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# Modeling and Evaluation of Transportation System With Three Modes of Displacement Using Hybrid Petri Nets

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## Abstract

The aim of this research is to associate the modeling capacity and analysis power of hybrid Petri netsHPN in order to perform formal verification of hybrid dynamic systems. We propose a hybrid Petri nets for modeling and verification of a complex transportation system with three modes of displacement (Bus, Train and tramway). This paper shows how this model can be used to describe the traffic functioning and to obtain control strategies that improve the traffic flow at connections between the modes of displacement. The general control structure based on hybrid Petri Nets is described using visual object net. We verify some qualitative properties of the transportation system such as, the feasibility of the passenger connections, the reachability of a desired situation and absence of blocking.

**Keywords:** Hybrid dynamic system, Petri Net, Hybrid Petri Net, Multimodal transportation systems, Modeling.

## Introduction

Several studies related to multimodality have been made in recent decades. They deal with issues ranging from the development of networks up their operations in real time, through traffic planning.

Thus, during the development of road infrastructure and transportation networks, the objective to facilitate and optimize travel and exchange between public and individual transport modes through the management of interchanges. It is very useful to have an exchange through an intermodal carrier between operation support systems of the transport network, especially in degraded condition or crisis (congestion, breakdown, strike, etc.). Thus, some recent studies have addressed these multimodal information systems that aim, among others, to reduce uncertainty for travelers and, wherever possible, to increase the attractiveness of public transportation, the benefit of an optimal use of infrastructure and priority to public transport.

The literature mentions some work using the PN for modeling and performance analysis of dynamic discrete event systems such as production and transport systems. However, few studies have focused on modeling the discrete part or continuous aspect that we have studied the hybrid case. In this context, we propose this approach to modeling acomplex transportation system with three modes of displacement (Bus, Train and tramway) while using the similarities between the transfer of the flow and the waiting time of each mode of transport.The primary goal of our contribution through this paper is the use of hybrid Petri net in order to bring control to the problems encountered in the management of passengers in their moving by minimizing their waiting times in the exchange points.

The remainder of this paper is structured as follows: Introduction is presented in section 1, Section 2 presents the related work and gives an overview of developed researches in this field. Then the description of the studied system is given in Section 3. Section 4 we describe the modeling and simulation of the multimodal systemand exposethe obtained results. Conclusion and future work are given in Section 5.

## Related Work

In the field of multimodal transportation systems, several approaches have been used for modeling, simulation and evaluation.

Graph theory is one of the most used for the representation of a transmission system tools. Graphs by modeling are to describe the stops by nodes and travel between stations by directed arcs and weighted[1].

For the traffic flow model based on a discrete Petri Net (PN), Wang et al. proposed a Petri Net (PN) model that includes both traffic signal control logic and traffic flow [2]. In [3], List had described how PN can be used to model traffic control situations in urban networks. On the other side, the model based on a continuous Petri net is suitable for macroscopic description, [4] and [5]. And recently, hybrid systems have received much attention [6] and [7] and have been applied for the modeling and control of transport systems [8].

Ghaffari used the Petri nets for modeling the flow of travelers [9]. As Petri nets allow for a simulation of the behavior of the transport systems, the authors in[10] presented a stochastic Petri Nets model representing both lines and passenger flows of a transport network bus. This modeling was used to present a rather fine and very simply the movement of passengers in the network and the relationship between the change of the flow and the passage of vehicles at the stations [11][12].

Dridi contribute to the resolution of problems of regulation in transport systems in a multi-criteria context by evolutionary approach[13].

## System Description

The studied system is a complex system very close to reality.

The system contains three transportation modes (bus, train and tram-way) which are connected by a connection station enabling the exchange of passengers. These modes are linked by two main lines L1 and L2.

Each public transportation mode is assigned to a transportation line and makes a circuit from its departure station to its arrival station (called also terminus) while serving other lines of the same mode or those of other transportation modes via connection stations or exchange platforms in line 1 and line 2.

Line L1 includes correspondence respectively -Bus Train, Bus-Bus and Bus - Tramway and this in both directions of travel.

Similarly, L2 includes correspondence respectively -Bus Train, Bus-Bus and Bus - Tramway and this in both directions of travel.

The process of evolution of traffic and passenger flows in multimodal systems can be simulated with a hybrid dynamic system whose evolution passenger queues is described by a continuous part and the occurrence of discrete event.

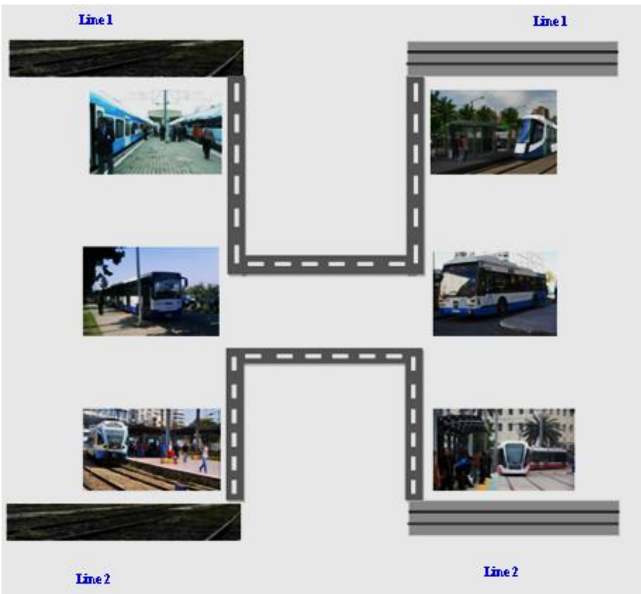


**Figure 1:** Multimodal Transportation System

## Modeling The Multimodal System By HPN

In this section we present the modeling of the system by Hybrid Petri Net.

Several contributions in this framework have been presented in the last decade, as well as some interesting extensions with respect to the original model. Since the complexity of the regulation, we used the first class of Hybrid nets defined by David and Alla [6]. It is the first hybrid formalism to be defined from PNs, the authors, simply, gave it the name of hybrid PN. This formalism combines in the same model a continuous PN, which represents the continuous flow, and a discrete T-timed PN, to represent the discretebehavior.

- Discrete “places” represent entities which can be numbered (by tokens).
- Continuous “places” represent entities which cannot be numbered. A real number is associated with each continuous place.
- Discrete transitions are fired after a timedelay.
- Continuous transitions continuously are fired at a rate.
- Normal arcs activate transitions by consuming resources.
- Inhibitory arcs inhibit transitions and consume resources.
- Test arcs activate transitions without consuming resources.

Petri Net was used to model our system is based on the net Visual Object tool. A configuration of an exchange platform of a multimodal transportation system is given in Fig.2.

The continuous part corresponds to the exchange of passenger flows between different transportation modes e.g., bus, tramway and train. While the discrete part represents the means of transportation as discrete entities.

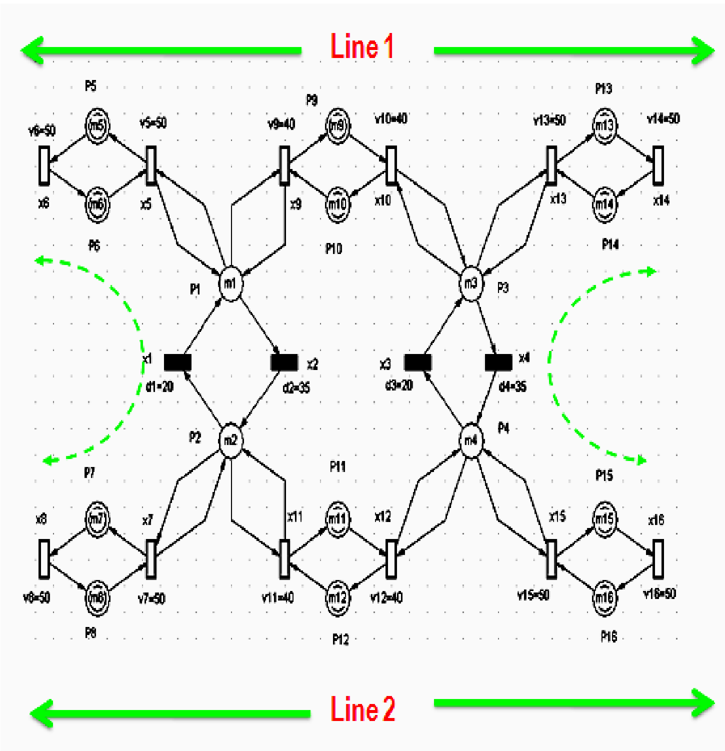


**Figure 2:** Modeling three modes transportation by Hybrid Petri Nets

There are 16 places and 16 transitions can be modeled as own resources, every place can be occupied by a single mode and a limited number of passengers.

## A. Places Description

Places are: P1, P2, P3, P4 (discretes places) and P5, P6, P7, P8, P9, P10, P11, P12, P13, P14, P15, P16 (continuous places).

Signification of all places and transitions is shown in Table V.1 and Table V.2 respectively.

**Table 1:** Places Description

| **Places** | **Places Significations** |
|---|---|
| $P_1$ | Correspondence 1 between Bus-Train in the line L1 |
| $P_2$ | Correspondence 2 between Bus-Train in the line L1 |
| $P_3$ | Correspondence 3 between Bus-Tramway in the line L2 |
| $P_4$ | Correspondence 4 between Bus-Tramway in the line L2 |
| $P_5$ | Transfer passengers returning from bus to train at line L1 |
| $P_6$ | Transfer passengers returning from train to bus at line L1 |
| $P_7$ | Transfer passengers returning from bus to train at line L2 |
| $P_8$ | Transfer passengers returning from train to bus at line L2 |
| $P_9$ | Transfer passengers returning from bus line L1 to correspondence of tramway |
| $P_{10}$ | Transfer passengers returning from bus line L1to correspondence of train |
| $P_{11}$ | Transfer passengers returning from bus line L2 to correspondence of tramway |
| $P_{12}$ | Transfer passengers returning from bus line L2 to correspondence of train |
| $P_{13}$ | Transfer passengers returning from bus to tramway at line L1 |
| $P_{14}$ | Transfer passengers returning from tramway to bus at line L1 |
| $P_{15}$ | Transfer passengers returning from bus to tramway at line L2 |
| $P_{16}$ | Transfer passengers returning from tramway to bus at line L2 |

### B. Transitions Description

Transitions are: x1, x2, x3, x4 (discrete transitions) and x5, x6.x7, x8, x9, x10, x11, x12, x13, x14, x15, x16 (continuous transitions).

**Table 2:** Transitions Signification

| Transitions | Transitions Significations |
|---|---|
| $x_1$ | Bus station to the Train station to go to line1 |
| $x_2$ | Bus station to the Train station to go to line L2 |
| $x_3$ | Bus station to the Tramway station to go to line L1 |
| $x_4$ | Bus station to the Tramway station to go to line L2 |
| $x_5$ | Connecting passengers Bus - Train in the line L1 |
| $x_6$ | Connecting passengers Train -Bus in the line L1 |
| $x_7$ | Connecting passengers Bus - Train in the line L2 |
| $x_8$ | Connecting passengers Train - Bus in the line L2 |
| $x_9$ | Connecting passengers Train-Bus-Tramway in the line L1 |
| $x_{10}$ | Connecting passengers Tramway-Bus-Train in the line L1 |
| $x_{11}$ | Connecting passengers Train-Bus- Tramway in the line L2 |
| $x_{12}$ | Connecting passengers Tramway-Bus-Train in the line L2 |
| $x_{13}$ | Connecting passengers Bus- Tramway in the line L1 |
| $x_{14}$ | Connecting passengers Tramway-Bus in the line L1 |
| $x_{15}$ | Connecting passengers Bus- Tramway in the line L2 |
| $x_{16}$ | Connecting passengers Tramway-Bus in the line L2 |

## Model Validation

The system is evaluated and analyzed using the HPN fundamental equation. Its evolution is studied and analyzed using IB-state techniques.

Using the developed HPN model, we verify some qualitative properties of the system such as, the feasibility of the passenger connections, the reachability of a desired situation (the transfer of a desired percentage of passengers with a minimum waiting time), absence of blocking, etc.

Our modal contains two similar parts:

Part 1 present the travel flow of 2 modes of transportation Bus and Train and their displacement from one station to another on line 1 and line 2.

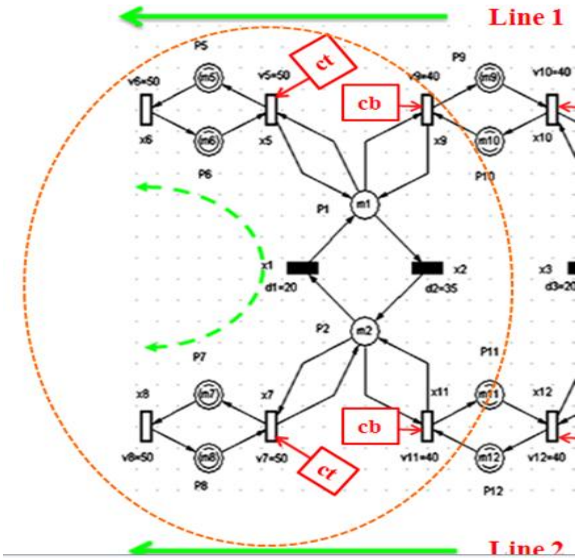


**Figure 3:** Control part1 of model

Part 2present the travel flow of 2 modes of transportation Bus and tramwayand their displacement from one station to another on line 1 and line 2.

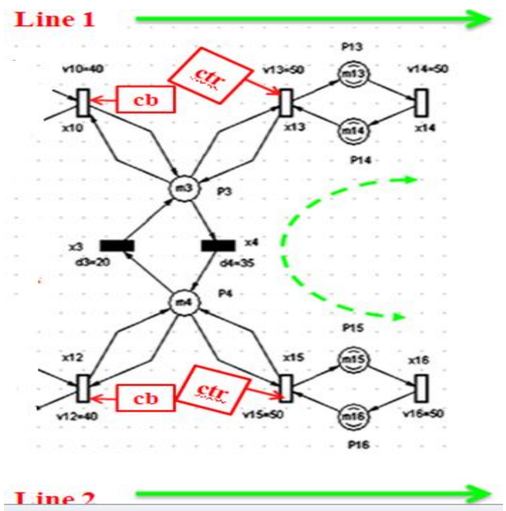


**Figure 4:** Control part 2 of model

For the raison of the analogy between the two model parts, we only describe the Control Strategy of Part 1analyzed using IB-state techniques.

Control is done at the continuous transitions x5, x6, x7, x8, x9, x11 passenger flow control in the lines L1 and L2 match for the train and the bus.

With the initial marking of the HPN model, as presented in the Fig.3, the transition $x_5$is strongly enabled because $P_6$is not empty and the place $P_1$ contains a token. Hence, $x_5$ can be fired with a maximal speed $v_5$ = 50 (as shown on the HPN model). At the same time, the transition $x_6$is also stronglyenabled because $P_5$ is not empty. However, the transition $x_7$is not enabled because the place $P_2$ is empty from tokens. This means that the firing speed $v_7 = 50$. This transition will beenabled and fired after time 40 units, the required time for the bus to reach the connection station with the train L2 and then puts down the passengers wanting to make the connection with the train L2.

The marking the D-places and C-places of the HPN model verify the following expressionsconstitute the marking invariants (1):

$$\begin{cases} m_1 + m_2 = 1 \\ m_3 + m_4 = 1 \\ m_5 + m_6 = 100 \\ m_7 + m_8 = 100 \\ m_9 + m_{10} = 120 \\ m_{11} + m_{12} = 120 \\ m_{13} + m_{14} = 160 \\ m_{15} + m_{16} = 160 \end{cases} \quad (1)$$

The marking is completely known from($m_5$,$m_6$,$m_7$,$m_8$). This illustrated in Fig.3. Where m(0) represents the initial marking. The evolution of the hybrid PN may be analyzed thanks to the evolution graph in Fig.4.

Hence the marking of each C-place of the HPN defined according to the algebraic subtraction of instantaneous speeds of its input and output transitions.

We present the fundamental equation when time is involved.

The marking of the HPN model at a given time “t” is expressed by the following equation(2).

An IB-State is such that the marking of discret part and the instantaneous speed vector of the continuous part remain constant as long as the system is in the same IB-state.

$$\begin{bmatrix} m^D & t \\ m^C & t \end{bmatrix} = \begin{bmatrix} m^D & 0 \\ m^C & 0 \end{bmatrix} + \begin{pmatrix} W_{DD} & 0 \\ W_{CD} & W_{CC} \end{pmatrix} \cdot \left( \begin{bmatrix} n_D(t) \\ 0 \end{bmatrix} + \int_{u=0}^{t} \begin{bmatrix} 0 \\ v_C(u) \end{bmatrix} du \right) \quad (2)$$

$$W_E^{+} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (3)$$

$$W_E^{-} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (4)$$

$$W = W^{+} - W^{-} = \begin{bmatrix} -1 & 1 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 1 \\ 0 & 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} n_D(60) \\ nC\ 60 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{6}$$

The marking of the HPN model at t=60 is given by:

$$M(60) = \begin{bmatrix} m^{D}\ 60 \\ m^{c}(60) \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ 80 \\ 20 \\ 65 \\ 35 \end{bmatrix} \tag{7}$$

## Analysis and Discussion

The IB-state is such that the marking of discrete part and instantaneous speed vector of continuous part remain constant as long as the system is in the same IB-State. For example, IB-state 1 in Fig.5: the marking of discrete part is $(m_1,m_2)=(1,0)$ and the instantaneous speed vector is $(v_5,v_7,v_9,v_{11})=(50,50,\ ,40,40)$, the marking of the continuous marking evolves continuously and linearly as long as the system is in the same IB-state.

From the variation of markingof part1 of model, it is obvious that the marking in the place $p_5$ is $m_5 = 80$ ,in the place $p_6$is $m_6 = 20$,the marking in the place $p_7$ is $m_7 = 65$, the marking in the place $p_8$ is $m_8 = 35$ at the time $t = 60$. The Fig.5shows the periodic behavior regarding the marking evolution for each 60 time units. With this behavior, we deduce that the transfer of the maximum flow of passengers is reached at the time $t = 60$. Even the maximum flow of passengers is transferred at $t = 60$, the connection station is not yet saturated taking into account the equation of the system.

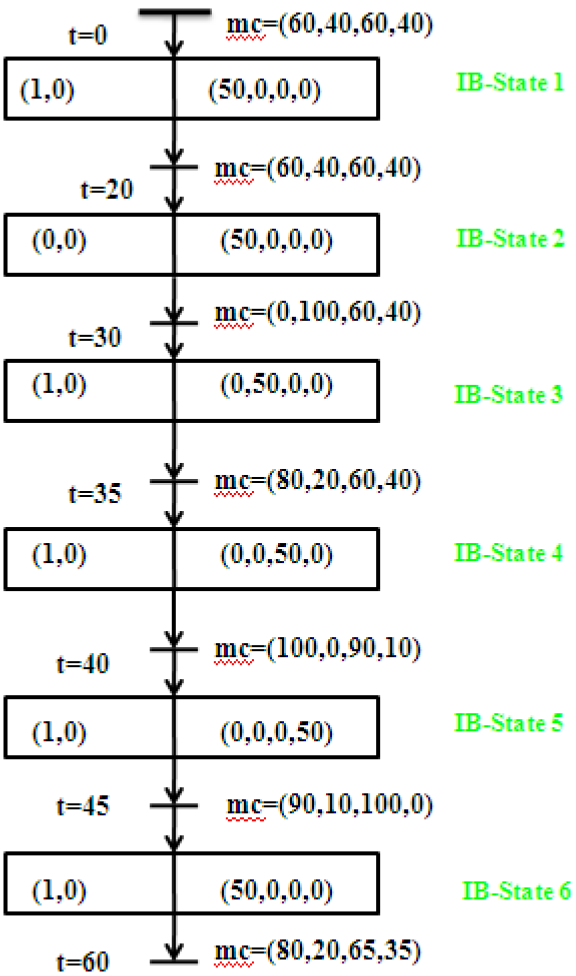


**Figure 5:** Evolution graph

## Conclusion

In this paper, we have presented Hybrid Petri Nets modeling of complex transportation system with three modes of displacement (Bus, Train and tramway). Hybrid PNs combine discrete Petri Nets and a continuous Petri Nets.

The system is evaluated and analyzed using the HPN fundamental equation. Its evolution is studied and analyzed using IB-state techniques.We precise the continuous transitions for simulate the passengers flow by evolution graph of two modes Bus and Train, show by IB-State.

In our future research, we try togeneralize the existing results to the control of hybrid systems modeled by the finite state automata.

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