Modeling and Simulation of Urban Mobility in a Smart City

Abstract—**Agent based urban modeling for smart cities face many challenges dealing with complexity of systems and requiring expertise in various domains. Simulation models could be used to offer decision support and a tool to evaluate different scenarios and modeling. Agent based modeling has been used to create a case study for a simulation of mobility urban of smart city.**

Keywords—smart city, urban mobility, simulation, modeling, agent based approach

I. INTRODUCTION

According to recent studies the world's urban population is on the rise. Consequently, cities will face challenges concerning growth and urban concentration, competitiveness, and residents' livelihoods. The global urbanization trends and the increased number of residents living in urban areas generate additional mobility. Most cities in the world are confronting to establish a sustainable traffic system, which is essential for maintaining and improving the urban environment [12].

The potential risk of worldwide climate change is another argument for a strong need for urgent actions, to reconceive the way to consume and produce the energy that is need. The integration of renewable energy sources into urban energy networks and the increase in energy efficiency in cities are some of the core topics to be addressed in the near future. As urbanization is progressing worldwide and due to the fact that almost two thirds of our energy is consumed in urban environments, intelligent cities will play a significant role in the cities of the future and urban transformation. There is an urgent need to improve the understanding of cities and their metabolism, however, is pressed not only by the social relevance of urban environments, but also by the availability of new strategies for city-scale interventions that are enabled by emerging technologies. Leveraging advances in data analysis, sensor technologies, and urban experiments, Smart City approach can provide new insights into creating a data-driven approach to urban design and planning. To apply this approach is need for a scientific understanding of cities that considers the built environments and the people who inhabit them [10].

The term "smart city" was coined towards the end of the 20th century. It is rooted in the implementation of user-friendly information and communication technologies developed by major industries for urban spaces. Its meaning has since been expanded to relate to the future of cities and their development [1].

Smart cities emerge as the result of many smart solutions across all sectors of society: Smart mobility, smart safety, smart energy, water and waste, smart building and living, smart education, smart finance, smart tourism and leisure, smart retail and logistics, smart manufacturing and, construction, smart government.

The emergence of the smart cities permits to have goals as :

- Economic growth,
- quality of life,
- a good city to live in,
- ecological footprint

these goals can permit the challenges as:

- controlled transision of labor market to automation.
- winning the war on talent between metropolitan areas.
- Social cohesion, inclusiveness, solidarity.
- Secure digital environnement, privacy.
- Resilience.

Smart cities forward-looking, progressive and ressource-efficient while providing at the same time a high quality of life. They promote social and technological innovations and link existing infrastructures. They incorporate new energy, traffic and transport concepts that go easy on the environnement. Their focus is on new forms of governance and public participation. Intelligent decisions need to be taken at the strategic level if cities want to become smart. It takes more than individual projects but careful decisions on long-term implementation. considering cities as entire systems can help them achieve their ultimate goal of becoming smart.

Smart cities fully tack the current global challenges, such as climate change and scarcity of ressources. Their claim is also to secure their economie competitiveness and quality of life for urban populations continuously on the rise.

Main fields of action in this context are energy, mobility, the environment, the economy, society, politics, administration and quality of life. Some of the above are intertwined and increasingly networked with the support of IT. Technical, economic and social innovations provide the foundation for such activities. Smart cities build on sustainability but also on resilience in the sense that cities as systems are made more resistant and adaptable to influences from inside and out [1], [4], [5].

In the literature several studies have been carried out on environment sustainability, concerning every individual which is one of the most critical problems in world. The main objective in this area is to preserve scarce resources and reduce CO_2 emissions in order to prevent environmental degradation. In recent years the potential of information systems (IS) as a driver for environmental sustainability has emerged under the term "Green IS" and other researches on the theme of urban development. Given that cities represent a huge share of environmental degradation due to factors such as mobility, energy and water consumption, and waste production, the municipal domain offers huge potentials in terms of sustainability. The advent of smart cites is an attempt to address this concern. In IS environmental sustainability research a crucial topic is presents and two different approaches are addressed: Green IT and Green IS. Whereas Green IT considers information technology (IT) to be a cause of environmental pollution, Green IS regards information systems and the inherent IT involved as a possible solution for reducing environmental degradation, [11].

In these context our research on mobility is to participate in presenting the information system in order to find a solution to the problem by modeling and simulating of mobility in the city, in order to facilitate the leaders to take decisions. The decisions based on information given by simulation to improve mobility, reduce CO2 emissions, preserve sustainability and facilitate human life in cities.

Our work is about smart mobility which means innovative traffic and transport infra-structure that saves resources and builds on new technologies for maximum efficiency. Accessibility, affordability and safety of transport system, as well as compact urban development are essential factors in this context. New user-friendly will make it easier for pepole to switch to integrated transport systems focused on environmentally friendly transport modes. Joint utilization, i.e. "car sharing", instead of private owner ship is what counts these days when using motor véhicles [6], to study intelligent mobility we must use new technologies in order to model the system and then simulate it in order to make some decisions concerning the planning of intelligent mobility or to add other infrastructures that will allow us to make intelligent mobility.

Agent-based models (ABM) include mobile and interacting agents in a spatially large urban context. Agent-based models mainly differ from Cellular Automata(CA) in that the used agents are objects without a fixed location. Agents can interact with each other as well as the environement in a acting autonomously. Succinctly, an ABM has the following characteristics:

- Agents are explicitly designed to represent a particular mobile object (e.g., a person); there may be more than one agent type in single simulation thus the agents are implicitly distributed throughout the environment.
- Agents can sense and act within their environment in one of several ways: behavior can be reactive (e.g., they behave solely on their surroundings) or deliberative (e.g., they have their own agenda or goal which drives their behavior); clearly the design of agents sensing and acting is critical to a simulation. Altogether, agents exhibit a form of autonomous behavior and thus lend themselves to a variety of simulated behaviors including emergent patterns. Within urban simulation, many works have focused on examining cities as self-organizing complex systems, and solutions have been designed to explore the emergent properties of agents with relatively simple behavioral rules embedded by the modeler. However, relatively other research has used the smart city representation using the 3D geometric representation which emits the cities from static and dynamic view. This presentation is not as easy to use and requires experts in modeling because some real situations are difficult to present, more that, modeling cities and urban spaces in general is a daring task for computer graphics, computer vision and visualization. Little attention has been paid to issues of validating models using observed data or trends and as with (CA) models, traditional ABM urban simulation have behaviors influenced only by a localized context [2], [3], [6], [7].

We propose a modeling of intelligent urban mobility, an example of a simulation case based on agents of the proposed modeling executed on the Netlogo platform. Individual car agents and pedestrians have been placed on the road network. Experiments out to asses the mobility system in a smart city. The following section briefly presents the agent-based PASSI modeling approach used in the context of this work. Section 3 introduces into the Netlogo platform the simulation example at the level of which presenting us results and comments on these results. A conclusion finalizes this document.

II. The Design Approach

Multi-Agent Systems (MAS) differ from non-agent based systems because agents are intended to be autonomous units of intelligent functionality. As a consequence, Agent-Oriented Software Engineering (AOSE) methods must complement standard design activities and representations with models of the agent. Some methods coming from artificial intelligence community adress social knowledge and relationships but have high-level design abstractions as their end points. In our work we use PASSI [9], which is a method for developing multiagent software that integrates design models and philosophies from both object-oriented software engineering and MAS using UML notation. The method has evolved through several stages, it has has been previously applied in the synthesis of embedded robotics software and they are currently exploring its applications to the design of various agent-based information systems. In PASSI an agent is a significant unit of software at both the abstract (low-fidelity) and concrete (high-fidelity) levels.

According to this view, an agent is an instance of an agent class that is the software implementation of an autonomous entity capable of pursuing an objective through its autonomous decisions, actions and social relationships.

An agent may occupy several functional roles during interactions with other agents to achieve its goals. Where a role is the collection of taskes perrformed by the agent in pursuing a sub-goal. A task, in turn is defined as a purpose ful unit of individual or interactive behavior.

The methodology is composed of five models, in which the agents are present [9]. Now we will present the diagrams of our approach to develop our application. We will follow the steps outlined of the approach in [9].

A. System Requirements Model

An anthropomophic model of the system requirements in terms of agency and purpose. Developping this model, involves four steps :

- **Domain Description :** A functional description of the system using conventional use-case diagrams.
- **Agent Identification :** Separation of responsability concerns into agents, represented as steriotyped UML packages.
- **Role Identification :** Use of sequence diagrams to explore each agent's responsibilities through role specific scenarios.
- **Task Specification :** Specification through a use case diagram and auxiliary descriptions of the capabilities of each agent.

Domain Description : Case name "Car Agent", fig1.

Agent Identification :

The main agents : Car (Cognitive agent)

This is the car driver he has knowledges of:

- Traffic lights status
- The traffic code
- Objects, people, animals, cars

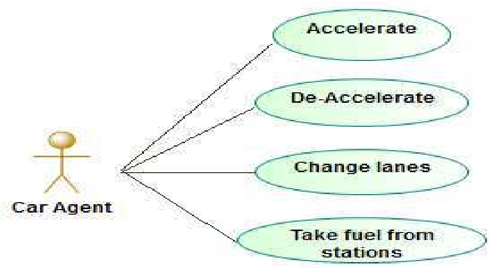

Fig.1. Car Agent use case diagram

Cars can make their own decisions, they can even turn at intersections.

Task Specification of Car Agent, fig.2.

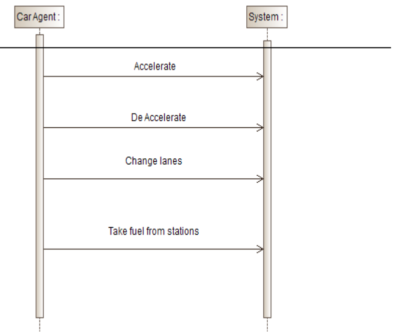

Fig.2. Car Agent Sequence Diagram

Domain Description :

Case name : "Agent pedestrian", fig.3.

Agent Identification :

The main agent : pedestrian (Cognitive agent).

He has knowledges of:

- Traffic lights status
- The traffic code
- Objects, people, animals, cars

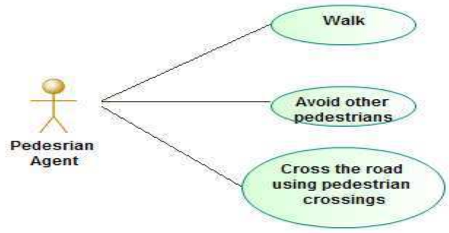

Fig.3. Pedestrian Agent use case diagram

The pedestrian agent who can walk, avoid other pedestrians cross the road using the "crossings".

Task Specification of Pedestrian Agent, fig.4.

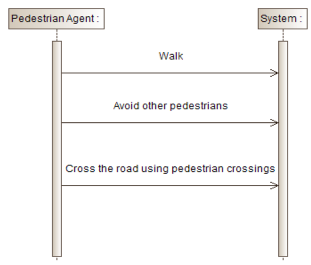

Fig.4. Pedestrian Agent communication protocol diagram

B. Agent Society Model

Amodel of the social interactions, fig.5 is presented by the sequence diagram which descibes the communication protocols :

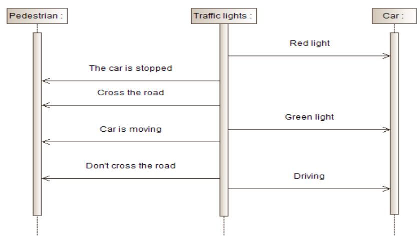

Fig.5. Communication Protocol diagram

The traffic light agent sends two types of signals to the car, if the signal is red the light informs the pedestrian that the car is stopped and that he can cross the road. If the opposite case the trafic light sends a light green towards the car to allow it to move and should not cross the road.

C. Description of the Domain

Used to describe the agent society from a domain point of view (class diagram called domain diagram) and the exchange of information between agents (class diagram called communication diagram).

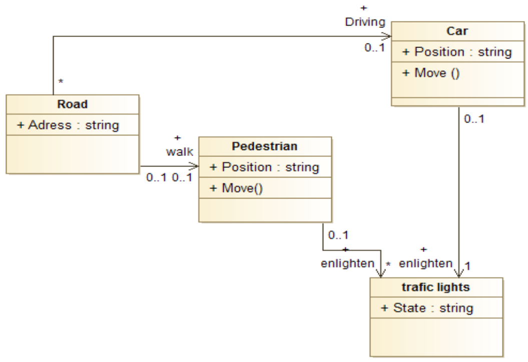

Fig.6. Ontology class diagram of the city's transport mobility flow diagram

The fig.6 shows the relationships between the road, car, pedestrian and traffic light classes and when can pedestrians cross the road by operating on the traffic light, if it is green or red and the cars that can move, respecting the signaling order given by the fire. The construction of domain diagram is to built the database of the system to be implemented.

In this section we have presented the design of our system using the PASSI approach that is proposed for the agent-based modeling of a city's transport mobility flow. The implementation of our system will be presented in the next section. In this section, we will detail the implémentation part of our application. First we present NETLOGO platform. Then, we expose parts of the source code of our system and finally we will finish with some screenshots of the application.

III. Development Tools Netlogo Platefform

Netlogo is a programming environment for the modeling /simulation of natural collective phenomena well suited to the modeling of complex systems composed of hundreds, thousands of agents acting in parralel. Possibility to « play » with many simulation in sociology, biology, medecine, phisics, chemistry, mathematics, computer science, economics and social psychology. Possibility of creating your own models [8].

A. Agent concepts

The world of Netlogo is made up of agents, who can follow instructions. The activities of the different agents run simultaneously. There are three agent types: turtles, patches, and observer.

- Turtles are the agents that move around the world. They correspond to the agents seen in progress.
- The world is in 2D or 3D, divided according to a grid (toric or not) of patches.
- A patches is a portion of the ground on which turtles can sit and move. The patches correspond to the concept of environnement seen in progress.
- The Observer looks at the word of turtles and patches from the outside (is not located in the world)

B. Simulation of the application

In the nexte part we present some main screenshots of our application.

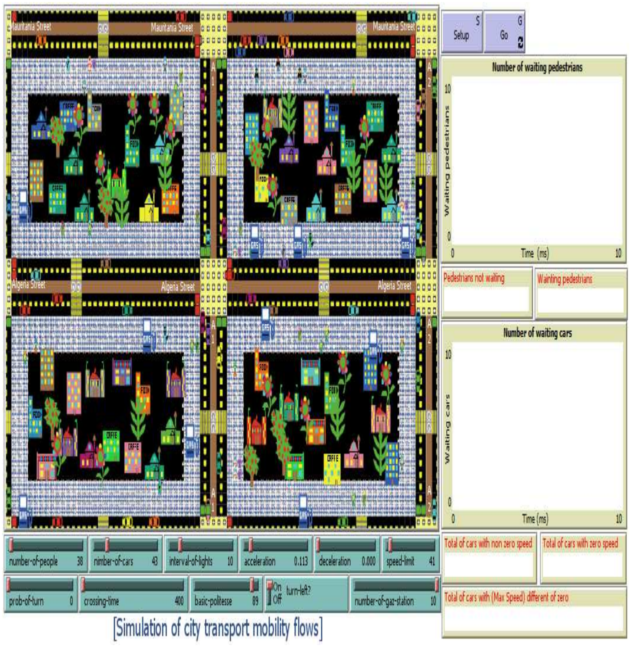

Fig.7. Dashboard of the application

The fig.7 shows the dashboard of the application for example the simulation screen which shows the houses, the trees, the flowers, the cars and fuel stations, the roads and the people who live in the city and other tools, it offers the Netlogo platform such as sliders, switches, buttons. All the tools that exist in the simulation were not shown due to the screenshot witch is small.

```
breed[cars car]
;breed[trucks truck]
breed[houses house]
breed[trees tree]
breed[crossings crossing]
breed[lightsR lightR]
breed[lightsL lightL]
breed[lightsU lightU]
breed[lightsD lightD]
breed[persons person]
breed[stations station]
```

Fig.8. breeds definitions

The fig.8 above shows a slice of code and shows that Netlog allows you to define different breeds of turtles and breeds of links. Once these breeds are defined, you can go one step further and give these different breeds behaviors. For example, you can have called persons and sidewalks and then have the persons walk on the sidewalks and and vehicles travel on the roads.

```
patches-own[
   meaning
   will-cross?
   used
   traffic
]
globals[
   redV
   greenV
   redH
   greenH
   speedLimit

]
persons-own[
   speed
   walk-time
   crossing-part
   waiting?

]

cars-own[
   speed
   maxSpeed
   will-turn?
   turnX
   turnY
   politeness
   will-stop?
]
```

Fig.9. Definition of variables

The fig.9 shows keywords, like :

- **Patches-own :** it defines variables that all patches can use,
- **Globals :** it defines new global variables the "global" variables are accessible by all the agents and can be used anywhere in a model.
- **The turtles-own :** it defines the variables belonging to each turtle as persons-own and cars-own, and its keywords can only be used at the start of a program, before any function definition. It defines the variables that all patches can use. All patches will then have the given variables and can use them.

Example: at the cars-own level we have the speed of the car speed, then the maximum speed that the cars can reach **maxSpeed,** then **will-turn** ? which represents whether the car is going to turn or not and the turn X/Y which represents left or right turning then we politeness of cars, that means how often they will stop and let people cross the road, then the will-stop ? that means if the car will stop or not.

```
to setup
  ca
  set speedLimit speed-limit
  draw-sidewalk
  draw-roads
  draw-houses&trees
  draw-crossings

  place-cars
  ;place-trucks
  place-lights
  place-people
  place-stations


  reset-ticks
  tick
end

to go
  move-cars
  ;move-trucks
  control-traffic-lights
  move-people
  plot-waiting
  plot-waitings
  tick
end
```

Fig.10. The setup and go procedures

In the fig.10 we have the procedure to setup which starts to define a procedure named « **setup** », « **ca** » is the abbreviation of clear-all. This command will clear the screen, initialize any variables you might have to 0, and remove all turtles. Basically it cleans up the slate for a new run of the project, « **set** » define the variable to set the value given here draw-roads, draw houses and trees, draw crossings this means to draw the roads then the houses and the trees and the crossings, the procedure togo lance the simulation for example to make move the cars and the people, to control the traffic lights.

```
to plot-waiting
  set-current-plot      "Number of pedestrians waiting"
  set-current-plot-pen   "Pedestrians waiting"
  plot (count persons with [waiting? = true])
end

to plot-waitings
  set-current-plot      "Number of Cars waiting"
  set-current-plot-pen   "Cars waiting"
  plot (count cars with [speed = 0])
end
```

Fig.11. The code of the number of pedestrians and cars waiting

The previous fig.11 shows the code of the number's waiting pedestrians and the number's waiting cars.

The fig.12 below shows the results in the "**plots**" on the dashboard of the simulation number's waiting pedestrians and the number's cars waiting in milliseconds.

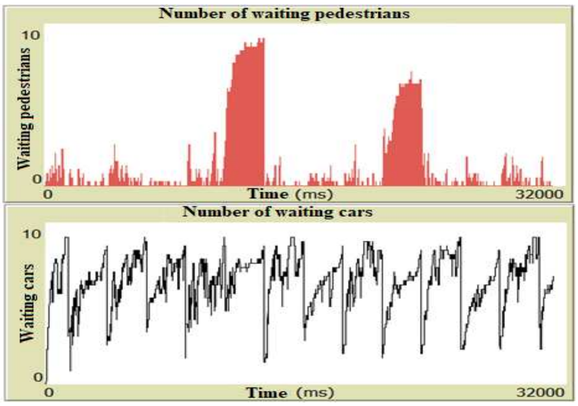

Fig.12. The display of pedestrian "plots" and waiting cars

The fig.13 below shows the "sliders" and the "switches" number of people, cars and fuel stations has the role of increasing or to decrease the number of people and cars and fuel stations in the city. The acceleration and deceleration sliders have the role of increasing or decreasing the speed of the cars. The interval-of- lights "slider" defines the traffic light interval, the speed-limit slider to set the speed limit of cars in the city, the prb-to-turn slider sets the probability of turning, that is, indicates the probability of the cars turning on the right / left at the junction, the time-of-crossing slider says how long pedestrians have to walk before they start looking for a passage and decide to cross the road, the basic-politeness "slide" sets the value of input for calculating the courtesy of cars, finally, do we have the left-turn switch ? Says whether cars will be able to turn left or not.

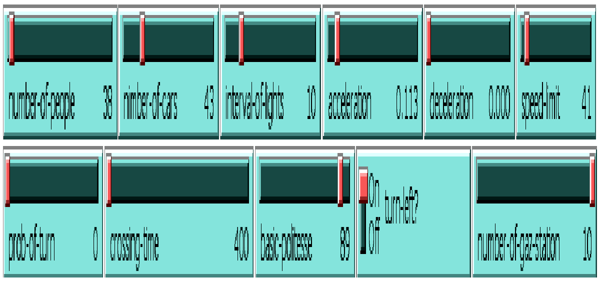

Fig.13. Sliders and switches

This fig.14 shows the number of pedestrians waiting or not waiting in the city.

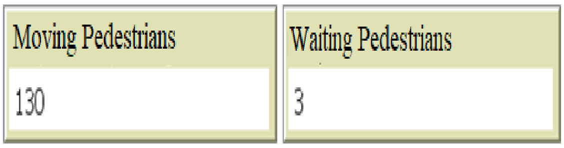

Fig.14. The number of pedestrians waiting and not waiting in the city

The fig.15 shows the number of cars whose speed is different from zero, i.e. the cars which circulate in the city then the cars which do not move i.e. the cars whose speed is zero and the cars whose maximum speed is different from zero.

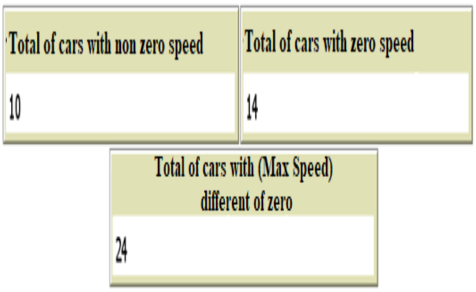

Fig.15. The number of cars wich zero and maximum speed and different to zero

The following fig.16 shows the number of fuel stations in operation in the city and the number of cars and the number of pedestrians in the city.

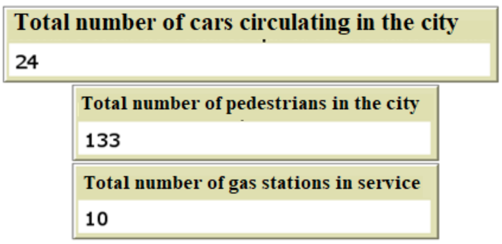

Fig.16. Stations, cars and pedestrians in the city

The fig.17 shows the street names Algeria Street, and Mauritania Street and streets A1 and A2 which represent A1and A2.

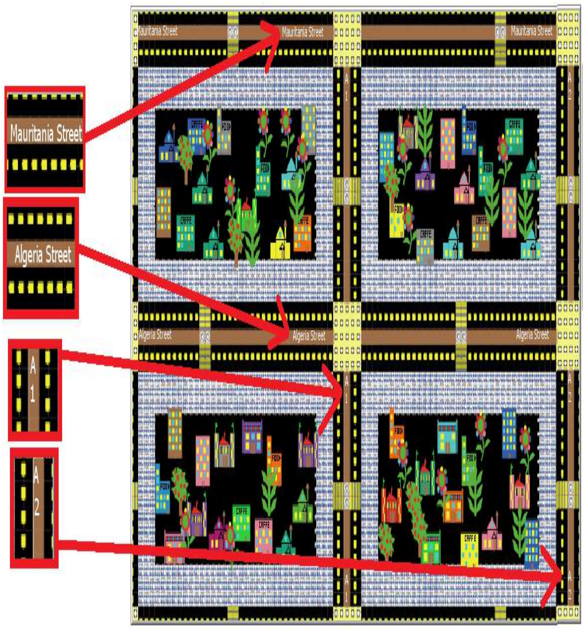

Fig.17. The Streets of the city

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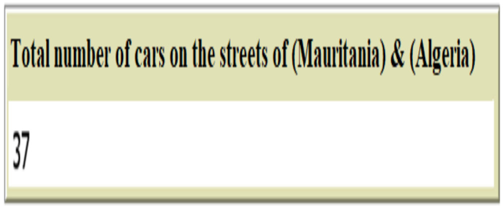

Fig.18. Total number of cars on the streets Algria and Mauritania

The fig. 18 above displays the number of all the cars which circulate on the horizontal streets Algeria and Mauritania are 37 cars.

Discussion

We have provided a challenge for smart urban mobility modeling and simulation that is not too detailed, but the simulation model can offer decision support and can provide a tool with which different scenarios and designs can be compared. and evaluated in an iterative manner with a team of leaders and experts in urban mobility to address the socio-technical nature of cities.

There are key challenges to change or improve mobility to make it smart, such models require teamwork and collaboration between experts in order to give a reliable model and which also requires data collection in cities using information systems if they exist to avoid redoing because it requires hardware (such as cameras and software) that can provide us with the data necessary to study the simulation with real data and from that the experts according to the needs of the cities will propose solutions to the master plan.

Through the use of agent-based modeling the master plan can be iteratively evaluated in real time as part of the normal workflow, this is where the real power lies, as complex planning and design decisions are made can be tested and verified instantly by simulating the real impacts that a new urban proposal will have on a city.

In order to provide solutions for urban mobility it is necessary to rethink the way in which people can move through the new road traffic, the means of transport used, the car parks which help in the ease of parking and avoid congestion by certain means of transport.

We also have to think about how to make traffic flow smoothly during rush hour to reduce the increase in CO2 emissions from transport. All of this requires smart techniques and advanced intelligent information systems to make city mobility in cities, smart.

Conclusion

Transport was one of the sectors to integrate digital devices to better manage flows in the city. Globally, three dimensions are used to capture the transport and intelligent mobility of a city :

1) improving logistic flows to ensure greater efficiency of businesses through increased knowledge of the network ;

2) providing real-time digital information to users on traffic conditions ;

3) helping to develop collaborative or alternative modes of travel for people in the transition to mobility less dependent on the private car.

In the example of the simulation we have used two types of agents which are vehicles and pedestrians. Our objective is to simulate an intelligent digital system which reflects the real system and which contains all of these agents. Each agent works individually but in collaboration with the other agents is the better regulate traffic and to ensure adequate pedestrian passage and to avoid traffic jams on the roads.

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