collection of changes; $t_1=(t_1,t_2,t_3,...,t_k)$ is represented as a set of time transitions; $t_i=(t_{k+1}, t_{k+2}, t_{k+3},...,t_n)$ represents a set of instantaneous changes, which can represent jobs, events, services, calculation steps, and information processing, etc.
- $F \subseteq a^+ \cup a^-$, the set of directed arcs representing the changes of Petri nets, among them $a^- \subseteq p \times t$ is the set of input arcs for Petri net transition, $a^+ \subseteq t \times p$ is the set of output arcs for the Petri net transition; $a = a^+ - a^-$ is the incidence matrix of the Petri net.
- $V \subseteq p \times t$ is denoted as the forbidden arc of Petri net transition t.
- $W{:}F \rightarrow N$ is expressed as the weight function of the directed arc of the Petri net, N=(1,2,3...) represents the mapping of the directed arc set to the weight coefficient space, that is, the Petri net weight coefficient space.
- $M_0{:}p \rightarrow N_{Token}$ is expressed as the initial identification of the Petri net system, N_{Token}=(1,2,3...) is expressed as the token quantity of Petri net place, $M_i(p_j)$ is expressed as the token quantity of place p_j under the i^{th} M mark of Petri net. It is the weight function (weight) of the directed arc on N. If there is no value on the arc, the weight is 1 by default.

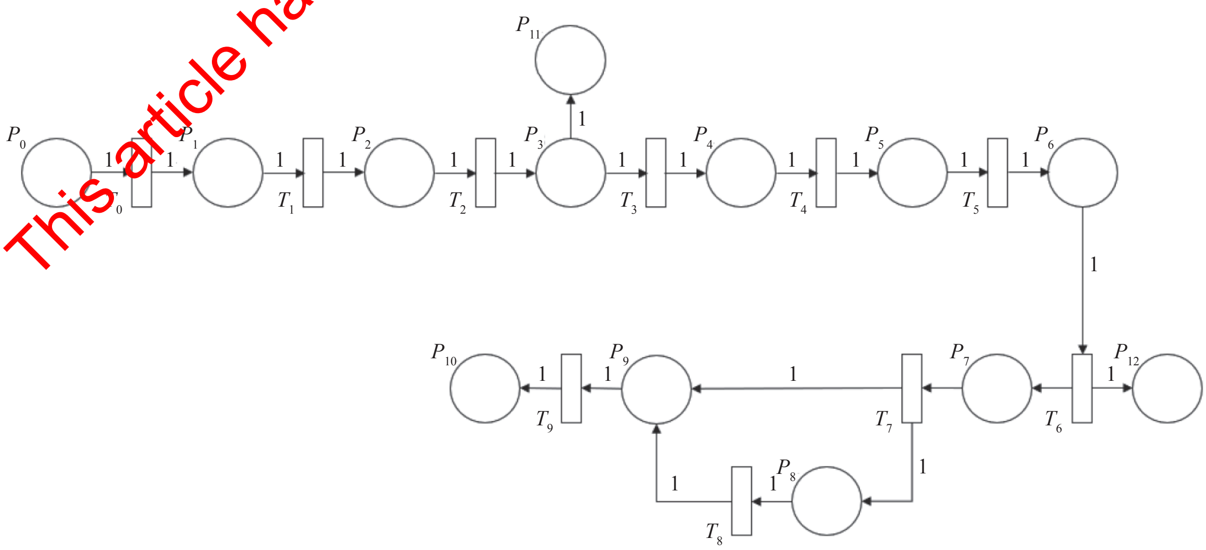

Figure 3 – An emergency logistics model for agricultural products coupled with blockchain and Petri net

– $\lambda=\lambda_{\Gamma}\cup\lambda_{I}$ is expressed as a set of Petri net transition balance rates, $\lambda_{\Gamma}=(\lambda_1,\lambda_2,\lambda_3,...,\lambda_k)$ is expressed as a collection of the average rate of time transition of the Petri net, and the average rate of time transition obeys the exponential distribution. λ_{I} is expressed as the Petri net's instantaneous transition rate and the implementation delay of the instantaneous transition rate is zero [12].

Table 1 shows the element definition description of the condition set P and the event set T in the system of *Figure 3*.

From the definition [20], we can know that $\Sigma=(P,T;F,W,M_0)$ is a Petri net system, $P=\{P_0,P_1,...,P_m\}$, $m=|P|$, $T=\{t_0,t_1,\dots,t_n\}$, $n=|T|$, then the incidence matrix of Σ can be represented by a matrix A of m rows and n columns:

$$A=[a_{ij}]_{m\cdot n} \tag{5}$$

In the formula:

$$\begin{gathered} a_{ij}=W(t_j,p_i)-W(p_j-t_j) \\ i\in\{0,1,2,3,\dots,m\},\quad j\in\{0,1,2,3,\dots,n\} \end{gathered} \tag{6}$$

For analysis needs, $A^{+}=W(t_j,p_i)$, $A^{-}=W(p_i,t_j)$ is introduced here, A^{+} is called the output matrix of Σ, and A^{-} is called the input matrix of Σ:

$$A=A^{+}-A^{-} \tag{7}$$

According to the definition [20] in the net system Σ, $P=m$ and A is the incidence matrix of $\sum 1$. According to the Petri net theory, if there is a non-parallel m-dimensional non-negative integer vector X, $A^{T}X=0$, then X is called a P-invariant of the network system $\sum 1$. According to the definition [20], the output matrix A^{+} and the input matrix A^{-} of $\sum 1$ can be easily obtained, and the incidence matrix A of the network system $\sum 1$ can be solved using the *Equation 3* as follows:

$$A=A^{+}-A^{-}=\begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

In the network system $\sum 1$, the initial identification $M_0=[1000000000000]^{\tau}$, through analysis and judgment, the possible transition path can be obtained by observing the P-invariant in it:

$$\sigma_1=t_0t_1t_2t_3$$
$$\sigma_2=t_0t_1t_2t_3t_4t_5t_6$$
$$\sigma_3=t_0t_1t_2t_3t_4t_5t_6t_7t_8t_9$$

Then combined with the P variable, we can know that the path of the change is:

$$P_0t_0P_1t_1P_2t_2P_3t_3P_{11}$$
$$P_0t_0P_1t_1P_2t_2P_3t_3P_4t_4P_5t_5P_6t_6P_{12}$$
$$P_0t_0P_1t_1P_2t_2P_3t_3P_4t_4P_5t_5P_6tP_7t_7P_8t_8P_9t_9P_{10}$$

Table 1 – Model variables correspond to procedures

Place	Definition	Transition	Definition
P_0	Receive objects demand for agricultural products	T_0	Agriculture and commerce to gain market requirements process
P_1	Agriculture and commerce to complete customised production plan	T_1	Agribusiness production process
P_2	Agricultural commercial production completed	T_2	Processing and packaging process
P_3	Processing and packaging completed	T_3	Quarantine process
P_4	Quarantine qualified	T_4	Product transportation process
P_5	Warehousing	T_5	Stored procedure
P_6	Leave the warehouse	T_6	Quarantine process
P_7	Quarantine qualified	T_7	Product transportation process
P_8	Warehousing	T_8	Repackaging process
P_9	Reach the farmers market (for sale)	T_9	Consumption process
P_{10}	Reach consumers	T_9	Consumption process
P_{11}	Quarantine unqualified		
P_{12}	Quarantine unqualified		

Table 2 – 2003 Production of various crops in the Inner Mongolia province

Crop types	2003		
	Sown area (thousands of hectares)	Total production (million tonnes)	Yield [kg/ha]
Rice	541.00	318.20	5882
Wheat	22.10	6.00	2715
Maize	2627.20	1615.30	6148
Soybeans	430.00	150.30	3495
Vegetables	269.10	881.01	32703
Sunflower seeds	93.70	16.16	1726

Through the above process, the P-invariant of the network system $\sum 1$ is solved, and the model will be verified by the computer model simulation of PIPE4.3 below.

4. MODEL VALIDATION

First, a brief introduction to PIPE, the simulation tool used for this validation. PIPE (Platform Independent Petri net Editor) is a Javabased editing and analysis system for Petri nets. It has been improved by eradicating bugs, refactoring code to make it more efficient and understandable, and by adding two major pieces of functionality.

Because data on the New Crown epidemic things are difficult to collect, we chose data from Inner Mongolia for the 2003 SARS period, according to what was published by the National Bureau of Statistics of China, of which we selected vegetables as the crop for this study in the Inner Mongolia province in 2003. Since the duration of SARS was seven months, we used 70% of the total production as the model validation data [21].

In practice, the model built can be verified directly using the Petri network modelling and the simulation tool PIPE. Using animation mode, after many experimental operations, it is determined that the network system $\sum 1$ can operate properly. *Table 3* depicts the results of the classification analysis of the net system $\sum 1$ using the classification function module of the PIPE4.3 simulation tool, which shows that the net system $\sum 1$ belongs to an extended free choice net.

The PIPE 4.3 simulation tool Incidence&Marking function module can be used to calculate the output matrix A^+, input matrix A^-, and incidence matrix AA of the network system $\sum 1$. At the same time, the initial identification M_0 state of the system and the transition t_1 that can be triggered and also analysed, and any state identification M_0 of the system can also be analysed according to the transition change situation. Through simulation verification, the obtained A^+, A^-, and A are completely consistent with the correlation matrix analysis results. Here, the analysis results of the changes before and after the change t_0 of the network system $\sum 1$ using the Incidence&Marking function module are given, as shown in *Tables 4 and 5*.

Table 3 – Classification function module is used to classify and analyse the results of the network system

Petri net type	Classification result
State machine	false
Mark graphics	false
Free choice network	true
Expand free choice network	true
Simple net	true
Extended simple net	true

Table 4 – Change t_1 before network system $\sum 1$ initial logo M_0

Library	P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9
Initial identification	1	0	0	0	0	0	0	0	0	0
Current logo	1	0	0	0	0	0	0	0	0	0

Table 5 – Initial identification of the transition t_1 of M_0 network system $\sum 1$ has occurrence right

T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9
yes	no	no	no	no	no	no	no	no	no

Table 6 – P-invariants analysis results of the net system ∑1

P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}
2	2	2	2	2	2	2	2	1	1	1	0	0
1	1	1	1	0	0	0	0	0	0	0	1	0
1	1	1	1	1	1	1	0	0	0	0	0	1

Table 7 – T-invariants analysis results of the net system ∑1

t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9
-	-	-	-	-	-	-	-	-

The invariant analysis function module of PIPE4.3 simulation tool can realise the *P*-invariant and *T*-invariant analysis of the network system $\sum 1$ to verify the relevant properties of the model system. *Tables 6 and 7* respectively show the *P*-invariant and *T*-invariant analysis results of net $\sum 1$ obtained by simulation tools.

The analysis results in *Table 6* show that there are three *P*-invariants in the network system $\sum 1$ and the analysis results in *Table 7* show that there is no *T*-invariant in the network system $\sum 1$. During the analysis of the invariants of the net system $\sum 1$ using the invariant analysis function module of the PIPE4.3 simulation tool, the analysis conclusions related to the invariants are given in addition to the output of the invariants present. For the *P*-invariant in the network system $\sum 1$, the simulation analysis gives a conclusion that the net has a definite *P*-invariant coverage and that it is therefore bounded. For *T*-invariants, the simulation analysis gives conclusion that the net has no definite *T*-invariant coverage and therefore it is not possible to know whether it is bounded and active. The results of this analysis are in full agreement with the result of the invariant in the network system $\sum 1$ calculated through the incidence matrix analysis in Chapter 2, which also justifies the results of the previous analytical calculations.

At the same time, for the three *P*-invariants in the network system $\sum 1$, the simulation tool also gives the corresponding *P*-invariant equations after the analysis:

$$2M(P_0)+2M(P_1)+2M(P_2+2M(P_3)+2M(P_4)+2M(P_5)$$
$$+2M(P_6)+2M(P_7)+M(P_8)+M(P_9)+M(P_{10})=2$$
$$M(P_0)+M(P_1)+M(P_2)+M(P_3)+M(P_{11})=1$$
$$M(P_0)+M(P_1)+M(P_2)+M(P_3)+M(P_4)+M(P_5)$$
$$+M(P_6)+M(P_{11})=1$$

The above analysis and calculation of the net system $\sum 1$ using the Petri net incidence matrix and solving the *P*-invariant, and using the PIPE4.3 simulation tool to carry out simulation verification, thus ensuring that the Petri net model shown in *Figure 3* is conserved, reachable, bounded, and safe. It also fully shows that the designed agricultural product intelligent traceability service system architecture and its overall operating process are reasonable, reliable, and feasible in actual application development.

5. CONCLUSION

In view of the lack of widespread application of the blockchain technology in agricultural emergency logistics, this paper applies the Petri net and blockchain coupling technology to construct a coupling model of the Petri net and blockchain based on the main influencing factors of agricultural emergency logistics, and conducts a coupling feasibility analysis. Then, through model validation, a feasible solution is provided to a certain extent for the application of the Petri net and blockchain technology in agricultural products emergency logistics. After the analysis of the emergency logistics process, the advantages of the blockchain and Petri network in solving related problems are combined. The model not only provides a certain reference for the actual process, but also provides a case study for the application of blockchain and other technologies in agricultural logistics.

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葛慧敏 (1979-) 江苏连云港人，江苏大学副教授，工学博士，从事驾驶行为研究、载运工具运行安全、运输

规划与设计、物流系统规划与设计等。
刘海生（2000-）江苏大学本科在读，主要研究方向：物流系统优化
王　瑞（2000-）江苏大学本科在读，主要研究方向：物流系统优化
朱　帅（1998-）江苏大学本科在读，主要研究方向：物流系统优化
邵麟焙（1999-）江苏大学本科在读，主要研究方向：物流系统优化

基于*PETRI*网和区块链耦合的农产品应急物流模型研究

摘要

在此次新冠疫情中，由于现阶段对于突发性公共卫生事件对农产品物流造成影响的认识不够充分，使得农产品滞销、积压，损失严重。在配送过程中，既要保证时间周期短，避免外来细菌对农产品的污染，又要注意人力、物力、财力的浪费。因此，本研究主要通过*Petri*网与区块链耦合进而构建农产品应急物流模型，然后利用*Petri*网络建模与仿真工具*PIPE*对构建模型进行直接验证。通过*Petri*网和区块链结合构建的农产品物流系统的结构和整体业务流程是合理可靠的，在实际应用和发展中是可行的。同时希望本次研究能够为农产品应急物流提供一个参考方向。

关键词

*Petri*网；区块链；耦合模型；农产品应急物流

REFERENCES

[1] Lu X, Pan J. Discussion on the dilemma and countermeasures for the development of logistics industry under the environment of electronic commerce. *China Circulation Economy*. 2020;42(10): 123-125+98.

[2] Ye X, Shao Q, Xiao R. A supply chain prototype system based on blockchain, smart contracts and the Internet of Things. *Science & Technology Review*. 2017;35(23): 62-69.

[3] Li J. *Research on the traceability scheme of grain supply chain based on blockchain*. M.Sc. thesis. Beijing University of Posts and Telecommunications; 2019.

[4] Liu Y. *Design and implementation of a supply chain information platform based on blockchain*. M.Sc. thesis. Inner Mongolia University; 2019.

[5] Khiat Y, Bahnasse A, Ouajji H. Smart logistics: Study of the application of blockchain technology. *Procedia Computer Science*. 2019;160: 266-271. DOI: 10.1016/j.procs.2019.09.467

[6] Bagloee SA, et al. Tradable mobility permit with Bitcoin and Ethereum. A Blockchain application in transportation. *Internet of Things*. 2019;8(C): 100103. DOI: 10.1016/j.iot.2019.100103

[7] Jiang Y. Research on the Safety Traceability System of Beef Product Supply Chain Based on Petri Net. *Supply Chain Management*. 2020;1(06): 34-48.

[8] Ge D, Zheng H, Yao G. Emergency management workflow model based on Petri net. *Journal of Nanjing Normal University (Engineering Technology Edition)*. 2009;9(1): 64-68.

[9] Sun Q, Li X. Construction of inter-organizational emergency collaboration model based on stochastic Petri nets. *Journal of Safety Science and Technology*. 2015;11(09): 63-69.

[10] Zhang Y, He J, Hu J. Modeling and analysis of emergency management workflow based on GSPN. *Statistics & Decision*. 2012;(04): 44-47.

[11] Liu X, Lu T. Modeling and analysis of energy emergency management process based on GSPN. *Science and Technology Management Research*. 2014;21(35): 175-179.

[12] Liu S. Modeling and analysis of e-commerce cold chain logistics process based on generalized stochastic Petri nets. *Journal of Guizhou University of Commerce*. 2019;32(03): 48-56.

[13] Clempner J. Structure vs. trajectory tracking methods: Soundness verification of business processes. *IEEE Latin America Transactions*. 2015;13(12): 3980-3986.

[14] Setanas S, Chen Z. Modeling of flood-related interdePend-encies among critical infrastructures. In: Li J, Zlatanova S, Fabbri AG. (eds.) *Geomatics Solutions for Disaster Management. Lecture Notes in Geoinformation and Cartography.* Berlin, Heidelberg: Springer; 2007. DOI: 10.1007/978-3-540-72108-6_24

[15] Zhong M, et al. Study in Performance analysis of China urban emergency response system based on Petri net. *Safety Science*. 2010;48(6): 755-762. DOI: 10.1016/j.ssci.2010.02.017

[16] Zhu H. *Modeling and simulation of Fujian Province emergency logistics system based on Petri net.* Ph.D. thesis. Fuzhou University; 2017.

[17] Yang M, Wang M, Qu Y. Petri net modeling and performance analysis of emergency logistics rescue system. *Journal of Hebei University of Science and Technology*. 2017;38(03): 269-277.

[18] Dai J. *Research on DLS Company's Fresh Pork Quality Traceability System Based on the Coupling of Blockchain and Internet of Things*. Ph.D. thesis. Shandong University.

[19] Jiang C. Application of Blockchain Technology in Logistics. *China Circulation Economy*; 2019;(35): 23-26.

[20] Wu Z. *Introduction to Petri Net*. Beijing: Machinery Industry Press; 2006.

[21] Chinese National Bureau of Statistics. *Annual Report*, 2003.