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Research On Modeling Method Of Transportation Cyber-Physical System

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***Abstract*—Cyber-Physical Systems (CPS) has both continuous process and discrete operation in the application of traffic CPS. Therefore, based on the extended model theory, this paper introduces hierarchical model, colored set and timed attribute on the basis of prototype Petri Net, and proposes a Hierarchy Colored Timed Petri Net (HCTPN) model. In order to verify the usability of the proposed model, we modeled the vehicle and road units of Bus Rapid Transit (BRT), and simulated the scene of multiple passengers boarding. The final experiment showed that the proposed improved model could solve the safety problem of passengers boarding and alighting.**

***Keywords*-Cyber-Physical Systems; Hierarchy Colored Timed Petri Net; T-CPS Modeling;**

I. Introduction

CPS system originated in 2006. It mainly uses the synergy of computer, communication and control to effectively integrate two kinds of physical equipment and information systems to complete the dynamic control of large-scale real-time systems. In daily life, we often come into contact with CPS, not only in water conservancy, transportation, power grid, etc. with the development of technology, more and more physical devices are equipped with network communication functions, which can transmit data, so as to better realize intellectualization.

Petri net is a tool combining mathematical theory for analysis. It can not only describe the order, concurrency and conflict of components or processes in the system, but also have good modeling support for highly concurrent and heterogeneous systems [1]. However, the original Petri net can only model discrete systems, and many hybrid systems like CPS also include continuous systems. In order to strengthen the modeling ability of Petri net, the concept of hybrid Petri net came into being.

In summary,the major contributions of the paper are as follow:

1) We propose to use a hierarchical colored timed Petri net model, so that it can not only deal with the representation of multiple kinds of physical entities and states, but also clearly describe the state changes between libraries caused by changes. It can use relatively few objects and meet the requirements of describing different operations within the CPS system
2) We models and analyzes the BRT parking system, and puts forward an improved passenger boarding and alighting model after analyzing the passenger boarding and alighting scene The feasibility of the improved passenger boarding and alighting model is verified by comparing the results.

II. Relate Work

CPS system contains the integration of continuous process and discrete process, so the requirements for modeling are very high, which makes the model generated by modeling very complex.

Reference [2] introduces the process of CPS from initial design to modeling, final simulation and integration. Reference [3] describes a hybrid modeling method from discrete system model to continuous system model or from continuous system model to discrete system model. Reference [4] analyzes the three-tier CPS architecture framework, and puts forward high standard requirements for CPS in real-time, security and system performance. Reference [5] models CPS by hybriduml, converts generic models into formal models by using formal methods, and uses dynamic logic (DL) and hybrid program (HP) for modeling research and analysis. Zhang [6] and others conducted Modeling Research on the robot system of big data-driven cloud platform. They layered the CPS system and verified its feasibility with AADL.

Petri net has good description ability for asynchronous and concurrent operations in CPS system. Reference [7] analyzes the urban transportation system and uses hybrid Petri nets to model, simulate and verify it. Reference [8] uses colored Petri nets to model and analyze the data consistency of HDFS file system, and well distinguishes the workflow and changes of different node nodes through colored identification. Reference [9] proposed a testability modeling method based on generalized random colored Petri nets (cgspn). Taking a certain missile as an example, the complexity of the fault mode is analyzed, and the severity is expressed by color. Reference [10] establishes the architecture of coal mine CPS by using multi-agent nodes, and describes its internal subnet model through object-oriented Petri nets.

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III. The Proposed Mode

A. Petri Net

Petri net is a kind of mesh model expression, which contains two basic nodes, location and transition, as well as the directed arc and token information connecting them. In CPS system, tokens are usually used to represent state resources or operations, transitions are used to represent events, and libraries are used to represent conditions.

A prototype Petri net is represented by five tuples, and its structure is as follows:

$$PE = (P, T, F, W, M) \tag{1}$$

Where p represents a set of finite and non empty repositories; T represents a finite and non empty transition set; F represents the directed arc set connecting the location and transition; M represents the number of tokens,$M(P0)$ represents the number of tokens of P0 in the library, and $W = (pre, post)$ represents all directed arc weight sets. $Pre(T, P)$ represents the directed arc weight from the library p to the transition T, and $post(T, P)$ represents the directed arc weight from the transition T to the next library P.

The prototype Petri Net has the following rules:

1) In order to meet the duality between the repository and the transition, the repository set P intersects the transition set T, which is empty, and is recorded as $P \cap T = \emptyset$.
2) In order to meet the non empty principle between the repository and the transition, the repository set P and the transition set T are not empty, and are recorded as $P \cup T \neq \emptyset$
3) $F \subseteq (P \times T) \cup (T \times P)$($\times$ Represents Cartesian product)

For transition, if(2) is satisfied:

$$\forall p \in P : p \in t \rightarrow M(p) \geq 1 \tag{2}$$

When the transition occurs, a new mark M' will be obtained, and for $\forall p \in P$, the formula is satisfied as:

$$M'(p) = \begin{cases} M(p) + 1, p \in t' -' t \\ M(p) - 1, p \in' t - t' \end{cases} \tag{3}$$

Where $'t$ represents the pre location (input location) of transition T, and t' represents the post location (output location) of transition T.

B. Hierarchy Colored Timed Petri Net

Hierarchy Colored Timed Petri Net(HCTPN) is based on the prototype Petri net, adding layered model, colored set and timed attributes. These new attributes can better describe the traffic CPS system.

The formal expression of HCTPN nets is as follows:

$$HCTPN = (C, S, \Omega, M) \tag{4}$$

In the formula, $C = \{C_1, C_2, \ldots, C_n\}$ can contain a single color set or a composite color set, which is used to distinguish different token resources and operations in Petri nets; $S = \{S_1, S_2, \ldots, S_n\}$ represents a finite set of modules, satisfying $\forall S_i, S_j \in S$, $S_i \cap S_j = \emptyset$, where $i \in \{1, 2, 3, \ldots, n\}$,$j \in \{1, 2, 3, \ldots, n\}$, and $i \neq j$. Among them, each module S is a PN, including its own repository (P), transition (T), and the repository includes discrete repository P_D and continuous repository P_C, and $P_C \cap P_D = \emptyset$; Transition T also includes discrete transition T_D and continuous transition T_D, and $T_C \cap T_D = \emptyset$; In $\Omega = (f, t)$, f represents the occurrence interval function, and t represents the time interval parameter. M is the directed identification graph in HCTPN network, where M_0 is the initial state identification.

IV. Simulation And Results

A. Modeling Of BRT Intelligent Parking System

Nowadays, many cities in China have bus rapid transit (BRT). The door and shielded door of BRT bus are controlled by terminal signals, realizing the coordinated control of physical and information systems. Firstly, the scene is analyzed: the objects include vehicles, control terminals, safety doors, and passengers; Then analyze the status of each object: the status of passengers includes arrival at the platform, boarding and entering the carriage, the status of vehicles includes arrival, opening, closing and exit, and the terminal controller includes coordinating the opening and closing operations between the door and the safety door, so there are safety door open status and safety door closed status.

1) Vehicle Ground Control Model: Firstly, the BRT vehicle, control terminal and roadside unit are modeled and analyzed. Then, the vehicle, control terminal and roadside unit are connected in series through signal transmission to realize the opening and closing operation of door and safety door.

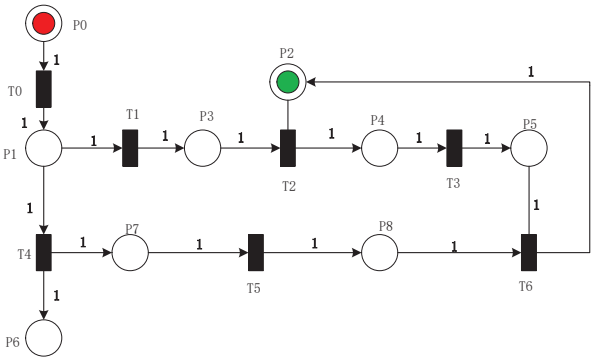

Figure 1. Modeling on BRT.

Accordingly, the corresponding model diagram is given, as shown in Figure 1. P0, P1 and P6 in the figure represent the arrival state of the vehicle, the opening state of the vehicle and the closing state of the vehicle respectively. P2 depot represents the closed state of the safety door, and P3 depot represents the terminal control equipment. When P2 and P3 have tokens at the same time, activate transition T2 to send the safety door opening signal to P4 of the roadside unit depot, and then execute transition T3 to complete the safety door opening operation. When the vehicle executes

the door closing transition T4, it first notifies the control terminal depot P7 to execute the transition T5. When the roadside unit depot P8 receives the closing instruction and the depot with the safety door in the open state P5 also has a token, it executes the transition T6 to close the safety door, the token returns to the safety door closed state depot P2, and the door token also reaches the closed state depot p6. In the figure, the green token represents the vehicle operation, and the red token represents the safety door control operation.

2) Vehicle Ground Control Model: In the passenger boarding and alighting model, the passenger object is added to the vehicle ground control model. In the passenger boarding and alighting model, the passenger status is mainly changed according to the status of the door and safety door, and the boarding and alighting operations need to be carried out from the opening of the door and safety door to the closing of the door and safety door. According to this workflow, it is necessary to make changes to the vehicle ground control model in the previous section. First, the control terminal controlling the safety door and the roadside unit are combined into the safety door control equipment, and the corresponding model figure 2 is drawn. Blue token represents passengers, green token represents vehicles, and red token represents safety doors.

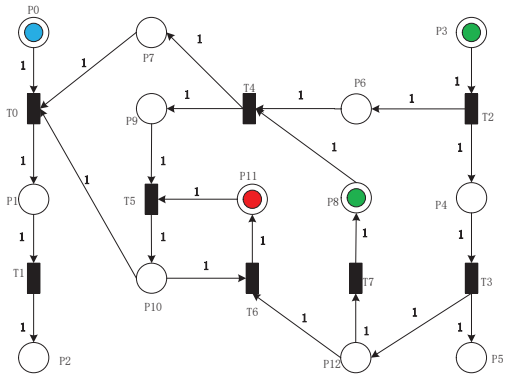

Figure 2. Modeling on bus and passenger.

If passengers want to perform the change t0 boarding operation, they need to have a token at the same time in the door opening state library P7 and the safety door opening state library P10. When the vehicle arrives at the station, it sends the door opening signal. Therefore, when the door closing state depot P8 and the door opening Equipment Depot P6 have a token at the same time, execute the transition T4 to arrive at the door opening state depot P7. At the same time, the token also arrives at the Equipment Depot P9 controlling the safety door, and the safety door control equipment executes the transition T5 to open the safety door; When the vehicle executes door closing transition T3, when the door closing device p12 and the safety door opening state P10 have a token at the same time, execute transition T6 to close the safety door, and execute T7 to close the door at the same time.

3) Improved Bus And Passenger Model: In daily life, it often happens that the safety door or the door pinches passengers. In the actual scene, the detection of objects (people or objects) should be added to the door and the safety door. When there is no object between the door and the safety door, it can be closed, and the closing pressure of the door and the safety door is also limited to a certain range to avoid pinching.

Therefore, the design of passenger boarding transition T1 needs to have priority over door closing transition T3. Therefore, in the design of the model, we can consider adding suppression arcs. When P0 and P1 of the depot have tokens, we should suppress the closing transition of the door and the safety door, that is, inhibit the transition T3, T6 and T7; Or add a new control library to limit it. You must first meet the transition t0 and T1 before you can perform the transition T3, T6 and T7 of closing doors and safety doors.

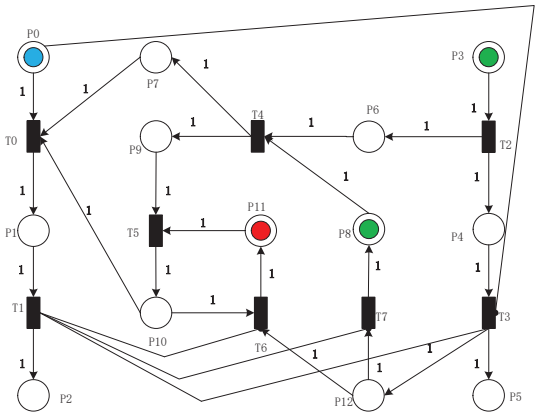

Figure 3. Modeling on improved bus and passenger model.

Figure 3 shows the improved passenger boarding and alighting model. After adding the suppression arc, when the token contained in P0 or P1 library will inhibit the occurrence of T3, T6, T7 changes, which can solve the state change of the right branch in the state m3 or M4, making the state develop in the expected direction.

B. Results And Discussion

CPN tools can express the dependency relationship between elements in Petri net and build the structural relationship between factors. It can group Petri nets and represent ”alternative transitions” in graphs, so it can be applied to hierarchical Petri nets modeling

Use CPN tools to simulate the model. Since the boarding and alighting operations are similar, only the boarding operation is analyzed here. As shown in Figure 4. At this time, set two passenger tokens corresponding to four door switch tokens and four safety door switch tokens. The expected result is that two passenger tokens are transferred to the lower left passengers, and the door tokens and safety door tokens return to the closed state.

But the result is that because no restriction depot and suppression arc are set, the door token and safety door

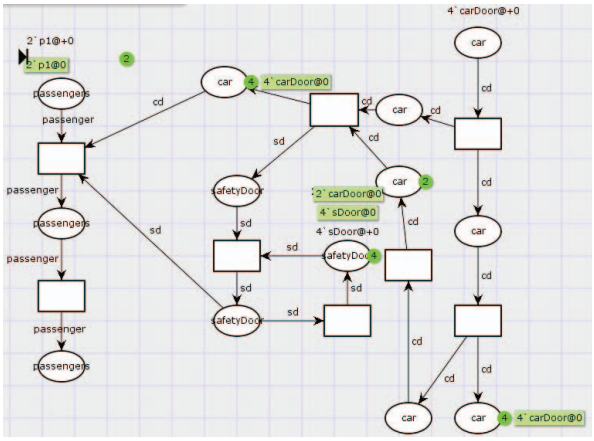

Figure 4. Simulation on passenger getting on.

token have returned to the closed state depot, while the passenger token still remains the original state depot, which is obviously not in line with expectations. Therefore, it can be seen that the above proposed ordinary passenger boarding and alighting model is not feasible.

Next, the simulation will be carried out according to the improved passenger boarding and alighting model. The suppression arc is drawn at the passenger waiting status depot and the passenger boarding status depot. If there are tokens in the passenger waiting state and passenger boarding state database, it will inhibit the door and safety door closing changes.

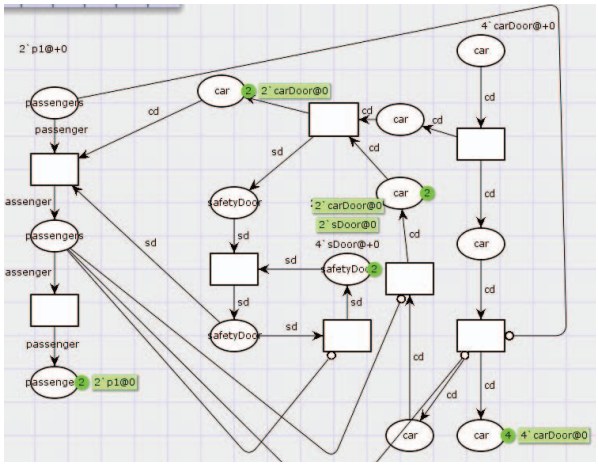

Figure 5. Modeling improved passenger getting on model.

As shown in Figure 5, the boarding operation of two passengers is also simulated. The expected result is that two passenger tokens are successfully transferred to the compartment state library, while door tokens and safety door tokens are transferred to the closed state library after the passenger token transfer is completed, which conforms to the sequence of passengers boarding and then closing.

V. Conclusion

This paper mainly proposes a hierarchical colored timed Petri net model, which is used to model the BRT parking system, and analyzes and experiments the model. Through the experimental results, we believe that hierarchical colored timed Petri nets have a good effect on the modeling and analysis of multi-level, multi structure and complex traffic CPS,

Although some achievements have been made in the research of traffic CPS modeling method in this paper, there are still some deficiencies. We still lacks consideration of the data security issues involved in the model. In the future, we will study how to better synchronize and persist the data of calculation, control, execution and other processes, and further explore and analyze the data security issues.

VI. Acknowledgment

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