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Petri Net Modeling and Controller Design of Unistar CSV24 Point Machine

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Abstract: Railway transportation has become essential in transportation systems because of its fast, safe, cheap and environmentally friendly structure. The safe navigation of trains depends on the correct design of the signaling system and its components. Developing technology also brings about changes in the standards used in rail transportation systems such that the railway safety standards recommend using Petri Nets in the modeling of point machines, which are the most basic actuators of signaling systems. The working principle of point machines can be easily explained with Discrete Event Systems (DES). In this study, a model was created for the Unistar CSV24 point machine, which is widely used in Turkey, by using Petri Nets. The validation of obtained model was verified using the TAPAAL interface. Electromechanical and Programmable Logic Control (PLC) solutions are presented to control the verified model. Siemens TIA PORTAL was used to obtain the PLC block of the point machine.

***Keywords**:* Point machine, Petri Net, TAPAAL, PLC control, Electromechanical control, Unistar CSV24

Unistar CSV24 Makas Motoru için Petri Ağı Modeli Oluşturulması ve Kontrolcü Tasarımı

Öz: Demiryolu taşımacılığı hızlı, güvenli, ucuz ve çevre dostu yapısı sayesinde ulaşım sistemlerinde önem kazanmıştır. Trenlerin güvenli bir şekilde seyir etmeleri ise sinyalizasyon sistemlerinin ve bileşenlerinin doğru tasarlanmasına bağlıdır. Hızla ilerleyen teknoloji raylı ulaşım sistemlerinde kullanılan standartlarda da değişimleri beraberinde getirmektedir. Öyle ki, demiryolu güvenlik standartları sinyalizasyon sistemlerinin en temel eyleyicisi olan makas motorlarının modellenmesinde Petri Ağlarının kullanılmasını önermektedir. Makas motorlarının çalışma prensibi Ayrık Olay Sistemleri (AOS) ile kolayca açıklanabilmektedir. Bu çalışmada, Türkiye'de de yaygın biçimde kullanılan Unistar CSV24 makas motoru için Petri Ağları kullanılarak model oluşturulmuştur. Elde edilen modelin doğrulaması TAPAAL arayüzü kullanılarak doğrulanmıştır. Doğrulanan modelin kontrolü için elektromekanik ve Programlanabilir Lojik Kontrol (PLC) çözümleri sunulmuştur. PLC çözümü için Siemens TIA PORTAL arayüzü kullanılmıştır.

***Anahtar kelimeler**:* Makas motoru, Petri Ağı, TAPAAL, PLC kontrol, Elektromekanik kontrol, Unistar CSV24

1. Introduction

Rail transport must satisfy passenger safety and comfort to compete with road or air transportation. Safe rail transportation is possible via the control of verified signalization systems. In railways, signalization systems are used to maintain the safety distance between trains on the same route and to perform crossings safely at the intersections of railway lines. Therefore, a fault in the signalization systems can cause accidents that lead to life-threatening losses [1]. The developing technology uses many software and control algorithms to model signalization systems and components and verify these models. The main components of railway signalization systems can be categorized as: points, signals, rail circuits or axle counters, level crossings, interlocking

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systems and central traffic control (CTC) [1, 2]. There are level crossings where the railway intersects with the highways. While the rail circuits/axle counters provide information about whether the railway is occupied by any railway vehicle, point machines allocate lines in one direction (reverse or normal) [1, 2, 3]. The data from all these field equipment, alarm conditions, route conditions, and line occupation information are collectors in the CTC. The interlocking between the equipment is managed from this center. Before the use of computer systems in signaling systems, especially in conventional lines, electromechanical control systems with relays were used. These control systems are currently being replaced with today's PLC-controlled computer and software technology to adapt to the newly added lines' signaling systems and control centers [4].

The point machine is the main actuator in the railway signalization system. The route of a railway vehicle may be set with the correct position of the point machines on the route. Then modeling and control of a point machine have significant importance. In railways, the EN50128 standard is used to meet safety conditions, and this standard suggests using Petri Nets in modeling signalization systems and components [3]. The Petri Nets are used to design, analyze and control discrete event systems with graphical and mathematical structures [5, 6]. For this reason, it is possible to see examples of Petri Nets in railways such that in the study [2], a Petri Net model was designed for a railway interlocking system and for this model, the Programmable Logic Control (PLC) block was created. The results were simulated on a small part of a railway. The Petri Net was used for modeling interlocking and signalization systems in [1], and these models were realized by using PLC. The functional safety requirements have been discussed for the Turkish National Railway Signalling Project. Petri Net models of signalization system equipment and software were developed using fail-safe PLCs [7]. Since it was more practical to obtain PLC codes in the SFC language from a Petri Net model, in this study, instead of function block diagrams (FBD) language, the Sequential Function Charts (SFC) language was preferred in coding PLC. The theoretical results for an interlocking system were tested on Interlocking Test Program with a railway field. The study [8] examined the Automation Petri Nets (APN) in railway signalization systems. The advantages of APN in railways were summarized. Then by using the Token Passing Logic method from the designed APN model of a railway yard with two crossover switches, a PLC ladder logic diagram was obtained and presented in the study.

In this study, an electrical point machine was modeled by using Petri Nets. The obtained model deadlock analysis was realized by using TAPAAL interface that presents an environment for editing and simulation of timed-arc Petri Nets. It also provides a verification module that automatically checks bounded timed-arc Petri Net models main structural properties. It is easy to design electromechanical / PLC control logic from validated Petri Net models [9]. Then, an electromechanical control circuit was designed for point machine by using relays. Although the electromechanical control systems support the real-time control, it is not possible to connect computers to relays directly. Therefore, today electromechanical control systems are being placed by PLC controlled systems. Then the PLC block for the point machine was created by using the Siemens TIA PORTAL interface. Since the Unistar CSV24 point machine is widely used in Turkey, all simulations were realized with Unistar CSV24 parameters.

The study is organized as follows: In Section 2, points in railways are summarized. The Petri Net graphical representation and structural behaviours are examined. A Petri Net model for an electrical point machine is studied in Section 3 while in Section 4, the point machine controller is designed by using both electromechanical control method and PLC. Study is concluded with Conclusions section.

2. Points

In railways, points allow the trains to go in the desired direction by changing their direction. A point has three position such that: *normal position*, *reverse position* and an *intermediate position*. The position of point in which the train goes without changing direction is called as the normal position, and the position where it goes by changing direction is called as the reverse position. The intermediate position which may cause trains to derail is used when changing from normal position to reverse position and vice versa. This feature makes the switches a vital element of the railway signalization systems [10].

The points can be classified into two groups such that motorized points that is controlled by an electrical motor and points with detector. While the electrical point machine may be controlled and its position can be seen from the central traffic control (CTC), only the position may be seen from the points with detector. Figure 1 shows widely used electrical point machine Unistar CSV24 structure. In this study, an electrical point machine Petri Net model was discussed for Unistar CSV24 parameters and both electromechanical and PLC controllers design were realized [11].

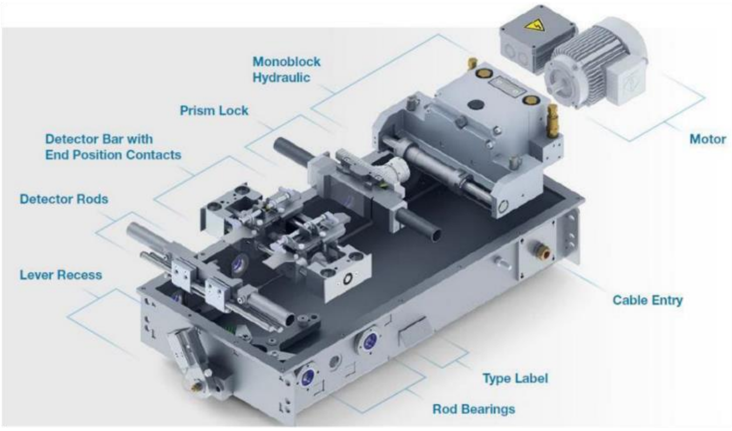

Figure 1. Unistar CSV24 point machine [12]

3. Petri Nets

The Petri Nets are used for modeling, analysis and control of discrete event systems. A Petri Net model consists of places, transitions and connections between them. In a Petri Net model, the circles denote the places (symbolized with P) while the lines show the transitions (named with t). The connections between places and transitions are realized by arrows. The "•" symbol is used for tokens in the graphical representation of Petri Net model. In a Petri Net model, firing of a transition is possible if and only if the number of tokens in the related place are equal to the weight of the arrow in between the place and the transition [5, 6, 7].

The Figure 2 shows an example of a simple Petri Net model that has the structure of $G = (P, T, N, O, m_0)$ which may be explained as below;

- $P = \{P_0, \dots, P_n\}$: The set of places (finite dimension)
- $T = \{t_0, \dots, t_m\}$: The set of transitions (finite dimension)
- $N: P \times T \rightarrow \mathbb{N}$: The input matrice from places to transitions
- $O: T \times P \rightarrow \mathbb{N}$: The output matrice from transitions to places
- $m_0: P \rightarrow \mathbb{N}$: Initial marking

According to the Petri Net model in the figure, since the place P_0 has one token and the weight of the arrow in between place P_0 and transition t_0, at first only t_0 can be fired. However, the transition t_1 could be fired if and only if the state P_1 has at least two tokens.

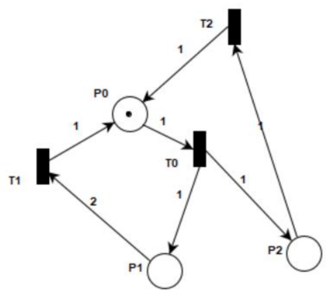

Figure 2. Petri Net model.

The reachability, liveness and deadlock are the three main structural properties of Petri Nets. In a Petri Net model, if the system can return to its initial condition regardless of firing order of transitions, the system is reachable. The liveness property guarantees that system has no deadlock. If a model has deadlock, it is not possible for the system to continue working [6].

The Petri Net models can be designed and analyzed via computer programs such that PNEditor, PNetLab, WoPeD, MATLAB, PIPE2, TAPAAL etc. In this study PIPE2 was used to design Petri Net model of Unistar CSV24 point machine and TAPAAL was used to verify these model.

3.1. The electrical point machine Petri Net model

Since the Unistar CSV24 point machine is suitable for points that are made in Turkey, then it is preferred in the signalization projects of Turkish State Railways (TCDD). The point machine may be controlled either automatically or manually (with a crack handle or manual command). While preparing a route for a train the point machine will be controlled automatically. In automatic control, if the point reach the desired position (reverse / normal) within the given time (for Unistar CSV24 the time is 10 s) the point machine will be locked electrically. In manual control electrical lock is not applied. If the point machine is tried to turn with a crack handle or the point could not reach its final position in given time (either automatic control or manual control) there will be a fault signal on the CTC [11, 13]. Then a Petri Net model was created based on this information and given in Figure 3.

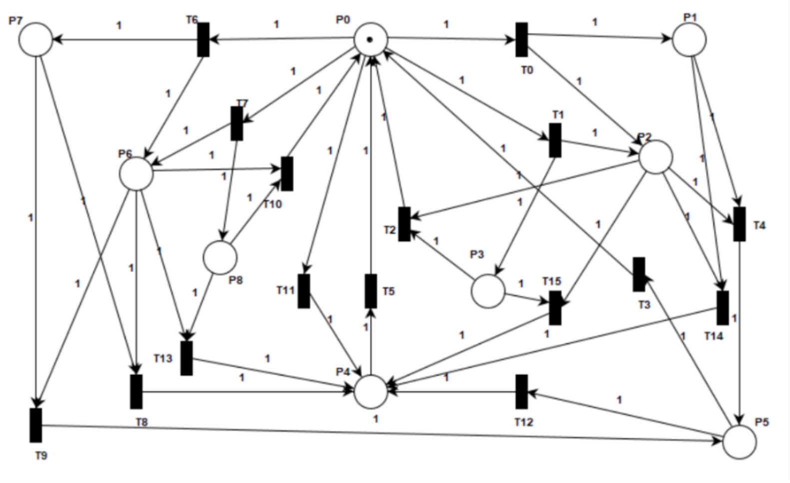

Figure 3. Petri net model of point machine Unistar CSV24

Table 1. Places of the Petri Net model

Place	Description
P_0 (State P_0)	Control Enable
P_1 (State P_1)	Automatic control for normal position
P_2 (State P_2)	Point machine turns to normal position
P_3 (State P_3)	Manuel control for normal position
P_4 (State P_4)	Fault
P_5 (State P_5)	Point machine locked electrically
P_6 (State P_6)	Point machine turns to reverse position
P_7 (State P_7)	Automatic control for reverse poisiton
P_8 (State P_8)	Manuel control for reverse poisiton

According to the figure, the places set $P = \{P_0, \dots, P_8\}$ is given in Table 1 while the transition set $T = \{t_0, \dots, t_{15}\}$ is presented in Table 2. The initial marking is given as $m_0 = [1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0]^T$ which means that at the beginning there is only one token in place P_0.

The model is verified to examine deadlock by using TAPAAL software. As a result, there is no deadlock on system and also the system is reachable.

Table 2. Transitions of the Petri Net model

Transitions	Description	Transitions	Description
t0	Turn to normal signal (automatic control)	t8	The reverse position is not reached in given time (automatic control)
t1	Turn to normal signal (manuel control)	t9	The reverse position is reached in given time (automatic control)
t2	The normal position is reached in given time (maneul control)	t10	The reverse position is reached in given time (manuel control)
t3	Point free signal	t11	Crack handle
t4	The normal position is reached in given time (automatic control)	t12	Crack handle (while point is locked)
t5	Reset signal	t13	The reverse position is not reached in given time (manuel control)
t6	Turn to reverse signal (automatic control)	t14	The normal position is not reached in given time (automatic control)
t7	Turn to reverse signal (manuel control)	t15	The normal position is not reached in given time (manuel control)

4. Point Machine Control

An electrical point machine is a mechatronic system that consists of sensors, a controller and actuators. Sensors collect data from the point machine such that “point in reverse position,” “point in normal position,” “point free signal,” and “crack handle”. In an electrical point machine, the actuator part is an electrical motor. ON/OFF controllers may be used to control such a system. The sensors and actuators remain the same even if the controller type changes. In this study, as an ON/OFF controller, the electromechanical control circuit and PLC block were designed for Unistar CSV24 point machine by using Petri Net model.

4.1. The electromechanical control

The electromechanical term has included both mechanical and electronical systems. In automation systems especially controlling of motors the electromechanical control circuits has been used for many years. The electromechanical relays, time relays and counter relays form the backbone of the electromechanical control circuits. The main advantage of the electromechanical control systems is that it provides real-time control. On the other hand, the connections between computers and relays could not be done directly [14, 15, 16].

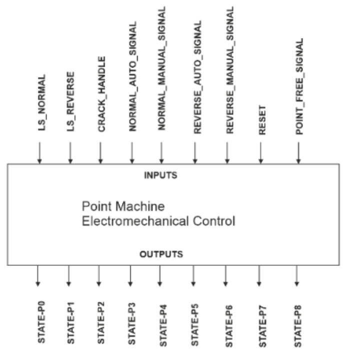

Figure 4. Electromechanical controller for Unistar CSV24

In this study for Unistar CSV24, an electromechanical control circuit was designed using Petri Net model. Figure 4 shows the electromechanical control unit with control circuits in Figures 5 - 6. The inputs and outputs are summarized in Table 3 and Table 4. In this electromechanical control unit for each sensor and CTC command, a relay is used as a memory variable (LS-N, LS-R and R1 – R6). The electromechanical control circuit is designed using the related contacts of these relays. In the control circuit, as shown in Figure 6, T1 and T2 are on delay timers and P0 – P8 are relays that correspond to the states in the Petri Net model. Though the relays can process real-time data (parallel signal processing), in recent years, the relay control has been replaced by PLC technology. The PLC control commands are evaluated based on time (serial signal processing), but PLC is not affected by bad environmental conditions. Also, relays could not communicate with computers directly. In case of possible error, fail-safe PLCs (especially those certified according to Safety Integrated Level – SIL) are preferred, which greatly contribute to ride and passenger safety by protecting the system. Then in this study, a PLC block was created to control Unistar CSV24.

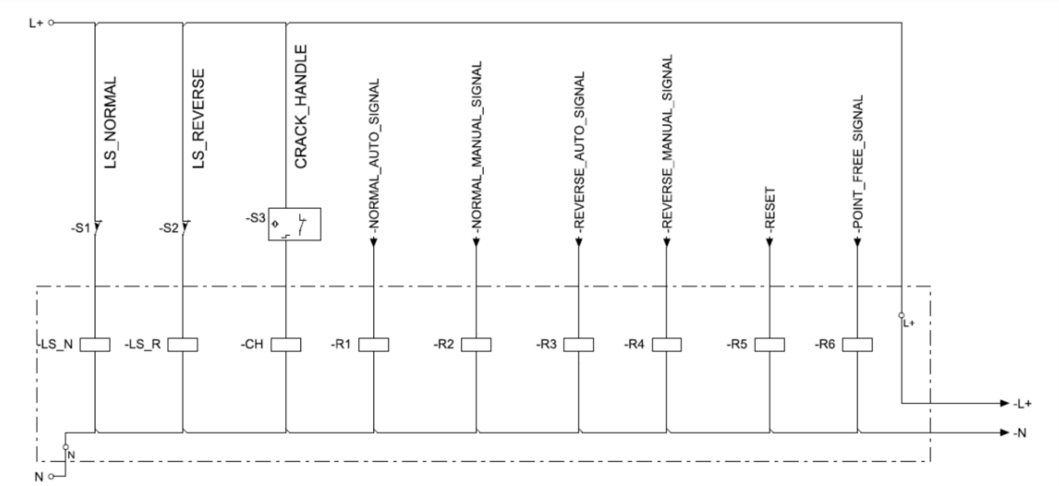

Figure 5. Electromechanical control circuit for Unistar CSV24

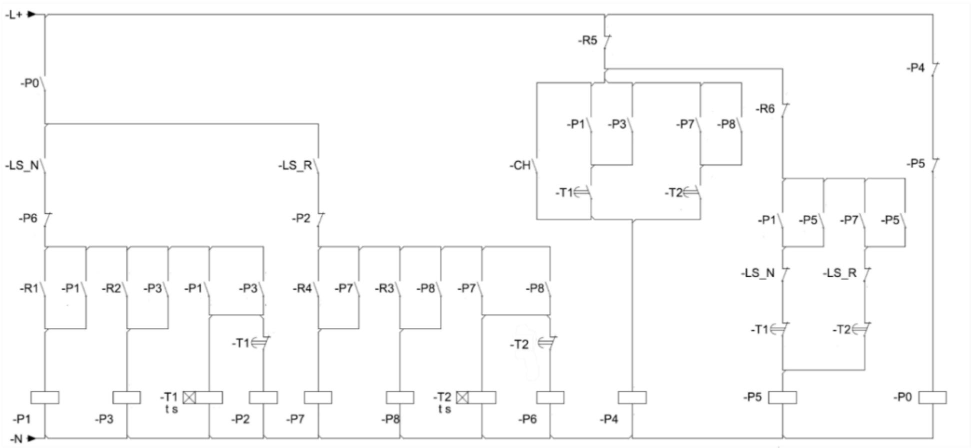

Figure 6. Electromechanical control circuit for Unistar CSV24

Table 3. The Electromechanical control circuit and PLC block Inputs

Electromechanical Inputs / PLC Inputs	Description	Petri Net Model Variable
LS_NORMAL	Point at normal position limit switch	$t_2 \| \| t_4$
LS_REVERSE	Point at reverse position limit switch	$t_9 \| \| t_{10}$
CRACK_HANDLE	Crack handle sensor	$t_{11} \| \| t_{12}$
NORMAL_AUTO_SIGNAL	Turn to normal signal (automatic control)	t_0
NORMAL_MANUAL_SIGNAL	Turn to normal signal (manual control)	t_1
REVERSE_AUTO_SIGNAL	Turn to reverse signal (automatic control)	t_6
REVERSE_MANUAL_SIGNAL	Turn to reverse signal (manual control)	t_7
RESET	Reset	t_5
POINT_FREE_SIGNAL	Point free signal	t_3

Table 4. The Electromechanical control circuit and PLC block Outputs

Electromechanical Outputs/ PLC Outputs	Description	Petri Net Model Variable
P_0 / State P_0	Control Enable	P_0
P_1 / State P_1	Automatic control for normal position	P_1
P_2 / State P_2	Point machine turns to normal position	P_2
P_3 / State P_3	Manuel control for normal position	P_3
P_4 / State P_4	Fault	P_4
P_5 / State P_5	Point machine locked electrically	P_5
P_6 / State P_6	Point machine turns to reverse position	P_6
P_7 / State P_7	Automatic control for reverse poisiton	P_7
P_8 / State P_8	Manuel control for reverse poisiton	P_8

4.2. The PLC control

In general, to obtain PLC logic from the Petri Net model Token Passing Logic (TPL) method is suggested [18]. According to this method, if a place has one token, one local variable will be defined. If the number of tokens is greater than one, a counter will be assigned. When the place or transition is related to time, on delay timer will be used. Then, the PLC block for Unistar CSV24 is given in Figure 7, with logic in Figures 8-12. The block was designed in Siemens TIA PORTAL software by using Petri Net model.

According to the PLC block, inputs (from field or CTC command), and outputs (to field or CTC) are given in Table-3 and Table-4. Memory variables (neither input nor output) are also used. The PLC block in Figure 7 consists of 5 parts. The first part of the PLC block shown by Figure 8 corresponds to place P0 in the Petri Net model, which means that the motor is enabled for control.

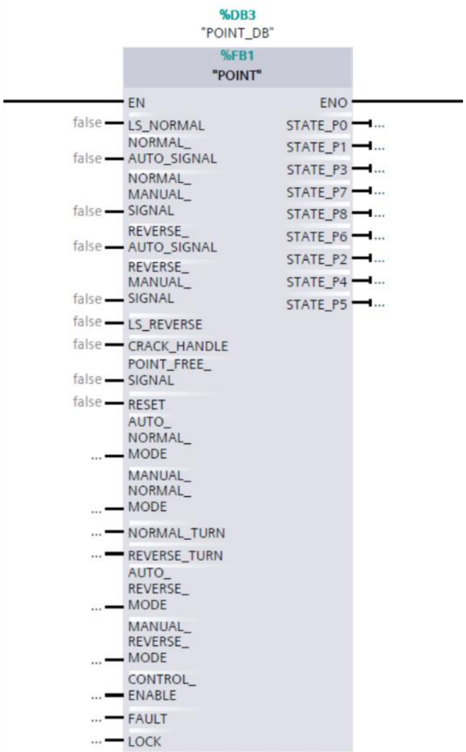

Figure 7. PLC block for Unistar CSV24

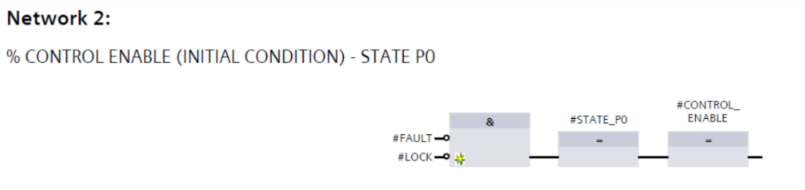

Figure 8. PLC block network2 logic for Unistar CSV24

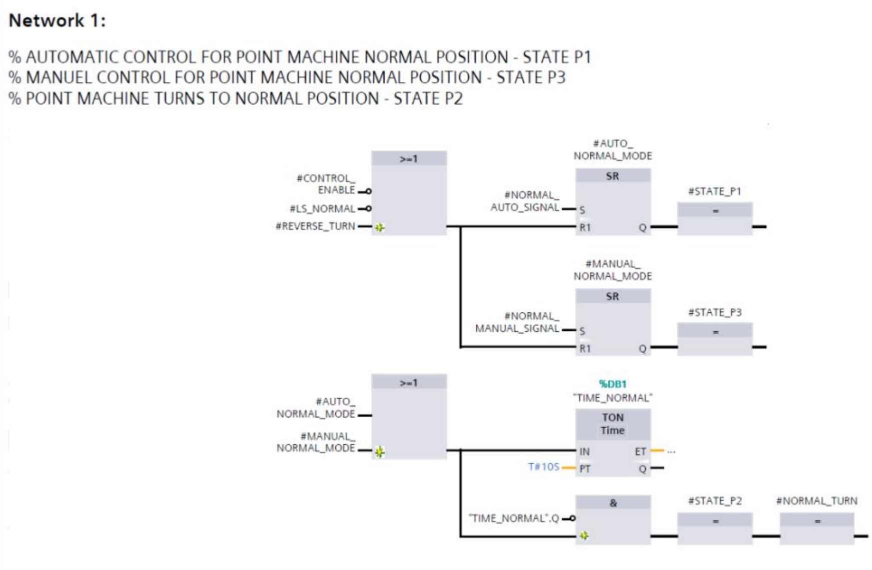

Figure 9. PLC block network1 logic for Unistar CSV24

Figure 9 and Figure 10 show the motor normal/reverse turnout commands that can be found in the Petri Net model state P2 and P6. The fault signal is generated in Figure 11 while, electrically locking is realized by using the program part in Figure 12.

The Siemens TIA PORTAL is an interface that may be used to program Siemens automation devices. The interface provides writing PLC codes with function blocks defined by standard IEC61131-3 [19]. The results are verified by computer simulations. Similar studies in the literature are generally creating Petri Net models to meet safety standards and creating PLC codes in different languages (ladder logic / FBD / SFC) using these models. In this study, Petri Net model of the point motor was created and PLC block was obtained from this model in FBD language. In this study, unlike the literature, an electromechanical control unit, which is one of the old methods, is also designed. It has been observed that similar methods are used to create a PLC block or electromechanical control unit of a signalization system element with a Petri net. Therefore, it is seen that it is explanatory discussion for railway workers in revising the systems of electromechanically controlled railway lines, in which relays are used, into new generation PLC-controlled systems, in which computers and software are used.

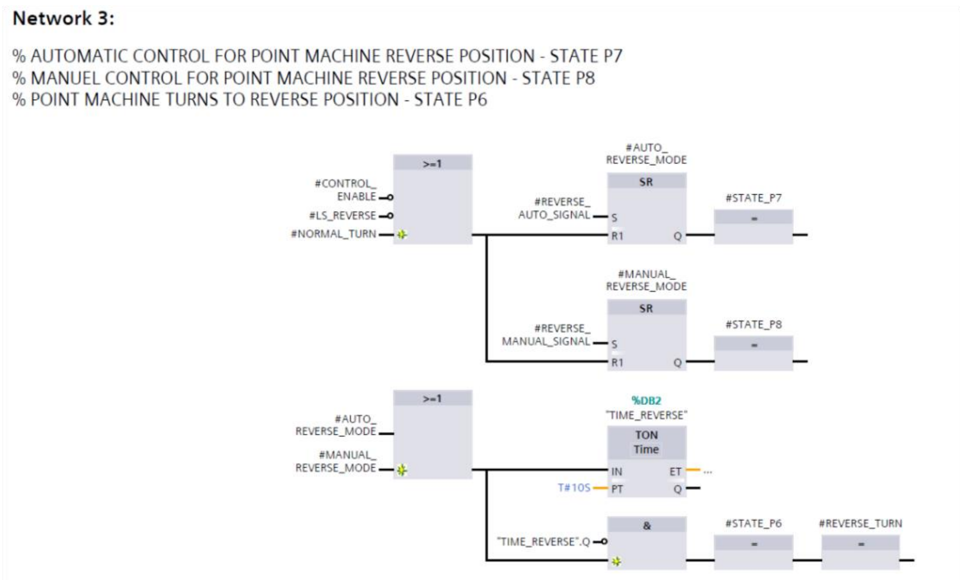

Figure 10. PLC block network3 logic for Unistar CSV24

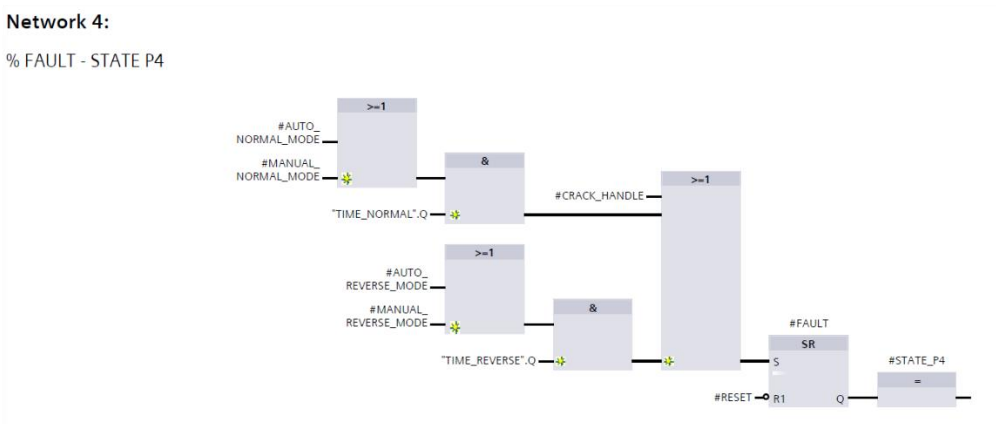

Figure 11. PLC block network4 logic for Unistar CSV24

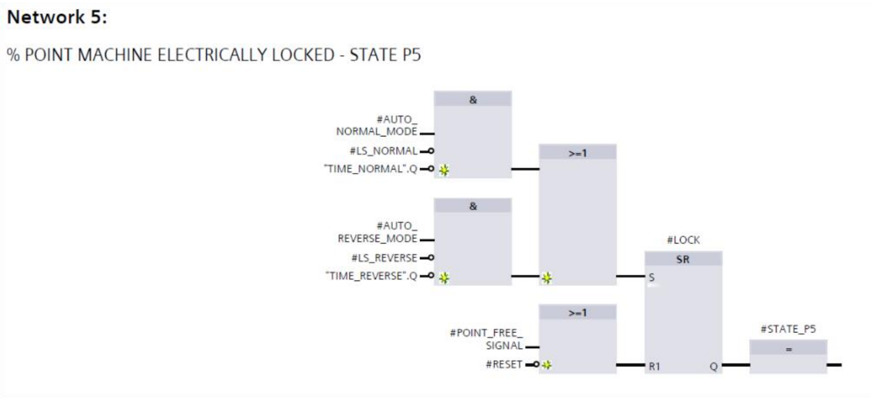

Figure 12. PLC block network5 logic for Unistar CSV24

4. Conclusion

In this study, the Petri Net model of an electrical point machine was obtained. For Unistar CSV24 parameters, the deadlock analysis was applied to the model by using TAPAAL. The deadlock verification of this model has a significant importance to ensure the reliability and continuity of the point machine control. In the past, the electromechanical control method was preferred for point machine control but nowadays PLC control is used. The PLC logic might be set up easily from the validated Petri Net model with token passing logic (TPL) method. In this study, for Unistar CSV24, at first an electromechanical control circuit was designed. Although the electromechanical control method has real time control capability, in this study also a PLC control block was designed by using today's technology. Designed controllers are simulated by using computer programmes. A fail-safe PLC block can be created, based on the PLC control block developed in this study. The point machines also used in the industry such that iron and steel industry or mining industry. The developed control blocks also may be applied to the point machines in the other industrial area.

References

[1] K. Akın, M. S. Durmuş and M.T. Söylemez, "Demiryolu sinyalizasyon sistemi bileşenlerinin otomasyon petri ağları ile modellenmesi ve PLC ile gerçeklenmesi", in TOK'10. *Turkish National Conference on Automatic Control,* Gebze, Turkey, 2010, pp.241-245.

[2] S. Saygın, İ. Yakın, M.S. Durmuş and M.T. Söylemez, "Petri ağlarıyla demiryolu makas bölgelerinin anklaşman ve sinyalizasyon tasarımı", in TOK'09. *Turkish National Conference on Automatic Control*, İstanbul, Turkey, 2009.

[3] M.S. Durmuş and M. T. Söylemez, "Railway signalization and interlocking design via automation Petri Nets", in ASSC2009. *7th Asian Control Conference*, Hong Kong, China, 2009.

[4] S. Karayanık, "Marmaray Sinyalizasyon Sistemleri", Demiryolu Mühendisliği, no. 4, pp. 71-77, 2016.

[5] A. Aybar and A. İftar, "Controller design to enforce boundedness, liveness and reversibility in Petri Nets", in IFAC-IMS2003. *7th IFAC Workshop on Intelligent Manufacturing Systems*, Budapest, Hungary, 2003, pp.199-204.

[6] T. Murata, "Petri Nets: properties, analysis and application", *in Proc. of the IEEE*, vol.77, no.4, pp.541-580, April, 1989.

[7] M. S. Durmuş, U. Yıldırım and M. T. Söylemez, "The application of automation theory to railway signaling systems: the Turkish national railway signalling project", *in Pamukkale University Journal of Engineering Sciences*, vol.19, no.5, pp. 216 – 223, 2013.

[8] B. Malakar and B. K. Roy, "Railway fail-safe signalization and interlocking design based on automation petri net", in ICICES2014. *International Conference on Information Communication and Embedded Systems*, Chennai, India, 2014.

[9] J. Byg, K. Y. Jørgensen and J. Srba. TAPAAL: Editor, Simulator and Verifier of Timed-Arc Petri Nets, in: Liu, Z., Ravn, A.P. (eds) Automated Technology for Verification and Analysis. ATVA 2009. Lecture Notes in Computer Science, vol 5799. Springer, Berlin, Heidelberg, 2009.
[10] M. L. Bliguet and A. A. Kjaer, "Modelling interlocking systems for railway stations", M.Sc. thesis, Department of Informatics and Mathematical Modelling, Technical University of Denmark, Lyngby, Denmark,2008.
[11] E. Dincel, "Anklaşman sistemlerinin hatada güvenli bir plc ile gerçeklenmesi", M.Sc. thesis, Control and Automation Engineering Program, ITU, 2013.
[12] O. Ovalı, "Comparison of constructional aspect of differenet railway point machines", Master Thesis, The Graduate School of Natural and Applied Sciences, METU, Ankara, Turkey, 2019.
[13] İ. Yıldırım, "Demiryolu sinyalizasyon sistemlerinin otomat yaklaşımı ile anklaşman tasarımı ve uygulaması", M.Sc. thesis, Electrical Engineering Program, ITU, 2012.
[14] M. Brown, J. Rawtani and D. Patil, *Practical troubleshooting of electrical equipment and control circuits*. Elsevier, 2005.
[15] J. Keljik, *Electricity AC/DC motors, controls and maintenance*. DELMAR Cengage Learning, 2013.
[16] R. Miller and M. R. Miller, *Industrial electricity and motor controls*. Mc Graw Hill Education, 2013.
[17] B. Hruz and M. C. Zhou, *Modeling and control of discrete event systems with Petri Nets and other tool.* Springer, 2007.
[18] M. Uzam, A. H. Jones and N. Ajlouni, "Conversion of Petri net controllers for manufacturing systems into ladder logic diagrams," in ETFA '96, *Proceedings 1996 IEEE Conference on Emerging Technologies and Factory Automation*. Kauai, HI, USA, 1996.
[19] Siemens Industry, "How do you program the PLC with STEP 7 (TIA Portal) in compliance with the IEC 61131-3 standard?",2013. [Online].Available: https://support.industry.siemens.com/cs/document/50204938/how-do-you-program-the-plc-with-step-7-(tia-portal)-in-compliance-with-the-iec-61131-3-standard-?dti=0&lc=en-TR [Accessed: 25-Jan-2023]

Resume

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