Holonic Models for Traffic Control Systems

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Abstract. This paper proposes a new time-placed net model for traffic control systems, respectively railway control traffic systems. This model can be interpreted as a holonic one, and contains three modules: Transport Planning Module, Transport Control Module and Priority Control Module. For railway traffic systems we introduce a strategy in a timed-place Petri net model to solve collision and traffic jam problems.

Keywords: Petri nets, planning module, priority module, control module, railway traffic, traffic jam.

1 Introduction

In this paper holonic traffic control models are examined, e.g. production tasks like assembly/disassembly or fork/join and traffic fluency of the vehicles with unreliable machines. The problem of maximizing the throughput is considered by achieving a balance among the tasks scheduling and processing of all machines under certain economical criteria [1, 2]. Due to the fact that complex systems built out of simpler subsystems display a remarkable autonomy and stability in the environment, Koestler realized that all the complex structures and stable processes have a hierarchical structure, like living organisms, social societies and non-living systems [3]. Complex systems evolve in shorter time out of simpler systems, with simpler character shapes between the simple and complex ones [4]. For a whole-parted system Koestler denoted the term "holon", derived from the Greek word *holos* = whole with the suffix – on (like neutron or proton) pointing out the part characteristic [5]. A holon could compile strategy out of its rules, which fits to its intentions, and goals and the interpolation of the environment [6]. Typical holonic applications or models are applied mostly to the production processes, called holonic manufacturing systems (HMSs), and we notice that similar to these approaches is that they are modeled domain specifically [7-9]. A complex holonic structure has a hierarchical order, rules and strategies framed by communication and reaction abilities. Most of the time, the hierarchies are looked at as rigid and inflexible shapes. However, some approaches are not following this like the approaches described in [6], and the one proposed here.

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Our approach uses the modeling power of Petri nets in order to build a holonic system for controlling the railway traffic. Petri nets are useful tools for modeling, analyzing and scheduling of a production system; they can provide accurate models of the procedure relations and concurrent, asynchronous events, e.g. holonic systems. Besides, they are also useful in synthesizing plausible control for discrete event dynamic systems. In this paper, a Petri net model is built to model the detailed behavior of a railway system in order optimize some a priori assigned performance criteria.

Due to the fact that the authors worked for more than 10 years for the Romanian Railway Company, the traffic system exemplified is a railway one, although we mention that the holonic models we propose are capable, with minimal changes, to be implemented in various fields of activities.

The ordinary Petri net model is not sufficient to capture the time-related system nature, and hence, timed-place Petri net have been defined and used. In the timed-place Petri net (TPPN), time is associated only with places and all transition firings are instantaneous; this is the model we selected for simulating a railway system. We notice that this paper made only a qualitative analysis of the railway systems; further papers will perform a quantitative analysis [15, 16]. Markings of the TPPN are deterministic during the evolution of the pertaining firing sequence from the initial marking. So, we can directly use the markings of the TPPN model to genuinely describe the states of the system and all the reachable markings can represent the state space of the modeled system. The outline of the paper is as follows: section 2 presents the main characteristics of the railway traffic control systems; section 3 introduces the main components of the proposed holonic models of railway control traffic systems: the transport planning module, the transport control module, and the priority control module. Section 4 concludes the paper.

2 Railway Traffic Control Systems Characteristics

Larger railroads may have multiple dispatcher offices and even multiple dispatchers for each operating division. Generally, railroads used to have their own set of operating instructions under various conditions. In some cases a rail crew might operate on a foreign carrier's lines, and would be required to also know their rules.

To ease this situation, a number of railroads would use a "consolidated code," or set of common operating instructions that were the same for all of the railroads using those.

One of the most common rules from this consolidated code was Rule 251 [14]:

> Rule 251. On portions of the railroad, and on designated tracks so specified in the timetable, trains will run with reference to other trains in the same direction by block signals whose indications will supersede the superiority of trains.

Centralized traffic control (CTC) is a signalling system used by railroads. The system consists of a centralized train dispatcher office that controls railroad switches in the CTC territory and the signals that railroad engineers must obey in order to keep the traffic moving safely and smoothly across the railroad. In the dispatcher's office there is a graphical depiction of the railroad on which the dispatcher can keep track of trains' locations across the territory that the dispatcher controls.

CTC was designed to enable the train dispatcher to control train movements directly, bypassing local operators and eliminating written train orders. Instead, the train dispatcher could directly see the trains' locations and efficiently control the trains' movement by displaying signals and controlling switches. It was also designed to enhance safety by detecting track occupancy and automatically preventing trains from entering a track against the established flow of traffic.

The basic component of a CTC system is detecting track condition and occupancy. The track at either end of the signal block is electrically insulated, and within the block a small electrical current passes through the track. When a train passes a signal and enters a block, the metal wheels and axle of the train short-circuit the current, which causes a relay associated with the track circuit to itself become de-energized. Additionally, any fault in the rail or failure in the signal system, such as a broken rail, a cut wire, or a power failure, will cause the relay to de-energize. When this relay is de-energized, the system understands the track to be occupied or damaged, and the signals show it as such to prevent a train from proceeding and encountering harm. What made CTC machines different from standard interlocking machines was that the vital interlocking hardware was located at the remote location and the CTC machine only displayed track state and sent commands to the remote locations [10].

A command to display a signal would require the remote interlocking to set the flow of traffic and check for a clear route through the interlocking. If a command could not be carried out due to the interlocking logic, the display would not change on the CTC machine. Key to the concept of CTC is the notion of Traffic Control as it applies to railroads. In single direction "Rule 251" operation, each section of track has a timetable defined flow of traffic.

Trains running against the flow of traffic need to be protected by special procedures usually involving some form of absolute block. Implementing a Rule 251 line is very straight forward as the logic for the signaling system is very simple. A bi-directional rail line also needs to avoid the situation of two trains approaching each other on the same section of track.

A bi-directional Rule 251 type system would allow trains to encounter each other head on, and most trains would end up approaching one another at restricted speed. This case would exist if one or both trains receiv a yellow or "Approach" signal and therefore they assume that the next signal block is unoccupied, when in fact there is traffic approaching head on. While the safety issues can be solved with signal block overlaps and other tricks, one will still end up with trains on the same track requiring one train to back up to the nearest passing point.

These systems are conventionally modeled using the operational researches formalisms (e.g. linear diffrential equations, fluency graphs, etc) that can hardly model the system’s resources. Our approach presented in the next section improve these models.

3 Holonic Models of Railway Control Traffic Systems

The timed-place Petri net model contains three major modules: Transport Planning Module, Transport Control Module and Priority Control Module. The three modules, of course, are interacted with each other to undertake the necessary actions in response to the triggering from another [18-20].

3.1 The Transport Planning Module

The purpose of the Transport Planning Module is to model the layout of the transport system. When a vehicle (trolley, wagon, or railway engine) needs to move from the current stop to the next stop, it needs to receive a "ticket" of movement first to know its destination. Then, the vehicle acquires the control right of the next stop to make sure that the stop is free at the moment. If both conditions are satisfied, it can start its movement to the next stop. In the same time, the control right of the current stop will be released to allow another vehicle to use it as a destination or pass-by stop. The Transport Planning Module consists of a number of Elementary Transport Layout Modules, as the one shown in Fig.1.

The notations of places used in Fig.1 are explained as follows: st i, $i \in N$ represents the stop at a workstation. A token in st i means that a vehicle stays at stop i; ctrl i, $i \in N$, represents the control right of Stop i. If the place ctrl i is marked, it means that Stop i is freed now and all vehicles are allowed to move to Stop i; otherwise, it means there is a vehicle right at the stop so that no other can move to that stop; mv ij, $i,j \in \{0,\dots,4\}$, with an arc connecting Stop i and Stop j in the layout directed graph, represents the status of the vehicle movement from Stop i to Stop j. A token in the place mv ij means that a vehicle is currently moving from Stop i to Stop j; tk ij, $ij \in \{0,\dots,4\}$, with an arc connecting Stop i and Stop j in the layout directed graph represents the "ticket" of the path segment from Stop I to Stop j. If there is a token in the place tk ij, it means that a vehicle wants to move from Stop i to Stop j; mv ok represents the status of completing the vehicle movement along a segment path. A token in the place mv ok means that the vehicle has completed the segment path movement.

For example five workstations as shown in Fig.2 are considered. The process flow is: a convoy of railway trucks leaves the garage line (LG) and is sorted in order to complete job 1, respectively to load/unload the wagons at line number 1 or number 3 and then it follows job 2: to load/unload the sorted wagons at line number 2. The next

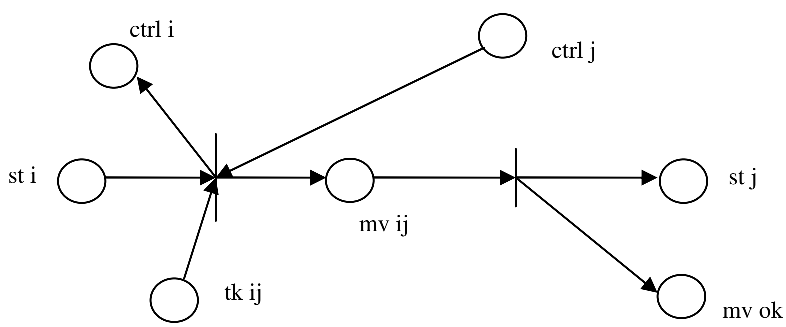

Fig. 1. Elementary Transport Layout Module

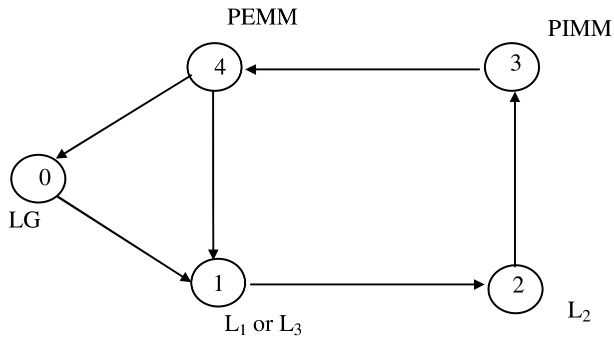

Fig. 2. Layout directed graph

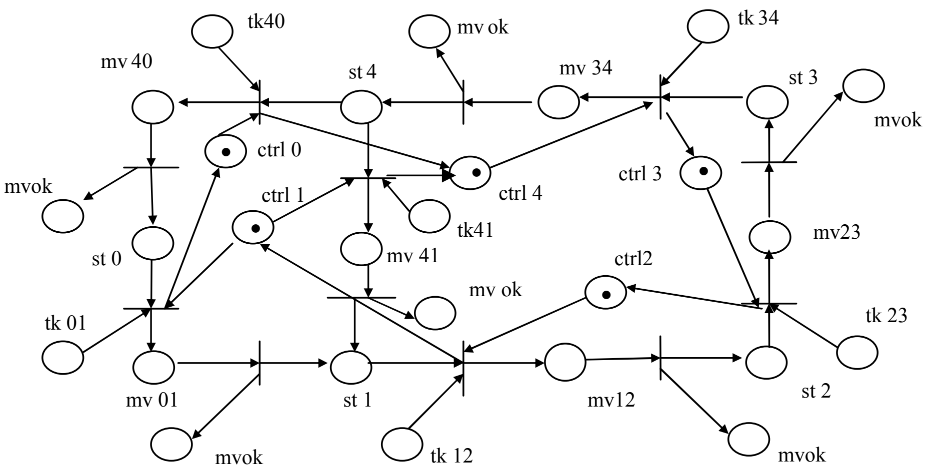

Fig. 3. The Transport Planning Module from Fig.2

operation is to return the wagons to the garage line passing through the expedition lines of the shunt board and to return the flaw wagons to lines 1 or 3. The Transport Planning Module for the layout directed graph in Fig.2 is shown in Fig.3

3.2 The Transport Control Module

This module corresponds to the decision-making Petri net model for vehicle routing. Each time a vehicle wants to move from the current stop to another stop, it must determine its route of movement first. The determined route can be sent to the Transport Planning Module through "ticket" places tk ij to entail the vehicle to move along that route. Therefore, for each stop, we need to have a corresponding Petri net model guiding the traveling path from another stop to it. Fig.4 illustrates the Transport Control Module for a vehicle to move from the current stop to Stop 3. The notations of places different from those in the Transport Planning Module are: mv st i represents the request of a vehicle that wants to move from the current stop to Stop i; at st i means

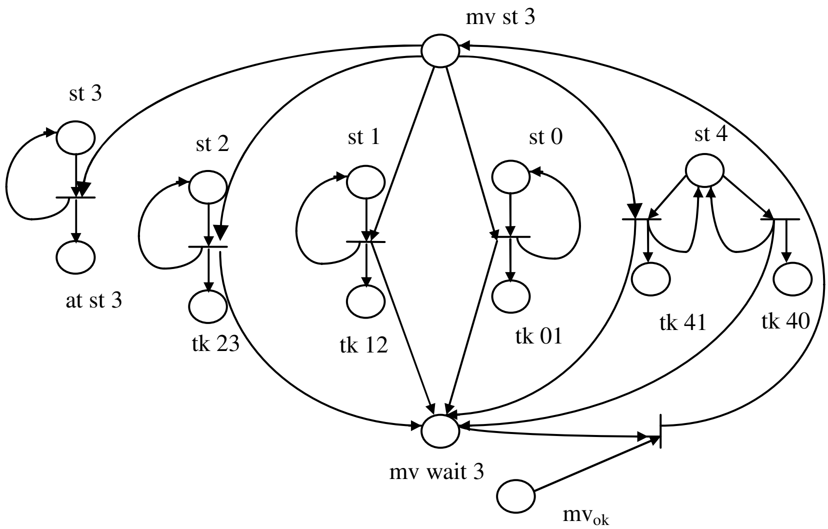

Fig. 4. The Transport Control Module

that the request of a vehicle that wants to move from the current stop to Stop i is fulfilled; mv wait i means waiting for the mv ok condition to generate a "ticket" for the next path segment; mv ok ensures the link with the Transport Planning Module.

3.3 The Priority Control Module

The objective of the Priority Control Module is to introduce a control method into the Petri net model with the aim of guaranteeing jam-free conditions among vehicles. The method is described as follows: when a mission vehicle found a stop on its traveling route was occupied by another vehicle, it will send a command to that vehicle to ask it to leave that stop. After a "ticket" is sent to that vehicle, it starts to move to its next stop and releases the occupancy of its prior residing stop. When the stop is completely released, the mission vehicle can resume its traveling on the same route path. Because the command may be sent to any other vehicle, we must build such models for every pair of vehicles to avoid this kind of traffic problem. The effectiveness of this strategy is limited to the layout geometry and the number of vehicles. But, unfortunately, this is the reality of physical systems [10-14], [21-23].

The Priority Control Model given in Fig.6 is built based on the Elementary Priority Control Model from Fig.5.

To distinguish the places associated with different vehicles, we add the subscript x to a place meaning that the underlying place is used by vehicle x. Consider every three adjacent stop points. If vehicle x is at Stop i and vehicle y is at Stop j and vehicle x wants to move to Stop j while vehicle y is idle, then vehicle y will be "pushed" by vehicle x to the other stop point, e.g., Stop k. Locations mv ok i, i=0, .., 4 ensure the links with the previous discussed modules. So, the Priority Control Module sends a token to the place tk jk y in the Transport Planning Module and, when vehicle y completes its movement, the module will send a token to mv ok y so as to inform vehicle

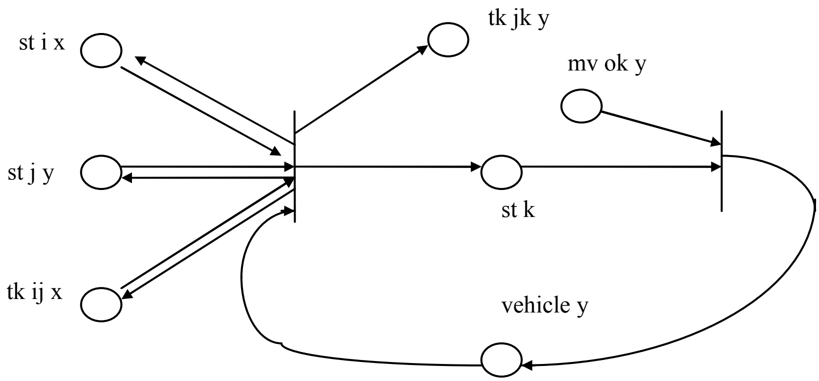

Fig. 5. Elementary Priority Control Module

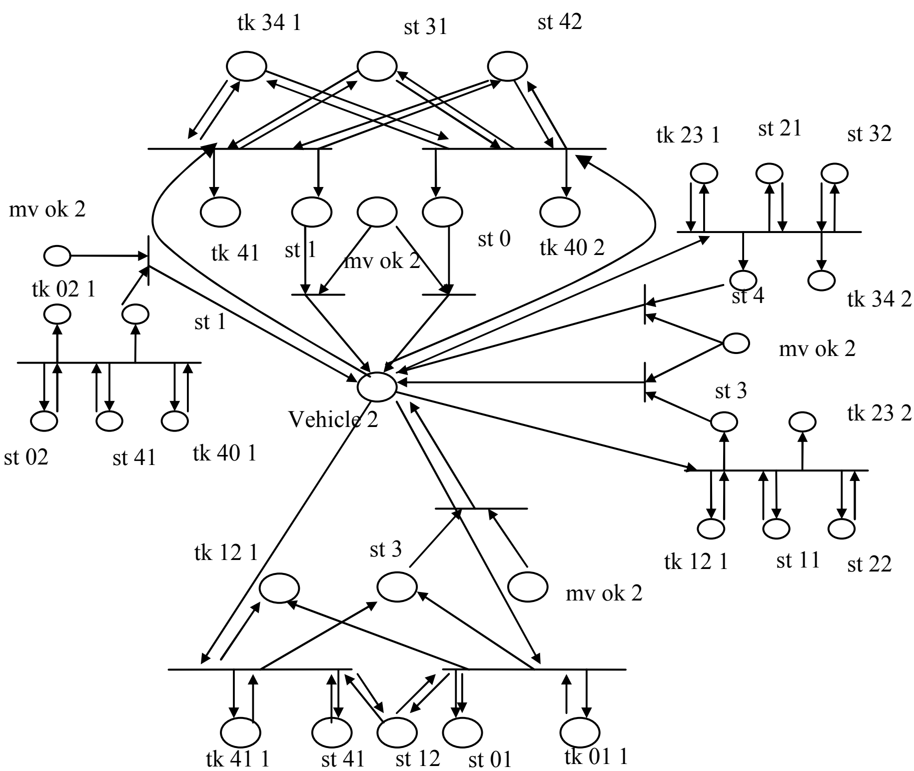

Fig. 6. Priority Control Module

x to start its movement. In Fig. 6 we show the Priority Control Module for the layout directed graph in Fig.2 when vehicle 1 “pushes” vehicle 2.

4 Conclusion

In this paper, we have proposed a new architecture for scheduling and controlling of holonic distributed systems using Petri nets formalisms and their properties [14, 15]. We exemplified this approach with three basic models for railway traffic control system. The proposed approach can be applied to the modeling and analysis of manufacturing systems, supply chains, job scheduling in a chain management system, such as flexible manufacturing systems, etc. The novelty of the approach is that the construction of large Petri nets is not required. Using a structural decomposition, the railway systems are divided into modules. For each module a control structure was derived in order to ensure the traffic safety and fluency. A comparison of the proposed approach with classic railway traffic control formalisms states that our model is less time-consuming, and also more safe, reliable, and versatile than other models. This is due to the fact that Petri net is an intuitive formalism that allows to verify the model by simulating it, and allows also to perform a dynamic change of the model’s parameters (e.g. structure) in order to deliver a safety model that display all the possible events and shows how to avoid the unwanted ones. The objective of the Petri net is to optimize the behavior of a vehicle traveling from the stop at which it currently stays to its destination by ensuring that vehicle collisions and traffic jam are avoided. The efficiency of the proposed method is limited to the layout geometry and the number of vehicles. The presented approach was implemented and tested in our laboratory of discrete event systems and we obtained a real time coordination of the railway system presented above.

The present study may be extended by designing a discrete event controller where there are choices to perform different routes.

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References

1. Murata, T.: Petri nets: Properties, analysis and applications. Proc. IEEE, 541–580 (1989)
2. Holloway, L.E., Krogh, B.H.: Synthesis of feedback control logic for a class of colored Petri nets. IEEE Trans. Aut. Contr. 35, 514–523 (1999)
3. Koestler, A.: The Ghost in the machine, New York (1976)
4. Fisher, K.: Agent-Based Design of Holonic Manufacturing Systems. Journal of Robotics and Autonomus Systems, Elsevier Science B.V. (1999)
5. Koestler, A.: Jenseits von Atomismus und Holismus – der Begriff des Holons, Wien (1970)
6. Peters, R., Többen, H.: A Reference Model for Holonic Supply Chain Management. In: Mařík, V., William Brennan, R., Pěchouček, M. (eds.) HoloMAS 2005. LNCS (LNAI), vol. 3593, pp. 221–232. Springer, Heidelberg (2005)

7. Bussman, S., McFarlane, D.C.: Rationales for Holonic Manufacturing Control. In: Proc. of the 2nd Int. Workshop on Intelligent Manufacturing Systems, Leuven, pp. 177–184 (1999)
8. Delfmann, W., Albers, S.: Supply Chain Management in the Global Context, Koln (2000)
9. Lackmann, F., Nayabi, K., Hieber, R.: Supply Chain Management Software, Planungssysteme im Uberblick, Germany (2003)
10. Ciufudean, C.: Discrete Event Systems for Modelling the Railway Traffic. Matrix Rom Publishing House, Bucharest (2002)
11. Ciufudean, C., Popescu, D.: Modelling Digital Signal Perturbations with Stochastic Petri Nets. Advances in Electrical and Computer Engineering 4(11)(1(21)), 71–75 (2004)
12. Ciufudean, C., Filote, C., Amarandei, D.: Control Charts of Workflows. In: Advances in Data Mning, 8th Industrial Conference, Leipzig, pp. 330–344 (2008)
13. Ciufudean, C.: Artificial Social Systems for Workflow Chart. University of Santander, 8th WSEAS Int. Conf. on Simulation, Modelling And Optimization, Spain (2008)
14. The Consolidated Code of Operating Rules, pp. 133–136 (2008), `http://www.mrcd.org`
15. Sampath, M., Sengupta, R., Lafortune, S., Sinnamohideen, K., Tewneketzis, D.: Diagnosability of Discrete Event Sytems. IEEE Trans. on Autom. Control 40(9), 1555–1575 (1995)
16. Jalcin, A., Boucher, T.O.: An architecture for Flexible Manufacturing Cells with alternate machining and alternate sequencing. IEEE Trans. Robot. Automat. 15(6), 1126–1130 (1999)
17. Recalde, L., Teruel, E., Silva, M.: Modeling and analysis of sequential processes that cooperate through buffers. IEEE Trans. on Rob. and Autom. 14(2), 267–277 (1998)
18. Proth, J.M., Xie, X.L.: Petri Nets. A Tool for Design and Management of Manufacturing Systems. Wiley, New York (1996)
19. Minis, I., Proth, J.M.: Production management in a Petri net environment. Recherche Operationelle 29(3), 321–352 (1995)
20. Zuo, M.J., Liu, B., Murthy, D.N.P.: Replacement-repair policy for multi-state deteriorating products under warranty. European Journal of Operational Research (123), 519–530 (2000)
21. Hopkins, M.: Strategies for determining causes of events, Technical Report R-306, UCLA Cognitive Systems Laboratory (2002)
22. Hall, K.H., Staron, R.J., Vrba, P.: Experience with Holonic and Agent-Based Control Systems and Their Adoption by Industry. In: Mařík, et al, pp. 1–10 (2005)
23. Brusey, J., McFarlane, D.: Designing Communication Protocols for Holonic Control Devices Using Elementary Nets. In: Mařík, et al, pp. 76–86 (2005)