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AN URBAN TRAFFIC NETWORK MODEL VIA COLOURED TIMED PETRI NETS

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Abstract: This paper deals with modelling of traffic networks for real time control purposes. A modular framework based on coloured timed Petri nets is proposed to model the dynamics of signalized traffic network systems: places represent link cells and crossing sections, tokens are vehicles and token colours represent the routing of the corresponding vehicle. In addition, an ordinary timed Petri net models the signal timing plan controlling the area. The proposed modelling framework is applied to a real intersection located in Bari, Italy. A discrete event simulation of the controlled intersection validates the model and tests the signal timing plan obtained by an optimization strategy presented in the related literature. *Copyright © 2004 IFAC*

Keywords: modelling, road traffic, Petri-nets, discrete event systems, traffic control.

1. INTRODUCTION

Traffic signal on surface street networks plays a central role in traffic management. Most of the currently implemented traffic control systems are grouped into two principal classes (Patel and Ranganathan, 2001, Wey, 2000): 1) fixed-time systems and 2) vehicle actuated systems. In the first group, the control system determines fixed timing plans by using an off line optimization performed by computer programs. The second class of traffic control strategies employs actuated signal timing plans and performs an on-line optimization and synchronization of traffic signals. In the real-time optimization control strategy, detectors located on the intersection branches monitor traffic conditions and feed information on the actual system state to the real time controller. Moreover, the controller selects the duration of the green phases in the signal timing plan in order to optimize a performance index (Patel and Ranganathan, 2001, Wey, 2000, Dotoli, *et al.*, 2003, Barisone *et al.*, 2002).

Two main different approaches are developed in the related literature in order to model and analyze the behaviour of vehicles in Traffic Networks (TNs) and may be classified according to the level of modelling detail. First, microscopic models describe both the system entities and their interactions with high level of detail. However, these high-fidelity microscopic models and the resulting software are costly to develop and execute. Second, macroscopic models represent the traffic streams in an aggregate manner, e.g. by scalar values of flow rate, density and speed. These lower fidelity models are less costly to develop and maintain, but their representation may be inaccurate and not valid.

Petri net based models are suited to describe signal traffic control and concurrent activities in TNs (Giua, 1991, Di Cesare, *et al.*, 1994). In particular, Di Febbraro, *et al.*, (2002) present a traffic model in a timed Petri net framework, where tokens are vehicles and places are parts of lanes and intersections. However, in ordinary Petri nets tokens can not distinguish among different vehicles and their associated routes. Colours are introduced in (Di Cesare, *et al.*, 1994), where a different colour is assigned to each vehicle entering the system. However, the model methodology developed in (Di Cesare, *et al.*, 1994) does not use the coloured Petri net paradigm to simulate the system, that is substantially modelled with ordinary Petri nets.

This paper has two objectives. First, it presents a Coloured Timed Petri Net (CTPN) model to describe in a microscopic formulation the flow of vehicles in an urban TN system. The token colour represents the path which a vehicle has to follow and places are cells accommodating one vehicle only. Moreover, the paper models the TN traffic light and determines the green phases duration using an optimization method based on a macroscopic model (Dotoli, *et al.*, 2003, Barisone *et al.*, 2002). Second, the proposed CTPN model generates the code to simulate real intersections and to test the actuated control strategy proposed in (Dotoli, *et al.*, 2003, Barisone *et al.*, 2002). Hence, a case study is presented and the traffic flow in a real intersection located in the city of Bari, Italy, is simulated in different traffic scenarios.

The paper is organized as follows. Section 2 recalls the basics of CTPNs. Moreover, Section 3 defines the CTPN modelling the TN and the traffic light. Section 4 describes the case study and reports the results of a simulation performed under different traffic scenarios. Finally, Section 5 summarizes the conclusions.

2. BASICS OF COLOURED PETRI NETS

A Coloured Petri Net (CPN) is a bipartite directed graph represented by a quintuple $CPN=(P, T, Co, \boldsymbol{Pre}, \boldsymbol{Post})$, where P is a set of places, T is a set of transitions, Co is a colour function that associates with each element in $P\cup T$ a non empty ordered set of colours in the set of possible colours Cl (Jensen, 1992). Co maps each place $p_i \in P$ to the set of possible token colours $Co(p_i)=\{a_{i,1},a_{i,2},\ldots a_{i,ui}\}\subseteq Cl$, where $u_i=|Co(p_i)|$ is the number of possible colours of tokens in p_i. Note that we use symbol $|A|$ to denote the cardinality of the generic set A. Analogously, Co maps each transition $t_j \in T$ to the set of possible occurrence colours $Co(t_j)=\{b_{j,1},b_{j,2},\ldots,b_{j,uj}\}\subseteq Cl$ with $u_j=|Co(t_j)|$.

H is a weight function for an inhibitor arc that connects a transition to a place. More precisely, an inhibitor arc labelled $a\in N$ between $p_i\in P$ and $t_j\in T$ (i.e., $H(p_i,t_j)=a$) implies that as soon as there are a tokens in p_i, the arc inhibits the firing of t_j. Note that N is the set of non-negative integers.

Now, we define a non-negative multiset α over the set D as a mapping α: $D\rightarrow N$ (Jensen, 1992). Matrices ***Pre*** and ***Post*** are the pre-incidence and the post-incidence matrices, respectively. In particular, each element $\boldsymbol{Pre}(p_i,t_j)$ is a mapping from the set of occurrence colours of $t_j\in T$ to the set of non-negative multisets $\mathcal{N}(Co(p_i))$ over the set of colours of $p_i\in P$. More precisely, we denote $\boldsymbol{Pre}(p_i,t_j)$: $Co(t_j)\rightarrow \mathcal{N}(Co(p_i))$ as a matrix of $u_i\times u_j$ non-negative integers, whose generic element $Pre(p_i,t_j)(h,k)$ is equal to the weight of the arc from place p_i with respect to colour $a_{i,h}$ to transition t_j with respect to colour $b_{j,k}$.

Analogously, $\boldsymbol{Post}(p_i,t_j)$: $Co(t_j)\rightarrow \mathcal{N}(Co(p_i))$ for each $t_j\in T$ to each $p_i\in P$ corresponds to the set of directed arcs from T to P. Hence, we denote by $\boldsymbol{Post}(p_i,t_j)$ a matrix of $u_i\times u_j$ non-negative integers and the scalar $Post(p_i,t_j)(h,k)$ is the weight of the arc from transition t_j with respect to colour $b_{j,k}$ to place p_i with respect to colour $a_{i,h}$. Finally, the incidence matrix $\mathbf{C}$ of dimension $|P|\times|T|$ is defined as $\mathbf{C}(p_i,t_j)=\boldsymbol{Post}(p_i,t_j)-\boldsymbol{Pre}(p_i,t_j)$.

For each place $p_i\in P$, we define the marking $\boldsymbol{m}_i$ of p_i as a *non-negative multiset* over $Co(p_i)$. The mapping $\boldsymbol{m}_i$: $Co(p_i)\rightarrow N$ associates with each possible token colour in p_i a non-negative integer representing the number of tokens of that colour that is contained in p_i. In the following we denote $\boldsymbol{m}_i$ as a $(u_i\times 1)$ vector of non-negative integers, whose h-th component $m_i(h)$ is equal to the number of tokens of colour $a_{i,h}$ that are contained in p_i. The marking $\boldsymbol{M}$ of a CPN is an m-dimensional column vector of multisets, i.e., $\boldsymbol{M}=[\boldsymbol{m}_1\ldots\boldsymbol{m}_{|P|}]^T$. Finally, a coloured Petri net system $<CPN,\boldsymbol{M}_0>$ is a CPN with initial marking $\boldsymbol{M}_0$.

Given a CPN and a node $x\in P\cup T$, the set $\bullet x=\{y\in P\cup T: (y,x)\in F\}$ is the preset of x and $x\bullet=\{y\in P\cup T: (x,y)\in F\}$ is the post-set of x. Now, a transition $t_j\in T$ is *enabled* with respect to colour $b_{j,k}$ at a marking $\boldsymbol{M}$ if and only if for each $p_i\in\bullet t_j$, we have:

$m_i(h)\geq Pre(p_i,t_j)(h,k)$ for $h=1,\ldots,u_i$.

If an enabled transition fires with respect to colour $b_{j,k}$, then we get a new marking $\boldsymbol{M}'$, where:

$m'_i(h)=m_i(h)+Post(p_i,t_j)(h,k)-Pre(p_i,t_j)(h,k)$ for $h=1,\ldots,u_i$ and for each $p_i\in\bullet t_j\cup t_j\bullet$,
$m'_i(h)=m_i(h)$ otherwise.

Now, to investigate the performance of the system it is convenient to extend the CPN with the time concept. To do this, we introduce a global clock, i.e., the clock values $\tau\in\Re^+$ represent the model continuous time. Moreover, the temporization of Petri nets can be achieved by attaching time either to places, to transitions (Desrochers and Al-Jaar, 1995) or to the expression functions of arcs (Jensen, 1992). Here we choose the second option and we consider timed transitions and immediate transitions. More precisely, the firing time of each transition t_j, namely FT_j, is a positive number specifying the deterministic duration of the firing of t_j. In this method, each token has a time stamp attached to it, in addition to token colours. The time stamp is described by the function s: $Co\rightarrow\Re+$ where $s(c)$ indicates the earliest delay after which the token of colour $c\in Co$ becomes available and can be removed by an enabled transition. Hence, as soon as the c-colour token arrives to the place p_i enabling transition t_j, $s(c)$ is set to FT_j.

Accordingly, after FT_j time instants, the enabled transition t_j becomes ready to fire. If FT_j is equal to zero, the transition is said to be an immediate transition.

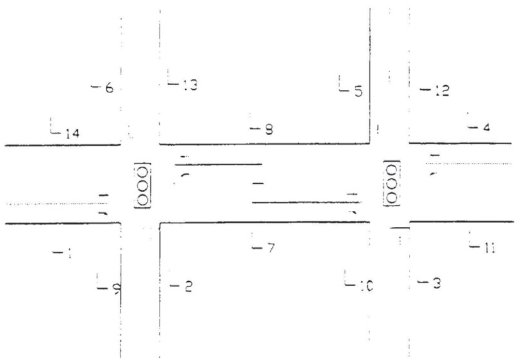

Fig. 1. Example of urban area comprising junctions pertaining to a common semaphoric cycle.

3. MODELLING A SIGNALIZED INTERSECTION AREA

3.1 The traffic network description.

In the proposed TN model, we consider the following fundamental components: signalized intersections, links and vehicles. More precisely, each link represents the space available between two adjacent intersections and may include one or several lanes. Hence, a generic signalized urban area comprises a number of junctions controlled by traffic lights pertaining to a common semaphoric cycle, including a set $L=\{L_i| i=1,...I\}$ of I links (see figure 1). A generic link L_i of length l_i with $i=1,...I$ has a finite capacity $C_i>0$ denoting the number of vehicles that a link can simultaneously accommodate. Hence, each link is divided in C_i cells with unit capacity. We assume that lane changing is allowed only in road.

Moreover, it is necessary to take into account the physical space that a vehicle crossing the intersection occupies. Such a physical space, named intersection cell, can be occupied by only one vehicle and may coincide with the whole intersection area in a very simple intersection or with a part of the physical space in a multi-lane intersection.

3.2 The coloured timed Petri net modelling the urban area.

In our model the CPN=(P, T, Co, H, ***Pre***, ***Post***) describes the TN in a modular representation. The CPN can be divided in two subnets: the first one describes the urban area comprising roads and junctions and the second describes the traffic lights pertaining to the common signal timing plan. Referring to the first subnet, a place $p_i \in P$ denotes a resource, i.e., a cell in a lane or in a crossing section, that a vehicle can acquire. More precisely, we have two types of places: places representing link cells and places corresponding to intersection cells.

In addition, transitions from $T_V \subset T$ model the flow of vehicles into the system between consecutive resources. We consider five types of transitions:

1) input transitions $t_{0,i} \in T_I$, modelling the input of a vehicle in a link from the outside of the considered intersection;

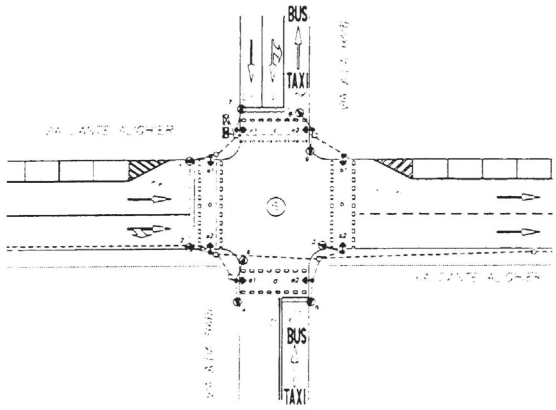

Fig. 2. Layout of a real traffic intersection located in the urban area of Bari, Italy.

2) output transitions $t_{i,0} \in T_O$, modelling the output of a vehicle from a link to the outside of the considered intersection;
3) flow transitions $t_j \in T_F$, modelling the flow of vehicles between two consecutive link cells;
4) intersection transitions $t_j \in T_C$, modelling vehicles entering or leaving a crossing section. The intersection transitions that model a vehicle entering the crossing sections are regulated as a multi-phase traffic light;
5) lane changing intersection transitions $t_j \in T_L$, modelling vehicles that change lane in road.

Transitions belonging to the set $T_V=T_I \cup T_O \cup T_F \cup T_C \cup T_L$ are timed transitions. The value of FT_j assigned to each $t_j \in T_F \cup T_L$ or $t_j \in T_C$ is equal to the average time interval in which a vehicle passes from a cell to the subsequent one or occupies an intersection cell, respectively, and depends on the vehicles speed. Moreover, the value of $t_{0,j} \in T_I$ ($t_{j,0} \in T_O$) is equal to the mean interval times in which vehicles can enter (leave) the system network. Obviously, these parameters can change during different traffic scenarios to model different congestion levels.

A coloured token in a place represents a vehicle. The colour of each token is the routing assigned to each vehicle indicating the different paths that a vehicle can follow starting from a particular position. For instance, with reference to figure 1, in link L_1 vehicles can have three different colours: a_1 if the vehicle has routing (L_1, L_7, L_{11}), a_2 if the vehicle route is (L_1, L_9) and a_3 if the vehicle route is (L_1, L_7, L_{10}). Finally, inhibitor arcs are introduced to model the finite capacities of each resource. More precisely, for each transition $t \in T_F \cup T_C \cup T_L$ and for each $p_i \in t\bullet$, there exists an inhibitor arc between p_i and t, i.e., $H(p_i,t)=1$.

Comparing our model with the model proposed in Di Cesare, *et al.* (1994), we point out that the above assumptions allow us to obtain a concise and modular model, so that the development of the resulting simulation software is inexpensive.

To show the modelling technique, Example 1 describes a real traffic intersection located in the urban area of Bari, Italy, depicted in figure 2. We consider in the example a single junction. However, the modularity of the proposed model allows us to represent several intersections and to connect two consecutive links simply considering the output transitions of the first link coincident with the input transitions of the next link.

Example 1.
The real traffic intersection shown in figure 2 is composed by 6 links L_i (i=1,...,6) with length $l_1=l_4=l_5=l_6$=60m and $l_2=l_3$=40m, respectively. The capacities of the links are $C_1=C_4=C_5=C_6$=12 PCUs (Passenger Car Units) and $C_2=C_3$=8 PCUs, respectively, derived by assuming that one PCU is l_0=5m long. Figure 3 shows the CPN modelling the intersection. Places p_i, p'_i, with i=1,...,9 are a subset of places modelling cell links and places p_i, p'_i with i=10,11,12 model the intersection crossing area composed of six cells. For the sake of simplicity, the figure shows just two places for each lane in an input link and one place for each lane in an output link. Moreover, in this example we suppose that lane changing is not allowed.

With reference to figure 3, transitions $t_{0,1}$, $t_{0,2}$, $t_{0,3}$, $t_{0,4}$ and $t_{0,5}$ are input transitions and transitions $t_{1,0}$, $t_{2,0}$, $t_{3,0}$ and $t_{4,0}$ are output transitions. Transitions t_1, t'_1, t_3, t_6, t'_6 model vehicles entering a crossing section and are controlled by the traffic light Petri net. Vehicles travelling in the intersection are tokens of 6 colours. More precisely, colours a_1 and a_2 are associated with vehicles following the routings (L_1, L_4) and (L_1, L_2), respectively. Moreover, colours a_3, a_4 refer to vehicles following the routings (L_6, L_2) and (L_6, L_4), respectively. Finally, colours a_5, a_6 represent vehicles following the routings (L_3, L_5) and (L_3, L_4), respectively. Referring to the definitions of matrices $\boldsymbol{Post}(p_i,t_j)$ and $\boldsymbol{Pre}(p_i,t_j)$ given in section 2, we show as an example the following matrix entries, obviously the other ones are determined similarly:
$Pre(p'_{10},t'_7)(1,1)=1$ and $Pre(p'_{10},t'_7)(h,k)=0$ for $h,k=2,\dots,6$,
$Post(p'_{11},t'_7)(1,1)=1$ and $Post(p'_{11},t'_2)(h,k)=0$ for $h,k=2,\dots,6$,
$Post(p_7,t_2)(2,2)=1$, $Post(p_7,t_2)(3,3)=1$,
$Pre(p'_{10},t_2)(2,2)=1$, $Pre(p'_{10},t_2)(3,3)=1$,

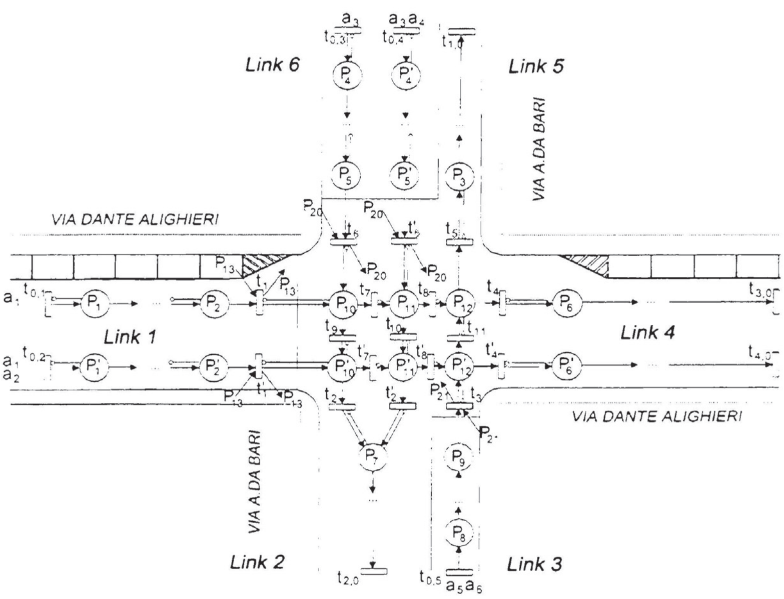

Fig. 3. The CTPN modelling the intersection in figure 2.

Table 1. The firing times of the transitions belonging to the CTPN modelling the intersection in figure 2.

FT_i [s]	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Fixed	Dynamic	Fixed	Dynamic	Fixed	Dynamic	Fixed	Dynamic
				Input transitions				
$FT_{0,1}$	6.7	6.7	5	5	4	/	5	5
$FT_{0,2}$	6.7	6.7	5	5	4	/	5	5
$FT_{0,3}$	6.7	6.7	5	5	4	/	2.9	2.9
$FT_{0,4}$	6.7	6.7	5	5	4	/	2.9	2.9
$FT_{0,5}$	26.7	26.7	20	20	16	/	20	20
				Traffic light transitions				
FT_9	28	32	28	32	28	/	28	49
FT_{10}	4	4	4	4	4	/	4	4
FT_{11}	2	2	2	2	2	/	2	2
FT_{12}	40	36	40	36	40	/	40	19
FT_{13}	4	4	4	4	4	/	4	4
FT_{14}	30	30	30	26	30	/	30	10
FT_{15}	4	4	4	4	4	/	4	4
FT_{16}	0	0	0	0	0	/	0	0
FT_{17}	2	2	2	2	2	/	2	2

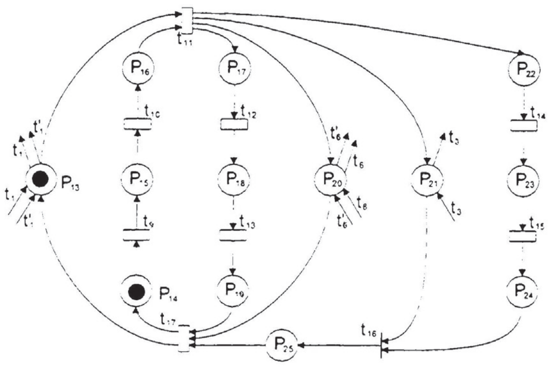

Fig. 4. The ordinary Petri net modelling the traffic light of the intersection in figure 2.

$Pre(p'_{10},t_2)(h,k)=0$ for $h,k=1,4,5,6$,
$Post(p_7,t_2)(h,k)=0$ for $h,k=1,4,5,6$.

The firing times of the input transitions $t_{0,j} \in T_I$ for the CTPN modelling the intersection in figure 2 are reported in Table 1 for four different scenarios, corresponding to different congestion levels (see the sequel for details). In addition, all transitions $t_j \in T_O \cup T_F \cup T_C \cup T_L$ have a firing time $FT_j = l_0/v = 0.45$ s, where $v=40$ km h^{-1} is assumed to be the vehicles average speed in the intersection.

3.3 The coloured timed Petri net modelling the traffic lights.

To model the traffic lights controller we use a formalism presented in the related literature (Di Febbraro, *et al.*, 2002). Since the Petri net modelling the traffic lights is rather simple, neutral colour tokens are considered. Moreover, places represent phases and transitions model the succession of red, yellow and green phases. To show the method to model a generic signal timing plan, we describe the Petri net representing the traffic light of the signalized intersection of Example 1, depicted in figure 4. To control the intersection in figure 2, a three-phase traffic light is used, modelled by three places representing the red, yellow and green phases, respectively. Hence, to model the phases of the cycle, nine places are necessary. In particular, a neutral colour token in place p_{13} enables transitions t_1 and t_1' to rule the vehicles of link 1. Moreover, places p_{14}, p_{15} and p_{16} describe the state of green, yellow and red, respectively. Moreover, the firing times FT_9, FT_{10}, FT_{11} referring to the corresponding transitions are the time intervals of green, yellow and all red (clearance time) of the traffic light of link 1. In a similar way, we describe the traffic light ruling link 6 and modelled by places p_{17}, p_{18}, p_{19} and p_{20} and the traffic light ruling link 3 and modelled by places p_{21}, p_{22}, p_{23} and p_{24}. Finally, the immediate transition t_{16} and place p_{25} are introduced to obtain for the traffic light in link 3 a different phase with respect to link 6, even if they start at the same time.

The start of the semaphoric cycle is with a token in p_{14} and in p_{13} (green for link 1). When the red phase begins for link 1 transition t_{11} fires and the green phases start for links 6 and 3 (tokens in p_{17} and p_{22}). The green phase for link 3 is shorter than the green phase of link 6: a token in p_{25} means that link 3 is in the red phase and link 6 is in the green or yellow phase. When transition t_{17} fires, the cycle begins again.

Finally, the firing times of the transitions for the CTPN modelling the traffic light in figure 4 are reported in Table 1 for the four traffic scenarios described in the sequel.

4. SIMULATION RESULTS

This section presents a simulation study performed for Example 1. The CTPN model of the signalized intersection reported in figure 3 was implemented and simulated in the Matlab environment. Indeed, the simplicity and modularity of the model suggest us to use an efficient software such as Matlab that allows us to simulate systems with a large number of places and transitions. Obviously, the CTPN simulation could be carried out in a generic commercial or freeware tool.

Starting from the initial marking $m_{13}=m_{14}=1$ and $m_i(h)=0$ for each $p_i \in P$ and for each colour $a_{i,h}$, the discrete event simulation program executes the CTPN in a fixed run time. Three simulation experiments are performed, each referring to a different traffic scenario. Each test is conducted for $K=3$ semaphoric cycles, of duration $C=80$s each, for a total run time $T=KC=240$s. In the first three experiments we use the fixed timing plans actually applied to the real intersection and independent from the traffic congestion. Table 1 reports the phases of the traffic light. In particular, the first case simulates under-saturated traffic: one vehicle every 6.7 seconds enters on average links L_1 and L_6 each, and one vehicle every 26.7 seconds enters L_3, respectively (see Table 1). The simulation model generates as an output the number of vehicles leaving each link L_i in the run time and the average number of vehicles queued in link L_i directed to link L_j. Figure 5 shows (light grey) the average number of vehicles queued in each input link L_i (i=1,3,6) and directed to an output link L_j (j=2,4,5). The second experiment simulates a medium congestion traffic condition: one vehicle every 5 seconds enters on average links L_1 and L_6 each, and one vehicle every 20 seconds enters L_3, respectively (see Table 1). Figure 5 (dark grey) reports the average number of vehicles queued in the input links, showing that these are characterized by a medium congestion, with queue sizes higher than those reported for scenario 1. In particular, L_1 and L_6 contain respectively 6.4 and 7.3 vehicles on average, then they are halfway to saturation, being $C_1=C_6=12$ PCUs. Finally, the third experiment simulates over-saturated traffic: one vehicle every 4 seconds enters on average links L_1 and L_6 each, and one vehicle every 16 seconds enters link L_3, respectively (see Table 1). Figure 5 (black) shows the average queue sizes. Now input link L_1 is oversaturated, with 12.5 vehicles on average and $C_1=12$ PCUs, while L_6 is almost saturated, with 10 vehicles on average and $C_6=12$ PCUs. Experimental evidence has proven that the simulation results are consistent with real traffic data in the considered scenarios.

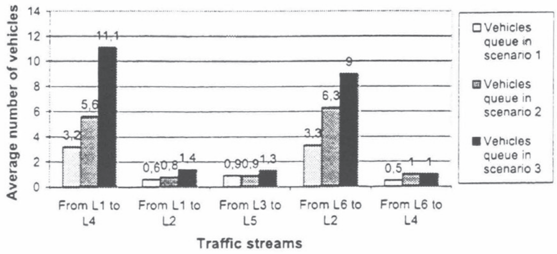

Fig. 5. Simulation results for the intersection under study with traffic scenarios 1, 2 and 3.

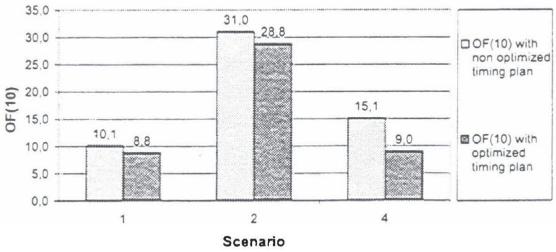

Fig. 6. Simulation results with traffic scenarios 1, 2 and 4 with original and optimized timing plan.

Now, in order to further validate the proposed model, with reference to Example 1, we apply a different signal timing plan obtained by the optimization method proposed in (Barisone, *et al.*, 2002, Dotoli, *et al.*, 2003). More precisely, the green phases of the connected traffic lights are determined dynamically, i.e., on the basis of traffic data, in order to minimize traffic congestion. In fact, the strategy is suited to be applied in an actuated control scheme. The minimized objective function is the following:

$$OF(K) = \sum_{i=\{1,3,6\}} \frac{1}{K}\left[\sum_{k=1}^{K} n_i(k)\right],$$

where $OF(K)$ is measured in K=10 cycles and denotes the average number of vehicles per cycle in the input links. In particular, the optimized signal timing plan differs from the original plan in the green phases allowing flow from L_1 to L_2 and L_4, from L_3 to L_4, from L_6 to L_2 and L_4 respectively. Moreover, Table 1 reports the values of FT_9, FT_{12} and FT_{14} of figure 4 obtained by the optimization method for scenarios 1 and 2 (dynamic).

Figure 6 shows that the simulation computes a lower number of vehicles in the queues if the intersection is controlled with the dynamically-optimized timing plan for K=10 cycles in scenarios 1 and 2. Comparison between the results obtained for the fixed and optimized timing plans under scenario 3 is neglected, since in such a case the TN is oversaturated. However, to stress the benefits of the optimization strategy, we consider a fourth traffic scenario, in which the L_1-L_4 direction is close to saturation and the L_3-L_6 direction is under-saturated (see Table 1 for the corresponding values of the input transitions firing times). Applying the optimization method yields FT_9=49, FT_{14}=10, FT_{12}=19 seconds, prioritizing the congested direction L_1-L_4. The simulation results with the original and optimized timing plans are depicted in figure 6. Clearly, the performance index OF(10) improves considerably controlling the network with the optimized plan. Hence, results show the benefits in applying an actuated traffic control strategy, that is able to modify the traffic lights phases with traffic congestion.

5. CONCLUSIONS

This paper provides a coloured timed Petri net model to describe a traffic network system focusing on real time control via a connected traffic light. The obtained microscopic model is able to give an accurate and valid representation to provide a simulation software not costly to develop. Moreover, the paper presents a real case study where simulation tests the traffic light phases derived by an optimization method proposed in the related literature. Simulation results give a confirmation of the model capability to correctly predict traffic performance measures.

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