Synthesis and analysis of AGV systems

Rozalia Lakner
Alba Regia Technical Faculty
Óbuda University
Székesfehérvár, Hungary
lakner.rozalia@amk.uni-obuda.hu

Botond Bertók
Faculty of Information Technology
University of Pannonia
Veszprém, Hungary
bertok@dcs.uni-pannon.hu

***Abstract*—Based on the similar structure of P-graphs and Petri nets, it is beneficial to merge their capabilities in solving specific problems. In the current work, the algorithmic synthesis of Petri nets by the P-graph framework is introduced and illustrated by an example of route planning of automated guided vehicle (AGV) systems.**

Keywords—colored Petri nets, P-graph, automated guided vehicle.

I. Introduction

The purpose of the automated guided vehicle (AGV) systems is to transfer objects between given points automatically, efficiently and safely.

To achieve this, the synthesis of feasible pathways is an important task in the AGV system design, where the synthesized models are used for simulation and analysis of the system.

II. Synthesis of Feasible Pathways of AGV System

Essentially, the synthesis is the determination of the process structure, that behave as required. For highly effective algorithmic solution of the synthesis problem, a mathematically rigorous framework, so called P-graph was introduced [1]. This method based on the combinatorial mathematics of graph theory, and a set of axioms expressing the properties of the feasible structures [2]. The P-graph framework generates the best and all of the alternative structures of the system, where the structures are represented by bipartite directed graph.

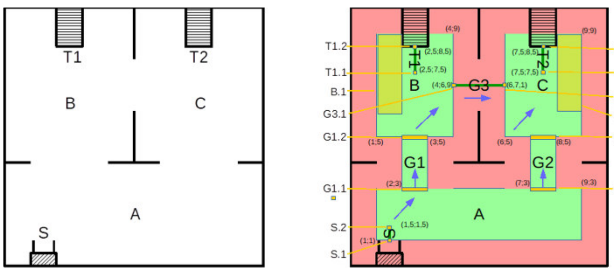

Fig. 1. The layout of the examined AGV system.

Fig. 1 illustrates the layout of the investigated AGV system, that consists of three rooms (A, B and C) and three gates connecting the rooms. There are three special stations: the charging station (S) for the AGVs in room A, the pick-up station (T1) in room B and the delivery station (T2) in room C. The AGV-s can travel among the various points of the layout for picking up and delivering packages on predefined paths. For safety movements of the AGVs, safety zones must be determined considering the dimension of the vehicle. These zones can be seen on the right-hand side of Fig. 1 with green colors, together with their special points. Based on the delivery request and its transportation order, there can be several feasible pathways involving movements of the AGV among the predefined locations.

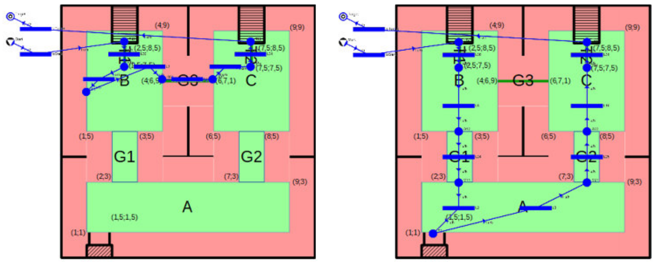

Fig. 2. Feasible pathways of the AGV system.

In Fig. 2 two of the eight feasible pathways of the delivery request is depicted, where the synthesis can be done by the publicly available software P-graph Studio [3]. The nodes of P-graph are the special places of the investigated system and the possible actions or vehicle movements between two neighboring places [4]. The starting and target points of AGV are at T1.2 and T2.2, respectively. The entity type nodes represented by solid circles in the P-graph represents potential vehicle locations, while activity type nodes represented by horizontal bars the possible vehicle movements between two neighboring locations.

Besides all the feasible pathways, the P-graph algorithms generate the maximal structure, that is the union of the feasible solution structures. The maximal structure of the AGV example is shown in Fig. 3.

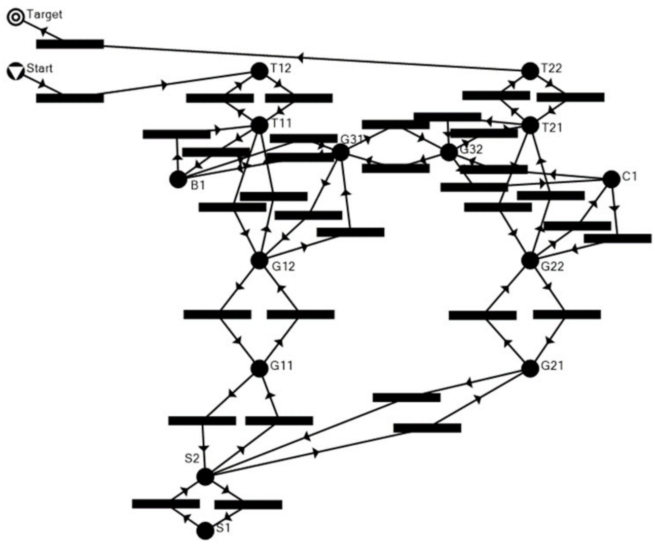

Fig. 3. The maximal structure of the AGV system.

P-graphs and Petri nets [5] have similar structures based on rigorous formal mathematical definitions and graphical notations. The similarity is observed in Fig 4., where the Petri net model of the layout of the AGV system constructed by CPN Tools [6] is shown.

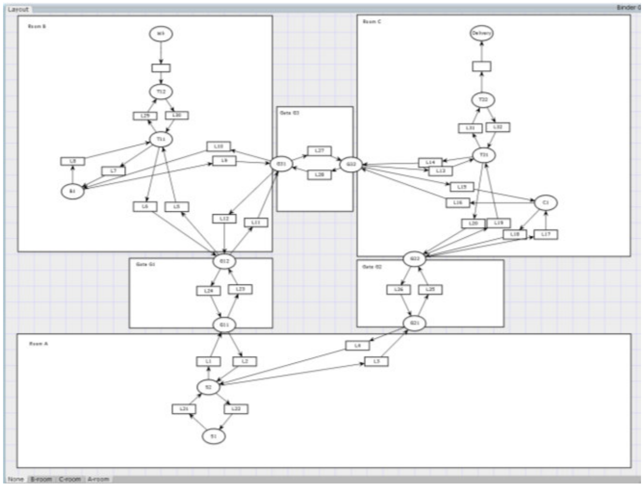

Fig. 4. The layout of the AGV system represented by Petri net.

The two frameworks aim at different objectives of systems design. While Petri nets are introduced primarily for modeling and analysis, P-graph framework has been developed for process synthesis. Even though the objectives are quite different, it is possible to merge their capabilities in solving specific problems, e.g., synthesizing Petri nets by the P-graph framework [7].

III. Simulation and Analysis of AGV System with Colored Petri Nets

Based on the similar structure of P-graph and Petri nets, the synthesized feasible structures serve as structures of Petri net models, where the special places and the possible actions of AGV-s in P-graph correspond to the places and transitions in Petri net, respectively.

The Petri net model of the AGV system with given delivery requests and their designated transportation pathways, defined by the initial state is shown in Fig. 5. In the examined case study, two AGVs are in the test environment at the same time. In the initial state one of the two AGVs is in position T12, and it delivers a package from pick up station (Wh) to delivery station (Delivery) through the pathway T11, B1, G31, G32, T21, T22. The other AGV starts from place T22 and travels on the route T21, G22, G21, S2, S1. The pathways assigned to the AGVs are shown in Fig. 6, where route of the first AGV is marked in red and route of the second AGV is marked in blue. The highlighted points in the environment affected by both AGVs are shown in purple in the figure.

In CPN model, the preconditions and consequences of AGV actions described with arc inscriptions and guards, the capacity limits of the places represented by anti-places.

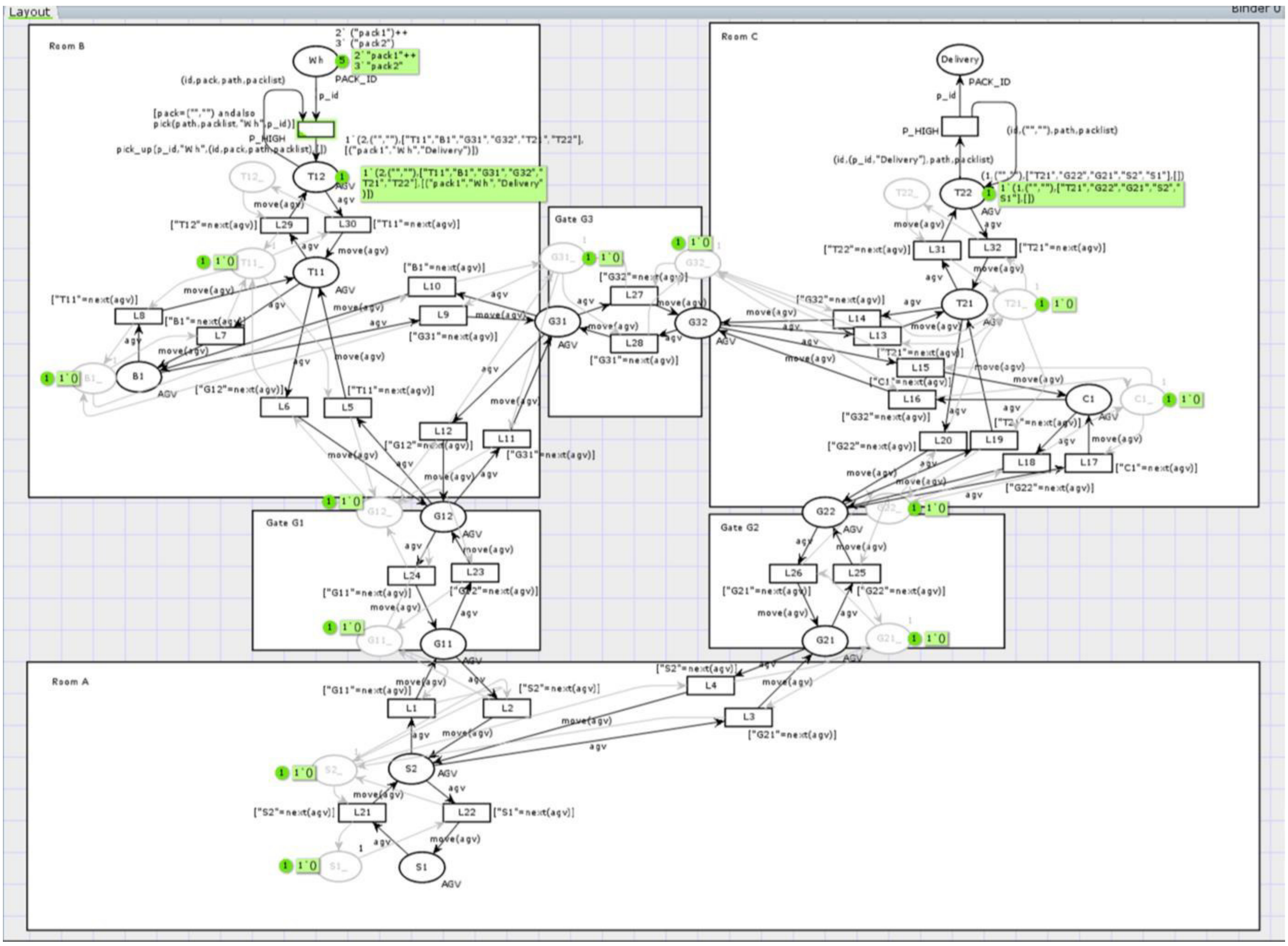

Fig. 5. The CPN model of AGV system with initial state.

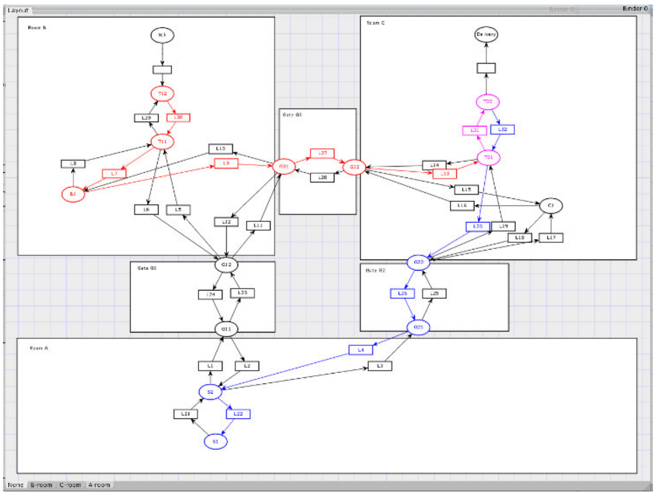

Fig. 6. The designated pathways of two AGVs in Fig. 5.

Besides simulation of AGV system, important properties, like reachability and deadlock are investigated by reachability graph analysis [8] with State Space Tool integrated into CPN Tools.

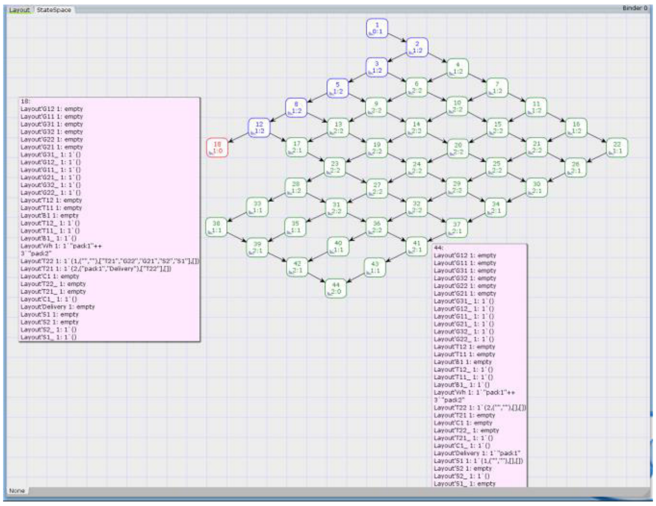

Fig. 7. The reachability graph of CPN model in Fig. 5.

The reachability graph of the system under study is shown in Fig. 7, where the states represented by rectangles. State 1 corresponds to the initial state, and states 18 and 44 are deadlocks. In state 44, one of the AGVs is located at S1 (filling station) and the other is at T22 (delivery station). The additional route to be traversed by both AGVs are empty, i.e. they have traversed the route assigned to them and transported the designated packages. The resulting deadlock is the expected final state of the system.

In state 18, one of the AGVs is at T22 (delivery station) and the other is at T21 (place right next to delivery station). The state is a deadlock, which is the unexpected final state of the system.

According to the expected and unexpected final states of the system, the partitions of the nodes of the reachability graph are as follows:

- nodes from which directed path leads only to expected final states (green nodes)
- nodes from which directed path leads only to unexpected final states (red nodes)
- nodes from which a directed path leads to both expected and unexpected final states (blue nodes)

Partitions are characterized by the fact that if we are in one of the states of the partition marked in green, we will definitely remain in the green partition even after performing any further transition. The same applies to the partition marked in red. Accordingly, the states of the red partition are to be avoided by the system, and the states of the green partition are the states to be reached by the system.

In the case study on Fig. 8, two AGVs move on two different, intersecting routes in the study environment. In the initial state, one AGV is at location S1 (filling station) and the other is at location T22 (delivery station), where their designated pathways are as follows: S1, S2, G11, G12, T11, T12, T11, B1, G31, G32, T21, T22, T21, G22, G21, S2, S1 and T22, T21, G32, G31, B1, T11, T12, T11, B1, G31, G32, T21, T22, T21, G22, G21, S2, S1. The designated route of the first AGV is from the filling station, it touches the pick-up station and the delivery station back to the filling station, while a package has to be transported from pick-up station (Wh) to delivery station (Delivery). The route assigned to the other AGV leads from the delivery station to the pick-up point and then through the delivery point to the filling station, while it has to transport a packet from Wh to Delivery.

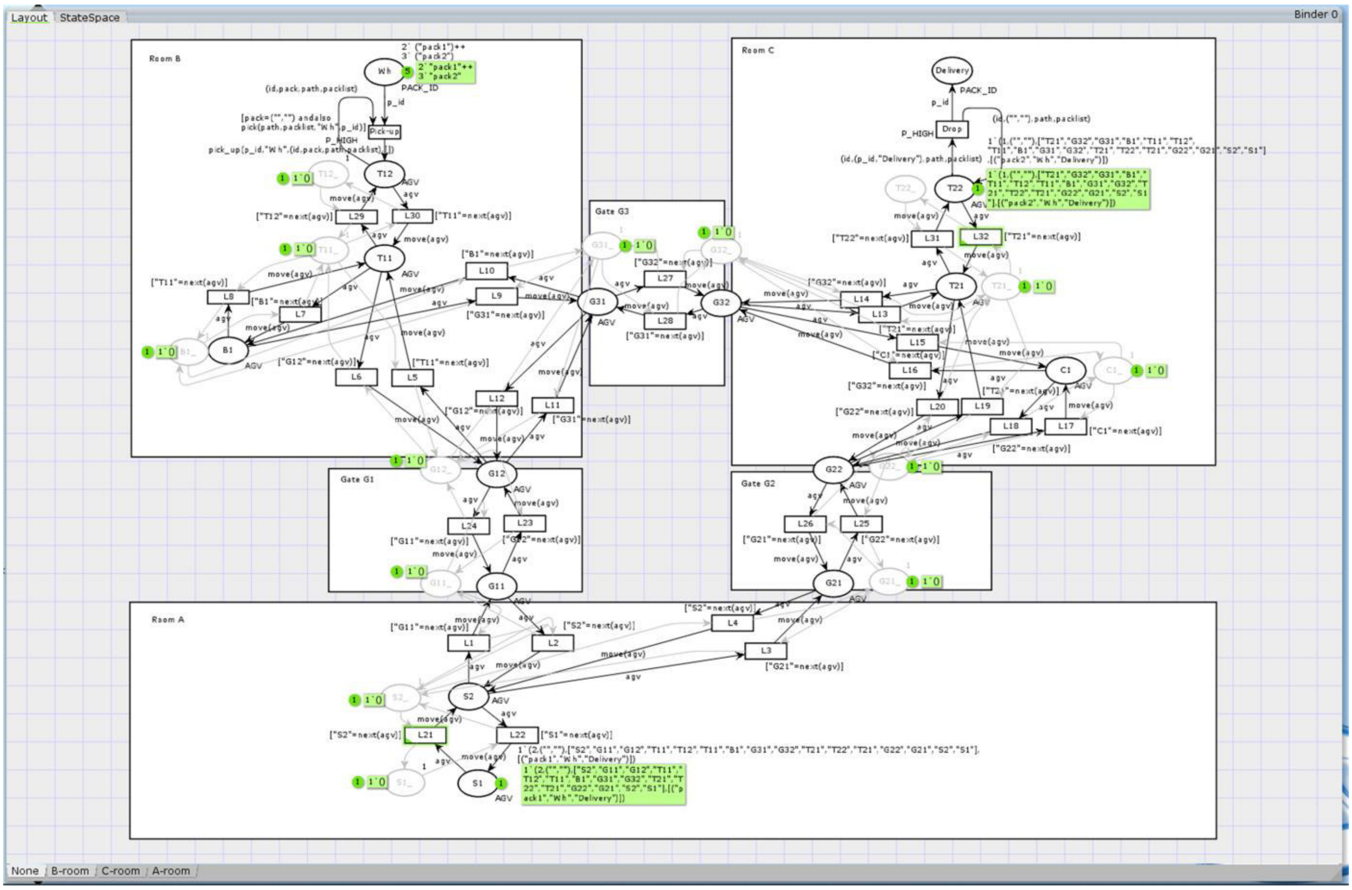

Fig. 8. The CPN model of AGV system with another initial state.

The designated pathways of the AGVs are shown in Fig. 9, where the places affected only by the first and the second AGV is marked in blue and red, respectively. The places in the environment affected by both AGVs are shown in purple.

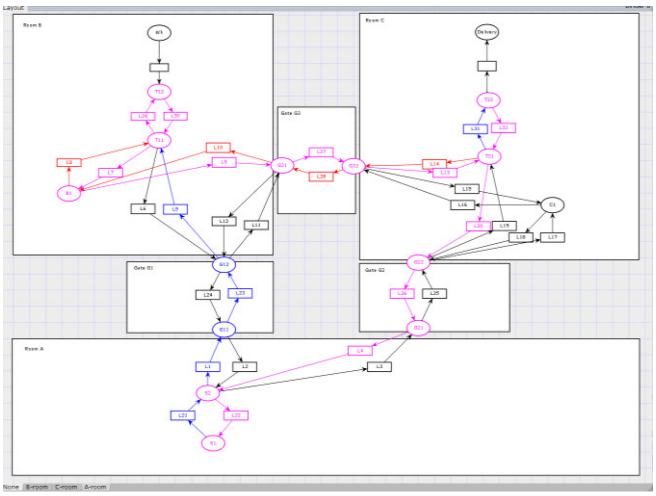

Fig. 9. The designated pathways of two AGVs on Fig. 8.

The reachabilty graph for the initial state of the examined system is shown in Fig. 10. It can be seen that the system has nine deadlocks, of which one is a expected final state (state number 205) and eight are unexpected final states. It can be seen from the partitions of the reachability graph that unexpected final states 68 and 172 can be easily avoided. However, before reaching the other six unexpected end states (states 69-74), we can enter a red partition 4-8 steps earlier, from where we arrive at an unexpected final state regardless of the execution order of the subsequent transitions. The "top" state of the red partition at the top right of the figure, i.e. state number 15, is shown in Fig. 10, from which the expected final state is certainly not reached, but the system reaches a deadlock only after seven steps.

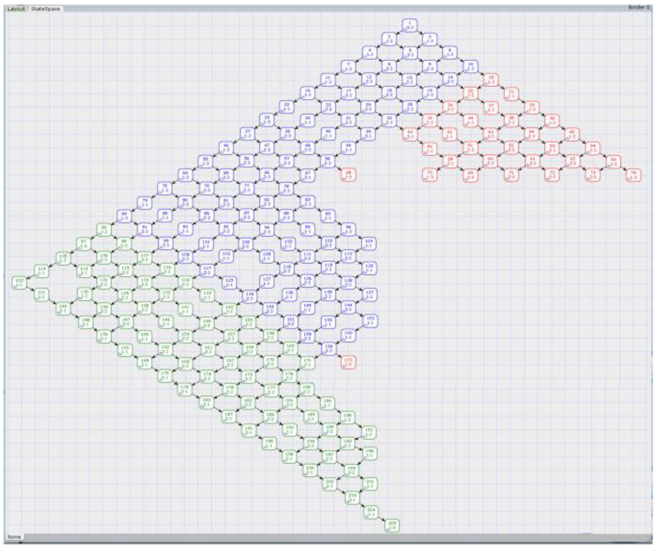

Fig. 10. The reachability graph of CPN model in Fig. 8.

CONCLUSIONS

The algorithmic synthesis of Petri nets by the P-graph framework is used for route planning of automated guided vehicle (AGV) systems. The resulted colored Petri net model appropriate to the simulation and formal analysis of the system. Analysis of the reachability graph have shown that in case of planning AGVs routes, it can be critical to identify and avoid deadlocks. Therefore, important to identify unexpected system states at an early stage and determine if there is a sequence of steps (and if so, which ones) that the AGVs can reach the expected final states.

REFERENCES

[1] F. Friedler, K. Tarjan, Y. W. Huang and L. T. Fan, "Graph-Theoretic Approach to Process Synthesis: Axioms and Theorems", Chem. Eng. Sci. 47, pp. 1973-1988, 1992

[2] F. Friedler, K. Tarjan, Y. W. Huang and L. T. Fan, "Combinatorial Algorithms for Process Synthesis", Comp. Chem. Eng. 16, pp. 313-320, 1992.

[3] Software P-Graph Studio, www.p-graph.com, Last accessed 01/09/2020.

[4] Barany, M., Bertok, B., Kovacs, Z., Friedler, F., & Fan, L. T. "Solving vehicle assignment problems by process-network synthesis to minimize cost and environmental impact of transportation", *Clean Technologies and Environmental Policy*, *13*(4), 637-642, 2011.

[5] J. L. Peterson, "Petri Net Theory and the Modeling of Systems", Prentice Hall, New Jersey. 1981.

[6] CPN Tools: A tool for editing, simulating, and analyzing Colored Petri nets, cpntools.org, Last accessed 01/09/2020.

[7] R. Lakner, F. Friedler, B. Bertok, "Synthesis and Analysis of Process Networks by Joint Application of P-graphs and Petri Nets", Lecture Notes in Artificial Intelligence, 10258, pp. 309-329, 2017.

[8] T. Murata, "Petri Nets: properties, analysis and applications", In: Proc IEEE, vol. 77. pp. 541-80. 1989.