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Agent-based Simulation of CO2 Emissions Trading and Large-scale Traffic Flow

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Abstract: The first commitment period of the Kyoto Protocols has started this year to prevent the global warming. There are many efforts and discussions on effective greenhouse gas (GHG) reduction. The emissions trading is one of important issues. Several experimental markets are starting by governments and private sectors. However, there are some opinions against the trading itself. Also, the estimation of trading amount and market price is difficult with such a huge and emerging market. In this paper, we introduce the international emissions trading with the agent-based approach and a scalable simulation framework applied to large-scale traffic flow.

Keywords: Kyoto Protocol, Agent-based Approach, Gaming Simulation, Emission Trading, Traffic Flow

1. INTRODUCTION

The first commitment period of the Kyoto Protocols has started this year to prevent the global warming. There are many efforts and discussions on effective greenhouse gas (GHG) reduction. The emissions trading is one of important issues.

Several experimental markets are starting by governments and private sectors. However, there are some opinions against the trading itself. Also, the estimation of trading amount and market price is difficult with such a huge and emerging market. It is needed to evaluate the effectiveness and risk of the carbon trading and construct the most appropriate market design as soon as possible.

The agent-based approach [1] is an inter-disciplinary approach between computer science and social science to investigate complex social systems. In real economic situations, the dynamic behavior and interactions between people are very complicated and may often seem irrational. However, traditional economic theories usually consider idealized representative participants in equilibrium states. It is very difficult to analyze dynamically changing situations involving heterogeneous subjects using such static and homogeneous methods. In the last decade, many researchers, including physicists and computer scientists, are starting to apply new approaches to investigate such complex dynamics in their studies of economics. One of these approaches is the agent-based simulation approach.

The agent-based simulation have become easily available recently, with the advent of fast, cheap, and readily available computers. This opens the door to the study of the interaction of large numbers of heterogeneous, interacting agents.

On the other hand, the gaming simulation with human players is also attracting researchers recently (for example, U-Mart Project [2] and RoboCup Project [3]). By using the methodology of gaming, it becomes possible to examine the behavior of real human players under controlled circumstances.

The cooperative utilization of agent-based computational simulation and gaming simulation is expected to reproduce complex phenomena in the economic and social environment, and helps us to experiment with various controlling methods, to evaluate the design, and to extract the fundamental elements for deep analysis.

In this paper, we first introduce a simple Java framework for easy implementation of the agent-based simulation constructed with the layered structure. With this framework, we have been investigating the CO2 emission trading under the Kyoto Protocol.

In addition to the computational simulation, gaming simulations with human players in an environment similar to the agents' environment are expected to help us in constructing plausible behavior models and extracting the essential dynamics. We implemented a remote accessing interface in the agent framework which enables human players to collaborate with software agents, and constructed a Web application for a gaming simulation modeling international emission trading.

So far, we utilized a simple framework with small number of agents for the simulation of emissions trading. To apply such an approach to the real society including emissions trading in private sectors, we need to manage enormous agents representing companies and people. For this purpose, we have developed a large-scale agent-based simulation framework recently and consider vehicles' CO2 emission simulation with a million of agents which covers metropolitan transportation as an first application.

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2. AGENT-BASED SIMULATION OF THE INTERNATIONAL CO2 EMISSION TRADING

In a series of works [4-7], we considered agent-based simulations including the international CO2 emission trading.

We are utilizing our simple Java framework for effective implementation of the agent-based simulation constructed with the layered structure as follows. The Agent Layer contains a basic agent class and the fundamental environment for the agents. The environment provides the fundamental facilities for agents and users to create agents, to dispose of agents, and to send messages through a MessageManager class. The Social Layer describes the basic role of agents in the society and gives the example of message exchanges for trade. We implemented Central, Participant, and Watcher agents and a simple market process using RFB and BID messages. The Central agent creates, registers and initiates Participant agents and Watcher agents.

With this framework, we have been investigating the CO2 emission trading under the Kyoto Protocol. COP agent is a subclass of the Central agent and manages the international trading. Nation agent is also a subclass of the Participant agent and correspond to countries or regional groups. In this model, we created 12 Nations; 6 are Annex I countries who are assigned reduction targets in the level of emission in 1990, and 6 are Non Annex I countries who are not assigned targets for reduction as in the CERT model [8]. Fig. 1 shows the main trading procedure. We consider dynamic market development through the first commitment period 2008-2012. In each trading year, the COP agent sends Request for Bid (RFB) messages to all Nations which have an asking price.

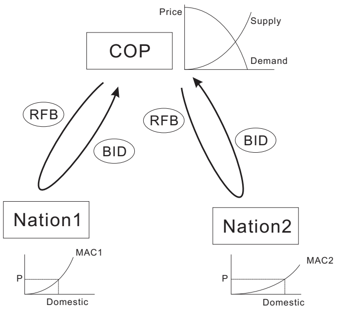

Fig. 1 Trading Procedure.

Upon receiving the RFB message, a Nation agent examines the asking price and his Marginal Abatement Cost (MAC) to decide the amount of the domestic reduction. Then he sends back a Bid message to the COP agent which says how much he wants to buy or to sell at the asked price. After repeating this RFB-BID process, the COP model will find the equilibrium price where the demand and the supply balance, and send the Trade message to approve the trades for the year. Thus, the equilibrium price for each year is determined when the MAC functions and the assigned reductions of all of the participants are given.

For the multiple trading periods, we considered a partition of the assigned reduction as a strategy of agents. The dynamics of MAC is given by the technology function $t_{in}(p)$ which gives the amount of reduction using the available technology at a given cost p for the Nation i at the year n.

As a simple dynamic process for the reduction technology $t_{in}(p)$, we adopt reusability $0 \leq \alpha \leq 1$ and deflation $0 \leq \gamma \equiv 1/\beta \leq 1$. Once the technology whose cost is lower than the price P^* is used, the reusability of the technology will be restricted with the coefficient α. On the other hand, the technical innovations and deflation decreases the cost of the technology. With $\bar{P}_{in} \equiv \max\{\gamma_i^n P_0^*, \gamma_i^{n-1} P_1^*, \ldots, \gamma_i P_{n-1}^*\}$, we can obtain the technology function as

$$t_{in}(p) \equiv \begin{cases} \alpha_i \beta_i^n t_{i0}(\beta_i^n p) & p < \bar{P}_{in} \\ \beta_i^n t_{i0}(\beta_i^n p) & \text{otherwise.} \end{cases}$$

We assume the initial technology function $t_{i0}(p)$ with two coefficients a_i and b_i to reproduce the quadratic MAC function in the CERT model,

$$t_{i0}(p) \equiv \frac{1}{\sqrt{b_i^2 + 4a_i p}}.$$

Fig. 2 shows an example of the simulation views. We can see brief reports on 12 agents and price changes from 2008 to 2012.

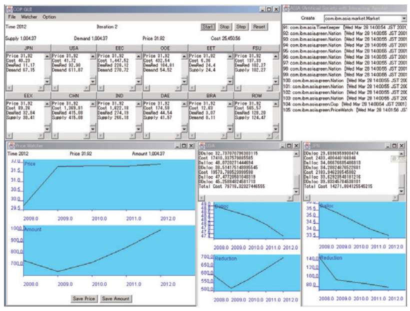

Fig. 2 Dynamic CO2 Emission Trading over the Commitment Period, 2008–2012.

3. WEB-BASED GAMING SYSTEM

Gaming simulations with human players in an environment similar to the agents' environment are expected to help us in constructing plausible behavior models and extracting the essential dynamics. We implemented a remote accessing interface in the agent framework which enables human players to collaborate with software agents, and constructed a Web application for a gaming simulation modeling international emission trading. In this section, we briefly introduce this gaming system (see Fig. 3) used for the gaming simulations in the following sections.

For remote access, we use RMI services and proxy agents at the Agent Layer. Through the RMI server, remote clients can create and dispose of agents. The RMI server also provides the naming service for agents and proxy messaging. A remote client who wants to talk with

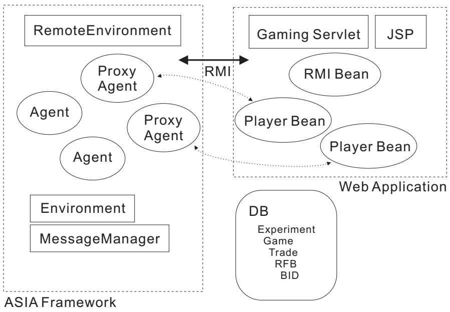

Fig. 3 Web Application and the Agent System

these agents needs to create a proxy agent with a message queue. The proxy agent acts in the same way as a normal agent in the framework, sends messages on behalf of the remote client, and passes the received messages back to the remote client. We also provide proxy versions of Participant and Watcher agents in the Social Layer.

We have developed a Web application using servlets for gaming so that most client PCs with Web browsers can easily access it.

In this system, as with typical Web applications, the servlets work as controllers and JSPs provide views. To retain information about the players, this application also requires Java beans corresponding to proxy agents. Messages like RFBs received by the agents are passed to the beans for the players in XML format, are interpreted, and displayed by servlets and JSPs. On the other side, player's inputs such as BIDs are packed into messages and sent through the proxy agent. In this simulation, players determine the amounts of the domestic reduction of CO2 and the amounts of the excess demand for international emission trading according to the presented price in the RFB at each iteration. Information such as the cost graph, the MAC, the total reduction target and the trading history are also given (see Fig. 4).


Fig. 4 Gaming Client for Double Auction

4. GAMING SIMULATION

In this section, we show the results of the gaming experiment in 2004 which was performed after the preliminary experiments presented at AESCS'02 [9] and CS'02 [10].

In the simulation, we tried two type of trading model; Walras equilibrium price and Double Auction (DA). For trading among computational agents, we used Walras trading for one or five trading years to find the equilibrium price and cost effective strategies. On the other hand, we introduced DA trading for human players since the iterative process of Walras trading is too troublesome for human and will not converge with dishonest and irrational bids. In reality, we tried the Walras trading for only one trading year with students in the preliminary gaming experiment in 2002, which could not reach the equilibrium. With DA trading, gaming players enjoyed free trading, and sell/buy permits to achieve the target positively.

Table 1 Gaming Simulation 2004 1st Day

Reference					
Nation	JPN	EEC	OOE	EET	FSU
Cost	47307	130852	24308	-25351	-84997
Gaming 04-1					
Nation	JPN	EEC	OOE	EET	FSU
Cost	7783	265821	12600	-10106	-41655
Perf	84%	-103%	48%	-60%	-51%
Gaming 04-2					
Nation	JPN	EEC	OOE	EET	FSU
Cost	112143	387817	30361	-58142	-128823
Perf	-137%	-196%	-25%	129%	52%

The most characteristic behavior emerged in the game was price control by sellers. Sellers (EET[1]and FSU[2]) were unwilling to sell until the market price became very high, and buyers (JPN, EEC[3], OOE[4]) were forced to pay more than the equilibrium. Even after we changed assigned countries of players, this tendency of high price controlled by sellers was sustained and sellers obtained greater revenue than the equilibrium trading of computational agents.

After the preliminary experiments, we performed the gaming simulation of the international CO2 emission trading again with different students in 2004. Through the years of gaming experiments, we used the same gaming system. Players and the game controller accessed to the gaming system with web browser. The game controller predefined the game nation's parameter, and controlled the procession of games. One game consists of 5 trading years and one trading year takes about 10 minutes in the real world. This web-based gaming system collaborated with the agent-based simulation framework. Hence, we can investigate the behavior of trading using the computational agents with the same factors given to game players.

Two samples of gaming results are shown in Table. 1. This gaming experiment was held at the university of Tokyo with 10 undergraduate students.

In the experiments (Gaming 04-1 and Gaming 04-2), five countries/area (JPN, EEC, OOE, EET, FSU) are assigned to players.

[1]EET: Economies in Transition of Eastern Europe
[2]FSU: Former Soviet Union
[3]EEC: 15 EU members
[4]OOE: Rest OECD

We consider the performance of students relatively by comparing their total cost to achieve the Kyoto targets with the results of the agent-based simulation with Walras equilibrium price.

In Gaming 04-1, JPN showed excellent performance. Investigating the summarized activities in this game, we can see how JPN players achieved such a performance.

Fig. 5 and Fig. 6 show annual trade amount and summary in Gaming 4-1. We can see that JPN made a large trade with FSU at the early stage. Therefore, JPN need not trade emissions after price rises rapidly and got the high performance.

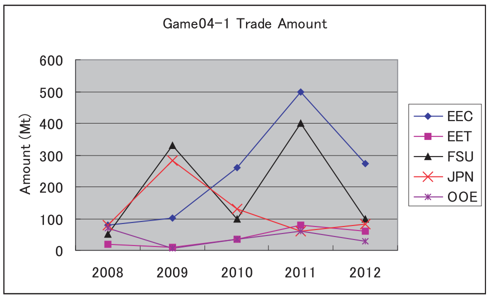

Fig. 5 Gaming 4-1 Trade History

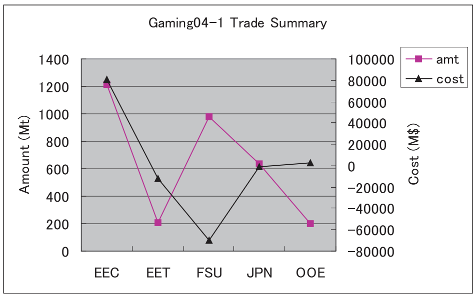

Fig. 6 Gaming 4-1 Trade Summary

On the other hand, Fig. 5 and Fig. 6 show that FSU and EET studied from the previous game and obtained huge profit by hesitating to trade until the later stage in Gaming 4-2.

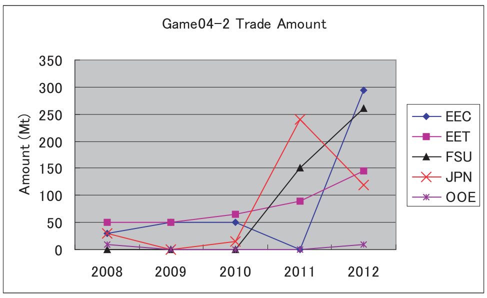

Fig. 7 Gaming 4-2 Trade History

In a game, bids for sell and buy are repeatedly sent from players before a trade happens. Numbers of these trial bids, performed trades, and calculation trials which check cost with various amount of domestic reduction are shown in Fig. 9 and Fig. 10. In general, JPN and EEC who depend largely on trade looks presenting many bids

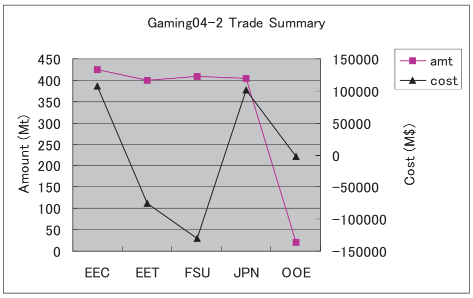

Fig. 8 Gaming 4-2 Trade Summary

to explore the market trend. And also, we can see that total number of trials is decreasing as becoming familiar with the experiments.

From these results, we can guess that students who did not have previous knowledge quickly studied during the short-term gaming experiments and behaved more effectively. Thus, such a gaming simulation also seems efficient for the teaching of complicated social interaction.

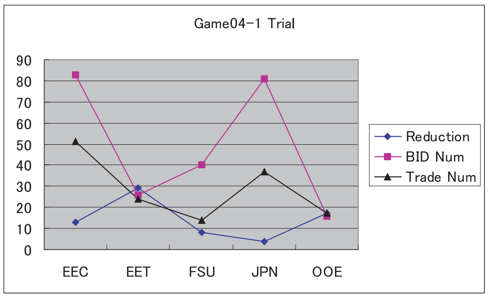

Fig. 9 Gaming 4-1 Number of Trials

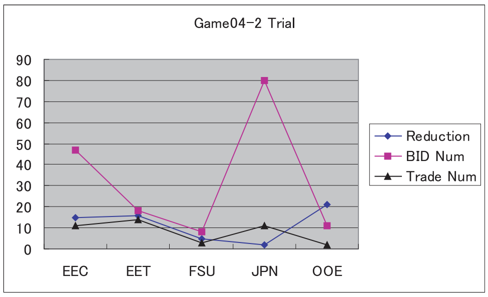

Fig. 10 Gaming 4-2 Number of Trials

5. VEHICLES' CO2 EMISSION SIMULATION

So far, we are utilizing a small number of agents on the simple framework for the international emissions trading. But now, governments have started various trials and studies for CO2 emissions trading in a country to motivate the domestic reduction where a large number of participants will be involved. To investigate such a situation, we have developed a large-scale agent-based simulation framework and consider a metropolitan traffic flow as the first application with millions of agents.

There are many macroscopic traffic simulators to simulate and estimate vehicles' CO2 emissions in a city. Such macroscopic traffic simulators are difficult to use since they are based on many assumptions and parameters which are hard to determine. There exist some microscopic traffic simulators that estimate vehicles' CO2 emissions around a small number of cross points. However, these simulators are not scalable and cannot be utilized to estimate CO2 emissions in a large city.

Recently, we have developed a large-scale agent-based simulation framework, ZASE. ZASE has a couple of advantages over existing traffic simulators. The first one is that, on this environment we can develop various types of agent-based simulator, such as auction simulator, traffic simulator, and evacuation guide simulator easily. Second one is that ZASE can generate and manage millions of agents. This enables us to execute an large-scale simulation required for real social studies with millions of peoples.

Using this environment, we have developed a large-scale traffic simulator with a million of agents. This means that we can simulate whole city traffic with millions of microscopic drivers. A traffic flow simulation of Kyoto City road network has demonstrated that our simulator can handle 0.81 millions of running vehicles. A snapshot for a Kyoto City road network simulation is shown in Fig. 11.

Fig. 11 Snapshot of the Traffic Flow Simulation

The user of this simulator can be an omnipotent for the virtual traffic world. This large-scale microscopic traffic simulator enables us to know the position, velocity and acceleration at each time step for every vehicles. With these data, we can estimate the CO2 emissions for every vehicles running in a city.

Oguchi et al. proposed a model for the CO2 emissions calculation as $F = F_{idle} + F_{run}$, where F denotes the fuel consumption ratio per unit time[11]. In this model the consumption ratio in the idling state, which is represented by F_{idle} is equal to 0.34[cc/sec] and that in the running state, represented by F_{run} equals to $F_{run} = 0.338 + 0.00895 \times v$ [cc/sec]. The total fuel consumption Q is calculated as $Q = K_c \times F$, where K_c denotes energy conversion factor and is equal to 0.0231[kg-CO2/cc].

Combining the large-scale traffic simulator with this fuel consumption model, we have calculated the total amount of CO2 emissions of Kyoto city in a year. The estimated total amount of vehicles' CO2 emissions in a year equals to $1.22Mt$, which is roughly agrees with the real value $1.91Mt$.

We are currently studying to fill in this gap by refining the traffic simulator and emission model.

6. CONCLUDING REMARKS

In this paper, we introduced our research on the international GHG emissions trading and a large-scale agent-based simulation framework. The agent-based simulation was utilized to investigate the dynamic and complex behavior in the emerging market. To compare the computational model and real human behavior, we performed the gaming experiment with human players. In addition, we developed a large-scale simulation framework to extend the emissions trading market from a small number of countries to a large number of people. We briefly introduced a simulation model of traffic flow and CO2 emissions as an application of the large-scale simulation framework.

We considered a dynamical simulation for the international CO2 emission trading with our agent-based simulation framework, and developed a Web application for the gaming simulation of the emission trading which works along with the agent system through network to study realistic human behavior. We executed the first prototyping gaming simulation in 2002 and then in 2003 and 2004 with strong support of Prof. Rokugawa and undergraduate students in University of Tokyo. The series of the gaming simulation showed emergence of dominant trend and learning by students.

The most characteristic behavior emerged in the game was price control by sellers. Sellers were unwilling to sell until the market price became very high, and buyers were forced to pay more than the equilibrium. Even after we changed assigned countries of players, this tendency of high price controlled by sellers was sustained and sellers obtained greater revenue than the equilibrium trading of computational agents. We also learned that these experiments are useful for traders' training in a complex emerging market.

As a future work, a large-scale CO2 emissions trading simulation should be investigated for the effective market design where citizens can participate for personal contributions to the sustainable society.

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