

Modeling and Supervisory Control of Urban Traffic Flows in Medium-sized Cities Using Hybrid Approach



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ABSTRACT

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This paper presents an optimal supervisory control technique of urban traffic flows, through a hybrid modeling approach of two phases intersections in medium-sized cities. These last are considered as a multi-agent system, this system is made up of all agents who represent all physical spaces of the urban traffic network. The behaviors of interconnected agents are supervised by Timed Petri Nets that control the traffic light cycles according to an optimal timing plan defined by the Continuous Genetic Algorithm and it can be used to estimate the delay of vehicles. A real intersection in Sidi Bel-Abbes City is presented as an example. The proposed timing plan is compared with the current one using SUMO software for the most important objective functions. Also, the proposed model's behavior is compared with TSIS-CORSIM software's model, and all obtained experiments results show the effectiveness of the approach and its possibility to be extended and applied to a many-phases intersection.

1. INTRODUCTION

The rapid growth in transportation demand within the limited capacity in infrastructures, Urban Traffic Network (UTN) has become one of the significant socio-economic issues in urban city life. Especially during last decades, researchers try to resolve several transportation problems as traffic situation where authors try to assess the traffic situations by the analysis of Annual Average Daily Traffic (AADT) [1], and approximate the traffic of main and secondary roads in the city's UTN, or to predicate the motion of nearby vehicles by observing their motions [2]. Obviously, the big cities are very noisy and congested, but also the problem of road congestion has passed to medium-sized cities, especially after the huge increase in the national park of vehicles in Algeria, and therefore this problem quickly influences on local development of these cities. Several research projects around the world have contributed to finding useful techniques and compatible with the local environment to reduce this problem, however, these techniques remain insufficient to achieve optimal road traffic management.

Recently, some researches propose a new view, the UTN is considered as Hybrid Dynamical System (HDS) [3]. If the traffic network is complex and we study it as a single system, the cycle time of this network becomes unsuitable, for this several kinds of research preferred to divide the networks into sub-networks and each one of them represents a single intersection see. e.g. [4]. If the number of sub-networks increases, in this case we need to determinate more variables and to impose more constraints, therefore the analytical approaches to control single intersections as in the study [5] become not suitable. For this, other proposals have been made

by integrating optimization in the form of heuristic algorithms [6]. Other approaches integrate traffic simulation models in order to get the optimally coordinated timings for intersections [7].

The Multi-Agent System (MAS) has been provided on many applications from robotics engineering to economics and social sciences [8]. MAS consists of interconnected dynamical and autonomous agents, the collaboration between them aims to carry out a complex global task. A representation of UTN systems using MAS is introduced by Chen and Cheng [9], and Guériau et al. [10]. The agents can be regrouped in different teams that cooperate with each other to exploit each other collective products, instead of exploiting individually the skills of agents from each team, this cooperation can help each team to realize or to enhance its own products [11]. MAS has been used also to review existing agent-based modeling of autonomous vehicles with the help of ODD (Overview, Design concepts, and Details) protocol [12]. We can also find in the literature, approaches that apply Petri Nets (PNs) in UTN modeling, simulation, or optimization [13]. The research works presented by Di Febraro et al. [14] use timed and colored PNs to describe UTN, where the token represents the vehicle position. The initial attempts which have used Hybrid Petri Nets (HPNs) model can be found in the study [15]. A Hybrid representation of UTN in a modular way through MAS is presented by Flores-Geronimo et al. [16], and the supervisory control is guaranteed using combined PNs.

It's proved by Mercader et al. [17] that the traffic light control system is one of the most profitable solutions for transportation problems, by improving the policies that control traffic lights. Urban traffic flows can be improved for a considerably lower cost, by minimizing the total delay at the

intersection [18]. We introduce several selected methods optimization-based signal traffic controls for single intersection: Webster method [19], some heuristic or metaheuristic methods [20], differential evolution bacteria foraging algorithm [21], and Genetic algorithm [22]. For this context, this paper is devoted. Moreover, several simulation platforms have been developed recently to evaluate different traffic models and/or control UTN flows, we can cite as an example: TSIS-CORSIM (Traffic Software Integrated System, CORridor SIMulation) [16] AIMSUN and SUMO (Simulation of Urban MObility), etc.

We aim by this work to develop a new competitive simulator, with which we can simulate, control and supervise the flows in intersections, in this paper we are only interested in introducing a new model which can give better results compared to results provided by existing simulators and the most important thing is to have remarkable improvements in the context of the well-known objective functions. Optimization is used to define an efficient timing plan of Timed PN (TPN) that control a two phases intersection taken from UTN of a medium-sized city, the TPN is combined with agents of MAS in a hybrid architecture. Each intersection's physical space is represented by an agent, and the supervision of MAS is assured using the TPN model. This paper addresses the following main contributions:

- The traffic light cycles are defined by the TPN model, with the supervising possibility of these cycles.
- To estimate the delay of vehicles, a new timing plan, different from the current one, is optimized and proposed, using the Continuous Genetic Algorithm, to represent transitions durations of the TPN model.
- The proposed plan is compared with the current one, fixed by the city's municipal authority, on SUMO software under different objective functions.
- The proposed hybrid model is compared with TSIS-CORSIM software's model on Matlab, in order to show the scalability of the approach.

Outline of the paper. Section 2 presents the general definition of TPNs. The physical problem is formulated as the MAS-based model in section 3, the hybrid architecture presentation for urban traffic flows control in a single intersection is introduced in section 4. An example of a real single intersection from a medium-sized city is supplied in section 5. Section 6 presents the timing plan problem and its solution. The obtained experimental results are given in section 7. Finally, future work and conclusions are given in section 8.

2. TIMED PETRI NETS DEFINITION

A TPN is a graph structure defined by the following six-tuple

$$TPN = (P, T, A, w, M_0, \delta) \quad (1)$$

- $P = \{p_1, p_2, \dots, p_n\}$ is a finite set of n Places.
- $T = \{t_1, t_2, \dots, t_m\}$ is a finite set of m Transitions.
- $A: A \subseteq (P \times T) \cup (T \times P)$ is a finite set of arcs; they connect transitions and places.
- $w: A \rightarrow \mathbb{Z}^+$ is the positive integer weights of arcs.
- M_0 is the initial number of tokens in each place p .
- $\delta: T \rightarrow \mathbb{R}^+$ is the finite set of positive numbers τ_i , such as $\tau_i = \delta(t_i)$ is the time delay of transition t_i .

3. PROBLEM FORMULATION IN MAS

Let $\beta = \beta_{st} \cup \beta_{cr} \cup \beta_{so} \cup \beta_{si}$ is the set of agents or physical spaces where the vehicles can be moved or placed in a UTN. $\beta_{st} = \{\beta_{st}^1, \dots, \beta_{st}^n\}$, $\beta_{cr} = \{\beta_{cr}^1, \dots, \beta_{cr}^m\}$ and $\beta_{so} = \{\beta_{so}^1, \dots, \beta_{so}^k\}$ are the sets of n agents representing streets, m agents representing intersections, and set of vehicle sources respectively. $\beta_{si} = \{\beta_{si}^1, \dots, \beta_{si}^s\}$ is the set of vehicle sinks i.e. agents containing vehicles that leave the UTN. These allow us to construct all differential equations, explained below. A real example of a single intersection that illustrates all of these physical spaces is given in Figure 1(a).

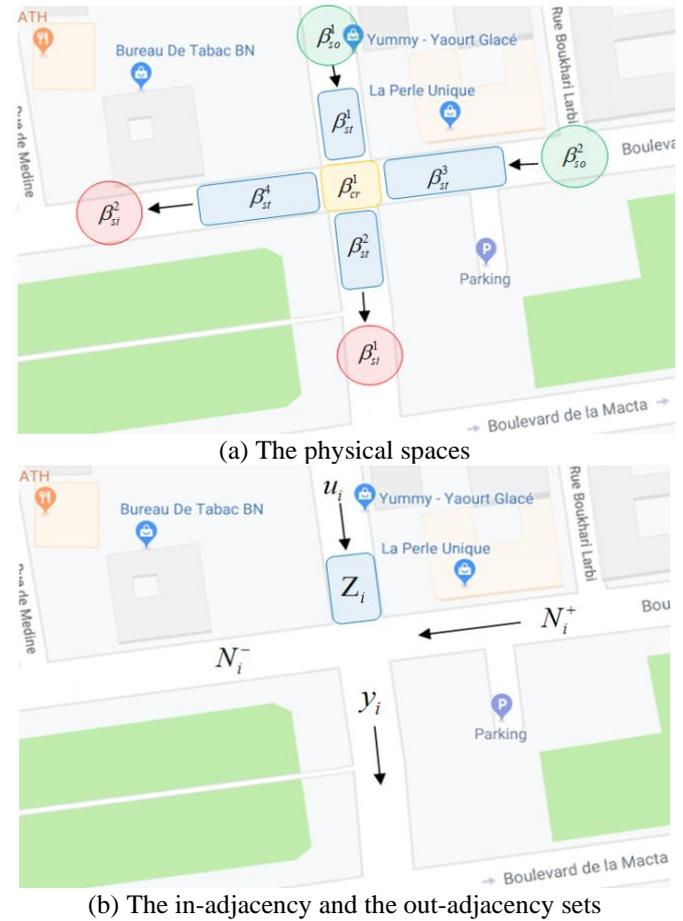


Figure 1. Physical spaces in a real single intersection

Let $N_i^+ \subset \beta$ and $N_i^- \subset \beta$ are the in-adjacency and the out-adjacency sets of β_i (Figure 1(b)), which represent all physical spaces providing and carrying out vehicles to and from $\beta_i \in \beta$ respectively. Streets, intersections, sources, and sinks interconnections are assured using these two sets. $z_i \in \mathbb{R}$ is the number of vehicles in each agent $\beta_i \in \beta$, $\alpha(z_i) \in \mathbb{R}$, $\forall \beta_i \in \beta$ is the vehicle's speed function that represents the inflow and outflow rates according to vehicle density change in each agent. Thus the hybrid model that will allow us to control vehicle density, distribution, and the optimal traffic lights, is consisting of:

- A MAS-based model in the form of differential mathematic equations in a modular way, taking account of the functions set $\alpha(z_i)$ that describes experimental data flows.
 - A TPN set $PN_i, \forall \beta_{cr}^i \in \beta_{cr}$ for traffic light management.
- The supervisory control is guaranteed using the relationships set, between both MAS and TPN models.

4. HYBRID MODEL PRESENTATION

This section gives a modular and mathematical representation of UTN, by developing differential equations set that represent all the agents in the intersection. This will permit to get easier the complex UTN to encompass all intersection variants. According to section 3, each agent could be represented in a modular way by:

$$\dot{z}_i = \sum_{\beta_j \in N_i^+} u_{j,i} - \sum_{\beta_k \in N_i^-} y_{i,k} \quad (2)$$

$$y_{i,k} = a_{i,k}(z_k) \Gamma_{i,k} \alpha_i(z_i) z_i, \quad \forall \beta_k \in N_i^- \quad (3)$$

We put z_i as the vehicle quantity in $\beta_i \in \beta$, $u_{j,i}$ and $y_{i,k}$ are the input flow to agent β_i from $\beta_j \in N_i^+$ and the output flow from β_i to agent $\beta_k \in N_i^-$ respectively. Therefore, and according to Eq. (2), the z_i dynamics are controlled by $u_{j,i}$ and $y_{i,k}$.

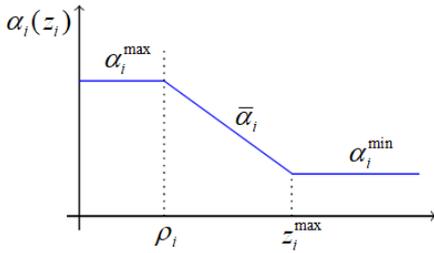


Figure 2. The α_i changes with respect to z_i

From Eq. (3), $\alpha_i(z_i)$ is a function that expresses the vehicles unloading flow (Figure 2), it can be detailed as:

$$\alpha_i(z_i) = \begin{cases} \alpha_i^{\max}, & \text{if } z_i < \rho_i \\ \bar{\alpha}_i, & \text{if } \rho_i < z_i < z_i^{\max} \\ \alpha_i^{\min}, & \text{if } z_i = z_i^{\max} \end{cases} \quad (4)$$

From Figure 2, z_i^{\max} is the vehicles maximum density for each agent, we can define the linear decrease of α_i as:

$$\bar{\alpha}_i = \left(\frac{\alpha_i^{\min} - \alpha_i^{\max}}{z_i^{\max} - \rho_i} \right) (z_i - \rho_i) + \alpha_i^{\max} \quad (5)$$

Each agent represents the physical length of each street, according to a minimum value $\alpha_i^{\min} < \alpha_i^{\max}$. The value of α_i^{\max} depends on the area of the agent β_i . In this case, the increase in the number of vehicles in β_i provokes a decrease in the rate of unloading flow [23]. Also, we define the activation functions $\Gamma_{i,k}$ and $a_{i,j}$ which activate and deactivate the output flows, $\Gamma_{i,k}$ is given by:

$$\Gamma_{i,k} = \begin{cases} c_{i,k} M_k, & \text{if } \beta_k \in \beta_{cr} \\ c_{i,k} M_i, & \text{if } \beta_i \in \beta_{cr} \\ 1, & \text{otherwise} \end{cases} \quad (6)$$

such as $M_k \in \mathbb{R}^{n_k \times 1}$ is the TPN's current marking vector with n_k places that represent the traffic light behaviors for the single intersection β_k , and $c_{i,k} \in \mathbb{R}^{1 \times n_k}$ correspond to the traffic light

cycle of each phase. $\Gamma_{i,k}$ is a linear combination of M_k (i.e. $\Gamma_{i,k} \neq 1$) if traffic light exists and thus a supervised control of agents, otherwise $\Gamma_{i,k} = 1$ i.e. non-controlled flows in this case.

The feedback information is represented by the functions $a_{i,k}(z_k)$ in order to master the output flow of β_i depending on the previous agent behavior $\beta_k \in N_i^-$, $a_{i,k}(z_k)$ is defined as:

$$a_{i,k}(z_k) = \frac{1}{1 + \exp\left(k_e \left(\frac{z_k}{z_k^{\max}} - \xi\right)\right)} \quad (7)$$

such as $k_e, \xi \in \mathbb{R}$. When β_k is filled, $a_{i,k}$ is almost zero, and the $y_{i,k}$ of the previous agent β_i will be stopped.

The flow switching is assured by adding TPN to the MAS-based model in order to ensure the supervised control, according to the scheme shown in Figure 3. Depending on certain traffic light cycles, the functions $\Gamma_{i,j}$ are activated by TPN, and the feedback signals $a_{i,j}$ are transmitted from the MAS-based model. This communication ensures the supervisory control of the single intersection. The traffic light cycle has been defined by applying an optimization method to get the optimal timing plan. The timing optimization problem will be resolved in section 6. A real example of two phases intersection is presented immediately to illustrate the approach.

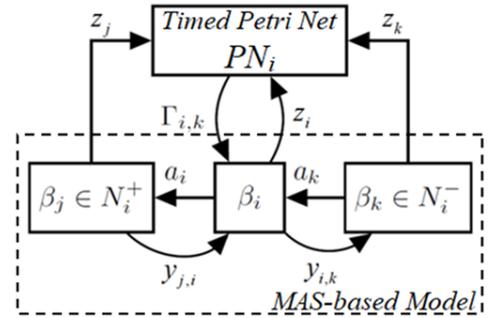


Figure 3. The proposed hybrid approach

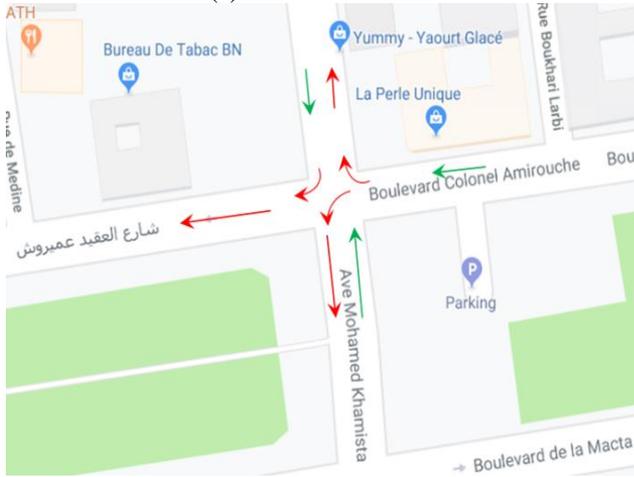
5. CASE STUDY

The MAS-based model for single intersections previously introduced is formalized on a real four road intersection in Sidi Bel-Abbes, as an example of a medium-sized city in Algeria, the signalized intersection of Colonel Amirouch Ave and Mohammed Khmista Ave is depicted in Figure 4. It admits three-vehicle inputs and three-vehicle outputs with two phases of signal control as illustrated in Figure 5. The interconnection and the distribution of agents are detailed in Figure 6 using the equations described in section 4. So that in our case, we have six streets ($n=6$), one intersection ($m=1$), three sources ($k=3$), and three sinks ($s=3$), this means: $\beta_{st} = \{\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6\}$, $\beta_{cr} = \{\beta_7\}$, $\beta_{so} = \{\beta_9, \beta_{11}, \beta_{12}\}$ and $\beta_{si} = \{\beta_8, \beta_{10}, \beta_{13}\}$. A TPN PN_7 is set for this intersection to control traffic light and supervise the MAS-based model. According to the agents' interconnection (Figure 6 (b)), the subsets of input and output flows for an agent β_7 (as an example) can be given by:

$$N_7^+ = \{\beta_1, \beta_3, \beta_5\}, \quad N_7^- = \{\beta_2, \beta_4, \beta_6\} \quad (8)$$



(a) The satellite view



(b) Possible circulation of vehicles

Figure 4. The studied real single intersection

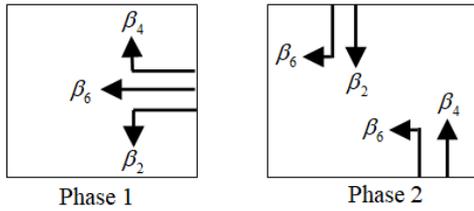
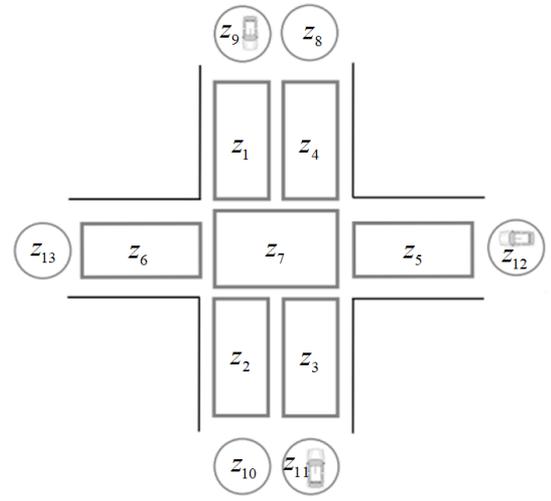


Figure 5. The two phases of the studied intersection

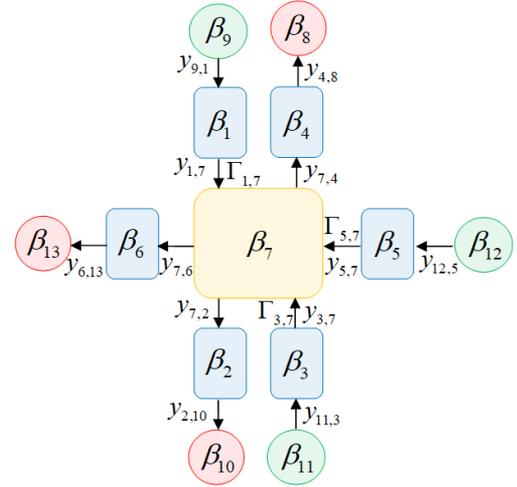
Therefore, outputs y_{ij} become inputs u_{ij} when we are interested in β_j (e.g. $y_{1,7}=u_{1,7}$), thus the equations set of each agent (e.g. β_6 and β_7) is defined bellow, by applying the Eqns. (2) and (3):

$$\beta_6 : \begin{cases} \dot{z}_6 = u_{7,6} - a_{6,13}(z_{13})\Gamma_{6,13}\alpha_6(z_6)z_6 \\ y_{6,13} = a_{6,13}(z_{13})\Gamma_{6,13}\alpha_6(z_6)z_6 \end{cases} \quad (9)$$

$$\beta_7 : \begin{cases} \dot{z}_7 = u_{5,7} + u_{3,7} + u_{1,7} - \alpha_7(z_7)z_7 [a_{7,4}(z_4)\Gamma_{7,4} \\ + a_{7,2}(z_2)\Gamma_{7,2} + a_{7,6}(z_6)\Gamma_{7,6}] \\ y_{7,4} = a_{7,4}(z_4)\Gamma_{7,4}\alpha_7(z_7)z_7 \\ y_{7,2} = a_{7,2}(z_2)\Gamma_{7,2}\alpha_7(z_7)z_7 \\ y_{7,6} = a_{7,6}(z_6)\Gamma_{7,6}\alpha_7(z_7)z_7 \end{cases} \quad (10)$$



(a) All physical spaces



(b) The agents interconnect

Figure 6. The design of the studied intersection

As long as there are no traffic lights, $\Gamma_{9,1}$, $\Gamma_{7,2}$, $\Gamma_{2,10}$, $\Gamma_{11,3}$, $\Gamma_{7,4}$, $\Gamma_{4,8}$, $\Gamma_{12,5}$, $\Gamma_{7,6}$, and $\Gamma_{6,13}$ are always equal to one. The same thing for the saturation functions $a_{4,8}$, $a_{2,10}$ and $a_{6,13}$, they are equal to one at all times since the maximal values z_8^{max} , z_{10}^{max} , z_{13}^{max} are infinite. The TPN (PN₇) that represents the traffic light cycle of each phase is shown in Figure 7. The green, yellow, and red lights are, respectively, represented by the places $\{p_1, p_2, p_3\}$ which control the vehicle flow coming from agent β_1 to β_7 . Also, $\{p_4, p_5, p_6\}$ represent the activation and deactivation of the outgoing flow from agent β_3 to β_7 , while $\{p_7, p_8, p_9\}$ represent the activation and deactivation of the outgoing flow from agent β_5 to β_7 . Note that $M_0 = [1, 0, 0, 1, 0, 0, 0, 0, 1]$ is initial marking of the TPN i.e. $\{p_1, p_4, p_9\}$ have one token, that means:

- 1- The green light is "on", there is a flow coming from β_1 and β_3 to β_7 (phase 2), so $\Gamma_{1,7} = \Gamma_{3,7} = 1$.
- 2- The red light is "on", there is no flow coming from β_5 to β_7 (phase 1), so $\Gamma_{5,7} = 0$.

It's important that the optimal choice of traffic light cycle, which is represented by the set of $\delta(t_i)$, leads to optimal activation of functions $\Gamma_{i,j}$, thus it gives an optimal supervisory control of intersection and allows avoiding congestion. The second problem presented here is an optimization problem, that's why the following section is devoted.

6. TIMING OPTIMIZATION PROBLEM

Firstly, the most used terminology for signal traffic single intersections are given in Table 1, in this work, we assume that "C" is not constant over time and is not prior unknown unlike in the work [22] where the authors consider the cycle length is constant over time and prior known, whether traffic demand. Where this hypothesis is restricted, however, lengths of particular phases (i.e., green times) can change over time; they are the decision variables in our optimal control.

Table 1. The most used terminology for signal traffic single intersections

Notation	Terminology
C	cycle length (sec)
c	capacity rate (veh/sec, or veh/cycle, or veh/h)
d	average delay (sec)
d_{un}	average uniform delay (sec)
d_{ov}	average overflow delay (sec)
g_i	effective green time (sec)
r_i	effective red time (sec)
y_i	effective yellow time (sec)
Td	duration of analysis period in time dependent delay models
x	degree of saturation, $x=(q/S)/(g/c)$, or $x = q/C$
t	time

For this, the delay is minimized according to the following equations of the U. S. Highway Capacity Manual (HCM 2000):

$$\sum_{j=1}^J d_{j,Td} \quad (11)$$

$$d = d_{un} * DF + d_{ov} \quad (12)$$

With:

$$d_{un} = \frac{C(1-g/C)^2}{2(1-xg/C)} \quad (13)$$

$$d_{ov} = 900 flx^2 \left[(x-1) + \sqrt{(x-1)^2 + \frac{mx}{cfl}} \right] \quad (14)$$

where, DF is the delay factor to account for signal coordination and controller type; m is the calibration parameter which depends on the arrival pattern and fl is the flow period in hours ($fl=0.25$ in 1994 HCM). Finally, the timing optimization problem for the model (11) is formulated as follows:

$$\text{Minimize}_{C, g_i, Td} \left(\sum_{i=1, \dots, I}^J d_{j,Td} \right) \quad (15)$$

Such as:

$$\sum_{i=1}^I g_{i,Td} = C \quad (16)$$

With: $g_{i,max} \geq g_{i,Td} \geq g_{i,min}$, $C_{max} \geq C \geq C_{min}$ and $g_{i,max} < C$ Where: $g_{i,min}$ is the minimum green time(s); $g_{i,max}$ is the maximum green time(s); C_{min} is the minimum cycle length time(s); C_{max}

is the maximum cycle length time(s); in equation (12) the function is non-linear and non-convex, that makes it difficult to obtain the best and the global minimums. In our case these minimums are obtained using the Continuous Genetic Algorithm (CGA) [24], it is an adaptation of the Genetic Algorithm (GA) to the continuous optimization problems. Several approaches have been presented in the literature to resolve optimization problems, the traffic flow [25] is optimized by simultaneously controlling the speeds and routes of vehicles, an optimization strategy for the coordination of controlled freeway ramps [26] is presented to guarantee the maximum traffic flow, optimization [27] is used to regulate and govern the course of transport and automated administration and implementation to make a difference in face of travel scenarios in urban cities, four populations of marking individuals [28] are created to find a route in the urban road network, an adequate programming of the traffic light cycles [29] helps to reduce vehicles' waiting time and improve traffic flow...etc.

GA was inspired by the evolution of species in their natural setting in order to provide solutions to problems that do not have solutions that can be calculated in a reasonable time analytically or algorithmically. CGA is the extension of GA for continuous problems, they use real binary coding, almost similar to the Hollands approach. A CGA will evolve a population in order to improve its individuals. The coordinates of each individual are associated with the objective function variables. The convergence criterion of Algorithm 1 is a minimum rate of the duration $d_{j,Td}$ that we want to reach for adapting the population to the posed problem.

CGA allows us to resolve the timing optimization problem, each individual in CGA stands for a timing scheme of the intersection, as, $g_i = \{g_1; g_2; \dots; g_I\}$ in which g_i represents the real green time of phase i in the scheme and it is the variable remaining to be optimized according to general steps of the algorithm presented below.

Algorithm 1: General CGA

```

<< Initialisation >>;
Define cost function, and variables;
Select GA parameters;
Generate initial population;
<<Chromosome_Cost >>, Evaluation of the fitness of each
chromosome in the population;
Select Mates for the reproduction;
Crossover and mutation;
<<Convergence_Check >>.
    if the criteria is satisfied then
        Return the solution;
    else
        Return to <<Chromosome_Cost >>;
    end if
End

```

7. EXPERIMENTS RESULTS

The hybrid model is built on Matlab, and the data are simulated using SUMO and TSIS-CORSIM Software. The real data were collected from the real single intersection (section 5), where the sources $\beta_9, \beta_{11}, \beta_{12} \in \beta_{so}$ provide approximately 700, 953 and 140(veh/h) respectively. The street agents $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6 \in \beta_{st}$ and $\beta_7 \in \beta_{cr}$ are initially empty. The maximum occupancy of vehicles in each

agent $\beta_i \in \beta_{st}$ is defined as $z_1^{max} = 110, z_2^{max} = 46, z_3^{max} = 46, z_4^{max} = 110, z_5^{max} = 17, z_6^{max} = 20$, and $z_7^{max} = 22$, in the case of sources $z_9^{max} = 800, z_{11}^{max} = 1050, z_{12}^{max} = 240$. According to the Current Traffic Signal Control Plan (CTSCP) which is fixed by the municipal authority of Sidi Bel Abbas city, time delays of PN₇ (Figure 7) are given by $\delta(t_1)=35, \delta(t_4)=45, \delta(t_2)=\delta(t_5)=5$ and $\delta(t_3)=\delta(t_6)=5$, so that $g_1=45$ sec and $g_2=35$ sec (green light of phase 1

and phase 2). CTSCP and our Proposed Traffic Signal Control Plan (PTSCP) are simulated using SUMO software. The obtained results are presented in Table 2. Table 3 shows the parameters of the vehicles such as waiting time, loss time, CO₂ and CO emission rate, NO_x nitrogen oxide, and noise under PTSCP and CTSCP. According to Table 3 the results shows that that PTSCP surpasses clearly the CTSCP for all objective functions.

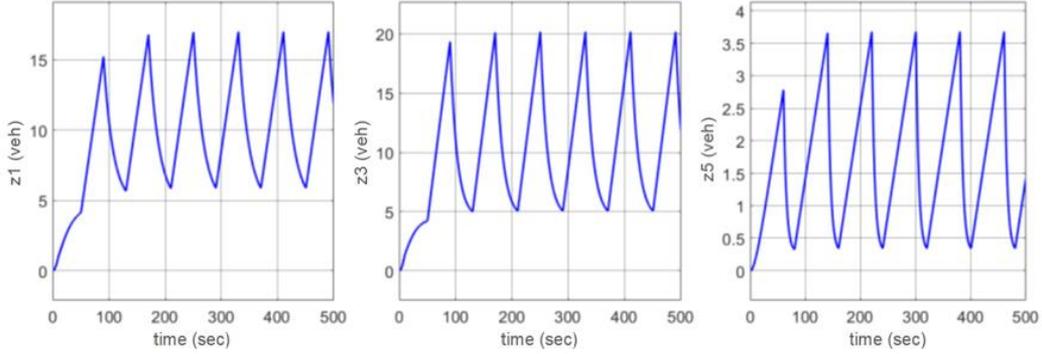


Figure 7. The behavior of agents $\beta_1, \beta_3, \beta_5 \in \beta_{st}$

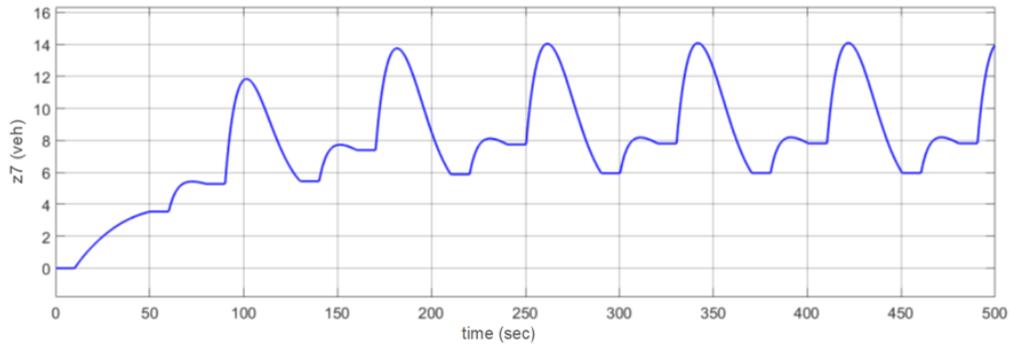


Figure 8. The behavior of the agent $\beta_7 \in \beta_{cr}$

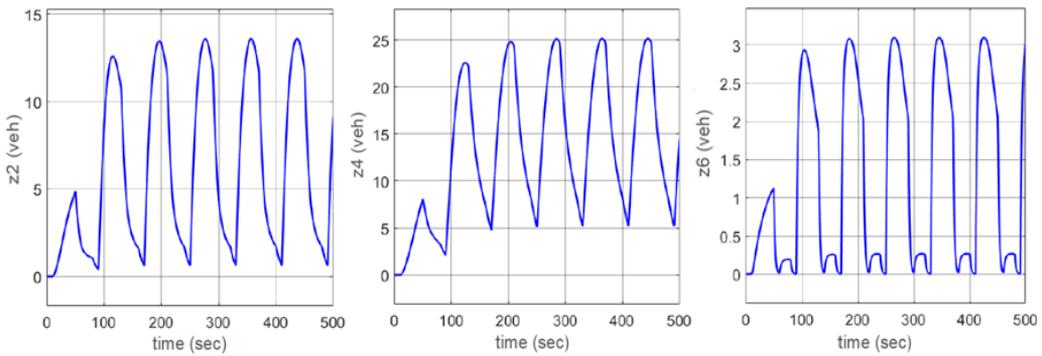


Figure 9. The behavior of agents $\beta_2, \beta_4, \beta_6 \in \beta_{st}$

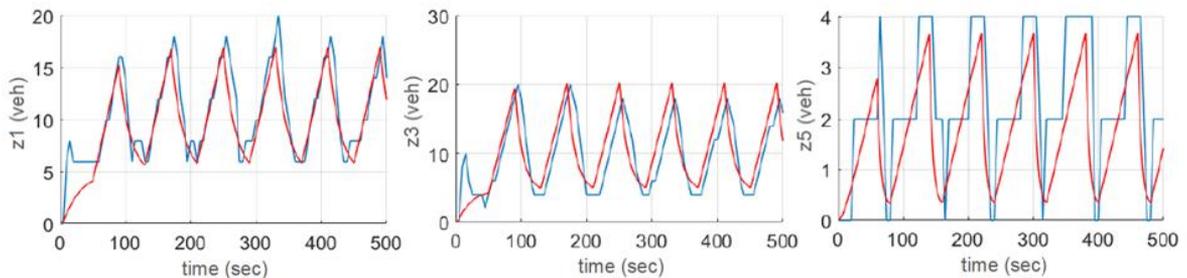


Figure 10. The input flows from $\beta_1, \beta_3, \beta_5 \in \beta_{st}$

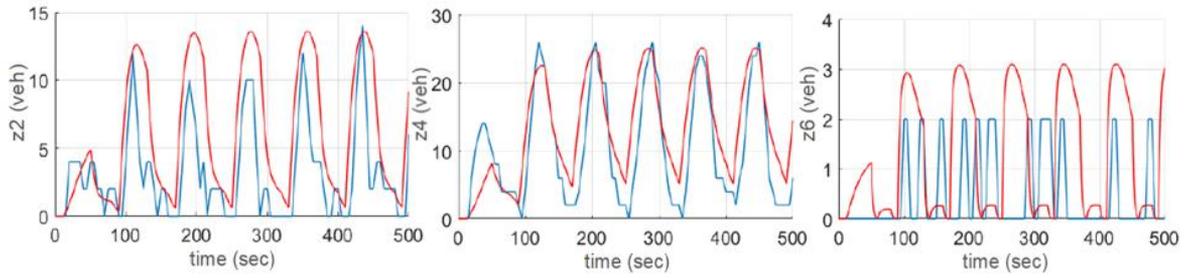


Figure 11. The output flows to $\beta_2, \beta_4, \beta_6 \in \beta_{st}$

Table 2. PTSCP and CTSCP of green lights

Phases	Phases duration (sec)	
	PTSCP	CTSCP
Phase 1	20	35
Phase 2	40	45
Cycle length	60	80

Table 3. Numerical comparison between PTSCP and CTSCP

Objective functions	PTSCP	CTSCP	Improvement (%)
Waiting time (sec)	31	54	42.59
Time loss (sec)	38	85	55.29
CO ₂ (mg/sec)	3986.31	6081.51	34.45
CO (mg/sec)	65	112	41.96
NO _x (mg/sec)	1.79	2.72	34.19
Noise (db)	46.13	49.41	6.63

Figures 7 to 9 present the simulation results of the agent's behaviors obtained from Matlab. Figure 7 describes the number of vehicles changing with respect to time in the street agents $\beta_1, \beta_3, \beta_5 \in \beta_{st}$ i.e. the input flow coming from $\beta_9, \beta_{11}, \beta_{12} \in \beta_{so}$, respectively.

Figures 8 and 9, present the behavior of the intersection agent $\beta_7 \in \beta_{cr}$, and the occupancy of $\beta_2, \beta_4, \beta_6 \in \beta_{st}$ respectively. According to the obtained results shown in these figures, we can observe that all agents β_i do not saturate due to our sequence of PTSCP (Table 2) of traffic lights.

Another simulation of the studied example was carried out to formalize the hybrid approach through the simulation software package, TSIS-CORSIM. The figures below were obtained using the same real data. The input and output flow provided by street agents $\beta_1, \beta_3, \beta_5 \in \beta_{st}$ and $\beta_2, \beta_4, \beta_6 \in \beta_{st}$ of the hybrid-based model approach, are compared with TSIS-CORSIM software's flows and the results are illustrated by red color graph and bleu one respectively in Figure 10 and Figure 11.

8. CONCLUSIONS

We have presented in this paper an optimal supervisory control of a two phases intersection, taken from UTN of a medium-sized city, through the TPN that controls the single intersection. The TPN is combined with agents of MAS in hybrid architecture and it supervises effectively the behavior of the interconnected agents due to the efficient timing plan (PTSCP) of the green lights. The green lights of each intersection phase optimized by CGA give the TPN an optimal performance to control traffic lights and, with a consequence, intersection traffic flows, thus the network flows optimization.

This approach has been applied to a real single intersection chosen from the UTN of Sidi Bel-Abbes city because of its

large capacity of sources, streets, and sinks. The effectiveness and scalability of the approach have been proven through the following two steps:

- The efficacy of the proposed timing plan (PTSCP) defined by CGA has been proven by comparing this plan with the current one (CTSCP) using SUMO software, under different objective functions.
- The results of the proposed hybrid model have been proved similar by comparing with the results of TSIS-CORSIM software model.

Future works include the use of the proposed model on other simulators by comparing all obtained results in the same and/or other medium-sized cities; and the exploitation of the proposed approach to developing a new competitive traffic simulator able to simulate control and supervise complex many-phases intersections in UTN of small and/or big-sized cities.

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