Towards Urban Traffic Regulation Using a Multi-Agent System

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Abstract: This paper proposes a bimodal urban traffic control strategy based on a multi-agent model. We call bimodal traffic a traffic which takes into account private vehicles and public transport vehicles such as buses. The objective of this research is to improve global traffic and reduce the time spent by buses in traffic jams so that buses cope with their schedule. Reducing bus delays is done by studying time length of traffic lights and giving priority to buses, more precisely to buses running late. Regulation is obtained thanks to communication, collaboration and negotiation between the agents of the system. The implementation was done using the JADE platform. We tested our strategy on a small network of six junctions. The first results of the simulation are presented. They show that our MAS control strategy improves both bus traffic and private vehicle traffic, decreases bus delays and improves its regularity compared to a classical s*t*rategy called fixed-time control.

1 INTRODUCTION

To improve route times of public surface transportation (bus, tramways, shuttles, etc.), cities often use regulation systems at junctions that grant priority to vehicles. These systems are referred as Urban Transport Control (UTC) systems. Usually these systems are equipped with bus priority. The aim of these strategies is to increase the average speed of private vehicles as well as public transport vehicles allowed to cross a junction.

The use of these systems is efficient when traffic is light or when they are used to improve a single congested bus route. However, reducing the time of bus journeys, although very important for operating a route, is not the primary factor considered by public transport operators whose obligation is to provide passengers services e.g. keeping interval between buses. To take into account the public transport vehicles specificity, TRSS (Transportation Regulation Support Systems) were developed. TRSS systems follow a micro-regulation based approach i.e. an approach that models the behavior of each bus [1], [2], [7]. One of the weaknesses of these systems is that private vehicle traffic flow is hardly taken into account. If it is taken into account, this is only as an external parameter that modify the route times of buses. Another weakness is that traffic light management which is one of the key factors of traffic jams and bus delays, is not included in TRSS systems

Our objective is to build a traffic control strategy for bi-modal traffic that is able to regulate both private vehicle traffic and public vehicle traffic. Classical control theory used to regulate bi-mode traffic (public and private vehicles) is confronted with the modeling problem. Traffic flow can be modeled at a macroscopic or at a microscopic level. Microscopic modeling, that is modeling the behavior of each bus, is time-consuming, and it is therefore not well adapted to build real time control strategies for wide urban networks. Macroscopic modeling, that is modeling traffic flows, has been used in [4], [5]. In these systems the objective is to reduce the time spent in traffic jams so that buses respect their schedule. However, macroscopic representation of buses does not allow more than an indirect consideration of the intervals. In [12] a hybrid model was used: macroscopic modeling for private vehicles and microscopic modeling for public transport. The complexity of bimodal traffic regulation strategies shows the limits of these classical modeling approaches.

Multi-Agent modeling can be a suitable answer to this problem. We note that multi-agent systems are increasingly present in the field of traffic regulation [1] [2] [10] [11] [13] [14] and [15]. The problem of traffic lights coordination on the thoroughfares of the route network has been studied in [7], [9], [10], [11] and [15]. The regulation system represented in [16] is related to traffic assignment using negotiation between vehicles and junctions. In [7] the authors present agent-based traffic control mechanisms to control both cars and traffic lights. However, these mechanisms do not take into account bus traffic and, a fortiori, control strategies that give priority to buses. None of these systems include bimodal regulation as well as strategies to give priority to buses, on large network where traffic is dense and where macroscopic as well as microscopic regulation has to be taken into account. To answer these shortcomings, we have developed a first prototype that shows promising results [6].

The second section describes our network model. In the third section, the identification of each type of agents is explained. In the fourth section we present the orchestration mechanism between agents and how agent interactions allow modeling the regulation process at a micro and a macro level. A detailed description of agents, their attributes, their objectives, as well as communication and collaboration protocols is given in section five. The sixth section provides the first results of the simulation tests carried out on the Jade platform. Finally, we conclude in the seventh section.

2 Network modeling

In our model, the urban network is represented by an oriented graph G. The set I represents the intersections (or junctions) and the set A represent the arcs that connect the intersections. Two intersections can be connected by one or several arcs depending on the number of lanes on the thoroughfare.

An arc is characterized by two types of information:

- *Static* information: its length *l* (in meters), its capacity *c* (the maximum number of vehicles on arc *i* in private car unit (in pcu)), its saturation output *d* (the maximum output of exits from the given arc (in pcu/second)).
- *Dynamic* information: the number *n* of vehicles on the arc (in pcu), *v* the average speed of the vehicles (in pcu/second), *b* the number of buses and *tf* the time necessary to evacuate the vehicles on the arc.

By private car unit (pcu), we mean that all vehicles on the arc are converted to their equivalent in private vehicles, for example a bus is 2.3 pcu depending on its length, a truck can be 2.3 or 4 pcu and so on.

An intersection is specified by a set of stages. A stage contains a set *E* of entering arcs corresponding to compatible streams of vehicles. These streams are compatible because they can safely cross the intersection simultaneously, else they are called antagonistic. A signal cycle is a repetition of the basic series of signal combinations at an intersection; its duration is called *time cycle*. A stage is a part of the signal cycle, during which one set of streams has right of way. The set of stages represents the configuration of the junction (the permitted movements and turns). Determining the stages is a task executed offline by the traffic experts. In our model, a stage is therefore defined thanks to its states s*t*, its duration *t* and an *index* that gives its priority.

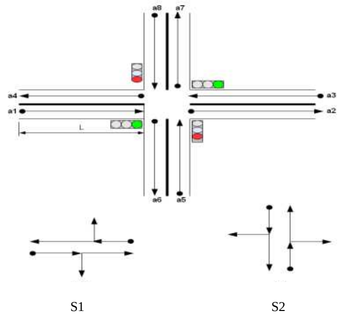
Our model is described in *BNF* notation.

```
G::= <I,A>
I::= {Intersection}
A::={arc}
arc::= <l, c, d, n, v, b, tf>
l::= meter
c::= pcu
d:: pcu/second
n::= pcu
v::= meter/second
b::= integer
tf::=second
Intersection::= {stage}
stage::=<E, st, t, index>
E::={arc}
st::= red| green| orange
t::=second
index::= integer
```

Model 1: Network Data Model.

In order to represent the different features of a network component, we use pointed notation. For example, the number of buses on arc *i* belonging to the stage *sa* is written *sa.i.b*, with $i \in sa.E$.

Fig. 1: Example of an intersection with 4 arcs and two stages S1, S2. S1 allows for the clearing of the arcs a1 and a3, because the entry flow a1 and a3 can leave the junction at the same green light period. Similarly, S2 clears arcs a5 and a8.



The network is used by a number of bus routes. Each bus route is defined as the number of buses from the same origin and in the same direction, and that service a number of predefined commercial bus stops at regular time intervals. The time spent by a bus at a commercial stop is equal to the pre-set time for passengers to mount, plus additional time to regulate the interval, if required.

3. Agent modeling

In order to identify agents and design the MAS, we represent an abstraction of the real system; for every entity of the real world is associated an agent in the virtual world to form a Multi-Agent System (MAS). Homogenous agents are called “agent-type”. Each agent-type is defined in the following way:

```
Agent-type::= <id, pk, behavior, communication>
id::= integer
communication::= send | receive
```

Model 2: agent-type model

pk and *behavior* correspond respectively to agent private knowledge and agent behaviors; their values are defined for each agent type, for example, *pk=<E, st, t, index>* for a Stage agent. Communication primitives enable agents to communicate. The primitive *send* (*receive*) enables an agent to send (to receive) a message. Performatives have the same meaning as FIPA-ACL performatives[1] (see Model 3).

[1] http://www.fipa.org.

```
message::=<performative, content, sender, receiver>
performative::= inform | cfp | propose | request
sender::= integer
receiver::= integer
```

Model 3: Communication model

The developed MAS is made up of the following agent-types:

Intersection Agent (IA): it is the key agent of our architecture. It is in charge of controlling an intersection with traffic lights, and of developing a traffic signal plan. The intersection agent modifies the planning of the lights according to data sent by approaching buses.

Stage Agent (SA): the traffic signal plan is elaborated thanks to the collaboration of the junction and the corresponding stage agents. Each SA determines the optimal green light split to clear the waiting vehicles on the arcs concerned by the stage. Thus, whatever the complexity of the junction is (and its physical configuration), it is managed by a set of stage agents interacting with the junction agent in order to develop a plan of actions for the traffic lights.

```
pk::= <s>
s::= <E, st, t, index>
behavior::= <optimize-stage>
```

Model 4: Stage Agent model

Bus Agent (BA): it represents a bus in the real world. It circulates from one arc (*current*) to another (*next*) and communicates with its Bus Route Agent (id_{BRA}). For each arc, it has the arc description and the id of the related intersection agents (id_{IA}). A bus halts at commercial stops, halts at red lights and obeys the instructions of the bus route agent (behavior *stopRegulation*). The objective of each bus agent is to minimize the time spent at traffic lights in order to minimize journey times (behavior *TrafficLightRegulation*).

```
pk::= <current, next, priority, id_BRA>
current::= <a, id_IA>
next::= <a, id_IA >
a::= arc
id_BRA::= integer
id_IA ::= integer
behavior::= <stopRegulation, trafficLightRegulation>
```

Model 5: Bus Agent model

Bus Route Agent (BRA): bus agents can only provide a local view of their environment, more precisely, only the journey covered by the BA. Thus, local optimization carried out by bus agents can have a negative impact on the route, notably on its regularity (i.e. the formation of bus queues or bus gaps). To tackle this problem, we propose an agent who has a global view of the bus agents on the route, and who can control and modify their behavior in order to guarantee an efficient and regular service.

4. Multi-agent interaction: the traffic regulation process

Before getting on the details of the sequence of actions that follows each agent, we present the orchestration mechanism betweens the agents. The four types of agents that we have defined and their interactions allow the modeling of traffic regulation at a micro level as well as at a macro level. As said in our introduction, few research projects have taken into account and have combined in a same system these two levels of modeling. Figure 2 gives a global view of our proposition:

1. Stage agents are based on a macroscopic modeling of the vehicles because each Stage Agent computes the green time it needs and its index of urgency taking into account global traffic flow expressed in pcu.
2. Bus Agents are based on a microscopic modeling of the vehicles. The interaction between the agents related to buses on the network ensures a micro-regulation process. The Bus Route Agent applies this regulation procedure to each Bus Agent that is late or in advance.
3. The Intersection Agent ensures a *macro-micro* **bimodal** regulation process. It computes the plan of traffic lights according to two criteria: 1) the need of the corresponding Stage Agents, which is based on a *macroscopic modeling* of the global traffic and 2) the priority requests of Bus Agents which are related to a *microscopic modeling* of buses.

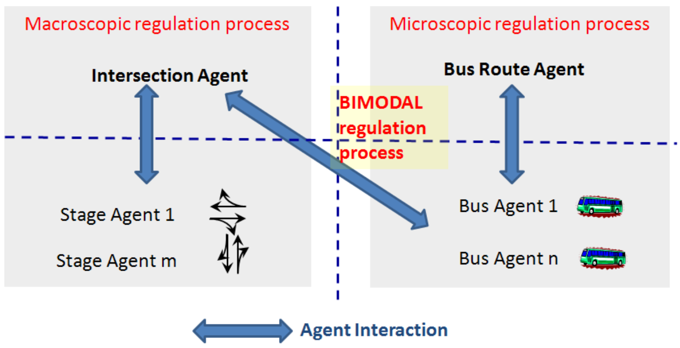


Figure 2: Multi-agent Interaction

5. Description of agent behavior

Bus Agent (BA): In order to minimize the time spent at traffic lights the bus agent interacts with interaction agents and its hierarchical superior agent (BRA). All buses have to provide a regular service and avoid bus queues, in other words, the frequency of buses passing commercial stops must remain stable. To achieve this objective, the BA receives orders from the BRA (for example, stay at the stop for t seconds, if the bus is ahead with respect to the position of the preceding bus).

Behavior of a bus agent: Let t_0 be the entering time of the bus agent which behaves in the following way:

- When approaching a stop, the BA executes the s*topRegulation* behavior (see Algorithm 1). It informs the associated BRA whose identification is id_{BRA}. The bus route agent then calculates the duration of the regulation interval and its level of priority and sends it to the bus agent. Before leaving the stop, the bus must wait during passenger loading time, as well as during the potential regulation time (not taken into account in the algorithm).

```
stopRegulation::=
 m:message
 send(query, "priority", id, next.id_bra)
 m =receive(inform, next.id_bra)
 priority = m.content
```

Algorithm 1: Bus Agent StopRegulation algorithm

- When approaching a traffic light, the BA executes the *trafficLightRegulation* behavior (see Algorithm 2) It sends a message to retrieve information from the arc (the number of vehicles that precede it, the length, capacity, and exit output of the arc).

With these data, the BA calculates a time-space request that is transmitted to the IA whose identification is id_{IA} in order to prevent an eventual stop at the red light at the following intersection. The IA then attempts to satisfy the demand (see intersection agent below);

Calculation of a green light request. This calculation is specified by the interval of time during which the green light is granted to the actual arc so that the bus can pass without stopping at the next junction. Let t_b be the beginning time and $t_e = t_b + \delta t$ be the ending time of the requested interval (δt is a constant value in seconds). The calculation of t_b is carried out as follows: the bus enters the arc and finds in the worst case *n* vehicles ahead of it, the vehicles move to the traffic lights lane to wait for the green light; the time to evacuate it is *tf*. In order to continue along its route, the queue of vehicles has to be dispersed before it arrives. The green light should thus be granted at the arc at the time: $t_b = t_0 + l/v - tf$.

The requested interval together with other information (id-number of the bus, its priority, the actual arc of the bus, the next arc to be traveled by the bus) are sent to the IA (at the next intersection) who attempts to modify the plan for the lights to satisfy the request. The algorithm 2[2] below gives the exact behavior.

```
trafficLightRegulation::=
 m: message, a: arc
 send(query, current.a, id, id_IA)
 m =receive(inform, id_IA)
 a = m.content
 t_b= t_0 + (a.l/ a.v) – a.tf
 send(request,
     <ba.id, [t_b,t_b+δt],current.a, next.a, priority>,
     ba.id, next.id_IA)
```

Algorithm 2: Bus Agent trafficLightRegulation algorithm

Intersection Agent (IA): The IA is the key agent of our architecture. The IA supervises the group of stage agents (SA) who collaborate together *to establish a plan for traffic lights*. This plan will, on one hand, maximize the capacity of the junction and, on the other hand, attempt to satisfy, as far as possible, the requested interval of buses. The IA use the static and dynamic data (Model 6).

Static data are the maximum value of the traffic light cycle (*TCMAX* = 120 seconds). For each cycle, there is an interval of lost time i.e. the period of orange or all red. The all red light is a period during which all the arcs from the same junction have a red light in order to clear the centre of the junction and thus prevent accidents. This fixed period, in conformity with the architecture of the junction, does not depend on the length of the cycle. It is fixed here to a two second period after each stage.

D*ynamic data* are the list of received requested data from Bus agents (see Algorithm 2) that have been processed in order to find the useful information for the *Macro-regulation* behavior and the data related to the stages. Each request is specified as follows: $R = <s, t_b, t_e, priority>$, where *s* is the stage that will allow the passage of the given bus, t_b the time when the bus is expected to arrive at the traffic light, t_e, the time when the rear of the bus leaves the arc, and finally *priority* is the level of bus priority defined by the bus route agent (see section below on

[2] Remember that the variables are written with pointed notation. For example `m.content` means the content of message `m`, `ba.id` means the id of bus agent `ba`, `a.l` means the length of arc a.

BRA). Each stage is defined by id_{SA} related to the intersection, its priority (*priority*) and the minimum time to evacuate the axes (*t*).

```
pk::= <S, TCMAX, R>
S={<priority, t, id_SA>}
priority::=integer
t::=second
id_SA::=integer
TCMAX::= second
R::={<sa, t_b, t_e, priority>}
sa::= stage
t_b::= second
t_e::= second
priority ::= integer
behavior::= <macro-regulation>
```

Model 6: Intersection Agent model

At the end of each cycle, the IA triggers the process of calculating the traffic signal plan for the given cycle. This plan determines the duration of the green light and the ranking of each stage. When the IA receives a request, it records it in the database. The IA then decides to accept or to refuse this request at time t_b. The modification of a traffic signal plan following a priority request by a bus is as follows: 1) Extension of a stage (delay or advance), without exceeding the maximal duration of a stage; 2) Introduction of a new stage into the plan.

Calculation of a traffic signal plan. The plan (*Plan*) is calculated through the collaboration of the Intersection agent (IA) and the corresponding Stage Agents (SAs). The IA plays the role of a manager in supervising the SAs that act as participants (see Algorithm 3).

The IA begins by forming a group of collaborators called *collab_group* including the list of stage agents that needs to be managed. IA initializes the variable *tc* that controls the size of the calculated cycle. IA sends a message *request* to the agents of the *collab_group* asking them for the time necessary to clear all the vehicles from their stages, beginning at instant *t*. Every agent of the *collab_group* calculates its desired green light duration and an index that measures the urgency of the stage. It sends these data to the manager (to simplify we suppose that the communication is synchronous) that updates its knowledge about this agent using the `update(sa, response.content)` procedure and the value of the duration of the proposed cycle (`d = d + sa.t))`.

When all the agents of *collab_group* have been updated, if $d > tc$ then the manager has to solve a conflict using the `conflict-resolution(collab-group, tc)` procedure since the size of the cycle exceeds the maximum size. Conflict is solved when *d* previously calculated becomes less or equal to *tc*. The manager selects the most urgent stage (`sa = argMax(priority, col-`

lab_group)). It sends an *accept* message to the stage agent in charge of operating this stage; It withdraws the corresponding stage agent from *collab_group*; It updates the variables *tc*, *t* and *Plan* (*update(Plan, sa)*); finally IA sends a request as long as *collab_group* is not empty.

```
Macro-regulation::=
  Plan = {}
  collab-group= S
  tc = TCMAX
  t= 0
  Repeat {
   d = 0
   For each (sa ∈ collab-group){
    send(request, <update, t>, id, sa.idSA).
    response = receive(propose, sa.idSA)
    update(sa, response.content)
    d = d + sa.t
   }
   while (d > tc)
    conflict-resolution(collab-group, tc)
   sa = argMax(priority, collab_group)
   send(accept,"timeValue", id, sa.idSA)
   tc = tc – sa.t
   t = t + sa.t
   update(Plan, sa)
   collab-group = collab-group – {sa}
until(size(collab-group) = 0)
Return Plan
```

Algorithm 3: Computation of a plan of lights

Conflict resolution. When the sum of green light durations requested by stage agents exceeds the size of the accepted value of the cycle, the IA must restore this sum to the maximal value of the cycle. To achieve a Δt reduction, the IA negotiates with the corresponding SAs using a Contract Net Protocol. The cost c of the offer is the number of buses penalized if the stage agent reduces its duration of Δt, i.e. the number of buses that cannot pass through the intersection during Δt.

Stage Agent (SA): This agent has a collection of both static and dynamic data as described in Model 1: Network Data Model. They represent its internal state. *Static data* are the list of entry arcs, the list of arcs authorized to clear if the stage is active (or green)

Dynamic data are related to 1) the state of the stage: active or inactive; 2) the duration of green light attributed to the stage; 3) the starting time of stage execution. ‘Active’ means that traffic lights controlling the arcs related to this stage are green. Vehicles are therefore authorized to depart.

Behavior of the stage agent. The SA participates to the calculation of the traffic signal plan, and is in charge of fixing the optimal duration of green light for the given stage. When the stage agent is asked about the desired duration of green light by the corresponding intersection agent, the duration d_i and an index I_i that measures the urgency of the stage, are computed and transmitted to the intersection agent. If the stage agent receives confirmation from the IA, the stage agent stops the process. If the stage agent receives a *cfp (call for propose)* with a cost c, it computes an offer and sends it to the IA.

Calculation of the desired duration of the green light

The optimal duration of green light is computed by the following formula:

$$T = \max_{i=1,\dots,m}\{T_i\} \qquad T_i = w_i \frac{\mathrm{N_i}}{\mathrm{D_i}} + (1-w_i).\frac{\mathrm{N_i} * \mathrm{L_i}}{\mathrm{C_i} * \mathrm{V_i}}$$

where $m=|E|$ is the number of entering arcs at the stage, t_i the time necessary to clear arc i, l_i the length (in meter) of arc i, v_i the average speed (in meter/second) on arc i, n_i the number of vehicles expressed in private car unit (pcu) and d_i the saturation of arc i.(pcu/h). The first part of the equation T_i expresses the time needed to evacuate the already formed queue at the traffic light and the second term expresses the time needed to evacuate vehicles entering the arc after the beginning of the green, assuming that they arrive at regular intervals

The optimal duration of green light is computed by the behavior *optimize-stage* (see Algorithm 4). Its value is the maximum duration to evacuate an arc of the stage.

To award priority to a bus, the urgency index of a stage is defined by the fact that the higher the index, the greater the urgency of the stage. $w_i = n_i/c_i \in [0,1]$ is a parameter that indicates the degree of congestion of the arc i and e is the Euler constant. When the arc is congested, its value is 1, which means that only the first part of the equation is used

$$I_j = \sum_{i \in E} (e^{w_i} + e^{b_i})$$

We can note that if there are several buses on arc a (if $b_i > 1$), the term e^{wi} dominant and therefore gives priority to stages with buses; if $b_i = 0$, the degree of congestion is then taken into account.

```
optimize-stage::=
tp ← 0
index ← 0
```

```
For each (i ∈ s.E)
   w_i = i.n/i.c
  t_i = (i.n/i.d) + ((i.n * i.l)/(i.c*i.v))
  index = index + (e^wi + e^i.b)
  if (t_i > t_p)
    t_p = t_i
End For
stage.index = index
send(propose,<t_p,index>, id, id_IA>
```

Algorithm 4: Optimization of a stage

Bus Route Agent (BRA).The role of the *BRA* is to supervise bus agents so as to prevent a local level regulation and the creation of bus queues. In other words, this agent can modify the behavior of bus agents in two different ways: 1) *directly*: by keeping those buses which are ahead in the plan compared to the preceding ones, at the bus stop for a certain period of time; 2) *indirectly*: by modifying bus priorities. This agent has a *global* view of the route it operates on, and can therefore detects bus queues and react to prevent queue formation.

Internal state of the route agent. The route agent encompasses the following data: 1) the set of arcs traveled by the bus on its route; 2) The set of stops on the route: for each stop, its position, and the distance separating it from the next stop; 3) The set of buses on the route; 4) The frequency of buses introduced onto the route. For two consecutive stops A_i and A_j, the route agent maintains the journey time $d_{i,j}$ of the last bus. This helps to follow the bus journey and to calculate whether the bus is ahead or late compared to the bus immediately preceding it.

Behavior of the route agent. When a bus agent moves to a stop, the time t taken to cover the distance $L_{i,i-1}$ that separates the two stops A_i and A_{i-1}, is transmitted to the route agent. The route agent then compares t to the time ($d_{i,j}$) taken by the preceding bus and consequently decides whether the bus is ahead or late. The route agent computes the new priority of the bus agent as well as the length of time the bus should wait at the commercial stop if it is ahead [6].

6. Experimentation and results

To test our bimodal control strategy, we have developed a Multi-Agent System prototype on the JADE[3] platform (Java Agent Development Framework). JADE offers Java middleware with the overall aim to provide a runtime support for agents.

[3] jade.tilab.com/

We have tested the strategy on a small network of six intersections (Figure 3):

- The distance between two adjacent junctions belongs to [200,400] meters.
- Each section comprises one or two lanes.
- The saturation flow, which is the maximum exit output of the arcs, is identical for each arc and equal 0.5 vehicle/second.
- At each entry onto the network, we have installed a source that generates private vehicles at a frequency F∈ [4 s ... 10 s].
- Some of the junctions have two stages while others have three stages.
- Two bus routes are considered on the network BR_1 and BR_2. On BR_1, the frequency of generated buses is 80 seconds and it is 180 seconds on BR_2.

We have compared the developed MAS strategy with bus priority to a fixed time strategy (same duration for all stages) with 30 seconds for each stage. We have run the simulation with these two strategies and for half-hour simulation time.

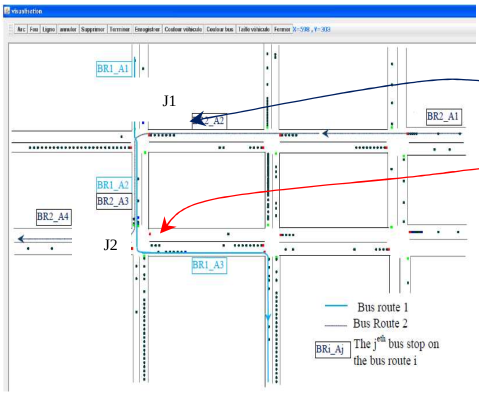


Fig. 3 The simulated network

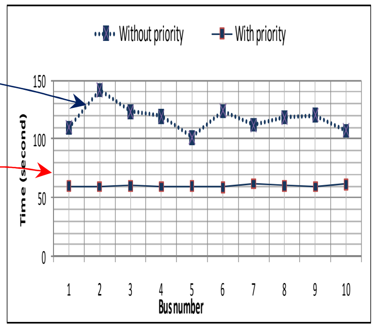


Fig. 4 Bus travel time with and without bus priority

Figure 4 depicts bus travel time: the higher curve shows bus travel time between the stops BR1_A1 and BR1_A2 when buses do not request priority at junction J1; the lowest curve show buses travel time between the two bus stops BR1_A2 and BR1_A3 when buses are asking for priority at junction J2. We can note that bus travel time improves from a mean of 120s to a mean of 60s and becomes more regular (flat curve) when bus priority is taken into account.

Figure 5 gives the results of the two strategies for very heavy traffic conditions: Figure 5.a shows the recorded delays for buses with the two control strategies and figure 5.b shows the same kinds of curves for private vehicles.

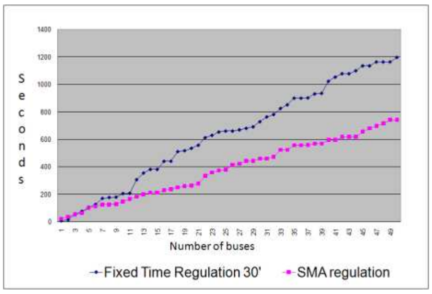


Fig. 5.a: Bus cumulated delays

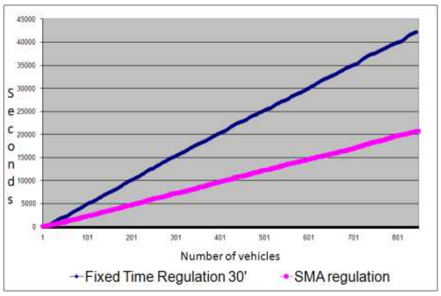


Fig. 5.b Private vehicle cumulated delays

These delays correspond to the sum of time lost by all buses (resp. private vehicles) when they stop at traffic lights. As shown in figures 5, the MAS strategy improves both traffic of buses and traffic of private vehicles. As we can see, there is a decrease of 38% on lost time spent by buses on traffic light; for the private vehicles, we got a decrease of about 51%. These results can be explained because giving priority to buses decreases traffic jams thus improving private vehicles traffic. These results should be studied in more details: to what point these results are still valid in heavy traffic. It would be interesting to find Pareto front and multi-criteria optimization of total traffic delays and public transport delays.

7. Conclusion

In this paper, we have developed a bimodal traffic control strategy based on a multi-agent system. Unlike other approaches, our model takes into account both public transport vehicles such as buses and private vehicle traffic and studies the regulation in a whole network. The objective of this research was to improve global traffic, to reduce bus delays and to improve bus regularity in congested areas (keeping regular interval between buses) of the network. We have shown that an agent-based model is well adapted to study complex traffic regulation strategies. In our model, the entities representing the urban network communicate among themselves and negotiate in order to solve traffic regulating problems. First, we have shown that classical methods of control systems of traffic regulation present several weaknesses: at a macroscopic level, they do not take into account mixed traffic and do not allow for the regulation of intervals between buses. Furthermore, computation at a microscopic level is time-consuming, especially for regulating large networks. Secondly, we have presented the multi-agent strategy that computes traffic signal plans based on the actual traffic situation and on priority needed by buses. Priority is given to those buses that do not deteriorate the intervals between the vehicles on the same route. Thirdly, we ran a simulation prototype on the JADE platform. A comparison between bus travel time with and without bus priority shows the capacity of the priority method we have developed to improve both travel time and regularity of buses. Our results also show that this bimodal MAS strategy improves conditions of global traffic and reduces bus delays. Additional work however is needed: a more realistic network should be defined in the simulation run and more validation and more testing should be undertaken with the definition of several indicators.

REFERENCES

1. Balbo, F., Pinson, S., 2010. "Using intelligent agents for Transportation Regulation Support System design", Transportation Research Part C: Emerging Technologies, Volume 18 (1), pp 140-156.
2. Balbo, F., Pinson, S., 2010. "Dynamic modeling of a disturbance in a multi-agent system for traffic regulation", Decision Support Systems 41(1), pp 131-146
3. Ana L. Bazzan. 2009. Opportunities for multiagent systems and multiagent reinforcement learning in traffic control, Autonomous Agents and Multi-Agent Systems 18 (3), pp 342-375.
4. Bhouri, N., 2009. Constrained Optimal Control strategy for multimodal urban traffic network. IFAC Workshop on Control Applications of Optimization (CAO'09), Finland.
5. Bhouri, N., Lotito P., 2005. "An intermodal traffic control strategy for private vehicle and public transport". 10th Euro Working Group on Transportation, Poznan, Poland.
6. Bhouri, N., Haciane S., Balbo F., 2010. "A Multi-Agent System to Regulate Urban Traffic: Private Vehicles and Public Transport". Int. IEEE–ITSC'10, Portugal, pp. 1575-1581.
7. Camurri M., Mamei M., and Zambonelli F., 2006. "Urban Traffic Control with Co-Fields". Series Lecture Notes in Artificial Intelligence. V. 4389. Eds. Weyns D., Parunak H.V.D., and Michel F. Springer, pp 239–253.
8. Cazenave T., Balbo F., Pinson S., 2009. "Monte-Carlo Bus Regulation", Int. IEEE-ITSC'09, St. Louis, MO, USA, pp. 340-345.
9. De Oliveira D, Bazzan A.L., Lesser V, 2005. "Using Cooperative Mediation to Coordinate Traffic Lights: a case study", AAMAS'05, New York, NY, USA, pp 463-470.
10. Ferreira, E.D., Subrahmanian, E., Manstetten, D., 2001. "Intelligent agents in decentralized traffic control". Int. IEEE-ITSC'01, Oakland (CA), USA, pp. 705-709.
11. France, J., Ghorbani, A., 2003. "A multiagent system for optimizing urban traffic". Int. IEEE/WIC. Washington DC, pp. 411–414
12. Kachroudi, S. and Bhouri N., 2009. "A multimodal traffic responsive strategy using particle swarm optimization", 12th IFAC Symposium, Redondo Beach, Ca., USA.
13. Mailler R. and Lesser V, 2004. "Solving distributed constraint optimization problems using cooperative mediation", AAMAS'04, IEEE Computer Society, pp 438-445
14. Mizuno, K., Y. Fukui and S. Nishihara, 2008. "Urban Traffic Signal Control Based on Distributed Constraint Satisfaction", Proceedings of the 41st International Conference on System Sciences. Hawaii, pp 65.
15. Roozemond D. A., 2001. "Using intelligent agents for pro-active, real-time urban intersection control", European Journal for Operational Research 131, pp 293-301.
16. Vasirani, M., Ossowski, S. , 2009. "A market-inspired approach to reservation-based urban road traffic management". AAMAS'09, volume 1, pp 617-624.