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Research on Mine Locomotive Scheduling Model and Deadlock Based on Petri Net

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Abstract. In order to improve the efficiency of coal mine locomotive locomotive dispatching and avert locomotive collision and clogging, a time-dependent petri net model was established according to the characteristics of underground locomotive dispatching. And the concepts of deadlock state and potential deadlock state are introduced. The deadlock state corresponds to the deadlock state equation, which is the reflection of the running state and resource status of a petri net. Then, the deadlock state equation is solved for each model. Meanwhile, PIPE is used to verify the results obtained, and the results prove the availability of the deadlock state equation for petri net deadlock state description. The whole experimental process and algorithm results show that the deadlock state equation can effectively simulate the deadlock state of the model, and prevent the generation of deadlock state of the model according to the potential deadlock state equation, so as to avoid the collision of locomotives and achieve efficient scheduling.

Introduction

With the development of industry, coal mine automation level needs to be improved. However, due to the narrow roadway, many locomotives and other unique characteristics, locomotive dispatching is always a difficult problem. If the problem is not solved, it will greatly affect the safety and efficiency of the whole coal mine. In 2016, Zhu Qihang et al. introduced the petri net theory into the underground rail transportation scheduling optimization of mines and established the petri net model based on ant colony algorithm[1].

Petri net is a computer system model suitable for describing concurrency and asynchrony, which can well describe the characteristics of asynchrony, parallelism and uncertainty in locomotive dispatching system. It is suitable for modeling and simulation of locomotive dispatching system. In 2007, Guo Zhiqi et al. modeled the dispatching rules of coal mine monitoring system by using petri net and taking KJ15a system as the prototype, and theoretically elaborated the applicability of petri net to the modeling of underground locomotive system [2], and the model could complete the basic deadlock function. In 2018, Zhang Ning combined petri net and A* search algorithm to optimize the tractor scheduling strategy in the flexible manufacturing system, and solved the problem of tractor route planning and collision prevention[3].

The above research proves that petri net is suitable for mine locomotive dispatching. According to the unique operation characteristics of mine, this paper introduces the concept of resource allocation, establishes the petri net model with different scheduling methods, then obtains the deadlock state and potential deadlock state of each scheduling method through the algorithm.

Establishment of Mine Locomotive Petri net Dispatching Model

Description of Locomotive Operation Condition

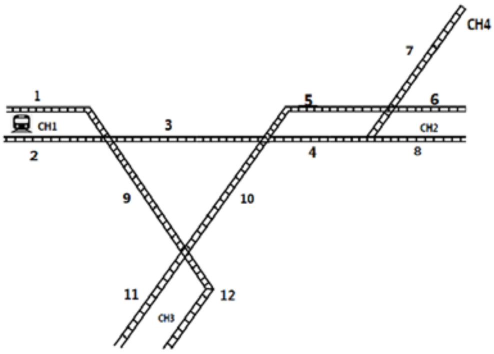


Figure 1. Locomotive running diagram

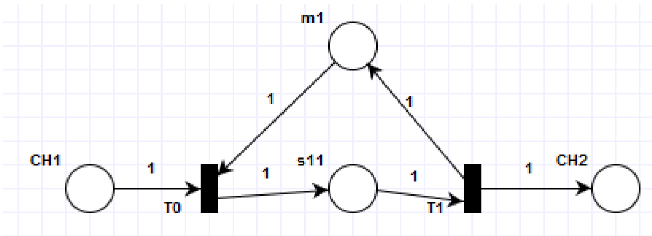


Figure 2. Resource/section model

In the mine operation, due to narrow roadway and numerous locomotives, it is easy to cause congestion or even collision of locomotives. As shown in figure 1, it shows a locomotive running diagram.CH stands for locomotive yard, yard 1 is an ordinary yard, all types of locomotives start from this yard. Yard 2, yard 3 and yard 4 are coal yard, these yard is used for loading coal.

Figure 2 shows the model resource/section. This model is an important concept of the building of locomotive dispatching model. Place S11 represents a section, it is a section place, which is denoted as p_q .m1 represents a section resource, if a token exists in the place, the corresponding section of the place is proved to be available. This kind of place is denoted as p_r .In the upper computer, the locomotive running route is divided into road resources and section resources, where the access includes one or more sections. Road resource is expressed as $p_{rr} = \{r_1, r_2, r_3 \cdots r_p\}$, $p \geq 1$;section resource is express as $p_{rs} = \{m_1, m_2, m_3 \dots m_q\}$,$q \geq 1$.

Petri net Model Based on Two Scheduling Method

According to the characteristics of underground locomotive dispatching, the following assumptions are put forward before the model is established:

1. All locomotives run back and forth between the ordinary yard and the coal yard according to their preset task routes;
2. All locomotives are divided into two types: heavy-load locomotive (represented by Z) and no-load locomotive (represented by K);
3. No-load locomotive runs non straight road; heavy-load locomotive runs straight road;
4. A section can accommodate up to one locomotive at each moment.

The scheduling model is established based on two scheduling methods[4]:

(1) Method 1: The first dispatching method is to issue a pre-occupation request for the next road and section when the locomotive is running in the last section of the current road. Pre-occupancy is completed when there are no locomotives in all sections contained in the current and next road only. As shown in figure 3:

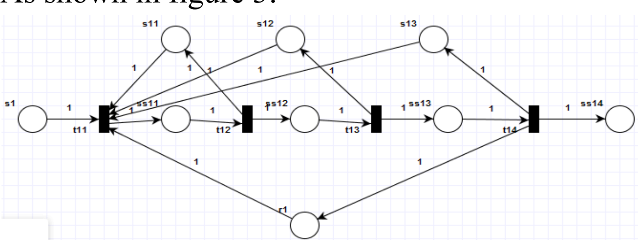


Figure 3. The first scheduling method model

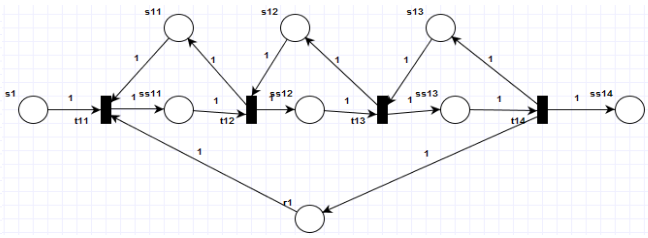


Figure 4. The second scheduling method model.

(2) Method 2: The second scheduling method is to issue a pre-occupation request when the locomotive runs to the last section of the current road. Only the next road and the first section of the

next road meet the pre-occupation condition, and then the pre-occupation can be completed. As shown in figure 4.

Establishment and Analysis of Locomotive Dispatching Petri Net Model

Figure 1 has shown the running track diagram of locomotives. In this chapter, petri net modeling will be carried out based on the trajectory diagram in figure 1.

The sections contained by each road are:

Table 1. Road/section comparison table

r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}
s_1, s_3	s_5	s_6	s_4	s_8	s_{13}, s_7	s_1, s_9	s_3, s_2	s_{11}	s_{12}	s_9, s_2	s_7

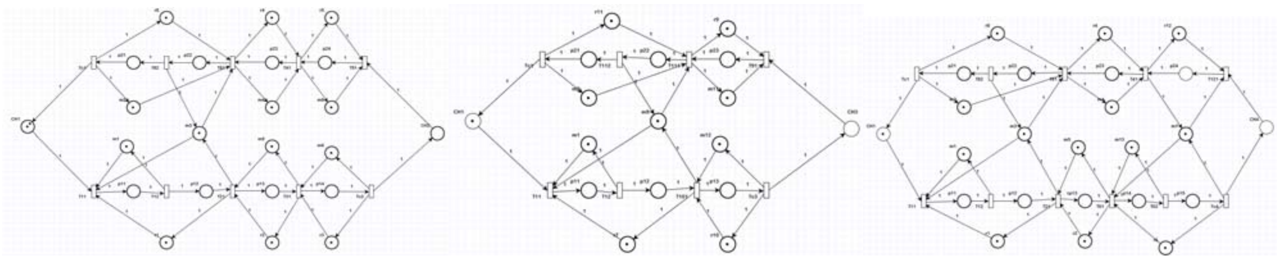
The task route is listed below:

Table 2. Task route table

Type	NO.	Task road	Section	Route
K	1	(r1,r2,r3)	{(s1,s3)(s5)(s6)}	CH1 TO CH2
Z	1	(r5,r4,r8)	{(s8)(s4)(s3,s2)}	CH2 TO CH1
K	2	(r7,r10)	{(s1,s9)(s12)}	CH1 TO CH3
Z	2	(r9,r11)	{(s11)(s9,s2)}	CH3 TO CH1
K	3	(r1,r2,r6)	{(s1,s3)(s5)(s13,s7)}	CH1 TO CH4
Z	3	(r12,r4,r8)	{(s7)(s4)(s3,s2)}	CH4 TO CH1

According to the corresponding relationship of task route, approach and segment, petri net modeling can be performed.

Modeling of Mine Locomotive Petri Net with First Dispatching Method



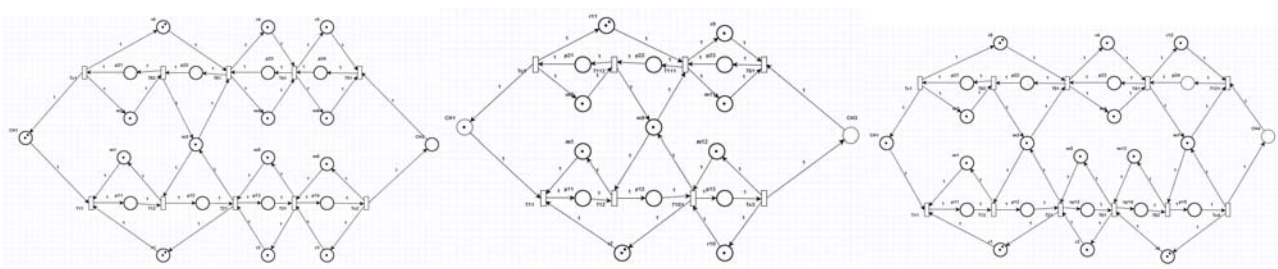
(a) (b) (c)

Figure 5. Dispatching model of locomotives with first method

The locomotive operation is modeled according to different routes based on the first method, as shown in figure 5.Locomotive issue a pre-occupation request for the next road and section when the locomotive is running in the last section of the current road. Pre-occupancy is completed when there are no locomotives in all sections contained in the current and next road only.

The locomotive dispatching under this method can ensure the safe passage of the locomotive, but the dispatching efficiency is slightly lower.

Modeling of Mine Locomotive Petri net with Second Dispatching Method



(a) (b) (c)

Figure 6. Dispatching model of locomotives with second method

The locomotive operation is modeled according to different routes based on the second method, as shown in figure 6.This method improves on the first method. The section feedback place m_i can control every section .The quantity of tokens that exist in the road resource place is equal to the number of sections that the road contains. A road can accommodate the same number of locomotives as the number of sections, thus improving transport efficiency.

Deadlock Analysis and Calculation of the Model

Deadlock State Analysis

Based on the nature of deadlock state equation, the following concepts are introduced:

Definition 3.1: For a petri net model,$^*t = \{p \mid (p, t) \in I\}$ are the input places set of t,and $t^* = \{p \mid (t, p) \in O\}$ are output places set of t. $^*p= \{t \mid (t, p) \in O\}$ are the input transitions set of p,and $p^*=\{t \mid (p, t) \in I\}$ are output transitions set of p. Where (x, y) represents an arc form x to y [5].

Definition 3.2: Resources $R_D \in R$ is said to be in a deadlock state under marking M if it satisfies the following two conditions: (1) All the workflow in R_D are occupied, i.e., $M(p_r)=0$ for $r \in R_D$. (2) All the workflow occupying resources of R_D are waiting for other resources of R_D, i.e., $^*(p_q{}^*)_r \in \{p_r \mid r \in R_D\}$ for $p_q \in \{p_q \mid R(p_q) \in R_D, M(p_q)>0\}$ where $R(p_q)$ denotes the resource occupied in processing step p_q [6].

The trigger of $t \in p_r{}^*$ will delete a token from p_r and move a token to $t^* \in \{ p_q \mid p_q \in (p_r{}^*)^*{}_q \}$. In the same way, the trigger of $t \in {}^*p_r$ will remove a toke from$^*t \in \{ p_q \mid p_q \in {}^*({}^*p_r)_q \}$ and and move a token to p_r. Hence, for a petri net and its resource r, the properties of the P-invariant are as follows:

$$\sum_{\{p_q \mid R(p_q)=r\}} M(p_q) + M(p_r) = C_r \tag{1}$$

Where C_r represents the initial token number of petri net model.

The following property can be obtained by defining 3.2 and the P- invariant:

Property 3.1: if the marking M satisfies the following Eq.2, then R_D is said to be in a deadlock state:

$$\sum_{\{p_q \mid R(p_q) \in R_D, {}^*(p_q{}^*)_r \in p_r, r \in R_D\}} M(p_q) = \sum_{r \in R_D} C_r \tag{2}$$

This equation is deadlock state equation of a petri net[6].

If one resource place controls two section place $p_{1,i}$ and $p_{2,i}$, Eq.2 need be changed as:

$$\sum_{\{p_q \mid R(p_q) \in R_D, {}^*(p_q{}^*)_r \in p_r, r \in R_D\}} M(p_q) = \sum_{r \in R_D} C_r - 2 \tag{3}$$

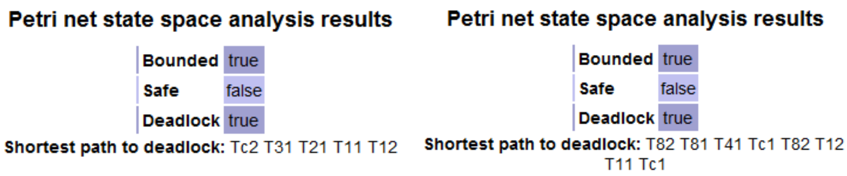
For locomotive 1 in figure 5(a), the dispatching petri net model of the first method, C_r represent the total section resources number.The section resource place m_3 controls two section place p_{11} and p_{12}, therefore it can be seen as one process. For models built using the second method(figure 6)and $R_D = \{m_1, m_2, m_3, m_4, m_5, m_6, m_8\}$, the deadlock state equation is:

$$M(p_{12}) + M(p_{13}) + M(p_{24}) + M(p_{23}) = C_{m1} + C_{m3} + C_{m5} + C_{m6} + C_{m8} + C_{m4} - 2 = 4 \tag{4}$$

Same as above, for locomotive 1 in figure 6(a), for resource $R_D = \{m_1, m_2, m_3, m_4, m_5, m_6, m_8\}$, the deadlock equation is:

$$M(p_{11}) + M(p_{12}) + M(p_{13}) + M(p_{24}) + M(p_{23}) + M(p_{22}) = C_{m1} + C_{m3} + C_{m5} + C_{m6} + C_{m8} + C_{m4} + C_{m2} - 2 = 5 \tag{5}$$

According to the results of Eq.4 and 5, the token will be placed in the specified place and simulated using software PIPE, the results are as follows:



(a) (b)

Figure 7. Deadlock state analysis results

Figure 7 (a) and (b)shows the deadlock state analysis of locomotive 1 under two scheduling methods.

Potential Deadlock State Analysis

Potential Deadlock State Algorithm

Based on the nature of the potential deadlock state equation, the following concepts are introduced:

Defimition3.3: If: (1) The resources in $R_D \in R$ are occupied. (2)At least one process currently releases resources, but the end result is a deadlock state. Then R_D is said to be in a potential deadlock state (PDS) under marking M[7] .

Due to the difference between the potential deadlock state equation and the deadlock state equation, a petri net potential deadlock state equation is obtained by referring to the construction algorithm in [8].Meanwhile, in order to adapt to the characteristics of mine dispatching, the construction algorithm is slightly alter:

Step1: Let all the resources $r \notin R_D$ be activated, i.e., $M(p_r) = C_r$, $r \notin R_D$.

Step2:From the definition and analysis of P-invariants:

$$\sum_{r\in R_D} M(p_r) + \sum_{\{p_q|R(p_q)\in R_D\}} M(p_q) = \sum_{r\in R_D} C_r \tag{6}$$

Step3: Depending on the nature of the potential deadlock state, then let:

$$\sum_{r\in R_D} M(p_r) = 0 \tag{7}$$

Combine Eq. 6 with Eq. 7, can get:

$$\sum_{\{p_q|R(p_q)\in R_D\}} M(p_q) = \sum_{r\in R_D} C_r \tag{8}$$

If one resource place controls two section place $p_{1,i}$ and $p_{2,i}$, Eq.8 can be written as:

$$\sum_{\{p_q|R(p_q)\in R_D\}} M(p_q) = \sum_{r\in R_D} C_r - 2 \tag{9}$$

Step4: If $R(p_{q,i}) \in R_D$, $R(p_{q,k}) \in R_D$ (k >i), then let

$$M(p_{q,i}) = 0 \tag{10}$$

Combine Eq. 10 with Eq.8, have:

$$\sum_{\{p_{q,i}|R(p_{q,i})\in R_D, \exists k>i, R(p_{q,k})\in R_D\}} M(p) = \sum_{r\in R_D} C_r \tag{11}$$

In the same way, if one resource place controls two section place $p_{1,i}$ and $p_{2,i}$, Eq.11 should be changed as:

$$\sum_{\{p_{q,i}|R(p_{q,i})\in R_D, \exists k>i, R(p_{q,k})\in R_D\}} M(p) = \sum_{r\in R_D} C_r - 2 \tag{12}$$

Step5: For all $p_{q,i}$, $R(p_{q,i}) \in R_D$, $R(p_{q,i+1}) \notin R_D$, $R(p_{q,k}) \in R_D$, k > i +1,l is the if the length of the scheduling route, token in $p_{q,i}$ can arrive at the place $p_{q,l}$ by a firing sequence from any marking satisfied Eq. 12, then let:

$$M(p_{q,i}) = 0 \tag{13}$$

Step6: Combine Eq. 13 with Eq. 11 or Eq.12, can get the PDS equation.

In a petri net model, the potential deadlock state equation is difficult to be directly obtained, so the above algorithm can be used to calculate the potential deadlock state equation

Solving of Potential Deadlock State Equation in Locomotive Dispatching Model

First dispatching method petri net model for locomotive 1: for $R_D = \{m_1, m_2, m_3, m_4, m_5, m_6, m_8\}$. p_{11} and p_{12} share resource m_3 , p_{21} and p_{22} share resource m_2 , according to Eq. 12 :

$$M(p_{11}) + M(p_{12}) + M(p_{13}) + M(p_{14}) + M(p_{24}) + M(p_{23}) + M(p_{22}) + M(p_{21}) = C_{m3} + C_{m5} + C_{m6} + C_{m8} + C_{m4} + C_{m2} = 6 \tag{14}$$

From Eq. 7, get:

$$M(p_{11}) + M(p_{14}) = M(p_{21}) = 0 \tag{15}$$

Combine Eq. 14 and Eq. 15, from Eq. 9, have:

$$M(p_{12}) + M(p_{13}) + M(p_{24}) + M(p_{23}) + M(p_{22}) = 6 - 2 = 4 \tag{16}$$

According to Eq. 16, if the sum of the number in places in figure 5 (a): $p_{12}, p_{13}, p_{24}, p_{23}, p_{22}$ is 4,then after several runs, the model will eventually become deadlocked. Therefore Eq. 16 is the potential deadlock state equation of this model.

Second dispatching method petri net model for locomotive 1: for $R_D = \{m_1, m_2, m_3, m_4, m_5, m_6, m_8\}$, according to Eq. 6 :

$$M(p_{11}) + M(p_{12}) + M(p_{13}) + M(p_{14}) + M(p_{24}) + M(p_{23}) + M(p_{22}) + M(p_{21}) = C_{m1} + C_{m2} + C_{m3} + C_{m5} + C_{m6} + C_{m8} + C_{m4} = 7 \tag{17}$$

From Eq. 7, get:

$$\mathrm{M\ (p14) = M\ (p21) = 0} \tag{18}$$

Combine Eq. 18 and Eq. 17, from Eq. 9, have:

$$M(p_{11}) + M(p_{12}) + M(p_{13}) + M(p_{24}) + M(p_{23}) + M(p_{22}) = 7 - 2 = 5 \tag{19}$$

According to Eq. 19, if the sum of the number in places in figure 6 (a): $p_{11}, p_{12}, p_{13}, p_{24}, p_{23}, p_{22}$ is 5, then after several runs, the model will eventually become deadlocked. Therefore Eq. 19 is the potential deadlock state equation of this model.

Conclusion

In this paper, based on the the characteristics of mine locomotive dispatching and the principle of petri net, two kinds of dispatching methods are used to carry out petri net modeling of designated locomotive operation diagram, and introduce the respective characteristics of the two dispatching methods.Then introduce the concepts of deadlock state equation and potential deadlock state equation , and carry out the deadlock state analysis of locomotive 1 in the model. The final result of software PIPE proves its validity.At last, the potential deadlock state equation of the model is calculated, thus prevent the clogging of locomotive and improve the scheduling efficiency.

Acknowledgements

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