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Topology Based Automatic TAPN Model Generation For Railway Systems

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***Abstract*— The use of formal methods in modeling and designing of railway transportation system is strongly recommended by CENELEC EN 50128 standart. Nowadays, the development of formal models of railway systems is completely performed manually. In this study, a software tool was developed by using C# programming language for automatic generation of the formal models of railway stations. The specially developed software tool generates the Timed-Arc Petri Net models, which is a formal method and highly recommended by the relevant standart, of the station components separately from the station topology.**

***Keywords*— formal methods; railway; automatic generation; station topology**

I. Introduction

Formal methods, which are based on mathematical foundation, are used for modeling, designing and analyzing of railway systems. The reliability and robustness of a system designed can be increased using these methods. Therefore, the use of formal methods in the modeling of railway systems is strongly recommended by CENELEC (Comite Europeen de Normalisation Electrotechnique) EN 50128 (Table A.17) [1]. There exist a great number of studies in literature regarding the designing and modeling of railway systems using formal methods. In a study [2], K. Winter formed a formal model for railroad interlocking system by using CSP (Communicating Sequential Processes), which is a formal modeling language. A. Giua and C. Seatzu [3] modeled a railway network by using Petri Nets. They formed a model for each component such as the point, track circuit and station separately. Such events in the station as designating the routes for trains, adjusting the point positions based on the designated route and movements of the trains occurs within a certain framework of time. These temporal acts have to be transferred into the system to obtain a powerful model, which describe the system. At this point, Timed-Arc Petri Nets enables temporal acts to transfer into the model better. In addition, the use of Timed-Arc Petri Nets, which is a formal modeling method, in modeling of railway systems is strongly recommended by the relevant standart.

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In our previous study [4], Bastabya Station on T4 Topkapı-Habibler line operated by Istanbul Ulaşım was modeled successfully using Timed-Arc Petri Nets. In modelling, each component like the point, track circuit, signal and station is modeled separately. The formal models was generated manually. Safety and reliability issues become more important for railroad transportation systems than for roads when the length, weight and passenger capacities of the trains are taken into consideration. For this reason, the automatic generation of models, which are currently generated manually, based on the station topology is very significant. Automatic generated models may be more reliable and so the reliability and safety of the whole system increases. There exist a limited number of studies [5, 6] in literature regarding the automatic generation the formal models of railway systems. Y. Cao, T. Xu, T. Tang, H. Wang and L. Zhao [7] have developed a toolset, which was designed by DSL-CBI (Domain Specific Language for Computer Based Interlocking Systems) for automatically generation and verification of the interlocking table of railway station.

Small stations can be modelled easily by hand. However, generation of the models is a very hard process in complex stations where have lots of points and routes. Automatic modeling of complex stations becomes more significant due to the fact that the probability of modeling faults increases because of the complexity. In this study, a software tool was developed using C# programming language, which is recommended by CENELEC EN 50128, for automatic generation of the Timed-Arc Petri Nets models of each component in a station. The relevant models are generated from the station topology through the tool. This generalized tool simplifies the development of station TAPN (Timed-Arc Petri Nets) models but its use is not limited to any station topology. The developed tool will also be able to use for modelling of different station topologies. TAPN models for Bastabya station are included in this paper as a case study. The main advantages of the tool are that it significantly reduces the human errors and improves the efficiency in the generation of the models, which describes the system. Moreover, the probability of modeling faults are reduced, reliability and safety of the whole system increases thanks to automatic generation of the system models.

II. Railway Basic Components

Railway system consists of some fundamental components such as points, signals and track circuits. This section gives brief introduction for each component.

A. *Points*

Points are one of the most important blocking blocks of railway systems. A railway point is a electromechanical tool, which is generally remote-controlled with an electrical motor. They are used to enable the trains to move from one track to another at a railway intersection according to the desired route. Points have usually two positions named as normal and diverging.

B. *Signals*

Signals are systems that transmit colored light notice and inform trains whether the destination line is available or not according to color of the transmitted light. In addition, notifications of the signals provide information the mode of movement (whether the vehicle will side to another direction or go straightforward to the destination) in railway stations.

C. *Track Circuits*

Track circuit is an electrical circuit used to detect the absence or presence of a railway vehicle in a certain part of a railway. The relevant mechanism works by using the rails in one part of the road as conductors and short circuiting the rails by the train wheels. If there is a train on a track circuit, rails are short circuited by the train wheel and it is understood that the relevant part of rails are occupied by the train.

III. Timed-Arc Petri Nets (TAPN)

Timed Arc Petri Net (TAPN) is defined with a 7-tuple TAPN={P, T, IA, OA, Transport, Inhib, Inv}, where,

- P : $\{p_1, p_2, p_3, \ldots, p_n\}$ is a finite set of places,
- T : $\{t_1, t_2, t_3, \ldots, t_n\}$ is a finite set of transitions,
- IA $\subseteq$ P x τ x T is a finite set of input arcs, with τ representing the time
- OA $\subseteq$ T x P is a finite set of output arcs,
- Transport : IA x OA $\rightarrow$\{true, false\} is a function defining transport arcs which are pairs of input and output arcs connected to some transition,
- Inhib : IA$\rightarrow$\{true, false\} is a function defining inhibitor arcs which do not collide with transport arcs,
- Inv : P$\rightarrow$ τ^{inv} is a function assigning age invariants to places.

Timed-Arc Petri Nets (TAPN) are an extension of the classical Place/Transition nets with time, which is the set of all non-negative real numbers. Time intervals are denoted by I and time intervals for invariants is denoted by I_{inv} . Tokens in TAPN have an age and arcs from places to transitions are labelled with certain time intervals, which $I ::= [a, a] \mid [a, b] \mid [a, b) \mid (a, b] \mid (a, b) \mid [a, \infty) \mid (a, \infty)$ and for invariants $I_{inv} ::= [0, 0] \mid [0, b] \mid [0, b) \mid [0, \infty)$, where a, b $\in$ N and a < b. Time intervals that are contained in the transitions restrict the age of tokens in their all input places. The enabling rule of a TAPN is a little bit different from the classical Place/Transition nets. t $\in$ T is enabled if for all input arcs except the inhibitor arcs, there is a token in the input place of the arc with an age satisfying the time interval of the arc. In other words, it is enabled when the age of the tokens in its all input places have reached its time intervals. Also, t $\in$ T is enabled if for all inhibitor arcs there is no token in the input place of the arc with an age satisfying the time interval of the arc. A transition t $\in$ T may be fired if it is enabled by the marking of its input places and if all time restriction related to its time interval are satisfied. Also for detailed information about TAPN refer to [8, 9].

IV. TAPN Model of Railway Components

The use of Modular Approach is mandatory for railway applications according to CENELEC EN 50128 Table A.4-Software Design & Imp. For this reason, modeling and design of the system was conducted on modular approach by forming separate models for point and signal. After that the models, belonging to the system, were generated automatically such as route and truck circuit by establishing the necessary relations between points, signals and train movements based on the station topology. No standard model was formed for the track circuit. It was generated automatically based on chosen route and train movements on this route.

A. *Point TAPN Model*

The same point model, which was formed in [4], was used. Point model consists of six places and four transitions. It is accepted that all points are at normal position at initial status. For changing the position of point, it should be enable, which means the point is not locked for any route and there should be no tokens in the RCM place, which means the point is not occupied by a train. When enabled, the point at normal position moves towards diverging position. It is required to reach diverging position by completing its movement within a certain time period interval ([max1, max2]). In case it does not achieve diverging position within [max1, max2] time interval, this will be identified as point position error and the intended route is not opened. The same rule applies for the point at diverging position when it moves from diverging position to normal position. The relevant Timed-Arc Petri Net model formed can be seen at Fig. 1.

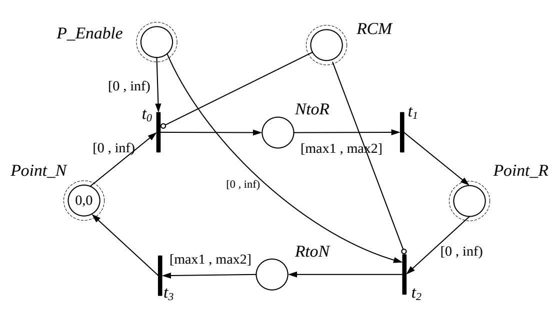

Figure 1. Point Timed-Arc Petri Net Model

TABLE I. DEFINITIONS OF PLACES IN POINT MODEL

Point_N	Point is in normal position
Point_R	Point is in diverging position
P_Enable	Point can change its position
NtoR	Point goes from normal to diverging
RtoN	Point goes from diverging to normal
RCM	Point is occupied

B. *Signal TAPN Model*

The same signal model, which was formed in [4], was used. Signal model consists of four places and two transitions. It is accepted that all signals are red at initial status. After the points on the route to be opened achieve the relevant position, the signal is enabled and green notification is transmitted to the train for allowing pass. As the train passes the signal and occupies the first track circuit (TrEntM), the signal indicates red once again. Timed-Arc Petri Net model formed for the signal can be seen at Fig. 2.

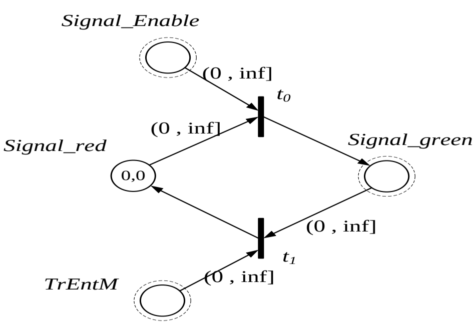

Figure 2. Signal Timed-Arc Petri Net Model

TABLE II. DEFINITIONS OF PLACES IN SIGNAL MODEL

Signal_red	Signal indicates red
Signal_green	Signal indicates green
Signal_Enable	Signal is enabled
TrEntM	Train enters the first track circuit

V. Automatic Generation of TAPN Models

A software tool was developed to generate automatically the system TAPN models from the railway station topology. C# programming language, which is recommended by CENELEC EN 50128, was used in development of the tool. The specially developed software consists of two parts, a graphical user interface, which allows users to be able to draw the station topology and application software, which creates the system TAPN models and stores them in a XML file. Users don't need to write an additional program through this tool. Main task of the user is to draw the station topology and add the necessary components to the station diagram.

A. *Graphical User Interface*

The graphical user interface provides a facility for drawing single line diagrams of the station. The flowchart for drawing the topology is shown in Fig. 3.

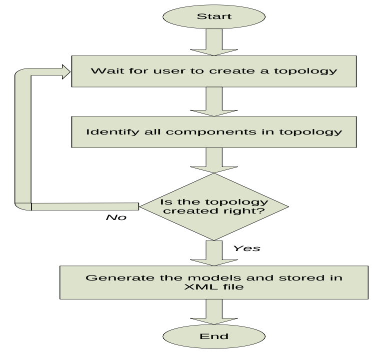

Figure 3. Flowchart of drawing the topology

In order to draw the station topology, the user has to know the number of tracks, the number of points and where these points connect to the tracks. There are four steps to draw the station diagram completely. All components are placed on the station layout by firstly choosing the relevant icon from the 'toolbox'. Firstly tracks are drawn by specifying the start and end locations by clicking on the interface. Secondly, points are created by determining their locations, where the point intersects with track. Namely, intersection between two tracks in the station diagram is identified as point. Thirdly, signals are placed. Their locations are also specified on the track as points. In the last step, user must indicate where trains can enter the station. To do this, the same process in the signal placement is performed. Entrances of the station are identified by clicking the locations where the train can enter the station. Finally, the user finalizes modelling by clicking the end button.

B. *Application Software*

The main purpose of the application software is to create the system model using information, which comes from the station topology in the process of automatic generation of the models. The validated information by graphical interface, belonging to system, is transferred to the application software. The application software generates the route and track circuit TAPN models and stores in XML file including all points and signals models. Automatic formed models can be seen by using TAPAAL, which is a tool for modelling, simulation and verification of Timed-Arc Petri nets. To do this, it is enough to open the created XML file through TAPAAL. Also for detailed information about TAPAAL refer to [10].

VI. Case Study

Bastabya Station on T4 Topkapı-Habibler line operated by Istanbul Ulaşım chosen as a model, the station has five points, five signals and ten track circuits. Sets to represent the following items at Bastabya Station, whose topology is drawn at Fig. 4, were defined: five points P={p_1, p_2, p_3, p_4, p_5}, ten track circuits RC={RCA, RCB, RCC, RCD, RCE, RCM1, RCM2, RCM3, RCM4, RCM5} first of five indicating the entering and departing of the station and the last five indicating the occupancy of the points as well as five signals S={ s_1, s_2, s_3, s_4, s_5}. In addition to these sets, other sets were also defined, for example, the set TR={ tr_1, tr_2, tr_3,…..tr_n} to represent the trains and the route set R={ r_1, r_2, r_3, r_4, r_5, r_6, r_7} that can be opened for these trains.

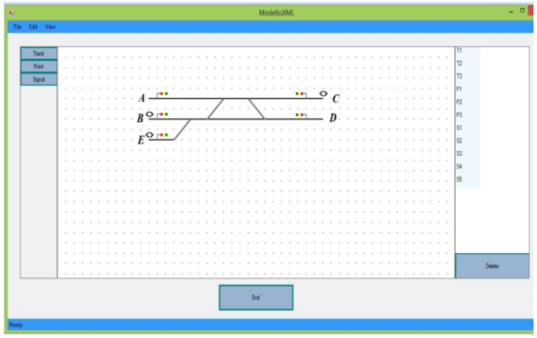

Figure 4. Bastabya Station Topology

According to the Bastabya Station topology, route and track circuit TAPN models were generated automatically by using the developed tool. The routes identified can be opened for the trains if and only if the relevant track circuits are not occupied by another train and the train proceeding on the second route to be opened should not be facing the train proceeding on the first route. Based on this, separate Timed-Arc Petri Net models were formed for each route. As an example, the route, which will be opened for the trains that entering the station form C, models are given. Similarly, other route Timed-Arc Petri Net models for trains entering the station from A and E were also formed.

Below can be seen the r_1 route Timed-Arc Petri Net model at Fig. 5, formed for a train which will be proceeding on CD route.

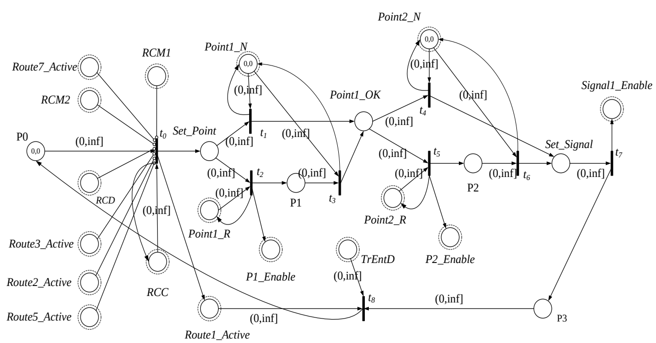

Figure 5. Route r_1 Timed-Arc Petri Net Model

r_2 route Timed-Arc Petri Net model can be seen at Fig. 6, formed for a train which will be proceeding on CA route. The r_3 route model for CE destination is almost same with r_2 route model because of they have the same points and signal. The only difference between r_2 and r_3 route is the control of RCE track circuit rather than RCA in r_3 route .

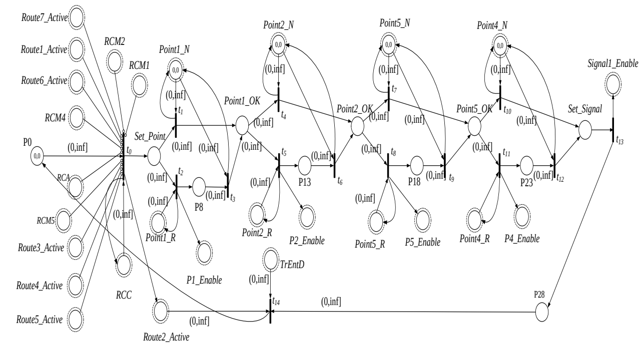

Figure 6. Route r_2 Timed-Arc Petri Net Model

r_3 route Timed-Arc Petri Net model can be seen at Fig. 6, formed for a train which will be proceeding on CE route.

The automatic generated Track Circuit Timed-Arc Petri Net model, which indicates the movements of the trains that enter the station from C can be seen at Fig. 7. Similarly, Timed-Arc Petri Net models for trains entering the station from A and E were also formed.

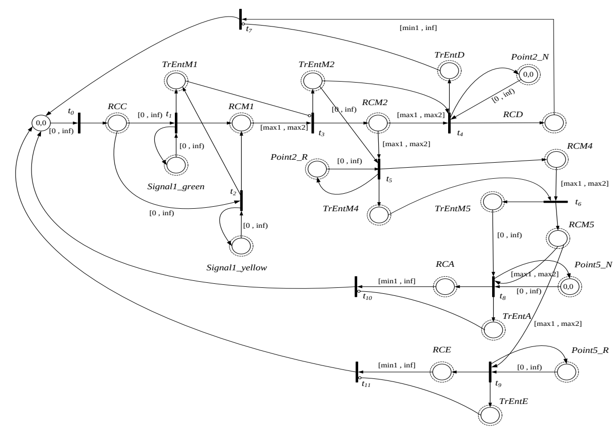

Figure 7. Track Circuit Timed-Arc Petri Net Model for Trains that Entering the Station form C.

For trains that entering from C, the table 3 represents the points, their relevant positions based on the routes to be opened, and which track circuits are controlled.

TABLE III. TRACK CIRCUIT, POINT AND POINT POSITION BY ROUTE

Entrance into the station	Route	Controlled Point and its Position	Track Circuit Controlled
	r_1(CD)	P1_N, P2_N	RCC, RCD RCM1,RCM2
C	r_2(CA)	P1_N, P2_R P4_R, P5_N	RCC, RCA RCM1,RCM2 RCM4,RCM5
	r_3(CE)	P1_N, P2_R P4_R, P5_R	RCC, RCE RCM1,RCM2 RCM4,RCM5

VII. Conclusion

Timed-Arc Petri Net models of Bastabya station, operated by Istanbul Ulaşım in Turkey, were successfully formed automatically by using the developed software tool based on CENELEC EN 50128. The tool was tried for more complex station and successful models were obtained. It was concluded that the tool significantly reduced the modeling faults caused by human factor and improve the efficiency in the generation of the models. Moreover, reliability and safety of the whole system increases thanks to automatic generation of the system models. Our future work will focus on the development of a process to generate the discussed models automatically from the programming codes, which are written in STL format in Programmable Logic controller.

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