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Regulation Models of Crossroad Based on Wireless Sensor Networks and Notions of the Fluid Mechanics

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Abstract: *The permanent growth of the population in smart cities has increased the number of vehicles. Consequently the problem of traffic congestion has become one of the main problems to be solved by today's traffic control systems, especially at traffic intersections. In fact, the traditional method which avoids the congestion in a crossroads is the classic command (Timing) by means of traffic lights. However, the traffic light management modes are sometimes based on classic models which make them unsuitable for the treatment of different experienced situations in traffic (either dense or fluid traffic). Fortunately, thanks to the significant progress made, especially the use of New Information Technologies and Communications for example Wireless Sensor Network, for the regulation of traffic, are solutions become central in the field of urban traffic management. They have made it possible to propose more effective control mechanisms to reduce the effects of traffic congestion.*

In this article, we will present the continuation of our work [1], the objective is to offer to the users of the road a crossing time as long as possible, while preventing the car cap to propagate over a distance that is set between two wireless sensors, to do this, we can act on the setting of the traffic light to regulate traffic in intersections.

Keywords : Regulation models, Traffic congestion, smart cities, wireless sensor network, Crossing time, fluid mechanics.

I. INTRODUCTION

In the big cities, the importance of vehicle use in everyday mobility has become indispensable for their movement and comfort. This situation has implications for the movement of transport in urban areas, which generates a saturation level of the network which is not acceptable in view of the important problems that it causes. Indeed, we can see a dramatic increase in the time lost in congestions, but also the number of accidents, pollution [2]. These solutions can contribute to improve traffic conditions but all of them require adequate traffic regulations, especially at intersections. To regulate traffic and struggle against congestion, we can rely on better Use of the infrastructure. By taking advantage of advancements in communication and information technologies, for example the use of wireless sensor networks [3-4]. The detection and data processing modules in a computerized traffic management system become capable of providing reliable and accurate real-time knowledge of traffic status. They are mostly designed to fluidify and manage road traffic, namely by intersections where the latter can directly affect the traffic lights. That is the principle of how smart cities ought to be managed.

Wireless sensors can react in case of saturation of the queue, by communicating, traffic status to the controller who makes decisions according to these algorithms and by adjusting the traffic lights. This is the case with an adaptive system **[5].**

In this article we will present the rest of our article that was recently published **[1]**. For that, we will begin by defining the different variables that make it possible to characterize the progression of vehicles on a lane, before we get interested in the fundamental relationship that connects the number of vehicles present at a time on a lane length to the number of vehicles passing between the two wireless sensors that are placed on each lane. The use of sensors is the basis for collecting traffic information. The sensors used make it possible to detect the presence of a vehicle at a given point in the infrastructure **[6,7]**.

They also make it possible to communicate the traffic status (dense or fluid) in order to obtain the optimal sequence of the traffic light **[8,9]** as shown in Fig. 1.

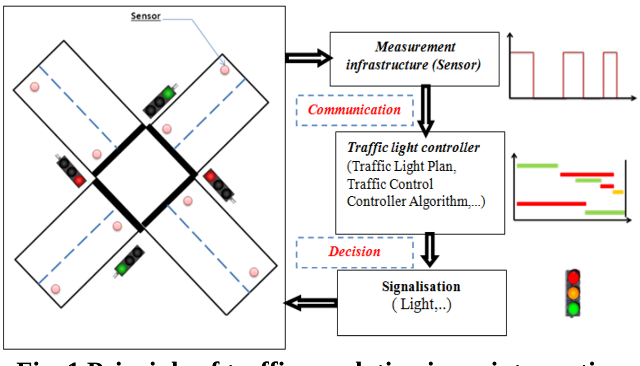

Fig. 1 Principle of traffic regulation in an intersection based on wireless sensors

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It should be noted that the maximum green light time has been the subject of numerous studies.

- Kell and Fullterton **[11]** observe that it must be between 30 and 60 seconds.
- Orcutt **[12]** suggests that this maximum time should be long enough to let pass 1.3 times the average length of the line concerned.
- Courage **[13]** indicates that a high maximum green light time has little impact on an adaptive system

The idea is to act on the setting of the traffic light via a light controller (that is, the duration of the "green" state and the duration of the "red" state), and to calculate the maximum time of the red light without the jams traffic extending over a distance separating the two sensors placed on each lane (Case n° 3), thus, the time that the traffic light must then green to be able to evacuate the cap created previously (case ° 1 and case° 2, **Fig. 2**). Wireless sensors can respond to queue saturation by communicating traffic status to the controller who makes decisions based on these algorithms.

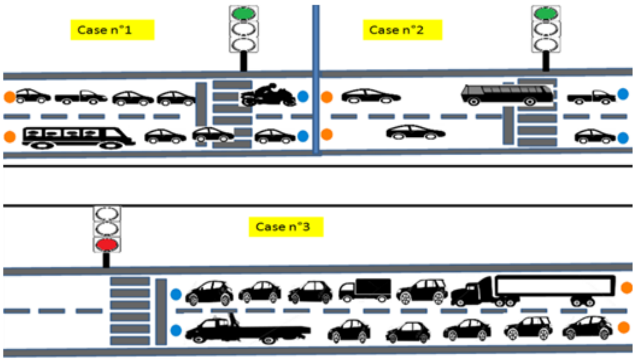

Fig. 2 .Perspective that has been proposed previously [2]

II. SITUATION PROBLEM

The authors **[14,15]** used this model which is composed of two wireless sensors per lane at a distance d and a traffic light, to manage traffic, as shown in **fig 2**.

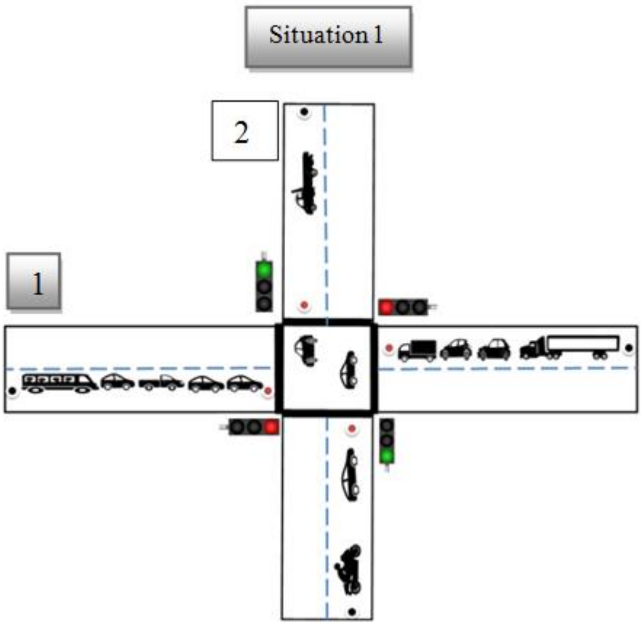

Fig .3a .State of traffic in an intersection at time t_0

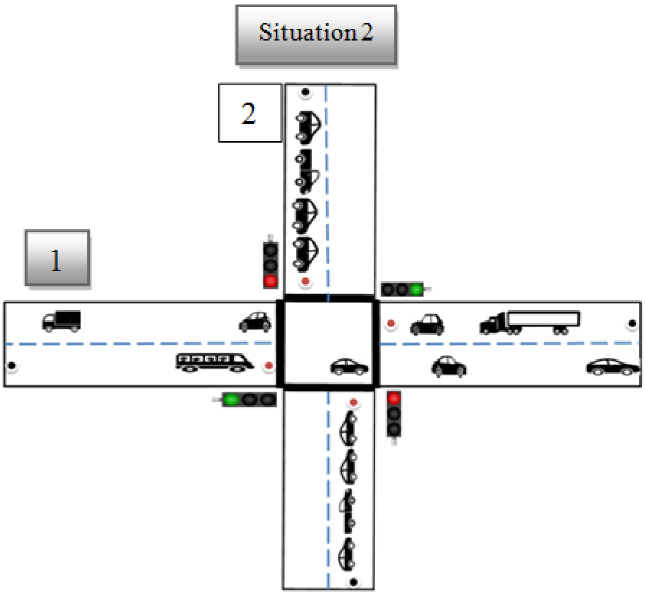

Fig .3b .State of traffic in an intersection at time t_1

At first, we want to study the passage of the green light, after the traffic light has remained red for an infinite time (**Fig. 3a**). After a few moments, the traffic resumes (**Fig. 3b**). As well as the speed of elongation of the jams traffic created by the passage of traffic light to red during a circulation initially uniform, as shown in **Fig .3c** (on the lane 1) and in a second step calculate the duration Tv of green light necessary to evacuate the jams traffic. .

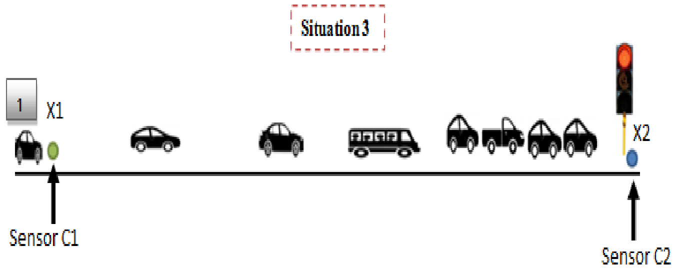

Fig. 3c .State of traffic in an intersection at time t_3 (traffic light has just passed to red)

III. RELATED WORK

A. Variables that characterize the progression of vehicles on a track

Each vehicle has a given position (x,y) and an orientation ω. The maximum speed v_m of vehicles is 10 m/s which is about 40 km/h.

- Number of vehicles noted $N(x,t)$
- The flow (cars / s) noted $q(x,t)$ The flow q is the number N of vehicles passing during a period dt at a point x, relative to the duration of the period: It is expressed in number of vehicles per unit of time (veh / h or veh /s in general);

$$q(x,t) = \frac{N(x,t \rightarrow t+dt)}{dt} \quad (1)$$

- Density (cars / m) noted ρ (x, t), corresponding to the number of vehicles per unit length lying on a section close to the x-axis, at time t:

$$\rho(x,t) = \frac{N(x, t \to t+dt)}{dt} \quad (2)$$

- The speed $V(x,t)$ corresponding to the optimal speed v_{opt} of the vehicles [2] located in section [x , $x+dx$] at the time

$$v_{opt} = \sqrt{\frac{2L_{veh}}{k.m}} \quad (3)$$

With $k.m$, it's " braking constant "
Our objective, first, is to calculate the speed of propagation of a traffic jam created by the passage from traffic light to red (Fig. 3c), that is to say, the corresponding density as a function of the duration of the red light (Situation 3).
Then, to calculate the duration of the green light T_g necessary to evacuate traffic jams created by the red light for a duration T_r

B. Presentation of the model:

In this section we present the model: it is assumed that moving cars on a single-lane road without possibility of overtaking , we will work on road portions bounded by sensors that are positioned on a track according to the coordinates x_1 and x_2 respectively to the sensor C_1 and C_2 which are placed before and after the traffic lights. The distance between the two sensors is given by x .
ρ (x, t) is the density of cars at position x and at time t

So, that $\int_{x_1}^{x_2} \rho(x,t)dx$ represents the number of cars between positions [x_1, x_2] at time t. Note also $q(x,t)$ is the flow of cars passing at point x at time t.

Our model will be based on the principle of keeping the number of cars in an interval [x_1, x_2] between the two times t_1 and t_2, which is mathematically translated by the following equation:

$$\int_{x_1}^{x_2} \rho(x,t_2)dx - \int_{x_1}^{x_2} \rho(x,t_1)dx = \int_{t_1}^{t_2} q(x_1,t)dx - \int_{t_1}^{t_2} q(x_2,t)dx \quad (4)$$

This equation can be rewritten as follows

$$\frac{d}{dt}\int_{x_1}^{x_2} \rho(x,t_2)dx = q(x_1,t)dx - q(x_2,t)dx \quad (5)$$

In other words, the variation of the number of cars N in the interval [x_1, x_2]for a duration t is equal to the difference between the number of cars entered in x_1 and the number of cars exiting in x_2 during this period. In our model, we assume that the flux depends only on the density:

$$q = q(\rho) \quad (6)$$

$$\int_{x_1}^{x_2} \frac{\partial}{\partial t}\rho(x,t)dx = \int_{x_1}^{x_2} \frac{\partial}{\partial x} q(x,t)dx$$

Bout these equations, we obtained:

$$\int_{x_1}^{x_2} \left(\frac{\partial}{\partial t}\rho(x,t)dx - \frac{\partial}{\partial x} q(x,t) \right) dx = 0 \quad (7)$$

The differential equation associated with our model is written:

$$\frac{\partial}{\partial t}\rho(x,t) - \frac{\partial}{\partial x} q(\rho(x,t)) = 0 \quad (8)$$

$$\partial_t \, \rho(x,t) - \partial_x \, q(\rho(x,t)) = 0 \quad (9)$$

Our objective is to find the solution of this equation and compare the results obtained by the simulation

C. Relation between speed and density

we define $v(x,t)$ the speed of a car at position x at time t.
We have the following relation between speed, flow and density :

$$q(x,t) = v(x,t).\rho(x,t) \quad (10)$$

v (x, t) vehicle speed depends on the density (cars per meter), then, the number of cars passing per second in x will be ρv, therefore:

$$v(\rho) = \frac{q(\rho)}{\rho} \quad (11)$$

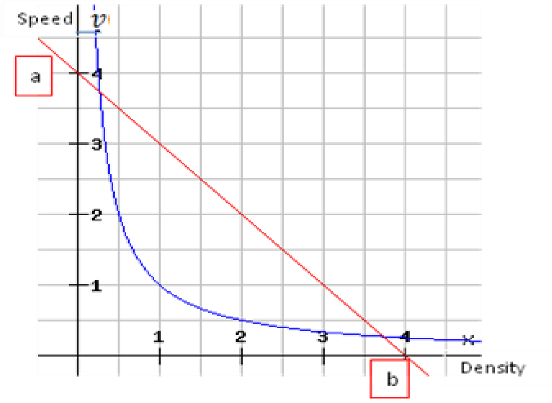

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Fig .4 Speed a function of the density curve

Fig .4 shows the graphical representation of equation (11)
So, the speed decreases according to the speed:

- The maximum speed allowed v_m (v_{opt}=30 klm/h [2]) when there are almost no cars on the road (density close to 0)
- The speed is zero (v = 0) when the density is maximum ρ_m.

The speed is thus of the form:

$$v = a\rho + b_2 \quad (12)$$

However,

$$v(0) = v_m \;➔\; b_2 = v_m \text{ and } v(\rho_m) = a\rho_m + v_m = 0$$

We obtained:

$$a = -\frac{v_m}{\rho_m} \quad (13)$$

It is the three mathematicians, Lighthill Witham and Richards [16] who provide us with this model, it is the LWR model: The flux being equal to the maximum speed times the density times minus the density divided by the maximum density.

$$v(\rho) = v_m\left(1 - \frac{\rho}{\rho_m}\right)$$

So, flow equation (10) becomes:

$$q(\rho) = v(\rho) * \rho \rightarrow q(\rho) = \rho \frac{v_m}{\rho_m}(\rho_m - \rho)$$

Finally:

$$\rho(\rho) = v_m\left(\rho - \frac{\rho^2}{\rho_m}\right) \qquad \textbf{(14)}$$

The Fig. 5a and Fig .5b show the flow q representation and her derivative q'.

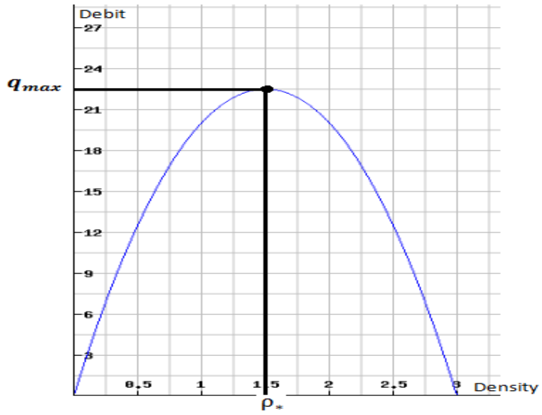


Fig .5a .Curve of $q(\rho) = 30\rho - 10\rho^2$

The graphic Fig .5a, above, represents the flow q as a function of the density ρ while, the graphic below represents q '(ρ). We have chosen to draw these curves of pose v_m =30 klm/h (results of my last publication [2]) and ρm = 3

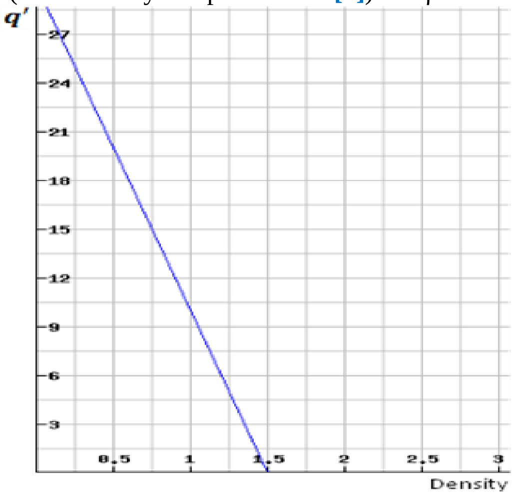


Fig .5b .Curve of $q'(\rho) = 30 - 20\rho$ $\quad \partial_t \rho - \partial_x q(\rho) = 0$

(15)

we define the advection speed as follows:

$$C(\rho) = q'(\rho) = v_m\left(1 - 2\frac{\rho}{\rho_m}\right)$$

Equation (15) becomes:

$$\partial_t \rho + C(\rho)\partial_x q = 0 \qquad \textbf{(16)}$$

To calculate a solution of (2), we will still know the density function at the initial moment t = 0 (this is the initial condition) and know the boundary conditions, that is to say information on the number of cars entering the portion of road considered, and now, at each moment of the simulation.

IV. SIMULATION RESULTS AND DISCUSSION

The simulator used to simulate road traffic. Open source interactive based on Java and available on *www.traffic-simulation.de* **[17]**. It breaks down in two parts : simulation of a vehicle traffic and control panel as shown in **Fig.6**.

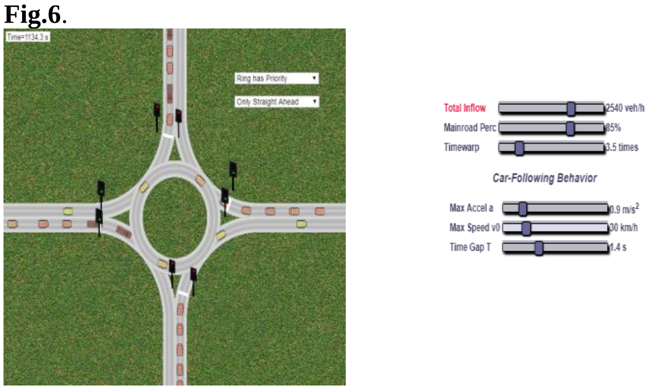
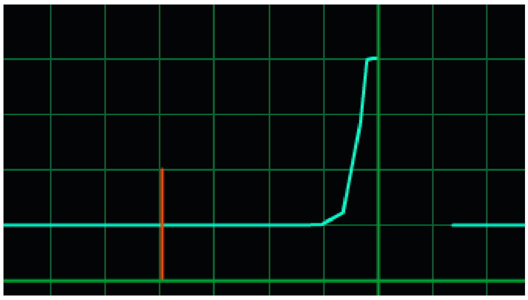


Fig.6 Graphical interface of the simulator used

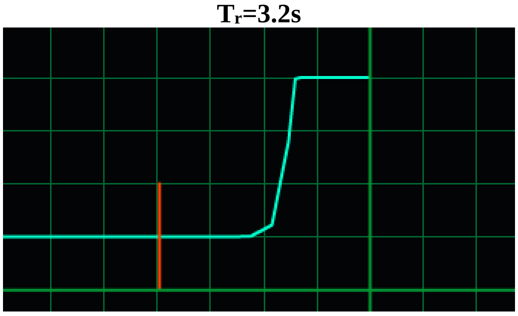
The vehicles traveling on a lane according to the state of the traffic and the traffic light.

The user can interact on the traffic thanks to control panel in

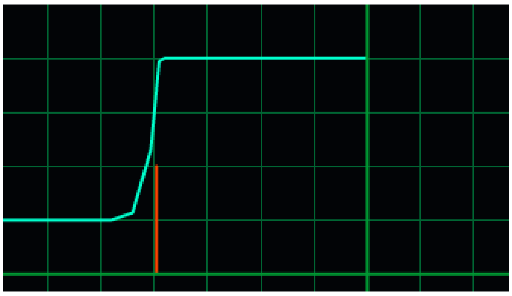
- stopping, continuing or resetting the simulation,
- changing the color of the light (green or red) either manually, either automatically by imposing the durations between each color change. The control panel allows measurements to be made:
- the optimal time of lights depending on traffic
- the speed of vehicles, through the sensor node
- the density as a function of the position and the time of each fire phase, by the density curve (Results simulation below)
- the flow of vehicles to a given place, through the sensor node.



T_r=3.2s



T_r=12.8 s

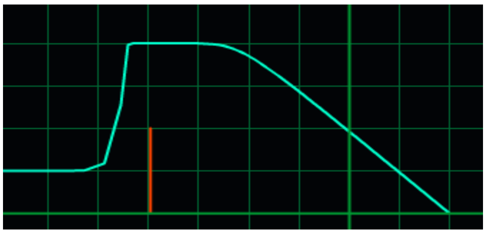


T_r=36.8

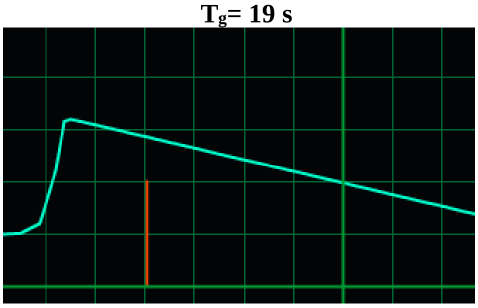
Fig .6 . Density ρ as a function of the time of the red light

The graphs in Fig .6 show the variation of the density ρ as a function of time of the red light, which corresponds to the speed of elongation of the traffic jams created by the passage of the fire to red during an initially uniform circulation. The traffic is saturated after 37 seconds of the red light.

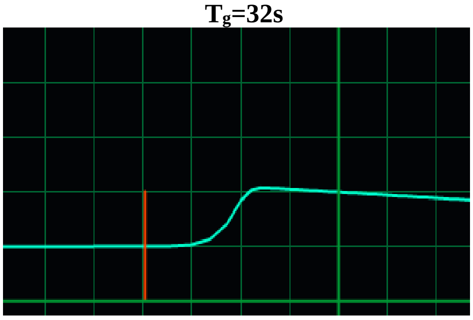
The red line corresponds to the location of a sensor node placed before the fire at a given distance. When the traffic is saturated, the sensor node sends a message to the traffic light controller [6]. This last is looking for an optimal solution, so, to find the algorithm which makes it possible to light the green light as soon as possible to evacuate the traffic jams.



T_g= 19 s



T_g=32s



T_g=44 s

Fig .7 .Density ρ as a function of the time of the green light (Evacuation of traffic jams)

The graphs in Fig .7 show the variation of the density ρ as a function of the green light time necessary to evacuate the plug. the traffic becomes fluid after 44 seconds of the green light.

Flow, density, speed and queue are key variables of an adaptive regulation system by the control of the lights. Indeed, most of these systems they search the best arrangement of the colors of the lights minimizing the average waiting time per vehicle on the junction. This solution is given using wireless sensor network.

However, this criterion expresses itself directly according to the evolution of the queue around time.

A queue appears when a vehicle stops at the light. It then continues each time a new vehicle is inserted. Conversely, it decreases when vehicles restart. The head of queue then retreats at each start, until all the vehicles are gone.

V. CONCLUSION

In this article, we presented a model for regulating traffic in single-line intersections. To reduce traffic jams and minimize waiting time on a line, we used wireless sensor networks.

The aim is to give road users the longest possible crossing time, while preventing traffic jams to propagate over a distance that is fixed between two wireless sensors C_1 and C_2, to do this, we have to act on the regulation of the lights to regulate the traffic in intersections.

This setting of the traffic light via a controller (ie the duration of the "green" state and duration of the "red" state), and to know the maximum time of the red light, without the traffic jams do not extend over a distance that separates the two sensors placed on each line (case n°3), thus, the time that the light must then green to be able to evacuate the jams created previously (Case n°1 and case n°2). Wireless sensors can respond to queue saturation by communicating traffic status to the light controller who makes decisions based on these algorithms.

This study presents a very concrete aspect, which is based on a Partial Derivative Equation. By allowing to connect the variations of the density according to the duration of the light (red or green). The tools for solving partial differential equations are varied. Here, we used the simulator to find the approximate solutions of this equation.

from the perspective, we want to solve the differential equation based on Mathamatic calculations to verify and justify the results obtained.

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