Agent Based Monitoring for Smart Cities: Application to Traffic Lights

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Abstract— **Traffic congestion in large cities became a huge problem, which can lead to a lot of losses especially at the human and material levels. This paper proposes a decentralized model based on multi-agent systems (MAS) and complex event processing (CEP). The new control scheme aims to improve green light time in order to reduce the average waiting time of vehicles in front of the traffic light, especially if the road is empty, and to reduce congestion at crossroad. This improvement is provided by the observation of the intersection through Cyber Physical Systems (CPS). This paper propose an auto-adaptive model for smart regulation traffic lights. The developed model will be evaluated and analyzed using different metrics and scenarios so as to test their influence on system performance.**

I. INTRODUCTION

In large and medium cities, traffic flows are increasing with the evolution of generations, this evolution lead to more congested traffic and to its adverse effects (queue, increase of travel time, energy loss, pollution...). From several years, the corner stone of developed solutions to reply to this issue have been performed taking into account mainly the infrastructure of the road network with increasing its capacity. Due to its cost, and urban space levels, this widespread solution reaches out its limits. As opposed to this town planning approach, research works have been performed on the optimization of the traffic management including strong effort on adaptive signalization [13].

These works show that suitable traffic light strategies can achieve a part of thinning by enhancing the efficiency of transport networks with ensuring a faster vehicle flow through the urban network. Even if the solutions currently applied have an important impact on the traffic congestion, an adaptive solution could be interesting to propose smart-traffic light. In this paper, we aim at using recent advances in Complex Event Processing (CEP) and Multi Agent Systems (MAS) to based own proposal.

The principal goals of an intelligent traffic light control are an increase crossroad reactivation, adaptation to new situation, and reduce delays, and an enhancement of the safety of people and vehicles. The expected effects of this kind of control are a better fuel consumption efficiency and a reduction of particles emissions, downtime and delays.

To achieve this goals We can distinguish between three principal approaches for traffic control: centralized, decentralized and hybrid control.

In the centralized structure, all entities depend on a single authority e.g. computer server.The communication in this type of systems may confront several failures, it has a great opportunity to be censored or its data can be changed as they are treated in a single treatment center. For large scale systems, centralized system need a developed several level of theoretical calculation and communication.

The second approach, using decentralized systems, doesn't relies on a main processing center. The main idea is that any entity of this system is a part of the network that does not have a principal authority, furthermore these authorities must have communication abilities. In this structure local controllers have a control role on subsystems. The use of local controllers reduces drastically computational load requirements, the collection and the storage of data. Local controllers do not interact with each other in this structure.

The overall function in the hybrid system architecture is distributed to several local nodes. Each node has a responsibility for one sub-area of the overall system and controls all components and terminals of this specific area. To reduce the risk that a single node fails, the nodes should of course be redundant.The external interfaces of this system can be connected to different nodes: e.g. to the nearest or to the most suitable node in terms of functionality.

The paper is organized as follows with Section 2 details previous approaches which are dealing the same issue. Section 3 provides details on the proposition of a realistic model to regulate traffic lights at a defined intersection with the different methods used, the decision making system and the agents hierarchy in the proposed model. The developed application, as well as the protocol used to monitor traffic state and the experimental analysis are included in Section 4. Finally, Section 5 summarizes the presented work with a conclusion where we identify the future directions of research within the area of intelligent traffic systems research.

II. STATE OF THE ART

To reach its objectives, an advanced road traffic control system can use different warp such as controlling the movement of vehicles, controlling interaction between vehicles and/or interaction between vehicles and infrastructure or create intelligent traffic lights that take into consideration the road conditions. The expected result is a reduction of traffic cost and an increase traffic system throughput. After analysis of the literature, we can say that these goals can be accomplished through one of the three level traffic road control (Centralized, Decentralized, Hybrid).

A. *Centralized Traffic Control*

In [7] authors proposed a framework named Model-based Data Collection (MDC) which aims to reduce the large amount of data transmitted from each vehicle. Thus, so as to reduce the amount of data, this method consists in the use of two types of vehicle side algorithms based two types of regression models (Linear regression and kernel regression)

in the use of pull and push methods on server side. These last are made for collecting efficiently the data from the vehicles.
In [8] a new scheme for Vehicular Ad-hock Networks (VANET) was introduced. It is based on the transfer of indications concerning the traffic state, these facilitating the driver decision process. This indications could be warning messages and traffic statistics from intelligent traffic lights (ITLs) to the driver. The decision is then taken by an on board unit.
In [10] , some traffic prediction systems are used to control traffic at rush hours. Travel time is predicted using a Kalman filter and artificial neural networks. This method can permit to avoid traffic jams with a decision support system. In traffic light control [1], other methods take into consideration isolated intersections by using artificial neural network to ameliorate the signal timing in traffic lights. This networks use a traffic signal controllers with a simple structure but with the neural networks, when traffic volumes increase performance will degrade.
In [2], authors propose a plan that present a centralized static methods, a predictive system was proposed, where a required speed is given by intelligent traffic light at current intersection to cross next intersection without stopping. This connection between intersections can then be considered as centralized.

B. Decentralized Traffic Control

Multi-Agent Systems (MAS) are used by many methods in literature where agents are characterize by: the autonomous, partially independence, local view by each agent, no agent can has a total global view of the system to reduce the level of complexity. [11] and [5] proposed a Multi-agent Reinforcement Learning (MARL) for traffic light control, the aim of this method is to reduce the average waiting time of cars in a town. Reinforcement Learning Systems select settings of traffic lights which are the combination of estimated suspense time for all associated vehicles. The main problem in these reinforcement learning-based controllers is the high number of state/action pairs possible for a large network.
To ameliorate the urban transportation, in [16] Traffic lights coordination are based on multi-agent system to maintain the green signal at local intersection , which can allow the coordination between intersections and travel continuously.
The tool developed in [12] is based on on-board signalization, which displays to the driver information using two types of lights (green or red). This proposal is aimed at achieving a cooperative intersection management. An agent is thus endorsing the role of intersection manager and can reserve space and time for every robot which is controlled by a driver agent.
In [6] is proposed another multi-agent method based on several defined rules to control traffic light. The principal role of agents in the system is to control all the traffic lights at one junction respecting the concept of observe-think-act. The management of traffic is done by the defined agents by observing the traffic conditions, and by collaborating with each other. Each agent has to transfer his observation to a supervisor agent who can solve the problems at a global level.
According to this literature study, it seems relevant to use multi-agent systems for that purpose. They generally a good efficiency in regulating traffic and in the reduction of average waiting time at intersections.
Cyber-Physical Systems (CPS) are used by some methods such as [9]. This type of systems aims to develop an intelligent transportation strategy. A new predictive model (Model Predictive Control MPC) is proposed to avoid collision in congested areas and autonomous intersections. This model enables vehicle-to-vehicle (V2V) coordination and vehicle-to-infrastructure (V2I) communication.
Besides, at intersections level, we can find a modeling of the traffic behavior using Petri Nets models. Some methods such as [15] are applying a platoon model to control the traffic at intersections in order to reduce waiting time on queue and to manage traffic at intersection.

C. Hybrid Traffic Control

In this type of control, constraints and objectives can be retouch to ameliorate system performance. The hybrid structures combines the advantages of a centralized with those of a decentralized architecture by trying to eliminate the disadvantages of these two structures. One major advantage of using a hybrid system architecture is that single points of failure can be avoided.
In addition, a hybrid architecture provides scalability, from small through to the largest systems.
Some papers are dealing with hybrid solutions using both local and global points of view. In [4], for instance, is proposed an hybrid architecture for big data on vehicles. This contains a centralized and distributed data storage. The centralized data storage aims to be accessible to massive amount data, but the distributed data storage is used in real time to analyze streaming data.

D. Discussion

According to this study, we can conclude that a centralized system is the easiest way to achieve traffic control considering the simplicity to prepare a technical plan for the system. Despite the simplicity of setting up the system, it is facing several drawbacks such as a long duration information processing in real time. A centralized communication system may also face with potential failures: this system can be easily censored or its data can be changed because they are processed in a single treatment center. For example, if there will an unexpected failure, it will lead to the stoppage of the service, This structure is appropriate for small-scale systems.
By contrast, decentralized systems try to move away from these problems. They are characterized by local controllers to control subsystems and in case of failures these systems can find local solution using nearest mates to compensate the failure. So in decentralized structures the computational load, data gathering and storage requirements can be hugely

decreased as compared to centralized approaches. In addition, the decentralized traffic control can also avoid having big data in the system and can lead to smart data processing instead.
Analysis show that Traditional methods with centralized traffic management faces different problem in the case of traffic in large scales, while decentralized methods have a high reliability to solve such problems [17]. Also for a dynamically changeable environment and in a geographical decentralized system , specifically in the transport domain, the system based on agents will be a suitable approach for regulating traffic due to its adaptive abilities [3]. These systems can achieve Smart control through agents providing a reliable, economical and flexible approach [14].

III. PROPOSED MODEL

A. Overview

In this part we present the architecture (fig.1) of the proposed system. The system respect a three levels hierarchy:

- The first level is composed of several numbers of sensors distributed in the environment to observe every variation overall the covered areas. In this level every sensor sent in real time information about the current state of the system so this repetitive readings can lead to Big Data. Cyber Physical System (CPS) is used to control the physical entities in the system, CPS sensors inform the second level about a specific behavior which can satisfies one of the defined rules agent.

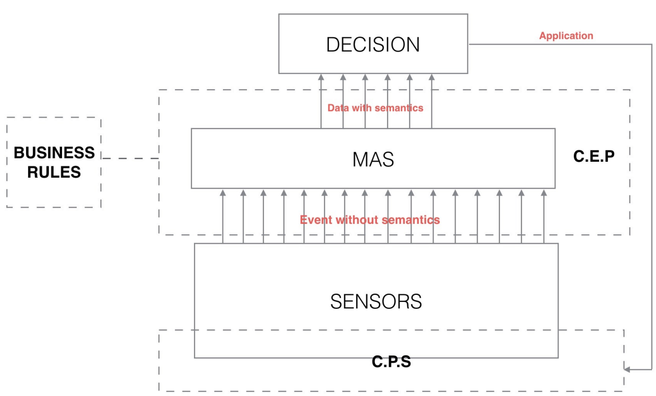

Fig. 1. Model Overview

- In the second level, to reduce the amount of read data taken by the sensors complexes Events are used to notify the systems about specific states in the system. Agents was added in this level to reach more reactivity in the system because Complex Event Processing isnt enough to decrease the amount of data and can only notify. The communication in real time between Cps-sensors, between sensors and agents become through events. Each event sent from one Sensor to an agent reflect the actual state of the observed object at the same moment.
- In the third level, after the treatment with a multi-agent system, the received events is more less than the events sent by the first level. The decision making become easier when the system receive a significant events that show the actual state of the observed environment, this hierarchy guaranty a decision with an after effect on the sensors in the system.

B. Complex Events Processing with MAS

A situation is an event occurrence that might require a reaction. One of the main objectives in CEP is the detection and reporting of situations so that they can be reacted to. In the early days, events was used in the form of exceptions whose role was to interrupt the regular flow of execution e.g. if a program tried to divide by zero an exception event would be raised that enabled the programmer to end the program with an error message. we are mainly concerned with computing events that correspond to events that occur in the real world.

1) Environment
In the proposed approach, event processing techniques are applied to a virtual software space.
This virtual space supports the concept of interactions between agents which is one of the interesting concepts in a multi-agent system. When the agents interact in a communication environment,problems can be solved by cooperating with each other. Two types of interactions are applied in the system:
   - ”inter-layer interaction” that allows interactions between agents from different levels e.g. agents who listen to sensors can interact with supervisors agents.
   - ”intra-layer interactions” which allows interactions between the same types of agents belonging to a specific layer.

   This environment allows communications between agents for interchanging essential information between local agents, or between local agents and their supervisor, or between supervisors agents. And the purpose of this communication is to build a clear observation of the environment and reach a logical decision. The multi-agent layer in the proposed model respect an hierarchy of different types of agents and each agent has a defined role in the system:
   - Sensor agent : is an agent that can observe every variation of a sensor. That sensor can generates report on one or more aspects of the physical environment in which it is situated e.g.smoke detector, GPS location devices can be used in a wide variety of monitoring and sensitive location services,Cameras, microphones ... After each observation the agent send information’s as events.
   - Actuator agent : can receives events from the system. It might take action as a result of receiving events. In industrial control applications actuators are used to power equipment on and off, to control

the operation of machinery, and to control the flow of liquids. An actuator could be physically packaged alongside a sensor in the same piece of hardware, we can talk about "CPSSensors" and a "CPSAgent" that can merge the two functions of these two previous agents.
- Software agent: is an event processing agent can ingests events and can forward events or emit new ones, so at one level they can be said to consume and produce events. The Software agent listen to the CPSAgent and receives events from this agent. Also all "software agents" can send new events to the "DecisionAgent" who can constitute a global view of the current state of the system at this moment and can treat all the received events based on defined rules and take finally a global decision.

2) Agents Interactions
Regarding the interaction between agents, different policies are applied. First the event is the means of communication used in our system. Complex Event Processing is used to benefit from several advantages. CEP can analyze and react to events especially in our system where we set up several sensors that detect and report various events. It is sometimes possible to add more event producers (e.g. sensors) into an existing application in a flexible manner through Event Processing. Rather than modifying the original application to add additional functions. Two types of events are differentiated that may appear in our approach:
- Discrete events: when it is necessary to check and react to certain situations (good or bad) as they happen. So in this case , an event-based approach allows an application to respond more quickly than a batch approach where the detection process works only intermittently.
- Stream events: in other cases, we will need to analyze a large amount of data sent continuously by producers events e.g.sensors, in order to provide an output signal which can influence on the overall observed environment. Multiple nodes e.g. agents can receive the data in the form of stream event, these nodes allows separate analyzes to be performed in parallel.

3) Decision Making System (DMS)
The overall decision of the system is realized in the last part after allowing the receptions of meaningful data to make high-level decisions. These decisions have an impact on the actuators of the system. Which has an influence on all the members of the system. All decisions in this level are based on repetitive consultations of a Business Rules Defines in this system. Business Rules ensures self-adaptability to the system and the achievement of different missions in several areas because thus rules are external of the system. Each agent in this system has a specific rules that allows it to receive or send events.

IV. EXPERIMENT STUDY

A. Overview

The proposed model was applied to a specific roads intersection. All the roads are 2-way roads, each side of which has 1 lane as depicted in Fig. 2. So it is necessary to have at this intersection four traffic lights $\alpha, \beta, \gamma, \delta$ that can emit either red light to mean "Stop" or the green light to mean "Go Forward". At each traffic light a gauge was used to manage the traffic red-light time. When the gauge is full in a traffic light the gauge permit to pass directly to green Light.
We use also several sensors in order to detect the state at every lane and to maximize the number of vehicle crossing the road. Two type of sensors are used in our model:
- Sensors (A, B, C, D) are used to detect the presence of a vehicle on the road and in this case they detect the desired direction by the vehicle.
- Sensors (S1, S2, S3, S4) are used to verify the presence of a vehicle in the second side of roads, this sensors aims to avoid conflicts in roads.

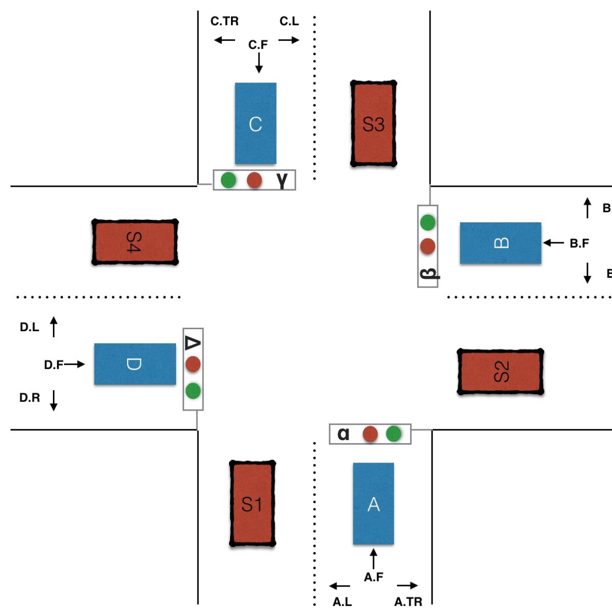

Fig. 2. Observed Crossroad

The principal problem that can affect traffic-light control is how to make decision and change lights from green to red to possible patterns and ensure the minimal waiting time of vehicle. So in this part we present several possible traffic light patterns (Fig.3).
The proposed model was applied to regulate the traffic lights. Our system is specific to a centered traffic light "α" that must communicate with other traffic lights. In order to observe the crossroad and to ensure a continuous traffic lights control in real time, we respect the "Perception-Decision- Action" cycle. All traffic lights in the scenario are initiated to red-light.
The principal objectives of our scenario (Fig.5) are the

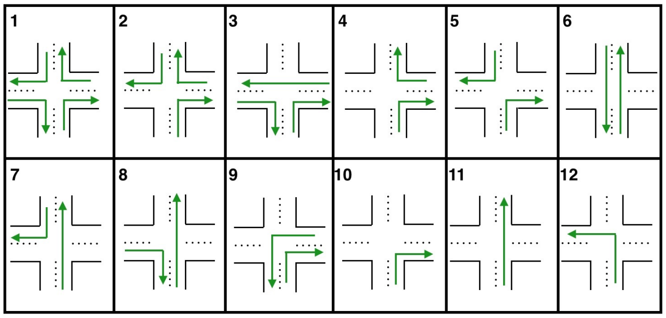

Fig. 3. Possible patterns in the modeled crossroad

regulation of the signal in the traffic light "α" centered in the observed road(Fig.2) and the management of traffic light signal to lead to the best decision and minimize the vehicle waiting time on the correspondent lanes.The individual behavior of agents can not achieve this objectives, it is necessary to establish the interaction between agents as mentioned before. Every agent send events based on his specific defined traffic-rules.
This scenario accept the proposed model hierarchy as we see in the table bellow:

CPS-Sensors	A1 - A2 - B - C1 - C2 - D1 - D2 - S3
CPS-agents	Pass - ConfB - ConfC - ConfD
Traffic Lights	$\alpha - \beta - \gamma - \delta$
Actuator-Agents	Order- Free - Gauge α
Software-Agent	Ag1 - Ag2 - Ag3
Decision-Agent	Decision

Also each of the defined agents has a specific role in the scenario (Fig.5):

- Pass-Agent: receives event from the CPS sensors that detect vehicles in front of the traffic light and they inform the destination of this cars, the purpose of this agent is to receive the demands to pass a road. and to inform the Conflict-Agents about this demands.
- Conflict-Agent: receives event from the CPS sensors that can detect conflicts may confronting a flow of traffic in the road by observing the other directions, the purpose of these agents is to discover conflicts.
- Agents (1,2,3): receives events from two or three conflicts agents in order to create a new event that can express the global conflict situation.
- Free-Agent: receives the event aggregating the conflicts at the intersection, and an event from the CPS-Sensor. After that he creates a new event that express the state of the two way roads.
- Decision-Agent: receives the event from the Free-Agent, he takes the decision taking into account the realized perceptions and by analyzing the actual state of traffic lights by interacting with the Gauge-Agents set for every traffic light.
- Gauge-Agent: used to manage the waiting time in front of a traffic light in the road. This agent receives the red event from the "Decision-Agent" in order to calculate in the gauge set for the traffic light the overall waiting time. when the Gauge of the traffic-light became full the Gauge-Agent send an event to the Order-Agent.
- Order-Agent: receives an event from the Gauge-Agent when the gauge became full and send orders to the traffic lights in order to change obligatory the light.

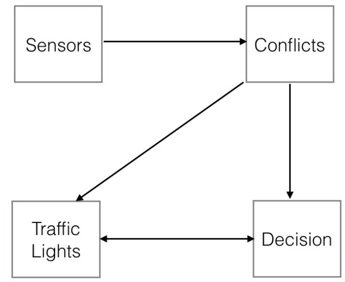

Fig. 4. Interactions hierarchy

The built scenario respects this hierarchy of interactions (Fig.4). Conflicts can be detected in the system using sensors. Conflicts have a large influence on the traffic light state and on the decision in this system. And to take the decision here, it is important to have interactions between traffic light and the decision model. We organized the CEP-MAS scenario in case of the pattern No.11 (Fig.3).

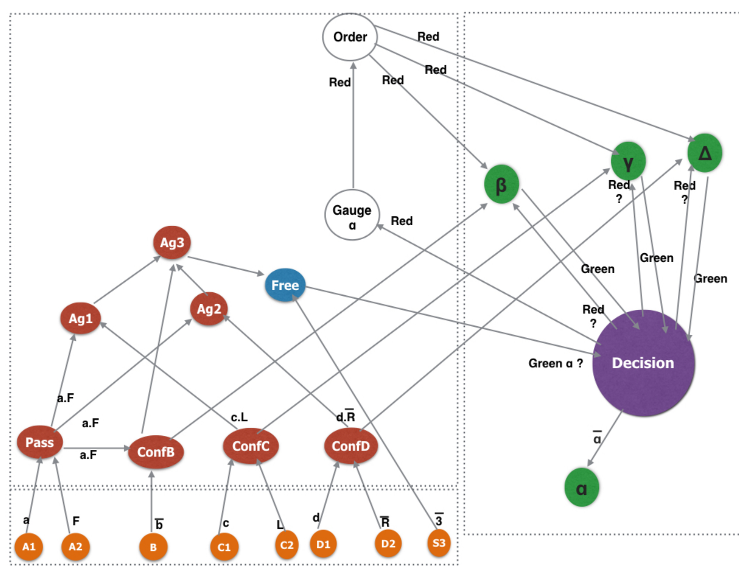

Fig. 5. Scenario to regulate traffic lights in case of pattern 11

CPS-Sensor "A1" detect the vehicle in front of the traffic light α. The CPS-Sensor "A2" detect that the vehicle want to go in the forward direction. CPSSensors send informations "F" and "a" to the Pass-Agent. The other sensors in the right lanes (C,B,D) send also their paths witch can lead to conflicts in the others roads to the respective Conflict-Agents. In this situation the car paths that can make conflicts when a vehicle in the position A want to go forward are :

- a car is detected by "D1" and the direction of this car detected by "D2" is the forward direction.
- a car is detected by "C1" and the direction of this car detected by "C2" is the left direction.
- a car is detected by "B1" with all possible direction of this car detected by "B2".

Produced and created events are Based on all defined rules. When the Free-Agent received events he created new event to permit to switch the "Traffic light α" to Green. The Decision-Agent received the event and began the interactions with traffic lights, in case of free roads Traffic-Light α change to green. The actual agent send also events to the "gauge α" when there were conflicts and the "traffic light α" remain the red-light. Finally after 100ms when the "gauge α" is full "gauge α" give an order to pass to green-light. In addition the meaning of events used in the scenario are presented in this table:

Events	Signification
a.F	a car was detected by the sensor « A1 » and the direction Forward « F » was detected by the sensor « A2 ».
$\overline{b}$	a car was detected by the sensor « B1 » with any choose direction detected by sensor « B2 »
c.L	a car was detected by the sensor « C1 » and the direction Left « L » was detected by the sensor « C2 »
d.$\overline{R}$	a car was detected by the sensor « D1 » and the direction Left « L » or Forward « F » was detected by the sensor « D2 »
$\overline{3}$	no cars detected by the sensor « S3 »
Green?	ask for the possibility to pass to green light
Red?	ask for the possibility to pass to red light
Green	order to change the signal to green light
Red	order to change the signal to red light
$\overline{\alpha}$	change the actual state of the traffic light α

B. Implementation overview

To establish the proposed model based on multi-agent and complex events processing, we developed an application using the Microsoft Visual studio with the object oriented language C# . This implementation aims to create every type of agents defined before (Sensor agent, Actuator agent , software agent), and manage all possible complex events based on a traffic business rules. This application allows reactive agents to receives events and also send environment, the first step consist to define the hierarchy of agents on the application and to create a listeners that allow every type of agents to observe a part of the system as presented on our model (fig.5). In addition, to assess our model and to test the effectiveness of the built scenario that aims to ensure the management of road traffic using complexes events processing based on multi-agent system and keep the green light for longer time. As future work, we plan to evaluate experimental results of the proposed system in comparison with different scenarios using Several metrics "Waiting time, Queue length, Travel time"

V. CONCLUSIONS

This paper used "Event processing" to monitor the traffic flows process by looking for the exceptional behavior (pass or conflicts) and by generating alerts when such behavior will happen. In such cases the proposed model used the agents to react after this alerts because the job of an event processing application is to produce the alerts only. The decentralized approach based on agents and Event processing guaranty the delivery of the right information to the right agent at the right time.

CPS-sensor can observe the entry and exit points of roads at a single intersection. Vehicles are detected based on analysis of a CPS-sensors reading . The main difficulty is extracting and interpreting the actual events from CPS-sensors. This system demonstrates the need to use of event processing to trigger business processes, where the events need to be obtained as a result of analysis. CPS Sensors have a principal role in the observation of the traffic flows by sending events to drive after that to actions performed by agents in the system. The agents dynamically react to the incoming events respecting the "perception-decision-action" cycle. This actions are based on business rules that can permit to manage signal and ensure a minimal waiting time of vehicles at a single intersection.

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