Multi-Agent Based Simulation of Environmental Pollution Issues: A Review

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Abstract. Environmental issues, specifically pollution are considered as major concerns in many cities in the world. They have a direct influence on our health and quality of life. The use of computers models can help to forecast the impact of human activities on ecosystem equilibrium. We are interested in the use of MAS (Multi-Agent System) for modelling and simulating the environmental issues related to pollution. In this paper, we present a review of recent studies using a MAS approach for designing environmental pollution simulation models. Interactions between the three components of the environmental problem (Social, Economic and Ecological) are presented. On the light of these interactions, studies published from 2009 to 2013 are reviewed. Models are presented in terms of: model's purpose, studied variables, used data, representation of space and time, decision-making mechanism and implementation.

Keywords: Multi-Agent System, Multi-Agent Based Simulation, Agent-Based Modelling, Environmental Modelling, Pollution.

1 Introduction

Environmental issues and specifically pollution are considered as major concerns in many cities in the world. They have a direct influence on our health and quality of life. The degradation in air, soil, and water quality has to be estimated before the establishment or the expansion of urban or industrial activities. Environment pollution simulation and decision support tools can help decision-makers to set up environmental management policies in order to preserve the ecosystem and ensure public health. Computer models allow environmental managers to predict the impact of theirs decisions on the environment. Pollution is mainly caused by anthropogenic activities, thus, modelling these activities and including them in the simulation process is a key element. Using these models the world was able to predict the global warming and climatic changes [19]. During the last decades many approaches have been used to model environmental problems. [1] Presents a comparative study of five modelling approaches for environmental problem: System Dynamics, MAS, Bayesian Networks,

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Knowledge Base and Coupled Component. To select the suitable model, the authors suggest three considerations: The purpose of the model, which can be: prediction, forecasting, management and decision-making, learning; used data; the representation of time, space and entities included in the simulation. In this paper, the aim is to present a review of recent studies (2009 to 2013) using Multi-Agents Systems or MAS, (also called agent-based or multi-actor modelling) to model environmental issues related to pollution, with a specific consideration to air pollution. The selection of studies was done using these criteria: Agent based modelling of pollution; Agent based Simulation of Pollution; Multi-Agent System modelling of Environmental pollution. This review, forms the first step for designing a MAS based simulation system of air pollution for the region of Annaba (North-East of Algeria).

The paper is organised as follows: Section (2) presents the typical environment problem components and theirs interactions. Section (3) presents a review of recent studies using MAS to model environmental related issues. We end the paper by a conclusion with the possible perspectives of our work.

2 Environmental Problem Components

Many conceptualizations have been proposed to represent the socio-natural system [20]. Figure 1, shows that an environmental simulation system can be represented as an interconnection of three components (or subsystems); each one is represented by a set of variables (attributes) forming its state at time *t*. The ecological component models the biotic and abiotic[1] parts. The economic component represents the economic point view and regroups the economic variables. The social component represents the human social networks implicated in the simulation; among them are decision-makers, firms and government agencies and etc. The change in the state variable of each component affects other systems' state variables. A typical example of this is the increase in demand of certain kind of fish, which motivates fishermen to intensify their exploitation; this in turn results in changes to the biodiversity. Six interactions may exist between the system components: (A) represents the interaction of the social subsystem with itself, altering some attributes affect other social attributes, for example: when political constraints are used to control the demography of the population; (B) Occurs when natural events alter the ecosystem equilibrium, an example of this is volcanic activities which affects the air quality; (C) happens between economic component and itself. Thus, economic variables are systemically interconnected, (e.g. prices-inflation); (D) Occurs between social and ecological components, which is the key element for the simulation, understanding this interaction helps preserve environmental resource and sustainability; (E) represents the interaction between social and economic components, for example: the demography-consumption relation.

[1] The non-living chemical and physical components of the environment (e.g. soil, water and air).

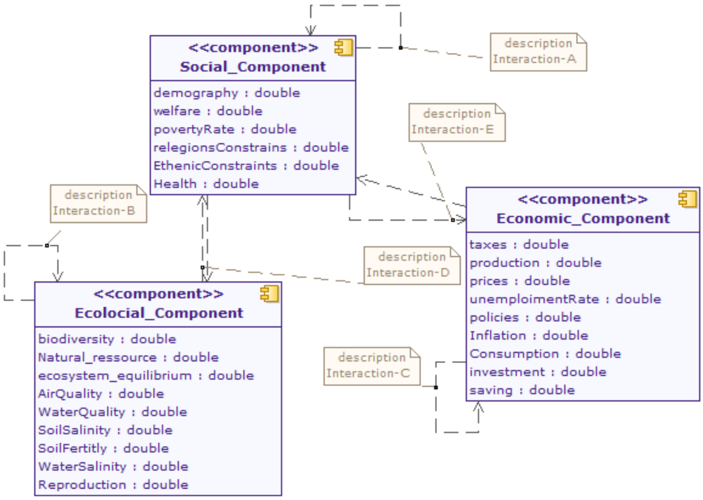

Fig. 1. UML Component Diagram, representing the interaction between ecological, social and economic components

The analysis of the studies focuses on six elements: (1) the purpose of the system, which represents the objectives of the simulation (decision support tools, learning, experimentation, prediction etc); (2) studied variables, according to the simulation objectives, the studied or target variables have to be defined (e.g. air pollution concentration, water pollution, biodiversity of a species, land use, etc) along with economic or social parameters (e.g. poverty rate, house income, demography, etc); (3) space and time representation, environmental problem are always spatially distributed and may include the use of real geographic data. Hence, the simulation system may use a GIS (Geographic Information System). The representation of time is very important because all environment phenomena are time related. In most cases a discrete representation is used; (4) data: some systems use real data collected from: monitoring networks, surveys, or a legacy database. Other systems use randomized data; (5) implementation: here, the technology used to develop the simulation system and the stage of implementation are presented; (6) decision-making model used by the agents (here, the agents generally represent human-beings) to choose an action to perform among all possible actions. For example: CBR (Case Based Reasoning), ANN (Artificial Neural Network), Fuzzy-Logic and coupled or hybrid models.

3 Multi-Agent Based Modelling of Environmental Problems: The State of the Art

MAS has emerged as a promising approach for modelling environmental issues. [2] Argues that the detection of macro-behaviours helps understanding the complex physical and ecological phenomena. MAS model is based on the fundamental principle of representing the interactions; in our case, between social-economic and ecological dynamics. It starts, on one hand, with modelling the actors at the individual level and/or aggregate level (groups of individuals, managers, governmental agencies) and on the other hand modelling the environment that contains a renewable resource. Usually the resource state is altered as a result of the actions performed by agents, whose behaviours are influenced by the state of resource as well. A methodology for building an Environmental Information System (EIS) based on a MAS is presented in [3]. Information about the environment are called EDO (Environment Data Object) that are grouped to forms ES (Environment States). Agents perceive and act upon these EDOs. An agent is seen as a mapping function from environmental state to action. The methodology defines two agent types: information carrier and decision-maker. The information carrier is the agent that behaves as a computing unit perceiving a series of environmental states and responding with a series of actions. The decision-maker agent models human-being or a group of humans-being; these kinds of agents use a reasoning engine to make decision D starting from a set of internal states. The methodology was used to develop two systems: O3RAA for air quality assessment and reporting; ABACUS which deals with metrological radar data surveillance. In [4] the aim is to help decision-makers in order to manage Insular Tropical Environments. An information system for environmental protection is designed using an: agent modelling approach, a database, a GIS and web services. The model is used to simulate and forecast the evolution of species (corals, marine turtles, forest, reef fish, etc). A MAS framework called GEAMAS-NG was used to help modelling the behaviours of agglomerations and urban extensions. The authors presented an approach called dynamic-oriented modelling which takes the dynamics as centre of the modelling process. The agent's behaviours and attributes are formed into two sets, and between them modify/influence relationships are defined. Two MAS were built using this approach: BIOMAS, which deals with the influence of agriculture on an ecosystem. The second is called SMAT which includes models of urban, agriculture and natural dynamics. The ocean ecosystem is subject to pollution especially when extracting and transporting oil. In [5] a simulation system combines MAS and CBR (Case Based Reasoning) to detect oil slicks and give predictions about their evolution and trajectory. The model uses meteorological parameters and satellite images. The coastal ecosystem is subject to disturbances by shellfish farming and aquaculture. To find the best way to exploit coasts without altering the balance of the ecosystem, a decision-maker may benefit from simulation tools. In [6] EcoSimNet is used to simulate the farmers' behaviours in order to forecast the impact of their decisions. The model used to optimize the farmer's actions based on economic parameters. Randomized data was used to feed the simulation model. Because people are spending increasingly more time indoor. Road traffic is the principal cause of air quality degradation in urban area. [7] presents ECROUB, a management system of urban quality based on a MAS. Using physical models, the system was able to generate information on the micro-climate (information about the climate in a very small geographic zone) of the Bari area in Italy. The system shows that a hybrid approach (MAS and physical models) can assist in the understanding and study of urban areas and ecosystems. [8] presents a MAS designed for monitoring air quality in Athena (Greece). It is composed of a set of software agents, controlling a network of sensors installed in different positions of an urban region. Agents verify and stock the data measured by sensors. In case of a sensor being damaged and data about the concentration of pollutant is therefore not available, the system uses a prediction given by an Artificial Neural Network. This prediction is used to estimate air quality. Real data about ozone concentration and meteorological data was used to feed the simulation system. In [9], a MAS is used to model air pollution in an urban area. The environment is represented by a two-dimensional grid *G(N, M)*. The purpose of the simulation is to find the dispersion of air pollution on the grid. Each cell *C(X, Y)* of the grid has a value of pollutant concentration. Neighbours with a close pollution rate (according to an initially set threshold) form a cluster. The pollution sources are represented by homogeneous agents that emit pollution in their areas (polluters). Each agent pollutes with an emission rate of ED. The pollution decay is modelled according to a destruction rate (evaporation) ER. As the simulation runs, clusters are formed with different values of pollution concentration. At the end, a single cluster is formed, thus, the dispersion of pollution is estimated. The results are used to give the dispersion of pollution specifying the number of polluters and the time required for the overall cluster shape. This model does not include meteorological parameters, does not address a specific pollutant types and does not use real data. The prototype was implemented using Repast Symphony framework. To understand pollution and health related problems. [10], presents DeciMas, a hybrid agent based decision support system. It includes data mining technique to extract dependent variables. The authors use MAS to evaluate environmental impact upon human health. The aim is to help experts to indentify the relationship between some pollutants and diseases. The data used includes datasets from different sources: health care system and environmental monitoring agencies. All these data were used to feed the simulation with real data. A list of 30 variables is used, with different forecasting models: Artificial Neural Network and linear regression. In order to reduce air pollution emitted from transport traffic, [11] presents a MAS for optimizing the fuel consumption in road intersection. The system models intersection as an agent and every vehicle is equipped with driver-assistant agent. Interactions between agents help to adapt the waiting time. It shows a reduction of 28% of fuel consumption. The model calculates the fuel consumption based on energy, air drag force, engine capacity, acceleration and speed. In [12] a MAS model is deployed on a grid-computing environment in order to gives visual simulation of the water pollution in the river. The Globus platform is used to build the computing grid. The water basin was modelled as a 3D mass, composed of numbers of agents called *WaterAgent*, cooperating with their neighbours in order to compute the influence of river flow on pollution propagation. [13] Presents an improvement of Agripolis(a MAS simulation system of land-use) to take into account the effects of agricultural policy on land use as well as biodiversity. The environment is represented by a matrix of *N x M* cells. Each cell represents a portion of the cultivable land with three fertility levels. The land may be owned, rented or abandoned. Each farmer (agent) may own or rent cells. As the simulation runs, the farmer-agent must make decisions about: the product to cultivate, the land to sell, or rent or buy, the abandon or not of the farming activity. The goal is to see how the farmers' behaviours can emerge and affect the structure of the ecosystem in the studied area. A MAS-Genetic algorithm model is presented in [14]. The model is used to optimize the management of waste to prevent the water pollution on the Urumqi river in Xinjiang (China). Each agent has attributes (energy, position in the grid of $N \ x \ N$ cells). The competition between agents and theirs neighbours identify how the system will optimize the process of waste treatment and help escaping from the local minimum. One of the principal advantages of MAS is the ability to model the human decision-making process. The poorly parameterized decision-making models lead to less realistic results and this can be a key weakness. [15] presents a framework for the parameterization of human behaviours in a MAS based environmental model. There are a several empirical methods used for the parameterization of agent behaviours modelling human decision-makers, the authors list: expert knowledge, participant observation, social survey, interviews, census data, field experiments, role-playing game, cluster analysis, asymmetric mapping and the Monte-Carlo method. The presented framework helps modellers to choose the appropriate methods for the parameterization of the behaviours of the decision-maker agent. The framework is used for the design of two MAS models: SimPaSI for simulating the socio-ecological system of the island of Java (Indonesia). The system includes agents that represent farmer, householders, and as outcomes the system gives information about the effect of fuel pricing policy on the socio-ecological system. The second system is used to simulate the response of farmers to changes in agricultural policy in a rural Dutch region. To understand human-environment interaction in agriculture system, [16] present a software package called MP-MAS (Mathematical Programming Multi-Agent System). MP-MAS helps to simulate a population of farmers subject to: Market dynamics; Environmental change; Policy intervention; Change in agriculture technologies. The objective of the simulation is to forecast the impact of these changes on agro-ecological resource such as water, or soil fertility. In MP-MAS the agent's decision-making about which activity to do is based on MP and constraint optimization problem. The agent before taking a decision

$$\max(z) = \sum_{j=1}^{N} C_j \times X_j \tag{1}$$

has to find the max value for Z (the farmer income). Where X is an activity among N possible farm activities and C is the expected return of the activity. In [17] the aim is to use a MAS based model to help investigate and understand environmental sustainability. The agents represent citizens and decision-makers, each of them have a set of behaviours designed to preserve energy and water resources. The approach selects be the most suitable behaviours for optimizing the use of energy and water. Citizens' behaviours are influenced by policy-makers agents (media agency, environmental protection etc.). Agents representing citizens are free to choose the appropriate behaviour according to their context. The process of restoration of a damaged ecosystem needs the interventions of experts from different domains (scientists, environmental management agencies, land owners, farmers etc).

Table 1. Summary table

Ref#	Name	Users	Purpose	Studied variables	Space / Time scale	Validation Data	Technologies	Decision-making model
[3]	O_3RAA	Gov. Agencies	Air pollution	Ozone concentration	N/A	Monitoring network data	JADE, WEKA, Protégé2000, PMML2,JESS	ANN, Expert System,CBR, decision tree
	ABACUS	Gov. Agencies	Meteorological parameters	Meteorological	N/A	Meteorological data		
[4]	BIOMAS	Agriculture policy planners	Agricultural dynamics on ecosystems	Collective organic matter fluxes	GIS,	N/A	GEAMAS-NG, ArcGIS	Mathematical model
[5]	OSM	Not mentioned	Oil slicks	Oil slicks expansion	2D space, Time representation not mentioned	Satellite images meteorological data	Web services,	Case based reasoning, ANN, BDI.
[6]	EcoSimNet	Not mentioned	Costal ecosystem and aquaculture	Biodiversity	1120 cells (32 x 35), spatial resolution of 500m. Time-step of 30 seconds; Horizon 1.5 year.	Economic parameters		Simulated Annealing algorithm
[7]	ECROUB	Not mentioned	Air pollution	Air quality	GIS	Meteorological ,measure data	GIS	Mathematical model
[8]		Not mentioned	Air pollution	Ozone concentration	6 hour ahead prediction	Metrological data	Jade, MySQL	ANN, Fuzzy logic
[9]		Not mentioned	Air pollution	Air pollution concentration	2D Grid ,	Randomised	Repast Symphony	
[10]	DeciMas	Health and ecologist	Health-pollution	Correlation between pollutant/health problems	N/A	30 parameters :Health care system,	Ontology, JACK, Prometheus	Regression, ANN
[11]		Not mentioned	Air pollution and road traffic	Fuel consumption	Space-continuous, discrete time with 23 minutes step.	Vehicle characteristics and road traffic		Mathematical model
[12]		Not mentioned	Water pollution	Pollution	3D GIS. Discrete time, Time step one second.	Data about Weihe river pollution incident.	Gird computing.	
[13]	Agripolis	agricultural policy makers	Land-use and biodiversity in agriculture	Biodiversity indicator	Grid of N **x** M cells, Discrete time, 1 year step, horizon 25 years.	Economic and agriculture parameters		
[14]		Not mentioned	Waste and water pollution	waste treatment	Grid of N x M cells			Genetic algorithms
[15]	SimPaSI	Not mentioned	Fuel pricing,/ecology	Forest and Fuel pricing	N/A			
[16]	MP-MAS	Not mentioned	Agriculture/ environment		N/A	Empirical data		Mathematical model
[17]		Not mentioned	Water management	Water-use	N/A			
[18]		Not mentioned	Ecosystem restoration	Forest restoration	N/A	Survey		Mathematical model

The decision-making in this case is a very complex task. In [18] a MAS is designed in order to understand the process of decision-making in ecological restoration. The model is a set of agents in form of hierarchies and groups. The inter-agent and inter-group interaction is used to update agent's choices. If the agents' choice is different than the other agents, the cost of dissent mechanism is used to reduce the respect of the agent on his own choice and increase his respect for other agents with which they interact. Empirical data were used to feed the simulation. Table 1 above presents a summary of the works discussed.

4 Conclusion

Anthropogenic activities are the main causes of pollution and environmental problems. These activities have to be included within the simulation models. Modelling the interaction between social and ecological component is a very important aspect of MAS approaches. MAS allow us to model the social network of human-beings sharing the exploitation of common environmental resource. By manipulating the behaviour at individual and groups levels this helps to gain more knowledge and makes the simulation more realistic. Studies treating air pollution, model well the physical aspect (concentration and dispersion of pollutant), but don't include human-decision about emission source within the simulation, consequently, the human activities causing pollution are not modelled. We hope exploiting this point in the next stage of our work, which aims to build a MAS based simulator of air pollution for the region of Annaba (North-East of Algeria), and taking the emission sources controllers as key element of our approach.

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