An agent based approach for simulating complex systems with spatial dynamicsapplication in the land use planning

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***Abstract*—In this research a new agent based approach for simulating complex systems with spatial dynamics is presented. We propose architecture based on coupling between two systems: multi-agent systems and geographic information systems. We also propose a generic model of agent-oriented simulation that we will apply to the field of land use planning. In fact, simulating the evolution of the urban system is a key to help decision makers to anticipate the needs of the city in terms of installing new equipment and opening new urbanization' areas to install the new population.**

Keywords-Multi-agent system; Geographic information system; Modeling; Simulation; Complex system; Land use planning.

I. INTRODUCTION

A great part of the challenge of modeling and simulating interactions between natural and social processes has to do with the fact that processes in these systems result in complex temporal-spatial behavior. To deal with this problem, we propose a general architecture based on two modules:

- A GIS module: to instantiate the simulation engine.
- A MAS module: to represent the interactions between the different agents of the system

We also propose a generic agent-oriented model for simulating complex systems with spatial dynamics.

We apply our model to the field of land use planning. In fact, we will study the urban system and simulate its long term evolution through a backdrop of demographic change in a temporal-spatial heterogeneous environment.

Our objective is to understand how public policy can influence the transformation of cities, especially in regard to the opening of new urban' areas and installing new equipments.

II. STATE OF THE ART

In this section, we will detail the multi-agent systems, geographic information systems, complex systems and agent-based modeling. These points are the core of our design model simulation.

A. Multi agents approach

1) Notion of agent

An agent is a physical or virtual feature, which owns all or part of the following:[1]

- Located in an environment: means that the agent can receive sensory input from its environment and can perform actions that are likely to change this environment.
- Independent: means that the agent is able to act without the direct intervention of a human (or another agent) and he has control of its actions and its internal state.
- Flexible means that the agent is:
  -Able to respond in time: it can sense its environment and respond quickly to changes taking place.
  - Proactive: it does not simply act in response to its environment; it is also able to behave opportunistically, led by its aims or its utility function, and take initiatives when appropriate.
  - Social: it is capable of interacting with other agents (complete tasks or assist others to complete theirs)

2) Multi agents system

A multi-agents system (MAS) is a system composed of a set of agents situated in some environment and interacting according to some relations. There are four types of agent architecture [2]:

- Reactive agent: is responding to changes in the environment.
- Deliberative agent: makes some deliberation to choose its actions based on its goals.
- Hybrid agent: that includes a deliberative as well as a reactive component
- Learner agent: uses his perceptions not only to choose its actions, but also to improve its ability to act in the future.

B. Geographic Information System

1) Definition

According to the Environmental Systems Research Institute (ESRI), "a geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information."

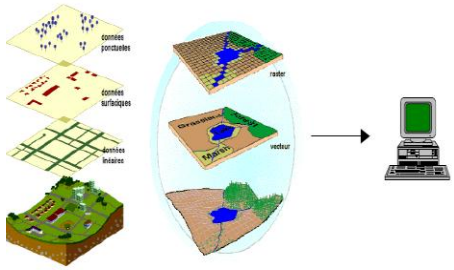

Figure 1.Geographic Information System.

2) Functions of GIS

The Functions of GIS describe the steps that have to be taken to implement a GIS. These steps have to be followed in order to obtain a systematic and efficient system. The steps involved are:

- Data Capture: Data used in GIS often come from many sources. Data sources are mainly obtained from Manual Digitization and Scanning of aerial photographs, paper maps, and existing digital data sets. Remote-sensing satellite imagery and GPS are promising data input sources for GIS.
- Data Compilation: Following the digitization of map features, the user completes the compilation phase by relating all spatial features to their respective attributes, and by cleaning up and correcting errors introduced as a result of the data conversion process.
- Data Storage: Once the data have been digitally compiled, digital map files in the GIS are stored on magnetic or other digital media. Data storage is based on a Generic Data Model that is used to convert map data into a digital form. The two most common types of data models are Raster and Vector.
- Manipulation:Once data are stored in a GIS, many manipulation options are available to users. These functions are often available in the form of "Toolkits."
- Analysis:The heart of GIS is the analytical capabilities of the system. The analysis functions use the spatial and non-spatial attributes in the database to answer questions about the real world. Geographic analysis facilitates the study of real-world processes by developing and applying models. Results of geographic analysis can be communicated with the help of maps, or both.

C. *Complex system*

A complex system is a set consisting of a large number of interacting entities that prevent the observer to predict its feedback, behavior or evolution by calculation. It is characterized by two main properties [3]-[4]:

- Emergence is the appearance of behavior that could not be anticipated from the knowledge of the parts of the system alone
- Self-organization means that there is no external controller or planner engineering the appearance of the emergent features

Traditional modeling approaches for complex systems focus on either temporal or spatial variation, but not both. To understand dynamic systems, patterns in time and spaceneed to be examined together.

The proposed architecture for simulating complex systems that is used in this study, meshes these fields together in an approach called Simulating Complex System with Spatial Dynamics.

D. Agent-Based Modeling of Complex Systems with spatial dynamics

We note that the Agent-Based Modeling (ABM) is well suited to complex systems with spatial dynamics. In fact, the various components of these systems can be represented by agents.

We mention below four characteristics that show why Agent-Based Modeling is well suited to complex systems with spatial dynamics [4]-[5]:

- Emergence: ABMs allow to define the low-level behavior of each individual agent in order to let them interact (over time and space) to see whether some emergent property arises or not, and if it does, under which circumstances.

- Self-Organization: ABMs do not have any kind of central intelligence that governs all agents. On the contrary, the sole interaction among agents along with their feedbacks is what ultimately “controls” the system. This lack of a centralized control is what enables (and enforces) its self-organization.

- Coupled Human-Natural Systems: ABMs allow considering together both, social organizations with their human decision-making with biophysical processes and natural resources. This conjunction of subsystems enables ABMs to explore the interrelations between them, allowing analyzing the consequences of one over the other.

- Spatially Explicit: the feature of ABMs of being able to spatially represent an agent or a resource is of particular interest when communications and interactions among neighbors is a key issue. This can either imply some kind of internal representation of space or even the use of a Geographical Information System (GIS) with real data. This feature is of special interest in the case of agro-ecosystems.

III. AGENT-ORIENTED SIMULATION VS CLASSIC SIMULATION

A. Definitions

Simulate is to reproduce a phenomenon in order to [6]:

- Test hypotheses to explain the phenomenon
- Predicting the evolution of the phenomenon

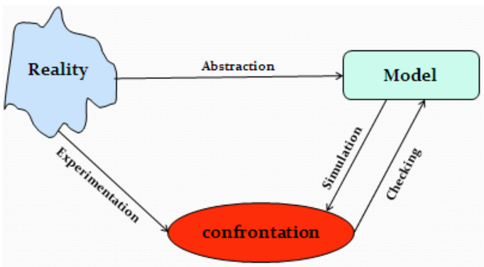

Figure 2.Simulation process.

Model is a simplified picture of reality that we use to understand the functioning of a system based on a question.

B. Classic simulation

1) Continuous models

Continuous time models are characterized by the fact that in a finite time interval, the system state variables change value continuously [6]-[7].

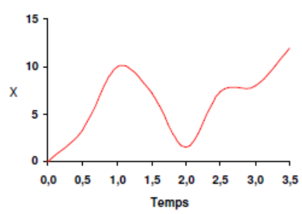

Figure 3.Continuous models

The simulation of continuous models encounters the difficulty of reproducing the continuity of the system dynamics due to the nature of the digital computer (solution: use of numerical integration methods)

2) Discrete models

The evolution of variables' state of the system is discretely at a time t after t + dt [7].

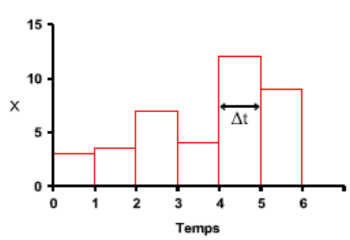

Figure 4. Discrete models

The simulation of discrete models can be summarized in two steps:

- Determine the function that implements the system dynamics.
- Increment time by one unit.

In this type of simulation the choice of the time step is very important because:

- If a large time step:

Problem of management competitive events; Events in rapid occurrence are not considered

- If small time step:

Problem of decomposition behavior in elementary behaviors

3) Discrete event models

The time axis is generally continuous; it's represented by a real number. However, unlike continuous models, the system state variables change discretely at precise moments that are called events.

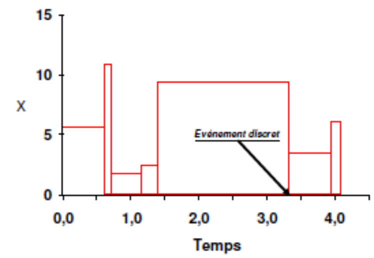

Figure 5. Discrete event models

In this type of simulation, there are three policies implementation:

- Scheduling of events: during the simulation, the future events that must occur on the system are predetermined;
- Analysis of activities: during the simulation, the events are not planned but triggered when certain conditions are met (collision of two vehicles, ...);
- Interaction process: this approach is the combination of the two others.

C. Limits of Classical Simulation

In the classical simulation, we found the following limits [6]:

- Equation in model with a large number of parameters;
- Difficulty of passing micro/macro, unable to represent different levels;
- No representation of behavior, but their results;
- Lack of realism (social sciences...);
- Does not explain the emergence of space-time structures;
- Difficulty of modeling the action.

D. Agent-Oriented Simulation

Agent-Oriented Simulation (AOS) is now used in a growing number of sectors, where it gradually replaces the various techniques of micro simulation and object-oriented simulation. This is due to its fundamental characteristics which are [6]-[9]:

- Representation as computer agents (state, skills, abilities, resources);

- Representation of possible interactions between agents;
- Representation of space-time environment (agent is located).

This apparent versatility make the AOS the best choice for simulating complex systems and it spreads in a growing number of areas: sociology, biology, physics, chemistry, ecology, economics, land use planning, etc. The four aspects of a simulation model are:

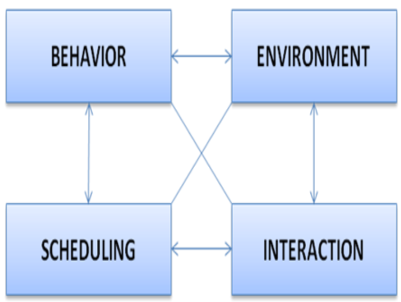

Figure 6. Agent oriented simulation model

- Module behavior: it relates to the deliberative process modeling agents;
- Module environment: the problem is to define the various physical objects in the world and the dynamics of the environment;
- Module scheduling: it concerns the modeling of the flow of time and the definition of scheduling used;
- Module interaction: it relates specifically to the modeling result of the actions and interactions they entail at time t.

IV. Proposed Approach

A. System Architecture

The simultaneous use of a geographical information system and a multi-agents system introduces an additional level of modeling complex system with spatial component. We propose the following architecture:

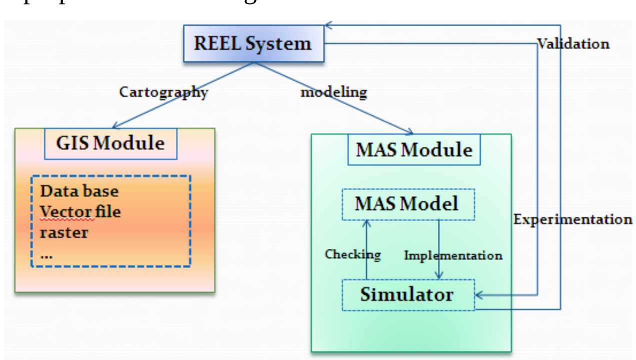

Figure 7.Proposed architecture.

- The module "GIS" is a descriptive representation of the reality that is used to initialize the multi-agent model, it contains the data to instantiate each one of the agents;
- The module “MAS” is used to model the real system and generate simulations involving agents that react and interact and so it can test scenarios.

B. Generic model of agent-oriented simulation

To simulate complex systems with spatial component, we propose the following generic model:

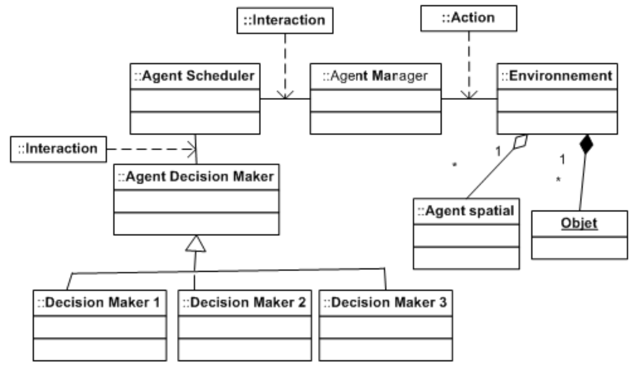

Figure 8.Generic model for agent-oriented simulation.

- The environment is heterogeneous composed of objects and spatial agents;
- Spatial Agent: This is the basic entity that represents the spatial part of our simulator.
- Agent manager: it is the agent that creates and acts on all environmental agents. Also, it interacts with the scheduler agent to determine the scheduling of its actions on the agents. It is responsible for the initialization of the simulation;
- Agent scheduler: Its role is to schedule the actions of the agents on the environment;
- Agent decision maker: it has several rules that must be applied to the environment

V. Application

A. Problematic of land use planning

We propose to apply our architecture to the field of land use planning. Our goal is to understand how public policy can influence the transformation of cities, especially in regard to the opening of new urban areas and installing new equipment. The simulation will determine when, during the dynamic of the city, public policy can act and have the most impact. As the modeling context we choose the city“Casablanca”, and more specifically the district “Dar Bouazza”.

1) Population dynamic

The population of Casablanca was established in the 2004 census, approximately to 3.63 million resident, 3 325 000 in urban areas and 305 000 in rural areas. It has an annual growth (50 500 persons per year)

For the district “Dar Bouazza”, it has a population of 115367 residents with a growth rate of 1.8% [10].

2) Spatial dynamic

- Not enough housing: Housing remains a subject of major concern for the government. In fact, the insufficient offer of housing is a major problem in the field of land use planning.

- Lack of equipment in some region: the district "Dar bouazza" is experiencing an apparent lack of equipment compared to the normative grid of equipment to provide:

Nature of equipment	***Users***	***Area (m²)***
Teatching		
primary school	1/8000	4000
school	1/16000	8000
high school	1/32000	10000
health		
Urban Health Center	1/30000	500-1000
Local Hospital	1/100000	15000-30000
Sports		
Sports area	1/45000	10000
Sports center	1/150000	50000
Public Services		
Marketplace	50000	2500 - 4000
Administratif		
Police station	1/45000	2000
civil Protection	1/100000	10000
Administrative Services undefined	1/45000	3000
cultual		
mosque	1/15000	3500

TABLE I. NORMATIVE GRID OF EQUIPMENTS

- Lack of green spaces: Casablanca knows deficiencies of green spaces. The average is less than 1m² of public green space per resident, compared to the standard 10 m2 per resident of the World Health Organization.

B. Agent-oriented simulation model

We apply our agent-oriented model in the context of land use planning, the system consists of: Agent Manager, Agent schedulor, LandUseAgent and two agents decision maker.

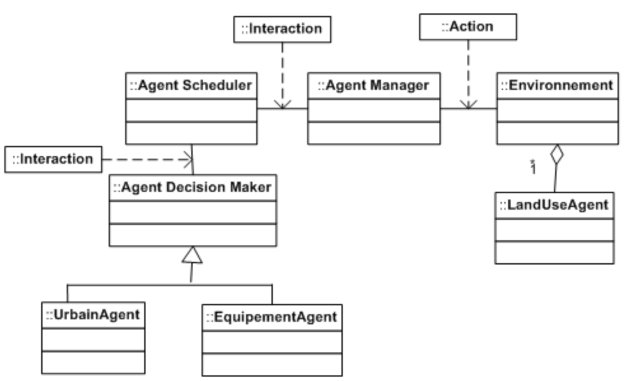

Figure 9.Agent-oriented model for simulation applied to the field of land use planning.

- Agent Manager: it initializes the simulation and creates displays. At each iteration, it executes the actions scheduled in the Agent Scheduler;
- Agent Scheduler: at each step, it called the actions of decision makers in a synchronous manner. The step in our model is one year;
- LandUseAgent: This is the entity that constitutes the spatial environment, it has:

An attribute "State": This contains information about the mode of land use. It can take the following values (bare land, land built, industrial area, green space)Attributes "potentiel_urban, potentiel_equip, potentiel_environnement": these attributes vary between 0-3 and indicate the potential of the cell to be intended to urbanization, to receive equipment or to be conserved as green space. The cell potential is calculated based on the master plan of Casablanca that indicates the destination overall soil over the next 30 years [10].

- UrbainAgent: its objective is to ensure urban sprawl for the installation of the new population; it obtained a surface demand. At each cycle, the agent performs the following operations:
  - • Get the value of the new population;
  - • Multiply this value by a stretch ratio set by the user;
  - • Obtain a surface demand.

According to the constraints defined by the user agent changes the state of the cells by taking them from its target list (starting from the highest urban potential of the cells).

- EquipementAgent: its aim is to provide a number of facilities to suit the new population. At each cycle the agent performs the following operations:
  - • Get the value of the new population;
  - • Calculate the number of existing facilities;
  - •Calculate the amount of equipment required for the installation of the new population;
  - • Extract a demand.

According to the constraints defined by the user, EquipmnentAgent changes the state of the cells by taking them from its target list (starting from the highest potential of the cells).

A. Realization

To implement our model, we chose the multi-agent simulation platform Repast Simphony 2.0 [11] and the GIS software ArcGIS.

Our work environment is:

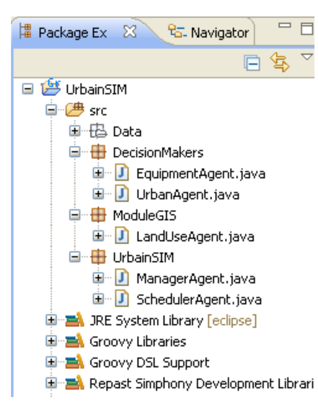

Figure 10.Environment work.

The user can specify the rate of urban growth and the ratio of urban sprawl by this interface:

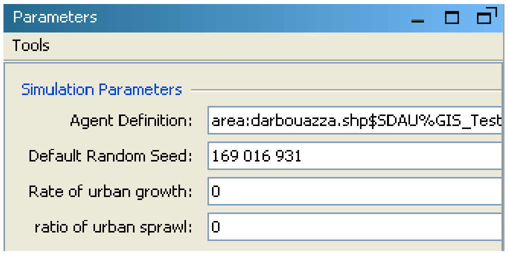

Figure 11.Environment work.

The initial state of the simulator is:

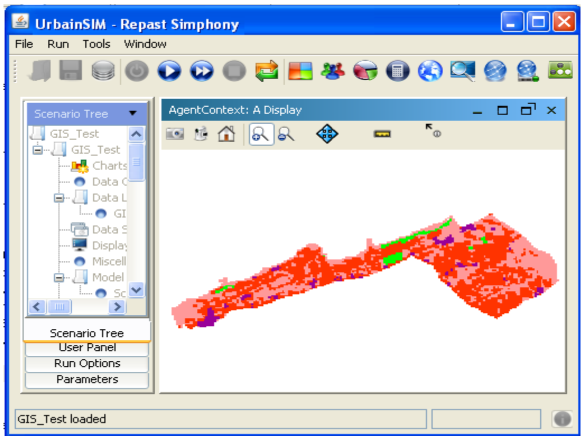

Figure 12.initial state of the simulator.

Legend :

Bare land

Built land

Industrial area

Green space

After twenty iterations, the population of “Dar Bouazza” has increased from 115 367 to 156 899 residents. To install the new population, UrbanAgent will open new areas to urbanization. It calculates the demand and changes a number of cells of the SpaceAgent (starting from the highest potential of the cells) to built land. The choice of cells to change is done in a random way. We obtain the following result:

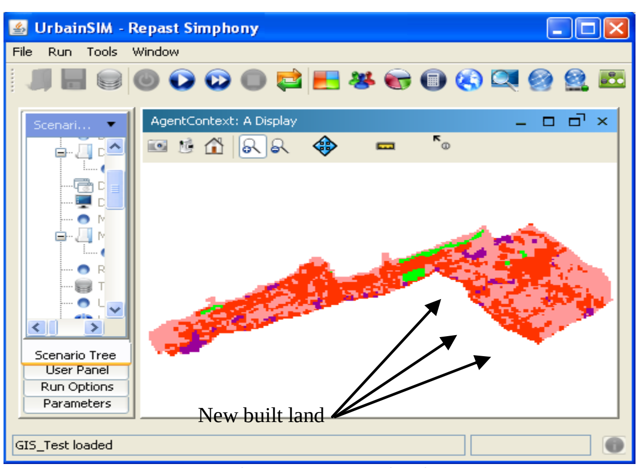

Figure 13.Results of the simulation after five iterations.

After 20 iterations, we see that the number of Equipment to create at "DarBouazza"is about twenty equipments as detailed in the diagram below:

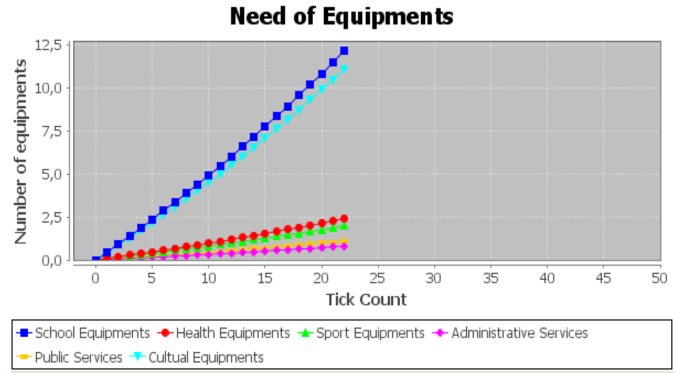

Figure 14. Need of equipments.

The installation of the new population will require the construction of:

- Eleven school equipments distributed as follows: Six primary schools, three schools, one high school.

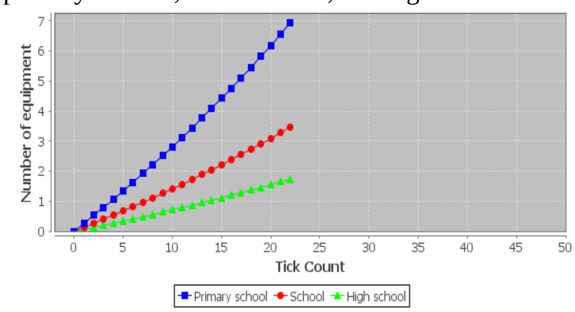

Figure 15. Need of school equipments.

- Ten cultualequipments (mosque)

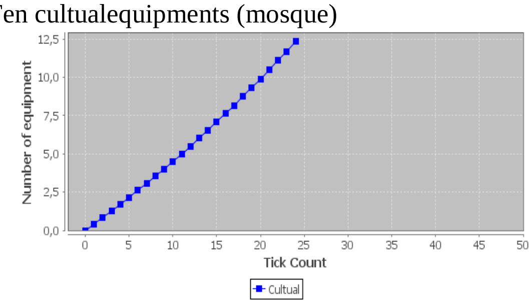

Figure 16. Need of cultualequipments.

- Two health equipments distributed as follows

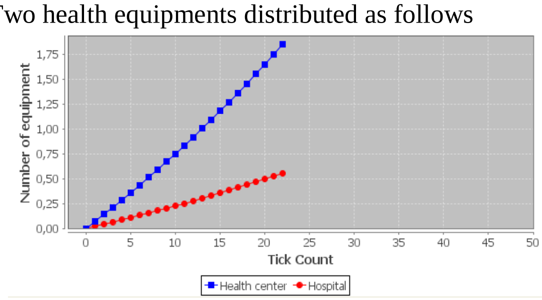

Figure 17. Need of health equipments.

- One sport equipment distributed as follows:

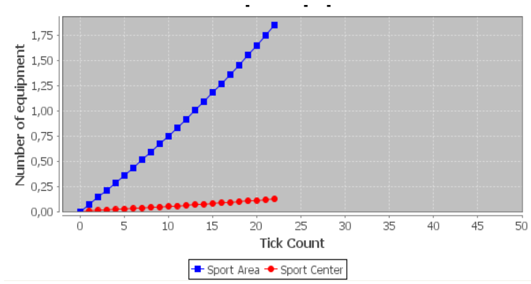

Figure 18. Need of sport equipments.

- Administrative services may not to be created as it's showed below:

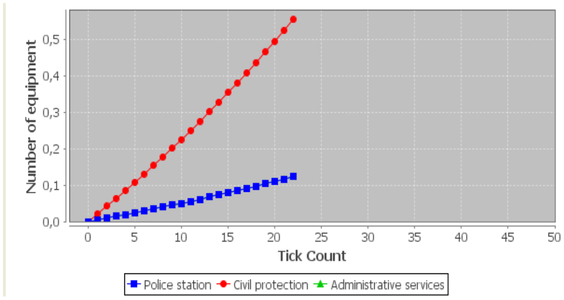

Figure 19.Need of administrative services.

- One public service:

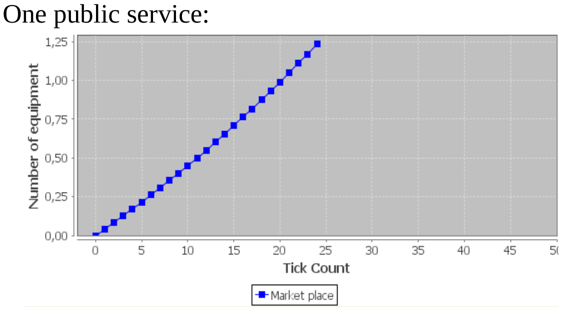

Figure 20. Need of public services.

VI. Conclusion

In this paper, we propose a new approach for simulating complex systems with spatial dynamics. First, we presented an architecture based on coupling between the two systems GIS and MAS. Then, we also proposed an agent-oriented simulation model. We applied our model to the field of land use planning. Our objective is to simulate the evolution of the city based on two dynamics: population dynamics and spatial dynamics. Results of the simulation show that after twenty iterations, it will be necessary to open about40 ha to urbanization and to construct about twenty equipments.

As perspectives to our work, we will enrich the knowledge base of Decision maker agent.

In fact, more this model will be enriched by heating engineers (City planners, statisticians, sociologists …) more it can help decision makers to have several simulation scenarios. Also, we can detail the agent scheduler to show how the scheduling system can influence the outcome of the simulation.

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