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TRAFFIC CONTROL AT INTERSECTIONS USING ARTIFICIAL IMMUNE SYSTEM APPROACH

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ABSTRACT: *Transportation has greater importance in our daily life and plays an important role in the development of countries and societies. Following the increasing size of cities and the number of cars, many phenomena of traffic congestion, especially at intersections are observed and generate direct and indirect costs.*

Although several graphical models, artificial intelligence approaches and metaheuristics have been developed in order to improve the traffic situations at intersections, we noticed that a limited number of researches reporting the use of AIS for this case. Hence AIS is relatively a new paradigm which applies biological immune mechanisms and actors to solve world problems. We develop in this paper a methodological approach for microscopic modeling of traffic at intersections using Artificial Immune System metaphors to detect and control anomalous traffic conditions. Simulation results show the pertinence of the AIS approach.

KEYWORDS: *road traffic control, intersections, biological immune system, artificial immune system.*

1 INTRODUCTION

Intersection plays an important role in the road network. It is defined by the SETRA (SETRA, 1996) as an area of exchange between several roads allowing vehicles to move from one to another. The traffic in signalized intersections is regulated by traffic lights piloted by the controllers. Following the increase of the numbers of cars and of the volume of traffic flow, intersections become the bottleneck of the network and the major source of traffic congestion. Thus, it's significant to study traffic flow at signalized intersections to relieve the congestion situations. The constructions of new infrastructure cannot be the right solution to such problem because it requires a large space and investments. So it it's necessary to optimize the use of existing infrastructure by setting techniques providing traffic control actions.

Several approaches and algorithms have been developed focusing on the regulation of traffic at intersection in order to improve flow of vehicles, to minimize the latency average and to guarantee the drivers safety.

The Artificial Immune System is a young emerging approach which borrows metaphors from natural immune system to solve world problem. This approach can operate in the field of optimization of the transport system.

The purpose of this paper is to regulate traffic at intersections equipped with traffic lights. The potential of biological immunity is explored to inspire properties and mechanisms able to improve traffic flow and to reduce the average latency. For this case, an Artificial Immune System algorithm is proposed.

This paper is organized as follow: Section 2 presents the state of the art of traffic control at intersections. In section 3, an overview of biological immune system is presented. Section 4 shows the application of principles of artificial immune system in order to tackle congestion situations at signalized intersections. In section 5, we conclude the work and we suggest some perspectives.

2 TRAFFIC LIGHT CONTROL: A STATE OF THE ART

The regulation of vehicle traffic flow is a complex task that has been the subject of several works in which authors are faced with several choices that depend mainly on the type of traffic and on objectives. These choices are related to the level of detail to be adopted and to the approach which seems the most appropriate for solving the problem.

According to the level of detail, traffic models may be classified into three types: microscopic models, macroscopic models and mesoscopic models.

Microscopic modeling of traffic system describes the behavior of system's entities as well as their interactions at a high level of detail (Hoogendoorn and Bovy, 2001). A less common model is Mesoscopic one which is located at the intermediate level between microscopic models and macroscopic models. This approach focuses on packets of vehicles characterized by the same properties which activities and interactions are described at an average level of detail (Iodanova, 2006). The movements of packets are modeled with macroscopic rules.

Finally, the macroscopic models describe traffic in a global way with a high level of aggregation and a reduced level of detail (Buisson, 1997). In this type of study, the interactions that occur between vehicles and turbulent personal vehicles are not taken into account.

When the modeler chooses the model that meets the application requirements, it will be forced to choose one or more of combined approaches allowing solving the problem.

Several regulation systems were proposed based on different approaches that aim at maximizing the flow of vehicles and minimizing the average latency.

For example, (Pappas and Mamdani, 1997) and (Liu and al., 1999) in their work have used fuzzy logic for traffic at an intersection. As for (Henn, 2001), he used fuzzy logic to model the traffic assignment and take into account the effects of the dissemination of traffic information to drivers. In (Fan and Liu, 2008), a fuzzy controller is proposed to link the length of a line of vehicles Δl and the duration of green light Δg at an intersection.

(Bomarius, 1992) proposed a multi-agent approach in order to model the urban traffic at intersections. His model is composed of three types of agents: "vehicles", "traffic light" (4 lights in an intersection) and "car". These agents cooperate and communicate with each other in order to minimize the waiting time of vehicles. (Ketata, 2007) was also simulated traffic system by adopting a multi-agent approach which aims is to ensure traffic flow and find solutions for complex deadlock.

Some approaches derived from biological systems have been used in this context. For example, (Ceylan and Bell, 2004) applied the genetic algorithm approach to solve traffic signal control and to optimize signal timing. (Chen et al., 2007) used the algorithm of ant colony for the development of intelligent transport and traffic control at an intersection. In the work of (Wei et al., 2008), the Ant Colony approach is combined with fuzzy logic in order to control traffic lights. (Negi, 2006), as part of his thesis, applied the artificial immune system approach to optimize urban traffic problems. This new paradigm has enabled it to detect, predict and optimize the flow of traffic.

There are also various works that have used the approach of neural network whose goal is to design intelligent controller's intersections (Pappas and Mamdani, 1997, Liu et al., 1999).

(Fan and Li, 2005, Fan, and Liu, 2008) combined fuzzy logic with the neural approach to determine the traffic light plans.

This paper tries to explain how the metaphor inspired from the biological immune system is adapted in order to tackle traffic problems at signalized intersections and to improve the situation.

3 OVERVIEW OF THE BIOLOGICAL IMMUNE SYSTEM

The biological immune system is a robust complex system. Its primary function is to protect human bodies from foreign pathogens such as viruses, bacteria, and other parasites. It is able to distinguish between items that belong to the body (self) and those that are foreign (non-self). The recognition of an antigen is provided by lymphocytes that are mainly classified into two types (T-lymphocytes and B-lymphocytes). B-cells produce antibodies (Ab) in response to an antigen. Each B-cell can only produce one particular antibody. On the other hand, T-cells induce the B-cells to produce antibodies .Each antibody is able to identify antigens because its surface is covered with receptors called paratope. The paratope binds to a specific part of the antigen called epitope. The link between a paratope and an epitope is even stronger than their shapes which are complementary (figure1). The strength of this connection is called affinity (Chabane, 2009).

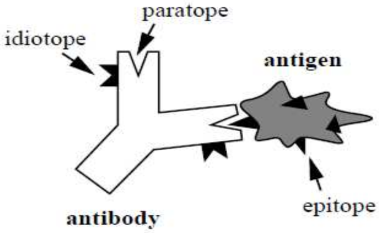


Figure 1: The affinity between an antibody and an antigen (De Castro and Timmis, 2002)

There are two basic types of immunity that fight to protect the organism: innate immune system and the adaptive immune system. The innate immune system is an unchanging mechanism that can detect and destroy certain antigens at first encounter, while the adaptive immune system responds to previous unknown foreign cells and builds a response to them that can remain in the overall body for a period of time.

Artificial immune systems are a relatively new area of research which constitutes intelligent methodologies inspired by biology and implementing immune mechanisms that can be used to solve real world problems. Like any area of research not yet fully explored, it is complex to provide a complete and concise definition. However, several definitions have been proposed. For example (Dasgupta, 1998b) defined AIS as "intelligent methodologies inspired by the immune system toward real-world problem solving. » Then (Timmis, 2000) defined them to be "an AIS is a computational system based upon metaphors of the natural immune system" The most recent definition is provided by (de Castro and Timmis, 2002), in which they define AIS to be "AIS are adaptive systems, inspired by theoretical immunology and observed immune functions, principles and models, which are applied to problem solving."

The most important biological immune system theories that are currently popular in the design of AIS algorithms are negative selection, clonal selection and immune network model.

The negative selection, also called mechanism of discrimination between self and non-self, manages the process of creation of lymphocytes. Indeed, when a T cell recognizes a self antigen, it will be excluded from the population of T cells and it will be destroyed. The rest of the population is allowed to leave the thymus and circulate in the blood and do their monitoring tasks (De Castro and Timmis, 2003).

The clonal selection is a theory used to explain the basic properties of an adaptive immune response to an antigenic stimulus. It establishes the idea that only those cells able to recognize antigens are selected to be proliferated. When the organism is exposed to an antigen, a B cell binds to it by producing a single type of antibody. By binding with an antigen, selected B cell is stimulated to produce clones of itself. In parallel, if its affinity with the antigen is sufficiently high, it will be saved as "memory cells" (De Castro and Von Zuben, 1999).

The Immune network theory, as proposed by Jerne on 1974, views the immune system as a regulated network of molecules and cells that recognize each other producing a self-organizing behavior and memory even in the absence of antigen. B-cells interact via receptors to stimulate and suppress each other form a regulatory network that forms an internal image of the antigenic patterns that the immune system observes (Farmer et al., 1986).

In order to improve the traffic situations at intersections, AIS concepts and techniques were adapted. For the same reason, several analogies between biological immune system and road traffic system are also made.

The following section shows how AIS concepts techniques and analogies will be adapted for traffic regulation.

4 THE ARTIFICIAL IMMUNE SYSTEM FOR THE REGULATION OF TRAFFIC AT AN INTERSECTION

4.1 Assumptions

In this paper several assumptions will be supposed in order to simplify the development of an efficient artificial immune algorithm.

- In this model, the regulation of traffic is done in a single isolated intersection composed of four unidirectional roads (figure 2).
- At each corner of the road, a panel of traffic lights is installed composed of two lights (green, red), yellow signs will not be considered, rather it is considered as a red light.
- The green light indicates a possibility of passing the intersection and a red light indicates a temporary prohibition to pass.
- Given the complexity of the traffic system and the multitude of modes of transport (cars, heavy vehicles, light vehicles ...), we simplify the model by assuming that traffic is homogeneous and that the intersection is composed only of cars. The heterogeneity of the traffic can be an extension of the proposed model.
- On each line, vehicles pass the intersection on First in First Out way.
- Cars are not allowed to make half turns in the intersection.
- There is no specific pathway for transport, heavy vehicles or bikes.
- The intersection is equipped with one of the instruments of traffic measurement able to measure the length of the queue: magnetic loop, pneumatic hose, video sensor, etc.
- The length of the queue is calculated by number of cars.
- Cars are supposed having the same length.
- The speed with which a car crossed a road in this model is not taken into account.

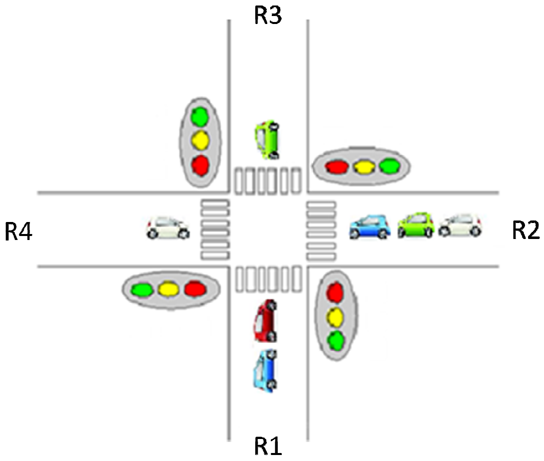


Figure 2: Example of a signalized intersection

4.2 Variables

In order to model our approach, a number of variables must be defined:

- R: it is the whole of roads R_i that exist in an intersection.
- i: the road number, i = {1, 2, 3, 4}.

- $R = \{R_1, R_2, R_3, R_4\}$.
- F_i: is the light activated at the road i. This variable can take two values:

$$Fi = \begin{cases} 0 \text{ if the red light is activated} \\ 1 \text{ if the green light is activated} \end{cases}$$

- L_i: the length of the queue detected at the i^{th} road junction. This variable is expressed in number of cars.
- L_{max} = const: the maximum length of a queue in each road junction. This constant is expressed in number of cars.
- P: The period of day.
    - P=1: that this is a rush hour.
    - P=2: that this is a normal situation.
    - P=3: that this is an extreme situation.
- Phase = $\{phase_1, phase_2, Phase_3, Phase_4\}$ is the switching of traffic lights. In a phase, one or more movements are allowed simultaneously in the intersection. The main role of a phase is to relieve traffic congestion while providing users with maximum security.

The different phases are shown in the following table:

	F_1	F_2	F_2	F_4
$phase_1$	green	red	red	red
$phase_2$	red	green	red	red
$phase_3$	red	red	green	red
$phase_4$	red	red	red	green

Table 1: The different phases of traffic light

4.3 Analogy between the biological immune system and urban traffic system at an intersection

In order to solve the problems of traffic at intersections based on artificial immune systems, a number of analogies between the biological immune system and road traffic system should be established.

At the body, immune cells can be attacked by the presence of antigens that disrupt normal operation. Similarly, in an urban transport system, the presence of queues at one or more roads of the intersection can attack vehicle and block the traffic. Hence, it is necessary to take an action of regulations derived from the traffic lights which eliminate perturbation and ensure the fluidity of the traffic.

Antigens may be assimilated to perturbations that prevent the urban traffic system and damaged cells can be seen as vehicles affected by the disturbance.

The cells of innate immunity are able to detect the presence of an antigen. In an urban traffic system, these cells could be regarded as one of the traffic measurement instruments (sensors) which are able to detect the presence of a perturbation in a transport system.

B cells are able to know and fight the antigens by producing antibodies. In the context of road traffic, the antibodies may correspond to different control actions derived from the traffic lights. These B cells are able to build an immune response described by the theory of clonal selection (Darmoul et al., 2006). When the degree of affinity between an antibody of a B cell and an antigen exceeds a predefined threshold, the cell will be stimulated to divide and proliferate by producing clones of themselves.

This cell is considered to be able to recognize and eliminate the antigen. Then, it will be preserved in memory to deal future meetings with the same antigen or an antigen that has a structure similar to that of a known antigen.

The mechanism of clonal selection could be used to respond to perturbations. When a queue is detected, B cells become activated producing different antibodies, each of them corresponds to a possible action of regulation. The best action is selected by evaluating the function of affinity between the antibody and antigen. The function of affinity depends on the predetermined objectives.

The best antibodies will then be applied as an action of regulation able to respond to perturbations and will be stored in order to respond immediately to a new manifestation of the same disturbance. These analogies between the biological immune system and the road traffic system are summarized in the following table:

Biological immune system	**Artificial immune system**
Body	Urban traffic system
The damaged cells of the body	The vehicles affected by the perturbation
Antigen	Perturbation: queue
Antibody	Regulatory action derived from the traffic lights
Cells of innate immunity	instruments of traffic measurement (air hoses, electromagnetic loop, video, …)

The degree of affinity between an antigen and an antibody	Evaluation of regulatory actions available to deal with the perturbation
immune memory	Storing control actions which are the most appropriate ones to meet the disturbance
immune response	Activation of the regulatory action stored to respond immediately to a new manifestation of the same perturbation.

Table 2: Analogy between the biological immune system and urban traffic system

4.4 Antibody- Antigen structure

4.4.1 Antibody

Each antibody is represented by a matrix containing the following data:

Antibody				
Road number (R_i)				
Length of the queue (L_i)				
Period of day (P)				
Control action				

Table 3: Antigen structure

4.4.2 Antigen

Antigen must have a similar structure. Thus, it is also represented by a matrix that records the following data:

Antigen				
Road number (R_i)				
Length of the queue (L_i)				
Period of day (P)				

Table 4: Antigen structure

4.4.3 Calculation of affinity between antibody and antigen

The degree of affinity calculated between an antigen and an antibody is based in this paper on the formula of *Manhattan*. To calculate this affinity, several arbitrary weights are assigned to different variables. $w_1 = 0.7$ is the weight of the variable L_i and $w_2 = 0.3$ is the weight of the variable P.

The affinity is calculated as the weighted sum of absolute values of differences between the values of the variables of antigens and antibodies.

$$\text{degaff} = 0.7\sum_{i=1}^{4}\left|L_i(Ab) - L_i(Ag)\right| + 0.3\sum\left|\text{P (Ab) - P (Ag)}\right|$$

4.5 Artificial immune algorithm

Our algorithm contains the following steps:

- Initialization: The system starts with a normal traffic. This system consists of a set of antibodies which represents the random initial population and retains attention to perturbations that can be achieved.
- Detection of a new antigen in the system.
- Evaluation: calculation of the degree of affinity between the antigen and the set of antibodies which exist in the initial population.
- Activation of the antibodies: antibodies that have a degree of affinity with the antigen below a given threshold of affinity will be activated.
- Comparison: antibody that has the lowest degree of affinity will be chosen as the specific antibody to that antigen.
- Intervention of the regulator: the regulator exercise mutations to the activated antibody to improve the affinity with the detected antigen.
    - If the antibody has previously been amended by the regulator, so this regulation will be applied to the antibody again.
    - If the regulator will create a new amendment, it will be recorded in the basic rules of change.

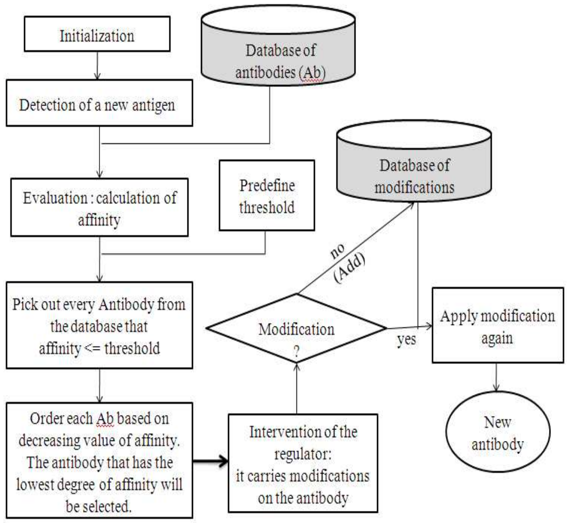


Figure 3: Logical flow of the AIS algorithm for traffic regulation

4.6 Tests and results

We simulated the traffic at an intersection in three different scenarios.

4.6.1 First scenario

The intersection operates under traffic lights plan composed of four consecutive phases. The duration of each phase is 15 sec, during which the rate of arrival of the cars to the various roads is 3 vehicles and the output rate is 5 vehicles. The simulation was done during a rush hour (P=1) and it lasted 750 sec.

Initially, we simulated the intersection before activating the control system. So we noted that the length of the queue of vehicles in roads was increased and exceeded the maximum length (L_{max} =30). So the traffic seems blocked. This event can be explained by the fact that the total flow of incoming and outgoing of vehicles is constant and the phasing has remained unchanged.

To improve the situation and reduce traffic congestion, we have activated the control system in which we integrated control actions that respond to perturbations inherent to the system. These actions act on the phases, which become dynamic. Eventually, we found a remarkable evolution of the queue of vehicles at the different roads. Figure 4 shows this evolution. The system responds as soon as the length of the queue reaches or approaches the value of L_{max} Therefore the length of the queue after regulation has stabilized at around L_{max} =30.

4.6.2 Second scenario

In the second scenario, we will increase the flow of vehicles entering the different roads of the intersection. The output rate of the vehicles, the phasing, the period of day and the maximum length L_{max} remain unchanged.

Firstly, we simulated the traffic without any regulatory action. So we found that the situation was complicated. Traffic starts to be blocked from the beginning of the simulation. In fact, every 15 seconds, the total flow of vehicles entering at each road is 15 and the output rate is 5 vehicles. And as the duration of the signalization still unchanged, the queue of vehicles has increased with an accelerated manner.

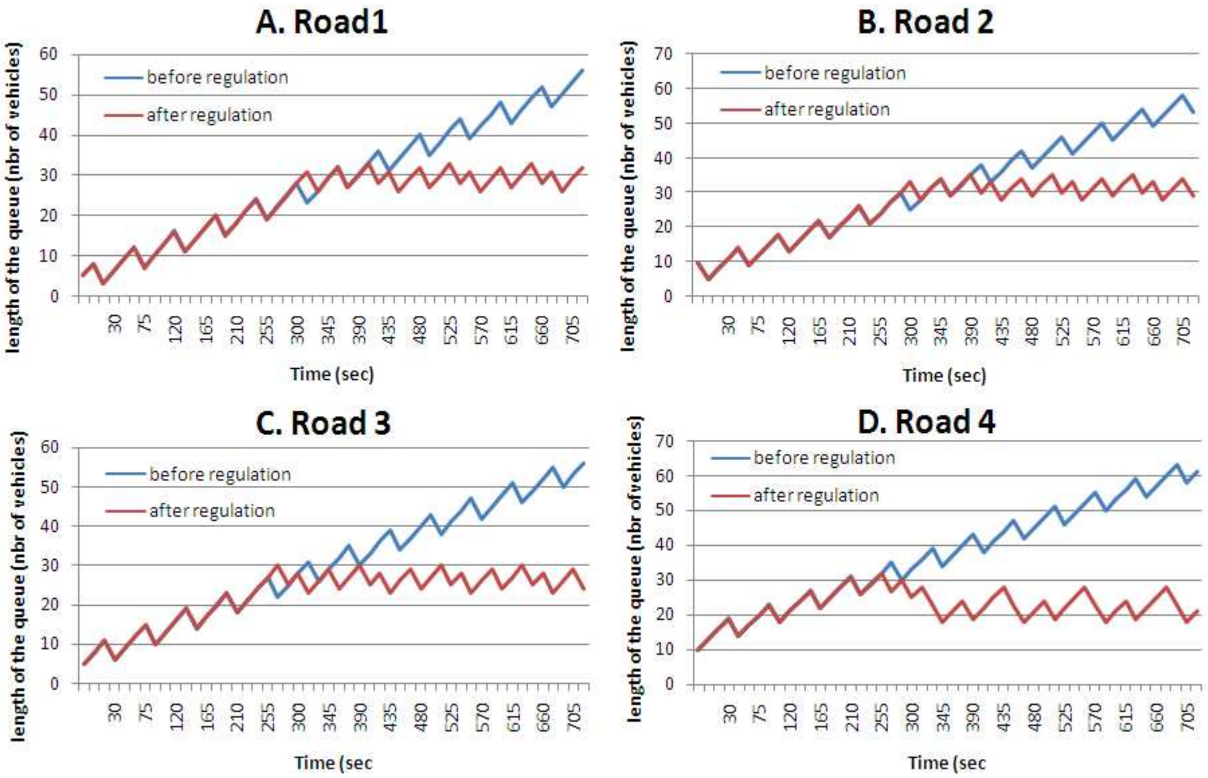
We conducted a second simulation in which we integrated control actions. Thus, we recorded a significant decrease in the length of the queue of vehicles. After a few seconds of the simulation, this length has stabilized at around 30 cars and the problem of traffic congestion is resolved. The results of the evolution of the length of the queue of vehicles before and after the inclusion of control actions are shown in Figure 5.

4.6.3 Third scenario

At the beginning of the simulation the flow rate of incoming and outgoing vehicles, the Period of day and maximum length are identical to those of the second scenario.

At t = 375 s, an accident occurred in the conflict zone (zone of intersection of four roads). The input rate of vehicles is still unchanged (5 vehicles per 15 seconds), while the output rate decreased from 5 to 2 vehicles per 15 seconds. Therefore, the situation becomes more complicated and the traffic becomes blocked.

Figure 6 shows a significant change in the length of the queue after the activation of the regulator. The situation is improved and traffic seemed more fluid. At the beginning of the simulation, the length of the line of cars has stabilized at around 30 vehicles. But after the occurrence of the accident (at t = 375 sec), this length exceeded L_{max}. The length of the queue after regulation is still lower than the length before the regulation. We can thus conclude that the proposed control system was able to give satisfactory results since it has improved the situation and the traffic flow. From these three scenarios, we find that the artificial immune system is able to optimize and solve problems of traffic congestion at intersections.

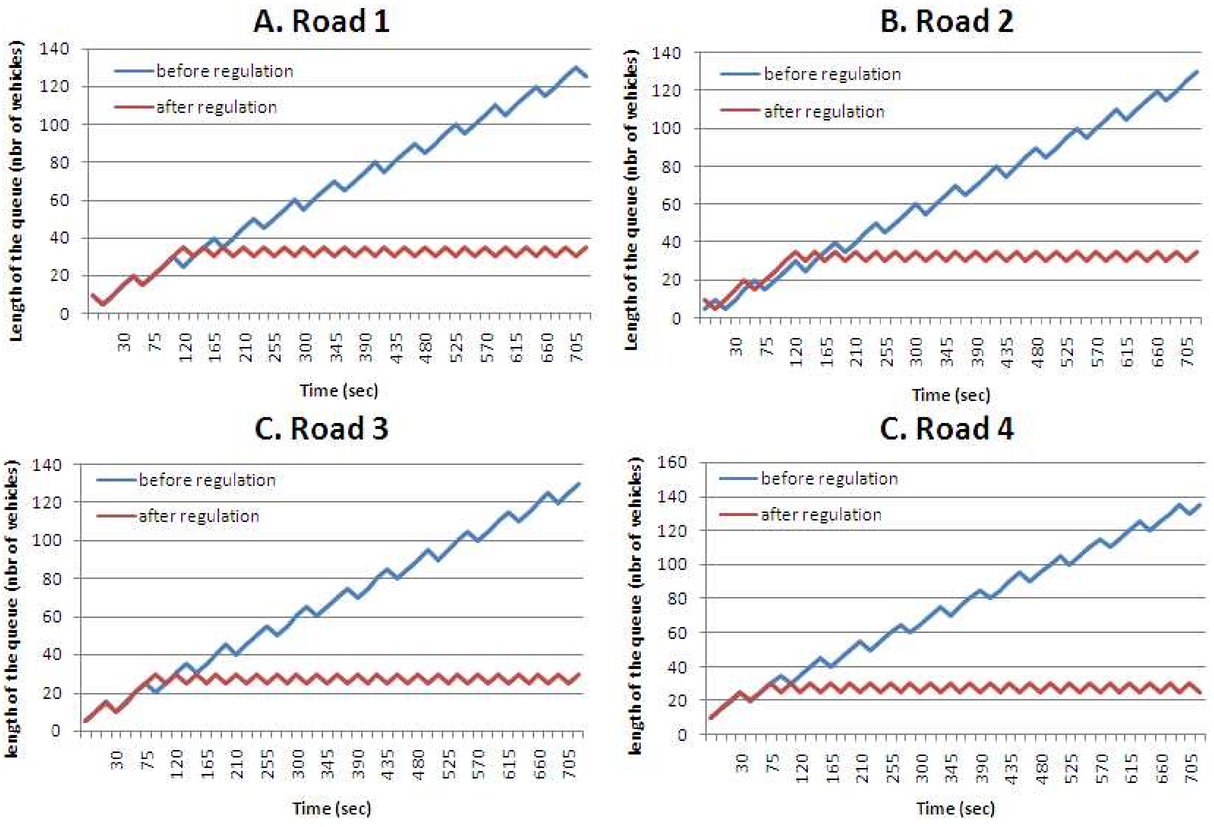

A. Road1

B. Road 2

C. Road 3

D. Road 4

Figure 4: Results of the simulation of the first scenario


A. Road 1

B. Road 2

C. Road 3

C. Road 4

Figure 5: Results of the simulation of the second scenario

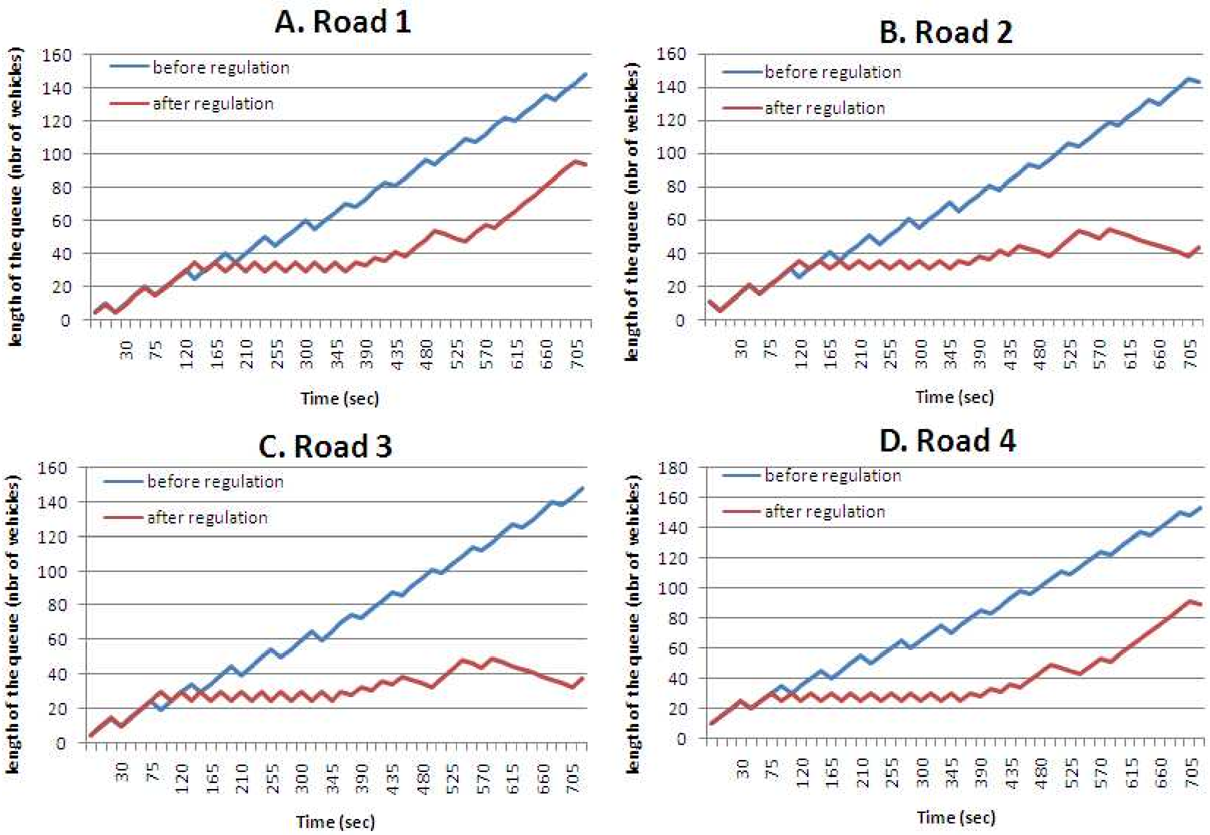


Figure 6: Results of the simulation of the third scenario

5 CONCLUSION AND PERSPECTIVES

In this paper, we proposed a strategy for urban traffic control at intersections equipped with traffic lights. This proposal is in response to situations of traffic congestion at any time of day. The purpose of the regulation is to increase the flow of vehicles and to minimize the length of the queues.

To achieve this goal, we exploited the potential of artificial immune system, as it is a relatively new paradigm, to tackle traffic congestion at intersections, to maximize traffic flow and to minimize the queues. To meet these objectives, we have established an analogy between the system of urban traffic and the immune system biology. This analogy has allowed us to define the different variables in the model. To simplify this model, we assumed different assumptions to solve the problems of urban traffic system.

We then simulated the traffic at a single intersection in three different scenarios and we presented the results of simulations.

Our work opens new perspectives of research. Indeed, we proposed a model which focuses on traffic congestion at a single isolated intersection composed of light vehicles. The heterogeneity of traffic could be taking further into account. In addition, the modeling of traffic can be extended to more complex situations and generalized the model to a set of intersections. Further researches can also take into account driver's behavior that can influence the flow of traffic. In the context of the artificial immune system approach, the use of other concepts and algorithms inspired by natural immunology as immune network theory, the theory of danger ... can be a new perspective.

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