Chapter 124
Emerging Scenarios Avoidance Policy for Railroad Level Crossing Traffic Control Systems

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Abstract Timed Petri nets (TPNs) are useful for performance evaluation discrete event systems due to their mathematical formalism. This paper proposes to use TPNs to model parallel railroad level crossing traffic safety control systems. Double-track railroad lines by using TPNs are illustrated. The resulting models allow one to identify and thus avoid critical scenarios in such systems by conditions and events of the model that control the phase of traffic light alternations. Their analysis is performed to demonstrate how the models enforce the phase of traffic transitions by a reachability graph with timed information method. The liveness and reversibility of the proposed model are verified. This helps advance the state-of-the-art in traffic safety related to the intersection of railroads and roadways.

Keywords Timed petri net · Discrete event system · Traffic control system

124.1 Introduction

As the number of vehicles grows sharply, traffic congestion and transportation delay on urban arterials are increasing worldwide; hence it is imperative to improve the safety and efficiency of transportation. Subsequently, several research

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teams focus their attention on the area of intelligent transportation system (ITS) [1]. Recently, Huang [2] proposed to use STPNs to design an urban traffic light controller that included eight-phase, six-phase and two-phase. Although [2] proposed a solution of the urban traffic light system, it did not consider railroad level crossing control systems. An intersection of a railway and a road on the same level, called *railroad level crossing*, can be found in busy cities.

Here, the vehicles heading are perpendicular to the crossing zone, called direct critical scenario. On the other hand, the vehicles heading are parallel with the crossing zone, called indirect critical scenario. Generally, traffic signals are usually used to manage conflicting requirements for the use of road space—often at road junctions—by allocating the right of way to different sets of mutually compatible traffic movements during distinct time intervals. However, critical scenarios happen when the road traffic light signals cannot be changed according to the train passing automatically. Hence, it is a significant issue to control traffic lights in parallel railroad level crossing control systems.

This paper presents a parallel railroad level crossing traffic control system that has two-phase traffic lights. For convenience, the two-phase lights are modeled with a fixed number of discrete time intervals by TPNs. And also the railroad level crossing system is modeled by TPNs that allows both zero-time-consuming transitions (called immediate ones) and timed one with exponentially distributed random delay. It is interesting that some critical scenarios could happen immediately while a train is approaching the parallel railroad crossing, called crossing zone in this paper. For example, a green traffic light is going on and a train is entering the crossing zone at the same time, resulting in a critical scenario. Therefore, it is an important issue how to evaluate the safety control policy for the parallel railroad level crossing control systems. This work proposes a new way to avoid the critical scenarios from being taken. Then the traffic safety can be guaranteed. In particular, PN toolbox [3] is used to extract the critical scenarios from such system. Reachability analysis is performed to ascertain the liveness, boundedness and reversibility of the developed model.

124.2 Basic of Timed Petri Nets

A Petri net is a particular kind of bipartite directed graphs populated by three types of objects. They are places, transitions, and directed arcs connecting places to transitions and transitions to places [4]. In a PN, it is natural to associate with a place a state which has some duration and to associate with a transition a change of state, this change having no duration. It is then natural to associate the duration of some operation or state with a place, and the time of waiting for an event to the transition to be fired when it occurs. Basically, two models of TPNs can be used; time is associated with the places or with the transitions. Transfers are possible form one to one model to another. In this paper, TPNs are with timings associated with transitions. TPNs allow three types of transitions: (1) immediate one that is represented by a thin bar and its firing takes no time; (2) random one that is represented by empty bars and its firing takes an exponentially distributed delay; and (3) deterministic one that is represented by empty bars and its firing takes a constant delay. Formally, a TPN can be defined as follows:

TPN = (P, T, I, O, H, M_0).

- $P = \{p_1, p_2, \ldots, p_m\}$ a finite set of places that can be marked with tokens.
- $T = T_{imm} \cup T_{\exp} \cup T_{\det} = \{t_1,\ t_2,\ t\ldots,\ t_n\}$ a finite set of transitions, partitioned into three disjoint sets, T_{imm}, T_{exp} and T_{det}, representing immediate, exponential, and deterministic ones, respectively. $P \cup T \neq \phi$, and $P \cap T = \phi$.
- I: $P \times T \rightarrow N$ is the input function that defines directed arcs from places to transitions.
- O: $P \times T \rightarrow N$ is the output function that defines directed arcs from transitions to places.
- $\mathrm{H} \subseteq \mathrm{P} \times \mathrm{T}$ a set of inhibitor arcs from p to t.
- M_0: $P \rightarrow N$ is an initial marking.

124.3 Modeling Track Line of Railroad Level Crossing System

An intersection of a railway and a road on the same level is called a railroad level crossing. In [5] deal with a particular phenomenon which may cause collisions at level crossings (LCs), and which corresponds to the accumulation of vehicle waiting queues on the LCs exit zone. However, they emphasize more particularly the phenomenon of a traffic jam in the LC exit zone and goal is to evaluate the collision risk on LCs induced by these circumstances.

Considering the safety of the double-track line railway traffic, two pairs of sensors are needed. The detailed configuration is depicted in Fig. 124.1. The function of the two pairs of sensors is as follows. One pair of sensors (A_1 and A_2) are used to detect the heading southbound trains. The second pair (B_1 and B_2) detect the heading northbound trains. For convenience, sensors A_1, A_2, B_1, and B_2 are set to correspond to transitions t_7, t_{11}, t_{15}, and t_{13}, respectively. Places p_{21}, p_{20} and p_{19} are used to model the barriers, red right, and green light, respectively.

Figure 124.1 shows a double-track railway system that always involves running one track in each direction. The double railroad track system allows the trains running in a direction for each track. To model a double railroad track system, the capacity of p_{17} is assigned two tokens. Figure 124.1 states that the system allows the two different heading trains to pass through the crossing zone concurrently. The inhibited arcs are able to avoid being hit by two trains on the same way.

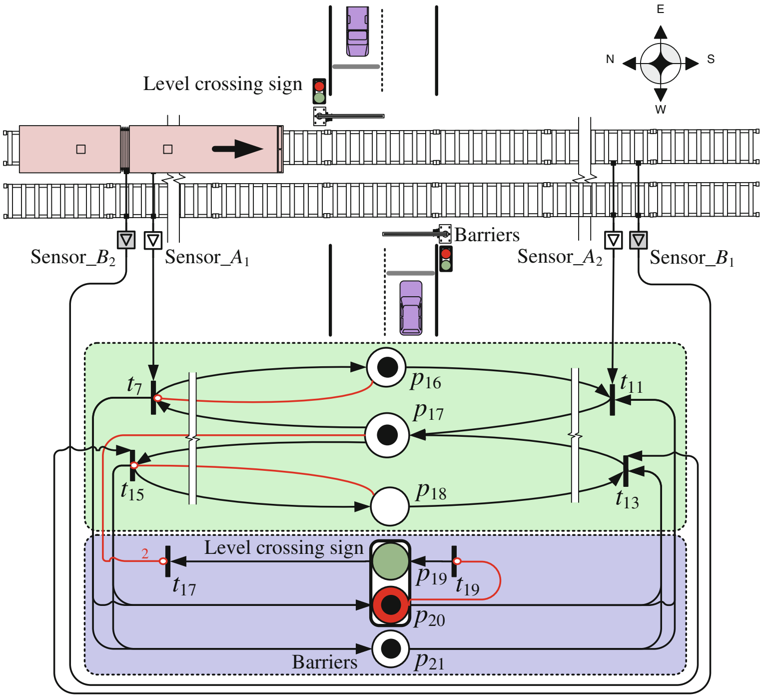

Fig. 124.1 A railroad level crossing model of a double-track line

124.4 Extraction of Emerging Scenarios

Emerging scenarios can happen at a railroad level crossing, especially when a road interacts with a parallel railroad crossing on the same level. To extract them, one has to deal with railroad level crossing control systems carefully. This study focuses on how to prevent a traffic jam on the level crossing-zone from being happened.

124.4.1 Three Indirect Emerging Scenarios

Places R_{we} and R_{ns} are marked: At this moment (i.e. Fig. 124.4), both the red lights are on. It is worthy to notice that the token of p_9 is used to ensure the duration of the traffic lights. Therefore, the traffic safety can be guaranteed while a train is passing through the crossing zone. The reachability graph with the priority information is as shown in Fig. 124.2 indeed proves that the system model is live and reversible. Obviously, $R(M_{0a}) = \{M_{0a}, M_1, M_2, M_3, M_4, M_5, M_{11}, M_{12}, M_{13}\}$. The circle I is normally run after the train passes through the crossing zone. The circle II will go back to the initial one while a train is approaching the crossing zone again.

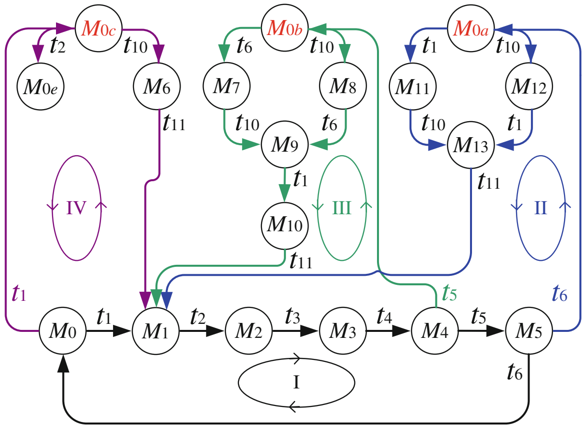

Fig. 124.2 A reachability graph of three indirect emerging scenarios TPN model

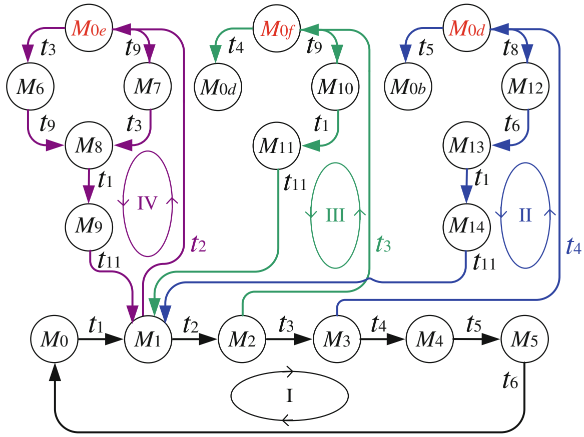

Fig. 124.3 A reachability graph of three direct emerging scenarios TPN model

Places R_{ns} and Y_{we} are marked: At this moment, the yellow light (place Y_{we}) that goes on while a train is entering the crossing zone. In this case, the proposed system model does not seem to do any control work, because the traffic light should be changed to red soon. The reachability graph is circle III in Fig. 124.2. Obviously, $R(M_{0b}) = \{M_{0b}, M_1, M_2, M_3, M_4, M_7, M_8, M_9, M_{10}\}$.

Places R_{we} and G_{ns} are marked: At this moment, the traffic light signals red (place R_{we})/green (place G_{ns}) along the east-westward/south-northward traffic direction. Then a conflict problem happens. As a result, the critical scenario can be avoided by our traffic control system. Case IV (firing t_2) is the same as discussed (Fig. 124.3). Next, direct critical scenarios are discussed, especially, when a green light is on at a crossroad-left traffic light system. At this moment, a train is approaching the crossing zone. Here, the reachability graph shows $R(M_{0c}) = \{M_{0c}, M_{0e}, M_0, M_1, M_2, M_3, M_4, M_5, M_6\}$.

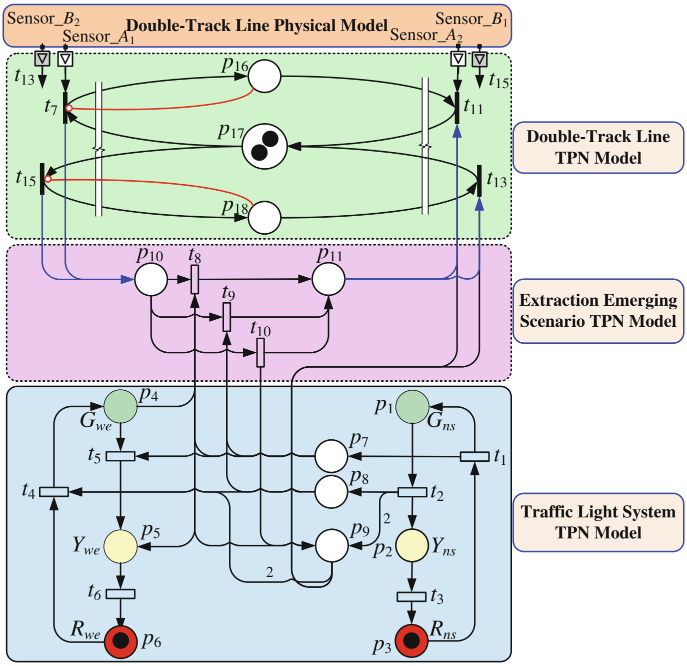

Fig. 124.4 The whole system TPN model of double-track line

124.4.2 Three Direct Emerging Scenarios

Places R_{ns} and G_{we} are marked: Fig. 124.3 shows a direct critical scenario. It states that the green light (i.e. place G_{we}) goes on while a train is entering the crossing zone. It also implies that this case is safe. Its reachability graph is shown in Fig. 124.3 and $R(M_{0d}) = \{M_{0d}, M_{0b}, M_1, M_2, M_3, M_{12}, M_{13}, M_{14}\}$.

Places R_{we} and Y_{ns} are marked: At this moment, the red light (R_{we}) is changing to green (G_{we}) while a train is approaching the crossing zone. It would be a very critical scenario if the traffic lights were not controlled. However, the critical scenario can be avoided by our traffic control system. In this case, $R(M_{0e}) = \{M_{0e}, M_1, M_6, M_7, M_8, M_9\}$ is obtained.

Places R_{ns} and R_{we} are marked (change phase): At this moment, the red light (R_{we}) should be changed to green while a train is entering the crossing zone. As a result, the direct dangerous scenario can be avoided. In this example, the reachability graph shows $R(M_{0f}) = \{M_{0f}, M_{0d}, M_1, M_2, M_{10}, M_{11}\}$.

124.4.3 The Whole System Model for Double-Track Line

A railway system with double-track line is considered. Usually, trains run on the same track when the trains are heading to the same direction. This work constructs a double-track line system model by extending the single-track one. It is obtained as shown in Fig. 124.4. The capacity of places p_9, p_{10} and p_{11} were modified from one to two and change the weight of arcs (i.e. $t_2 \rightarrow p_9$ and $p_9 \rightarrow t_4$) from one to two. In Fig. 124.4, the red light (R_{we}) is changing to green (G_{we}) while a train is approaching the crossing zone. The token of p_9 can be removed if t_9 fires. Once train leaves, the place p_9 is empty. It is worthy to notice that an arc ($p_9 \rightarrow t_9$) is used to describe how to ensure the system operation well while the train is leaving. It states that the system model allows two trains approaching the crossing zone concurrently whatever the heading directions of the trains are.

124.5 Conclusion

This work proposes TPNs models for the parallel railroad level crossing systems. It is worthy to notice that the concept of hybrid systems is used in the proposed models. It is important to point out that the emerging scenarios can be identified accurately from the proposed models. The advantage of approach is that the emerging scenarios in the parallel railroad level crossing system can be avoided by extraction emerging scenario TPN model.

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