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Fail-Safe Signalization and Interlocking Design for a Railway Yard: An Automation Petri Net Approach

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Abstract: The most important issue in railway systems is to provide safe transportation. Since no error can be tolerated in railway systems it is an obligation to use reliable signalization and interlocking systems which have to decide what to do in unexpected situations like switch disruptions or signal light defects. By the rapid development in railway systems more formal methods are needed for modeling such systems. In this study, a sample railway yard is modeled with extended type of Petri Nets (PNs) known as Automation Petri Nets (APNs). The model used in design covers both normal situations and possible failures (such as a switch break down) to avoid calamitous accidents.

Keywords: Petri Nets, Railway Signalization and Interlocking Systems, Fail-Safe.

1. INTRODUCTION

The most important issue in railway systems is to provide safe transportation because no errors can be tolerated in railway systems and errors can sometimes result in fatal accidents [1].

By the development of railways, trains became faster and the density on railways increased [2]. As a result, keeping the trains apart and guaranteeing safety has become more important. From this point of view, it is an obligation to use reliable signalization and interlocking systems to provide safety.

A fail-safe design guarantees permanency of the whole system under possible failures and provides required SIL (Safety Integrity Level) levels defined by related safety standards [3], [4]. When a fault occurs, the system either continues safely or moves into a predefined condition known as safe.

One of the most suitable method for modeling these kinds of systems are Petri Nets (PNs) [5-8] and which can be also used for many practical and theoretical application areas [9-11] including railways [12], [13].

An extension of the PN definition can be done easily by adding four terms to ordinary PNs and known as Automation Petri Nets (APNs) [14], [15]. In addition to ordinary directed arcs (→) defined in PNs, inhibitor arcs (⊸) and enabling arcs (—▷) are added in APNs structure. These newly added arcs are ineffective on number of tokens in places but enables or inhibits transitions [14-17]. APNs are also used for modeling railway yards [18-20].

In this study a sample railway yard is modeled by APNs because of their flexibility in modeling such systems and graphical and mathematical easiness [21]. The model also includes possible failure situations (such as a switch break down, situation of signal lights) to avoid calamitous accidents. The obtained APN model is then converted to Ladder Logic Diagram (LLD) [14-17], which can be implemented on a Programmable Logic Controller (PLC) to verify the accuracy of the APN model and signalization design. A SCADA interface is also developed to test the obtained interlocking code for all possible conditions.

2. RAILWAY COMPONENTS

To achieve safe transportation on railways there have to be a need for efficient and reliable signaling system. A simple railway yard is given in Figure 1.

2.1. Signal Lights

Signal lights are established in front of railway blocks if necessary. Like on the road signaling, colors of railway signals have different meanings. Meanings of signal light colors are given on Table 1. The signals are controlled by the interlocking system.

Two (dwarf signal lights with one red and one green), three (can be dwarf or tall with one red, one green and one yellow) and four aspect signal lights (tall signal light with one red, two yellows and one green) are used in Turkish railways. Aspect means the number of lights on the signal light. Dwarf signal lights indicate entering to next railway block with changing lines. All signal lights remains red until a reservation is made in order to provide safety.

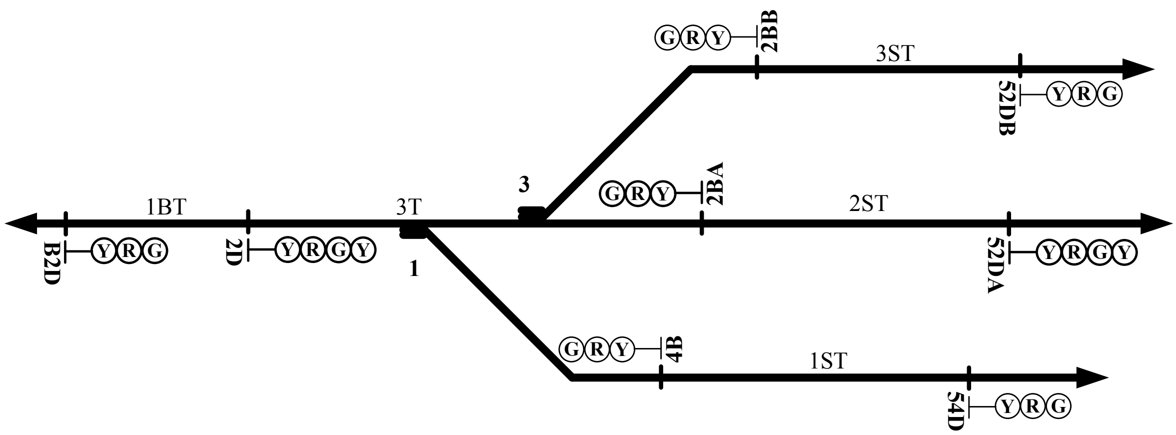

Figure 1: A simple railway yard.

Every signal light acts as a supervisor for its preceding signal light because, for example, if a signal light is red the preceding of this light have to be yellow. In Figure 1, 2D and 52DA are four aspect, B2D and 2BA are three aspect tall, 2BB, 52DB, 54D and 4B are three aspect dwarf signal lights.

Table 1: Meaning of signal light colors.

Color of the Signal Light	Meaning of Colors
Yellow (Y)	The next railway block is free, proceed with a predefined speed
Green (G)	The next two railway blocks are free
Red (R)	The next block is occupied, stop immediately
Yellow-Yellow (YY)	The next block is free, proceed with a track change
Yellow-Green (YG)	The next two blocks are free, proceed with a track change
Yellow-Red (YR)	A special colour for entering to an occupied railway block
Flashing Yellow (FY)	Flashing signal lights are used while leaving an unsignalled railway block
Flashing Green (FG)	
Flashing Red (FR)	

2.2. Track Circuits

A track circuit (TC) is a simple electrical equipment and use for detecting the absence or presence of trains on the railway blocks [22]. In a railway block, there can be more than one TC if necessary. In Figure 1, 1BT, 3T, 1ST, 2ST and 3ST are railway blocks.

2.3. Switches

Trains can pass from one track to another by the help of switches on railways. Switches are also controlled by the interlocking system and have two positions named normal position and reverse position. Position of switches can be detected by several methods and devices than this position information send to interlocking system as a feedback. Switches can be seen in Figure 1 labeled with 1 and 3, respectively.

2.4. Interlocking System

Interlocking is a kind of arrangement of signals and switches to achieve safety on railways. In Centralized Traffic Control (CTC), train movements are control from Traffic Control Center (TCC) for incoming or ongoing trains by reserving routes.

For instance, when a train arrives on block 1BT three different routes can be reserved if not occupied by another train. All possible route reservation scenarios have to be given on interlocking table.

2.5. Fail-Safe System

A fail-safe system is capable of returning to a predetermined safe state in case there is a failure or malfunction. For railway systems, if switch position indicators shows normal and reverse position at the same time or the position information did not receive even a predefined *t* time is passed, this means failure and the system have to be lapse into fail situation and have to arrange signal lights and other switches if necessary.

3. MODELLING WITH AUTOMATION PETRI NETS

The sample yard given in Figure 1 is modeled by using simple PNs, but for simplicity only trains coming from left (west) is considered. This model is used for monitoring movement of the train on railway yard. This is illustrated in Figure 2.

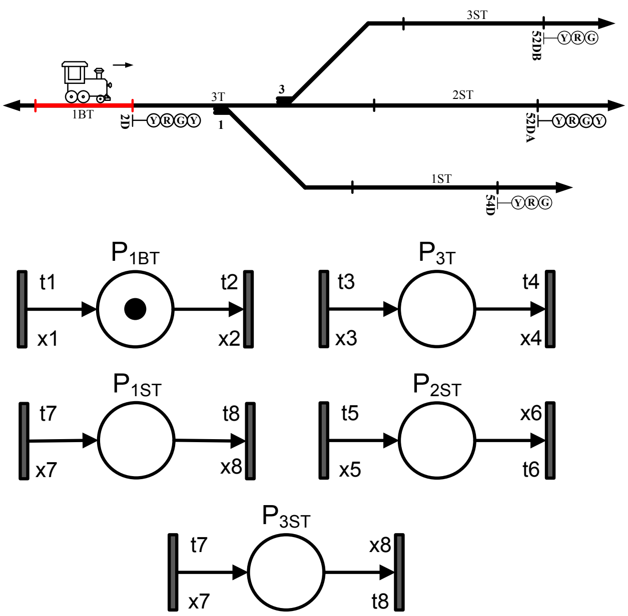

Figure 2: Possible routes for a train waiting on block 1BT and PN model of the track circuits.

Railway blocks, position of switches and colors of signal lights are modeled as places (P_{XXX}) and trains are modeled as tokens. Transitions (t_{XX}) are related with sensor information such as switch is on normal position or the signal 54D is red. Events are labeled with *x*, for instance x_{11} stands for requesting a route reservation (pushing a button). APN model of the TCC, switches and signal lights are given in Figure 3, Figure 4, Figure 5 and Figure 6. These models are obtained by using the interlocking table given on Table 2.

Table 2: Interlocking Table.

Route Selection	**Signal Light 2D**	**Position of Switches**	**Preceding Signal Light**
1BT-1ST	YG	Sw-1 reverse position	54D – Y
	YY		54D – R or YR
	YR		
1BT-2ST	G	Sw-1 and Sw-3 normal position	52DA – Y
	Y		52DA – R, YY, YG or YR
	YR		
1BT-3ST	YG	Sw-1 normal and Sw-3 reverse position	52DB – Y
	YY		52DB – Y or YR
	YR		

Firing conditions are written in rectangles and connected to related transition by enabling or inhibitor arcs.

For instance, for the given train in Figure 2, three possible routes can be reserved by TCC. If route 1BT-2ST is reserved (x_{12} is the related event (route request) of transition t_{12}) by TCC then the token on P_{TCC} passes to $P_{1BT\text{-}1ST}$ if all conditions on transition t_{12} are satisfied. By the help of Table 2, signal light 2D can be Green, Yellow or Yellow-Red. The color of the signal light 2D is dependent to signal light 52DA when 1BT-2ST route is reserved.

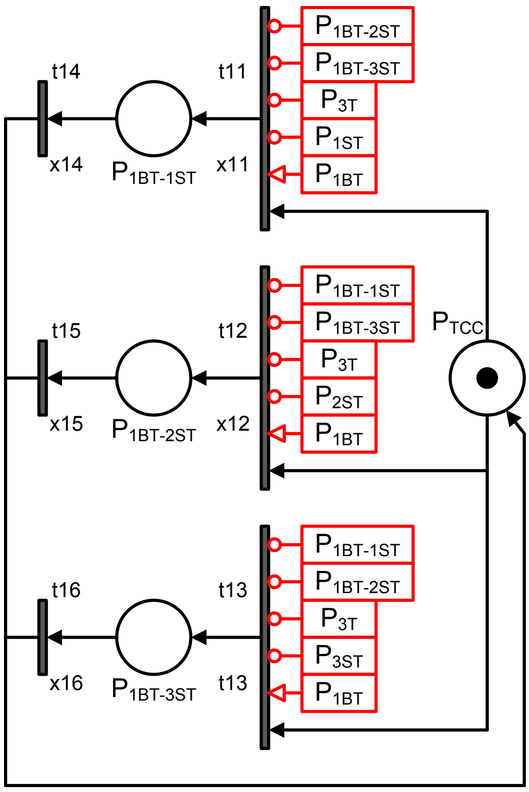

Figure 3: APN model of TCC.

When a route is reserved the related signal lights on that route change their colors while the others remain red. By movement of the train blocks get free and related signal lights become red for another reservation.

APN models of switches given in Figure 4 are also contains failure states. For example, the position of the switch has to be in only one situation; P_{sw1n} (normal position) or P_{sw1r} (reverse position).

When switch indicates both positions at the same time or if the switch can't reach any position in a given time the token on the switch model goes into fail state named P_{sw1f}.

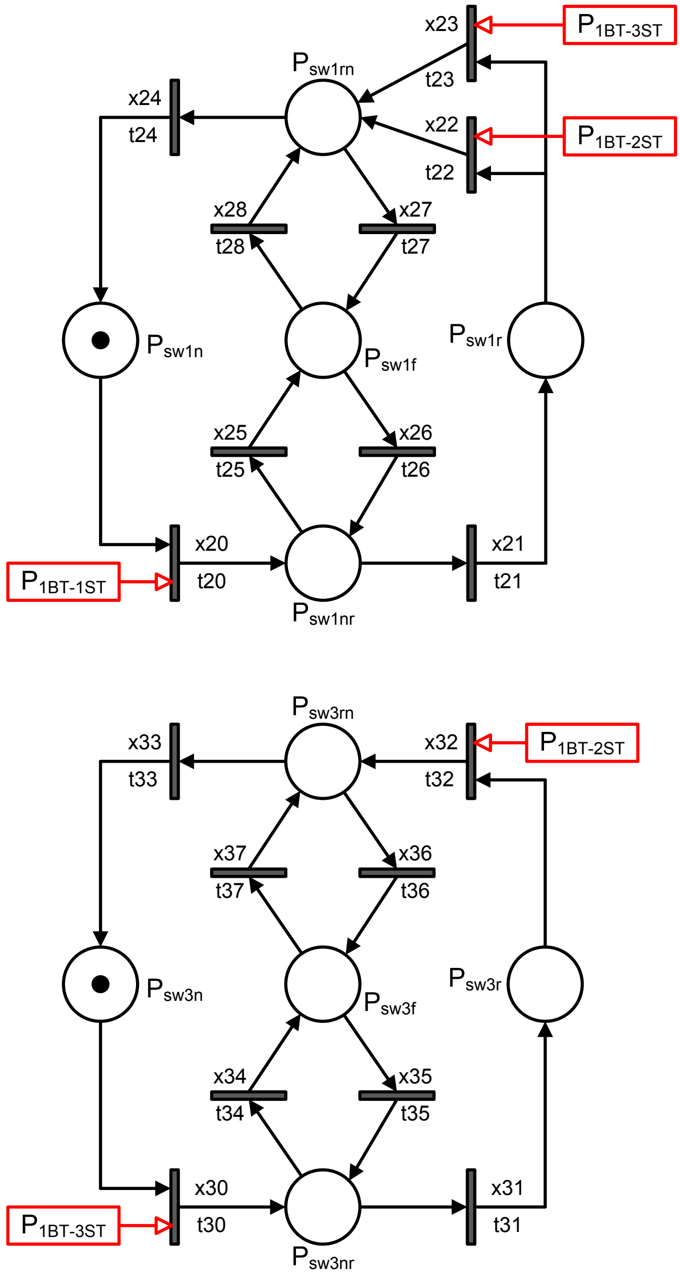

Figure 4: APN models of switches.

After malfunction is fixed related switch goes back to its former position. Some events are related with each other, for example, by the firing of t_{20} (if possible), transition t_{11} have to be fired.

These events are labeled with different numbers because switches can change manually from TCC when necessary.

Likewise, for the signal lights, all conditions have to be satisfied in order to change the color of the signal lights. All signal lights are on red and all switches are on normal position when there is no train or no reservation. Signal feedbacks are detected by the help of relays.

4. CONCLUSION

In this study, a sample railway yard is modeled by APNs for interlocking and signalization design. Switch and signal light failures are also considered to improve safety and reliability. The obtained APN model is then converted to FBD code to test the route reservation scenarios. The SCADA interface is given in Figure 7.

For further studies, the APN model and the code generated by the developed APN model have to be verified for different scenarios in order to provide required SIL (Safety Integrity Level) levels described by standards EN50126 - EN50129 and IEC 61508.

In addition to these, obtained models can be connected with each other for modeling complex railway yards.

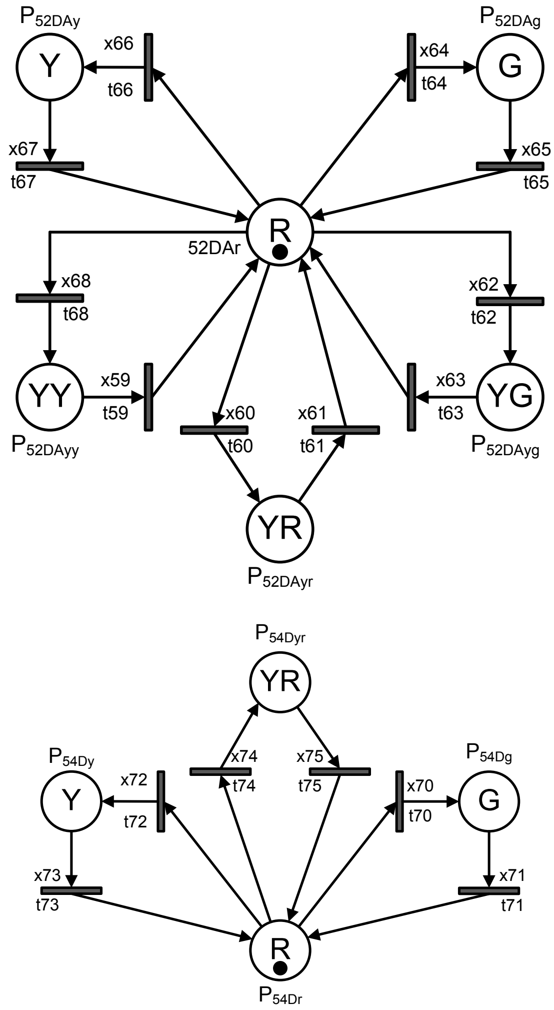

Figure 5: APN models of 52DA and 54D signal lights

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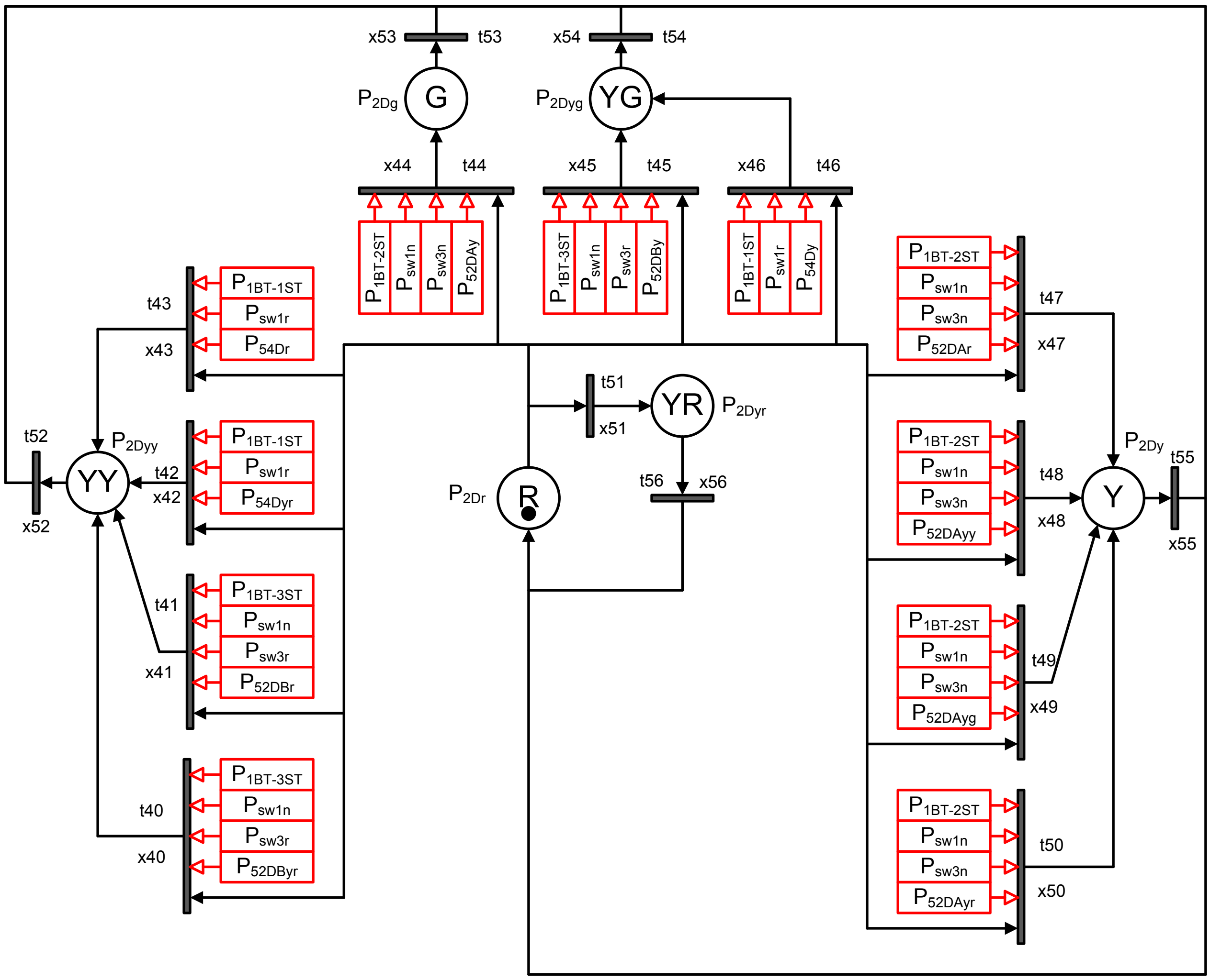

Figure 6: APN model of 2D signal light

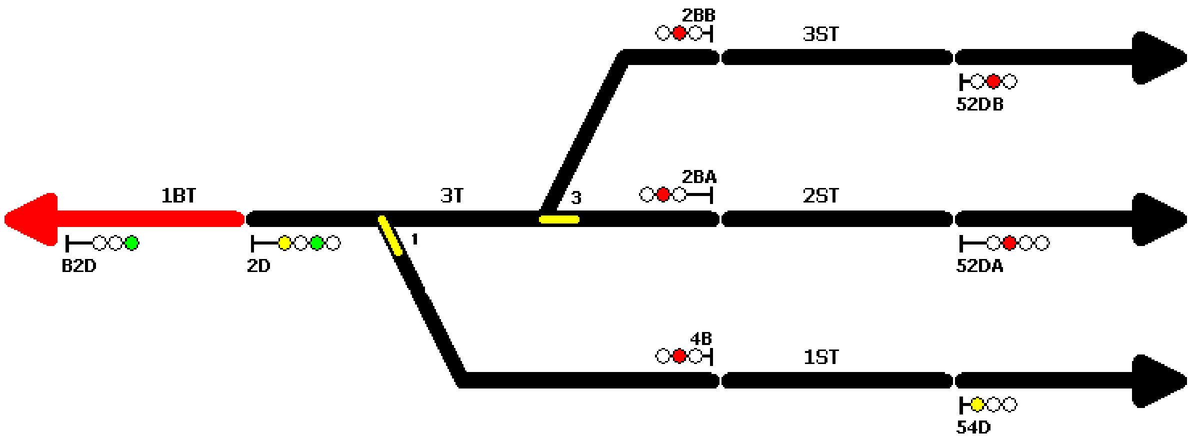

Figure 7: SCADA interface for the sample railway yard. A train is waiting on 1BT. 1BT-1ST is reserved, sw1 is on reverse position, 54D is yellow so signal light 2D is yellow-green.

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