Train Control System Formalization Modeling Oriented Movement Authority

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Abstract
Chinese Train Control System-3(CTCS-3) was integrated via various control system devices, assurance of CTCS-3 system transmission probability relied on empirical judgment, it is necessary to form its formalization to support integration for system stability of the whole CTCS-3. Movement Authority(MA) acts on the whole information process of CTCS-3 to control train, its process properties can be as the reflection of CTCS probability. Aiming at that, paper selected MA as the objective, proposed MA-oriented CTCS-3 formalization modeling. Paper designed generation and transmission algorithms of MA, formed MA computation models for application functions. Based on computation models, paper constructed MA hierarchical Colored Petri Nets(CPN) models, and completed MA timed CPN model, the report and experimental result demonstrate that the model proposed is effective and can reflect CTCS-3 system properties accurately.

Keywords: Train Control System; Movement Authority; Colored Petri Nets; CPN Model

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1. Introduction
Chinese Train Control System-3 (CTCS-3) is a train control system which checks up the state of train section occupied state though GSM for Railway (GSM-R) and track circuit methods [1,2]. In the mode of CTCS-3, the train Movement Authority(MA) is generated based on block information and route information by Radio Block Centre(RBC), transmitted to On-Board Unit(OBU) through GSM-R, and executes train movement controlling [2].

For CTCS-3, its complexity decides that it's difficult to be constructed, in the course of design and development, backtracking method must be executed repeatedly to look for system defects[3]. At the same time, equipments of various providers existed in train control system jointly, reliability of system integration must be considered. How to Construct an effective formal system model is needed to help design and integration. Many research about CTCS, such as railway networks switching, interlock controlling and RBC communication, have been proposed base on Petri Nets [4-6], all those mainly finished work flow formalization of one functional module. But for CTCS, the whole system trasmission and trasaction probability should be considered, method of manual judgement can not help to assure system stability.

In CTCS-3, the computation, control and communication units are integrated to form a hierarchical and distributed system, and MA's computation and transmission act a key role in train control, Its effectiveness is the reflection of CTCS performance, so based MA transmission and transaction, CTCS formalization modeling has been proposed in this paper.

2. MA Computation Model
Movement Authority(MA) is the train movement certification in safety, in which, the section information from the train tail to the front barrier are included. MA indicates the safe path and distance for train movement, it is calculated based on the train present position, train features and the track circuit occupation state. End of Authority(EOA) indicates the allowed stop position for the present train movement. Shorten Movement Authority(SMA) indicates MA update based on a new stop position. Conditional Emergency Stop Message(CEM) is a
message to require the train to stop before appointed position. On-Board Unit(OBU) calculates
the braking curve anew based on current state. Unconditional Emergency Stop Message(UEM)
is a message to require the train stopping immediately for some reasons, emergency braking
must be executed immediately. Protective Section is a safe section from the train head to the
dangerous point. Dangerous Point is a point before that the train can move safely. Section Time
is a set time value correlated to each section, if a train can’t enter route in the range of the
section time, route operation is canceled, the last section occupied is canceled also [2,3].

MA information includes no more than 10 sections information, each section information
is composed of section length, time, etc..

2.1. MA Functional Computation Models

MA computation is divided into 3 layers. The first layer is information collection layer.
RBC collects information coming from computer interlocking system, train control centre and so
on, and finishes series train path task, train location task and path update. The second layer is
MA generation layer. Firstly, the status judgment for train section occupied must be completed,
then based on series path, the CEM and EOA computation must be finished, lastly, MA
computation is extended based on different application functions. The third layer is MA
transmission layer. RBC of the current section finishes computing and transmits MA to OBU,
OBU answers RBC to confirm EOA, calculates MA, and generates EOA which has not been
confirmed.

Based on MA function, Paper has constructed MA computation functional models, the
second layer has been divided into normal control model, level change model, Temporary
Speed Restricted(TSR) model, etc.. In Level change model, computation instruction operates
frequently, MA-related communication and transition units cover the whole train control system,
due to the limited space of this paper, level change mode is selected as a detailed example to
be introduced.

![Figure 1. MA algorithm from C2 to C3 mode](image1)

In this mode, train movement level can be changed between C2(Chinese Train Control
System-2) and C3(CTCS-3), the whole process is supported by special functional balise groups.
GRE balise group provides GSM-R connection enrolling information to OBU, RE balise group
provides RBC connection enrolling information to OBU, LTA balise group provides movement
change announcement information, and LTO balise group provides change operation
information[2].

In change from C2 to C3, when the train moves into change area, MA is completed
through the following algorithm, OBU constructs GSM-R connection through GRE, OBU
communicates with RBC though RE, OBU accepts MA and other related parameters, OBU
operates train control with the help of LTA and LTO. The algorithm is restrained to the received

![Figure 2. MA algorithm form C3 to C2 mode](image2)
MA, if MA has not been received, the train keeps the existing level moving, until MA is received. Figure 1 is its algorithm.

In change from C3 to C2, it is the same course with the help of balise groups, figure 2 is its algorithm.

![Figure 3. MA algorithm for normal control](image1)

![Figure 4. MA Algorithm for TSR](image2)

MA algorithms for normal control and Temporary Speed Restriction(TSR) are described in Figure 3 and 4. In normal control, MA computation is a continuous extended or shortened process. In TSR, MA is generated by TSR server, and sent to RBC.

2.2. Formalization Model of MA based on CPN

Based on the MA computation algorithms which have been formed above, paper constructs MA formalization model based on CPN.

Top Formalization Model. The MA top model is described as Figure 5, its place and transition is described in Figure 6.

In the top model, the original status is “Start”. Firstly, we must judge the effectiveness of Last Related Balise Group (LRBG), compute offset for train location based on serial path information and section information, when the RBC receives the train location information, MA computation can switch to the corresponding application model, such as level change CPN model, normal control CPN model, TSR CPN model and so on. Now we give the place “Start” “LRBG is effective”, then the transition “Reference LRGB” is triggered.

Due to the limited space of this paper, we select level change submodel to dedicate. Level Change (LC) CPN model and description are described in Figure 7 and 8. For other submodels, we just introduce in brief.

For LC CPN model, as we have been introduced above, if train location has been finished, the correlated MA computation model is triggered. In order to avoid naming place and transition repeatedly, we use “Message 136*2” to separate from the initial location information of train, “Message 3” is transmitted if the level change condition from C2 to C3 has been satisfied.

For normal control model, train recieves rounded control train information. Its CPN model is described in Figure 9. “Message 136” in place “Train Location” triggers transition “Location Report”, normal control subsytem is live, and outputs msg1.
Figure 5. MA top CPN model

Figure 6. Top CPN model description

Figure 7. MA level change CPN model

Figure 8. Level change CPN model description

Figure 9. MA normal control CPN model

Figure 10. MA TSR CPN model
For TSR model, CPN model must search the temporary speed restriction information in first section of MA, judge its value, and decide whether transition “TSR Info” can be triggered, its CPN model is described in Figure 10.

2.3. MA Timed Colored Model

In order to analyze nets transmission characteristic, MA timed colored model has been completed based on original model, we selected LC model as an example to introduce. In LC model, because current train OBU must complete registering GSM-R and connecting RBC, the net’s interrupt or delay can lead to MA failed, so timed colored model integrated nets time delay parameter is finished.

OK(s,r) is a Boole function reflected the state of message sending or receiving. This timed model can be used to observe successful times of MA computation under the influence of nets delay, Figure 11 is MA timed colored model for LC from C2 to C3.

All transition have a timestamp, and each transition of Train Location, Send Related Info, and Compute MA has a timestamp of random function DEL(). Place SP is used to express nets system reliability, Ten0 means a random value from 0 to 100, Ten1 means a random value from 1 to 100.

Function OK(s:Ten0;r:Ten1) = (s>=r), means that if s>=r, then return True, and msg is transmitted via the arc, else msg is lost, and MA computation failed.

Figure 11. MA timed colored model

3. System Model Evaluation and Analysis
3.1. System Model State Space(SS) Analysis

When system runs, only one MA application can exist in some time, we can regard the MA transmisson process as an unidirectional system, and when the place “Train Location” in top model has the token “Message 136”, system enters the concurrent MA transaction, Figure 12 is system CPN reachability graph. Parts of SS report is shown in Figure 13.

SS report shows that the whole system model have 75 nodes and 79 arcs, and the computing time without considering nets delay is 0s. All these shows system model is bounded, live, and fair. the dead markings M16, M23, M67 and M75 are referred to ending marks of four MA functional submodels. All these demonstrate that the proposed model is effective [7-8].
### 3.2. System Property Analysis

Paper finished MA process success rate test with the influence of SP (System Transmission Probability) changing. In order to assure computational accuracy, time value of experiments is increased to 10 times. Figure 14 is the tendency chart of MA process success rate, which demonstrates that MA process success rate has descended with SP descending, it corresponds with C3 property.

![Figure 14. SP influence on MA success rate](image1)

![Figure 15. SP influence on MA success rate based on time delay](image2)

More, in MA timed CPN model, we use CPN' Replication $\text{repetition}$ 1000 to complete the nets time delay experiment by adding a timestamp. We suppose that the enrolling time for GSM-R is 40s, the connection time for RBC is 10s, the message transmission time is 20s, net delay time can be computed by $\text{DEL}()$, the total time of MA success computation is 70s, the experimental result is in Figure 15.

The result shows, when SP is greater than 99% and system time delay is in $0-2.5s$, the MA process success rate is greater than or equal to 99.9%, with SP descending, success rate becomes lower and lower. That is to say, system time delay must be controlled in a safety range in the course of C3 design and integration.
4. Conclusion

Paper proposed and finished MA-oriented C3 formalization model based on CPN. Based on the whole system model, paper completed the state space analysis, the report demonstrates that the MA model based on CPN is effective, properties can be satisfied. More, paper completed the simulation about CTCS probability’s influence on MA computation and transmission success rate, the simulation experiment of MA process success rate has proved its usability in design and development for C3 system.

References