Chapter 12
Agent-Based Simulation for Service Science

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Abstract The most important building blocks of service systems are human beings. Because of the dynamic and heterogeneous interactions among human beings with their bounded rationality, a service system is recognized as a complex adaptive system to which quantitative scientific analysis is difficult to apply. In this chapter, we discuss a computational approach for such complex adaptive systems called agent-based simulation. Since the 1990s, agent-based simulation has gained significance as a tool to reproduce complex stock market interactions by modeling human traders as software agents. Computer scientists and social scientists are working together to model social systems with interacting heterogeneous agents and simulating their dynamic behaviors using computers. As our computational resources continue to grow rapidly, the application areas for agent-based simulations are spreading into areas of social science that overlap with SSME research. We will introduce several examples of agent-based simulations for marketing, for emissions trading, for communications, and for traffic systems and discuss the contributions of this scientific approach to the study of service systems.

12.1 Introduction

Service systems are complex adaptive systems and also social systems involving human beings. Service systems cannot be represented with convenient sets of mathematical equations mainly because of the complexities and vagaries of human behavior. Therefore, it is quite difficult to evaluate and understand service systems quantitatively with scientific methods. In traditional economic theories, some simplifications such as static equilibrium state, representative agent, and full rationality have been introduced to construct comprehensive and elegant theories with feasible solutions, but in the last decade these assumptions have received increasingly strong criticism that they cannot capture the current economic crises and dynamic

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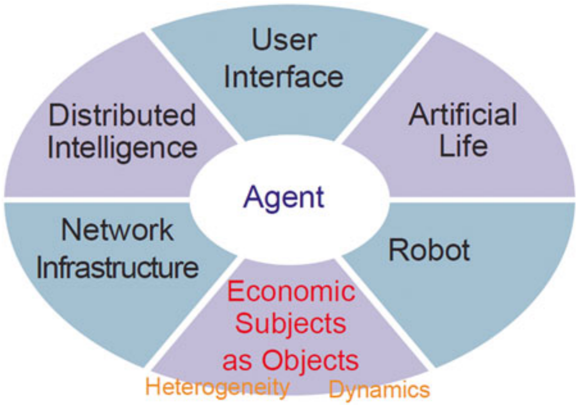

Fig. 12.1 Various meanings of the word "Agent"

economics of the Internet era. Various approaches from multiple disciplines try to tackle these complex emerging problems (Arthur et al. 1997).

For example, researchers from the fields of physics and computer science are analyzing enormous amounts of data from real-world markets, using statistics to find hidden patterns and new economic principles. This approach is called "EconoPhysics" (Mantegna and Stanley 2000), and it seeks to explore similarities between critical phenomena from physics and market behaviors from economics, such as the now well-known concepts of the long-tail and power-law scaling, phenomena that can be found in many natural and artificial systems.

To understand such systems, we believe agent-based approaches can offer a new set of powerful tools. Since the main method of an agent-based approach is an agent-based simulation (ABS) on computers, researchers using such approaches can model a target service system and its stakeholders with an agent-based model (ABM) and simulate the dynamic behaviors and interactions of the service system with microscopic agents emulated in computers (Namatame et al. 2002).

The word "agent" is used with a variety of meanings for different purposes, such as UI (user interface) agents, email reminder agents, physical agents, or software robots acting as agents to serve people (Fig. 12.1). In the agent-based approach, each "agent" represents a dynamically interacting economic (or social) entity, thus abstracting the stakeholders from the real world and representing their characteristics of heterogeneity and bounded rationality that traditional economics and social science have difficulty in understanding with models. By using computational agent-based simulations (often written with object-oriented programming languages), such heterogeneous and dynamic interacting agents with bounded rationality can be intuitively implemented as objects with their interactions based on message passing.

Various software technologies such as OOP (Object-Oriented Programming), AI (Artificial Intelligence), and network communications have relationships with ABS. In addition to knowledge of computer software, researchers also need domain knowledge about objective systems such as economics, social science, financial engineering, complex adaptive systems, or behavioral economics. Hence, ABS is a multidisciplinary science similar to SSME.[1]

Agent-based simulation evolved relatively recently as many researchers became able to conveniently use powerful PCs and popular programming languages in the 1990s. In the early period, agents were often designed to reproduce complex adaptive systems and financial markets (Izumi 1998). Then researchers applied ABS to social behaviors such as norm emergence, game theory situations, learning, and organization. Currently, ABS has begun to be used for more practical and concrete problems such as traffic systems, pedestrian flows, and business operations. In the balance of this chapter, we introduce our ABS and related projects.

12.2 Market and Auction Simulation

ABS reproduces a service system by modeling humans as heterogeneous agents. We introduce several examples from our ABS projects. At first, we applied ABS to understand phenomena in the market system. The stability of prices in asset markets

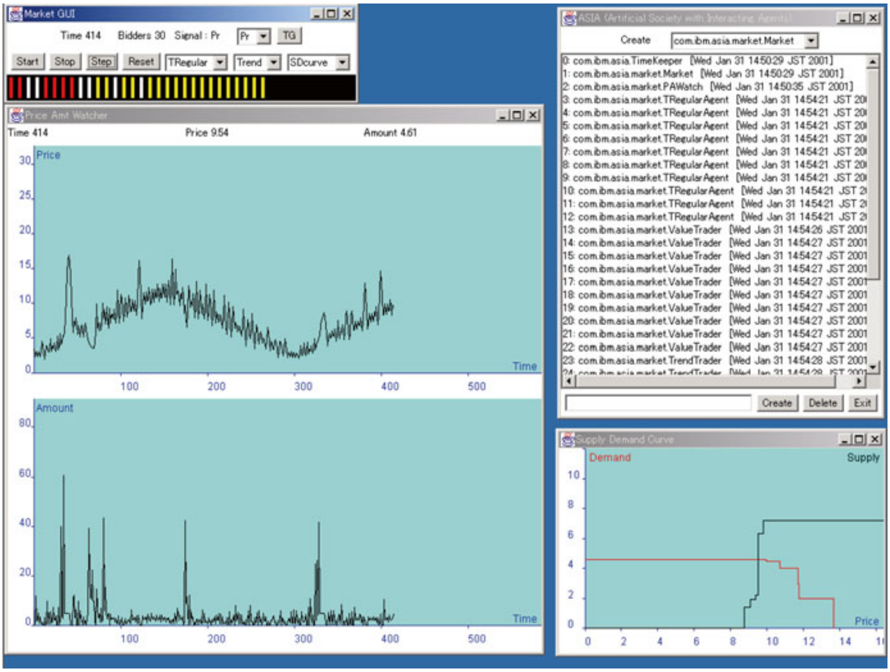

Fig. 12.2 Screenshot of the market simulation

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[1] SSME stands for Service Science, Management, and Engineering. Recently, it has also been called SSME+D which stands for Service Science Management Engineering and Design. Both these acronyms are often replaced simply with service science, which is the study of service systems and value-cocreation phenomena (Spohrer and Maglio 2010).

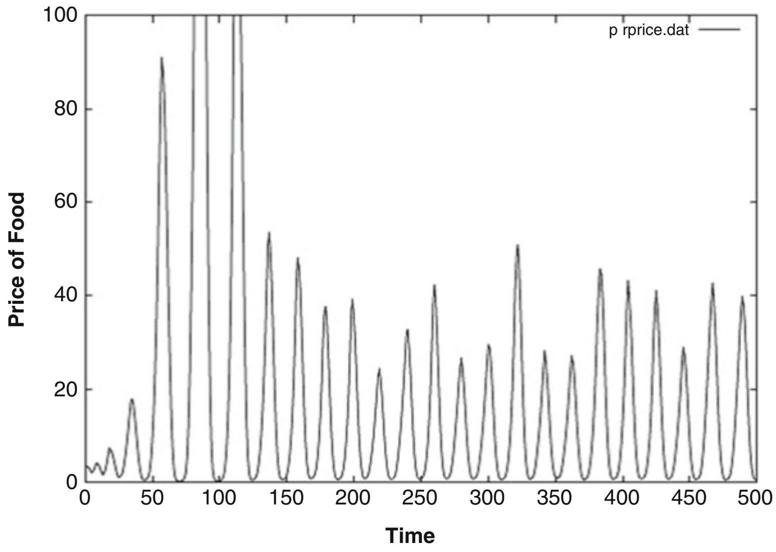

Fig. 12.3 Price vs. trading period with regular agents only

is clearly a central issue in economics. From a system's point of view, markets inevitably entail the feedback of information in the form of price signals, and like all feedback systems may exhibit unstable behavior. Steiglitz and Shapiro (1998) created the price oscillation and bubbles in a simple commodity market model with producer/consumer agents and two types of speculators. In Steiglitz's market model, three types of agents (Regular agent, Value trader, and Trend trader) trade food and gold. Regular agents produce food or gold depending on the price (exchange rate between food and gold) and consume food. Value traders and Trend traders are speculators with different strategies.

Mizuta et al. (2003) considered the stability in this model with various price signals and found that the inversely weighted average of bid price stabilizes the market dramatically. Figure 12.2 shows a screenshot of the simulation where price bubbles appear with heterogeneous agents. The largest window shows two graphs showing the market clearing price and the trade volume. With the simplest market only with Regular agents, the market price shows strong oscillation due to inventory cycle (Fig. 12.3). We showed that this price oscillation with producer/consumer agents is stabilized by introducing different price signals (Fig. 12.4). On the basis of the simulation, we also gave analytical results on the simplified dynamical system with different signals.

Next, we consider a simpler form of market, that is, auctions.

The use of online auctions has grown rapidly since the 1990s, and in general many segments of the economy are becoming granulated at a finer and finer scale. Thus, understanding behavior of auctions, and especially the interaction between the design of auctions, agent behavior, and the resulting allocations of goods and money, has become increasingly important—first because we may want to design auctions that are as profitable as possible from the sellers' point of view, but also because we may want to bid in auctions, or design computer systems that respond well to the loads that auctions generate.

To investigate such dynamic interactions between heterogeneous bidders and also the price formulation through successive auctions, Mizuta and Steiglitz (2000) developed an agent-based simulation of dynamic online auctions.

In a dynamic auction simulation, we investigated the behavior of popular online auctions with heterogeneous bidder types, e.g., Early Bidders and Snipers. The model considers a single auction involving the sale of one item by one seller to one of many bidders, who submit their bids over time in the interval $[0, T]$ to an auctioneer, who awards the item to the highest bidder at closing time. A bidder can submit more than one bid during the auction. In experiments, the starting bid price is fixed at 1, and the duration of the auction is $T = 500$ time units.

At the beginning of each auction, each bidder determines his first valuation of the item.

At each time period $0 < t < T$, each bidder receives the status of the auction, can update his estimation on a fixed schedule or probabilistically, and can submit bids if the conditions for his strategy are satisfied. In this model, early bidders can bid any time during the auction period, update their valuations continuously and compete strongly with each other, and snipers wait until the last moments to bid.

An example auction simulated is shown in Fig. 12.5. The graph for the second highest bid price shows price jumps at the last few moments. We also indicate histograms of winning prices by Early bidders and Snipers in Fig. 12.6. In most cases, Snipers win the item with broadly distributed prices. However, there are small chances for Early bidders win the item with very low prices or very high prices.

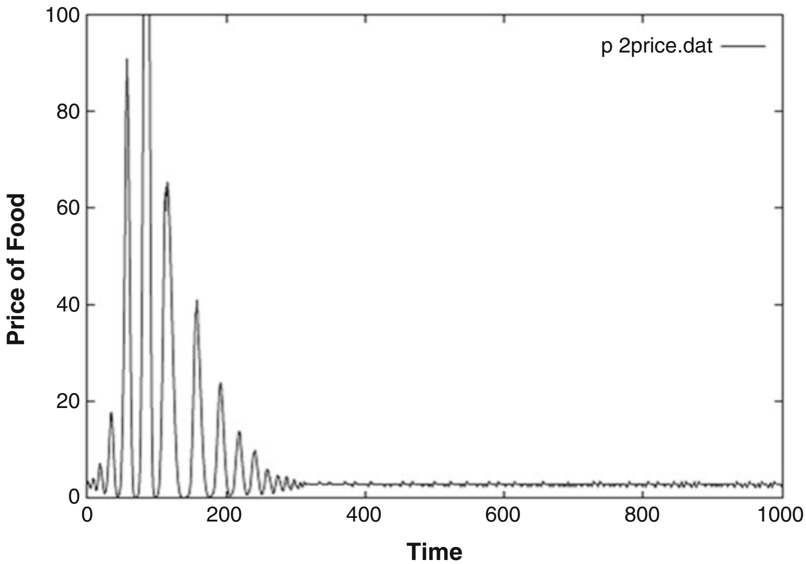

Fig. 12.4 Price vs. period with inversely weighted average bit prices as the signal

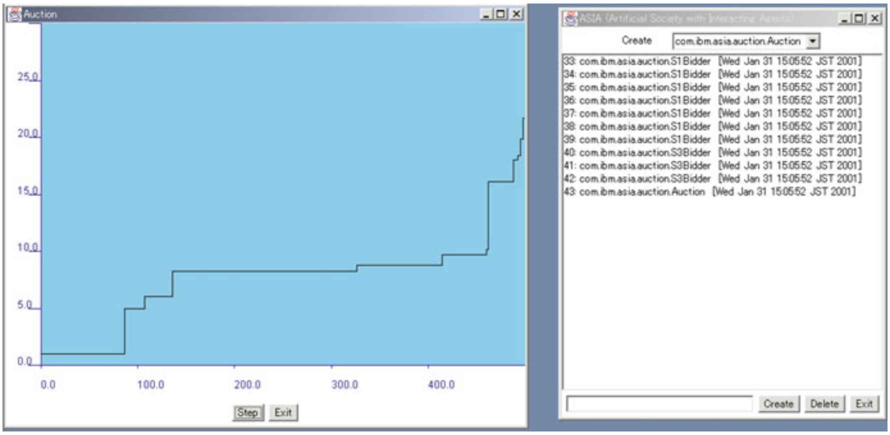

Fig. 12.5 Screenshot of auction simulation

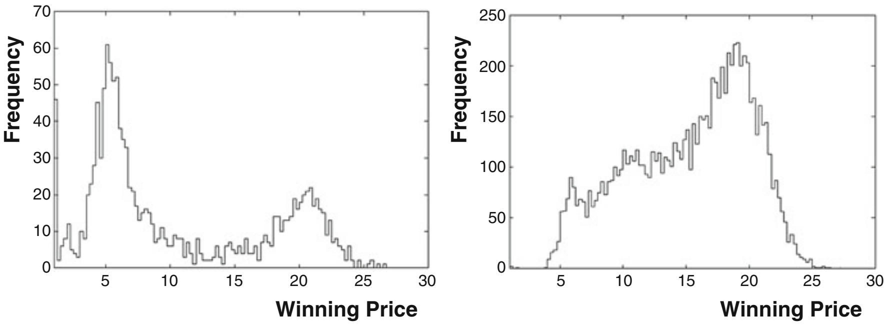

Fig. 12.6 Winning prices by early bidders and snipers

12.3 International Emissions Trading Simulation and Gaming

In a series of works (Mizuta and Yamagata 2001a, b, 2002), we considered agent-based simulations in a computer and gaming experiments with human players for the international CO_2 emission trading.

We have been investigating the CO_2 emission trading under the Kyoto Protocol. Nation agents correspond to participating countries or regional groups and COP agent is a Central auctioneer and manages the international trading. In this model, we created 12 Nations agents; six are Annex I countries who are developed countries and assigned reduction targets in the level of emission in 1990, and six are Non-Annex I countries who are developing countries and not assigned targets for reduction as in the CERT model by Grütter (2000).

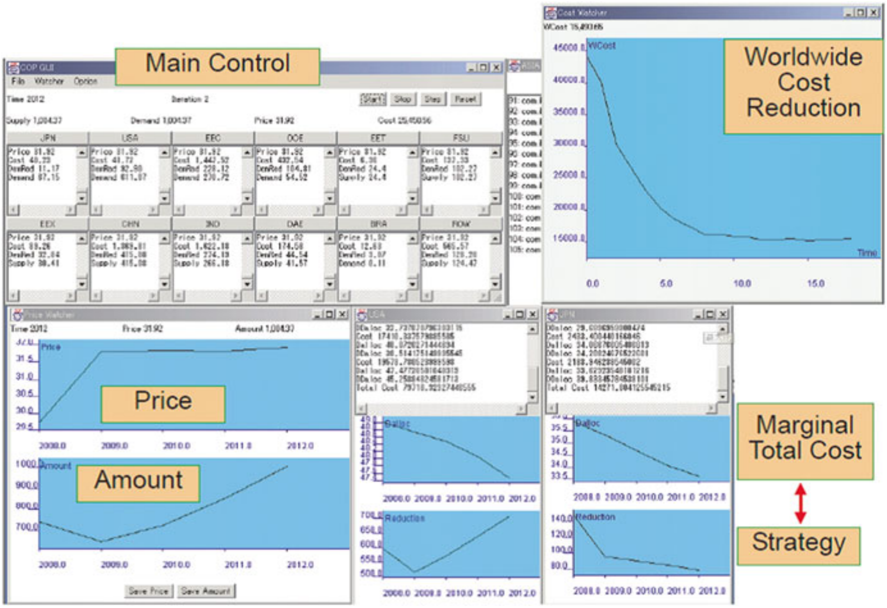

Fig. 12.7 Screenshot of international emissions trading simulation

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. 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 clearing 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 considering the available technologies for reduction.

As a simple dynamic process for the reduction technology, we adopt reusability and deflation. Once the technology whose cost is lower than the certain price is used, the reusability of the technology will be restricted. On the other hand, the technical innovations and deflation decrease the cost of the technology.

Figure 12.7 shows an example of the simulation views. We can see brief reports on 12 agents and price changes from 2008 to 2012.

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

Table 12.1 Reference and results of gaming experiments

Reference					
Nation	JPN	EEC	OOE	EET	FSU
Cost	47,307	130,852	24,308	−25,351	−84,997
Gaming 04-1					
Nation	JPN	EEC	OOE	EET	FSU
Cost	7783	265,821	12,600	−10,106	−41,655
Perf	84 %	−103 %	48 %	−60 %	−51 %
Gaming 04-2					
Nation	JPN	EEC	OOE	EET	FSU
Cost	112,143	387,817	30,361	−58,142	−128,823
Perf	−137 %	−196 %	−25 %	129 %	52 %

In this gaming simulation, players determine the amounts of the domestic reduction of CO_2 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.

We show the results of the gaming experiment (Mizuta and Yamagata 2005).

In the experiments, we tried two types 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 traders to use and will not converge with dishonest and irrational bids. In an experiment with real human bidders, we tried the Walras trading with students in a preliminary gaming experiment, which did not reach an equilibrium. With DA trading, gaming players enjoyed free trading, and sell/buy permits to achieve the target positively.

The most characteristic behavior emerged in the game was price control by sellers. Sellers (EET: Economies in Transition of Eastern Europe and FSU: Former Soviet Union) were unwilling to sell until the market price became very high, and buyers (JPN, EEC: 15 EU members, OOE: Rest OECD) were forced to pay more than the equilibrium. Even after we changed the assigned countries of the players, this tendency of high price controlled by sellers was sustained and sellers obtained greater revenue than the equilibrium trading of computational agents.

Players and the game controller accessed the online gaming system with their web browsers. The game controller predefined the game's nation parameters, and controlled the procession of each game. Each game consists of five trading years and one trading year takes about 10 min of real time. 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 12.1. 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/areas (JPN, EEC, OOE, EET, FSU) are assigned to players.

We consider the relative performance of students by comparing their total cost (M$) 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 recorded activities in this game, we can see how JPN players achieved such a performance. From the log data, we found 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. But, FSU and EET studied from the previous game and obtained huge profit by hesitating to trade until the later stage in Gaming 4-2.

Through these gaming experiments, 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 teaching interaction strategies in complex social systems.

12.4 Agent-Based Simulation Framework

In this section, we introduce simulation frameworks for agent applications.

It is possible to develop ABS application from scratch, but usually researchers use more general frameworks to implement their ABS (Fig. 12.8). For ABS, this framework should have common facilities such as creation, annihilation and management of agents, message transactions, simulation time control, and results reporting. In addition to these fundamental facilities, some frameworks have AI (Artificial Intelligence) components (e.g., genetic algorithm or reinforcement learning) and visualization components (e.g., simple cell lattice or fine-grained graphics). Well-known pioneer frameworks include Swarm (Bonabeau 1999) and SugarScape (Epstein and Axtell 1994) used to simulate aspects of social behavior in living systems. On the other hands, there are also several agent-based simulation frameworks developed in Japan, for example, SOARS (2012) and Boxed Economy (Iba et al. 2001).

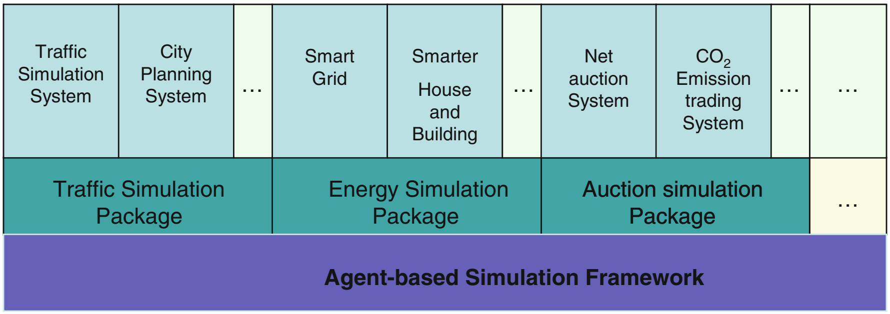

Fig. 12.8 Agent-based simulation framework

So far, we have used relatively small and simple framework developed in Java, which can run only several thousand agents in a single node. For more realistic experiments for real social issues required for city-scale simulations (e.g., smarter cities initiative), we need a large-scale framework with enormous number of agents and parallel execution on distributed computers. Hence, we developed a large-scale agent-based simulation environment known as ZASE (Yamamoto et al. 2006) initially developed in Java, then redeveloped as an innovative highly scalable framework known as X10-based Agents Executive Infrastructure for Simulation (Suzumura et al. 2012) which can be used for supercomputer. This framework can easily run over millions of agent with superior performance on various environment including supercomputers.

12.5 Metropolitan Traffic Simulator

By utilizing the large-scale agent-based simulation environment, we developed a metropolitan traffic simulator "IBM Mega Traffic Simulator" to support smarter cities research.

Using large-scale agent-based simulation framework, Kato et al. (2008) developed a whole city traffic simulator and examined the traffic flow with the road network in the Kyoto city. This traffic simulator considers each microscopic vehicle as agent, which travels through a given road network with cross points (node) and roads (links).

Using this traffic simulator, we also consider the future traffic of Yokohama city based on the land use estimation by land use equilibrium (LUE) model of NIES (National Institute of Environmental Studies in Japan) (Yamagata et al. 2010).

As a tool for what-if analysis, we perform trial simulation on the traffic simulator using two LUE scenarios. Though LUE assumes the real city (Yokohama), we use a simplified road network for simulations without traffic signals.

We generated a network definition file based on the real map data of Yokohama which has 38,464 cross points (nodes) and 115,124 roads (links). In this simplified network, the speed limit for all roads is 60 kph. In addition to the network information, the traffic simulator requires OD (Origin–destination) Trip information.

In two LUE scenarios (the dispersed city scenario and the compact city scenario), we use the same network information and different trip information. We generate trip data from OD traffic volume among zones estimated in the previous section for each scenario. The traffic simulator performs 1 h of microscopic vehicles' behavior on the simplified road network with given trip demands and output log files including road and vehicle information. A screenshot of the simulation viewer in which vehicles are drawn as dots with random colors is shown in Fig. 12.9.

We can evaluate the CO_2 emissions from vehicle log data. By Oguchi and Katakura (2000), fuel consumption per unit time, f (cc/s), can be estimated from a vehicle speed, v (Km/s), as $f = 0.338 + 0.00895\ v$ and CO_2 emissions E ($kg\text{-}CO_2$)

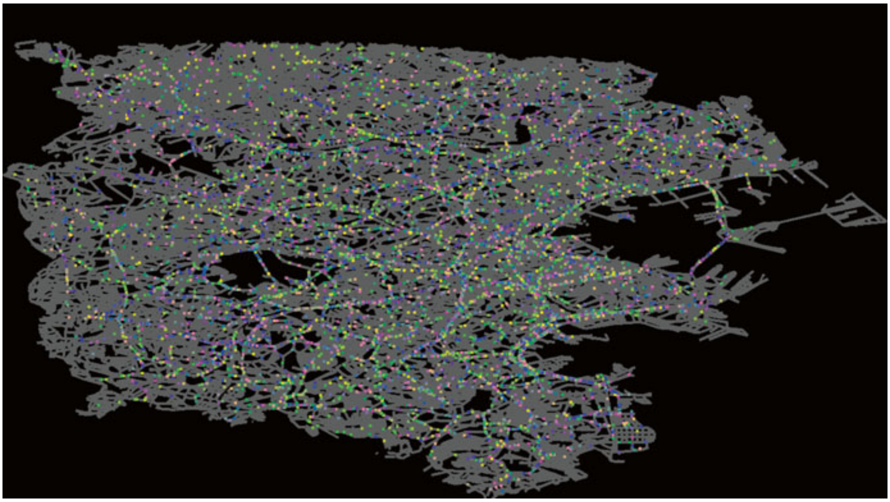

Fig. 12.9 Screenshot of the traffic simulation at Yokohama city

from total fuel consumption, *F* (*cc*), as $E=0.0231\ F$. From the simulation results, we obtained emissions per hour as *425* tCO_2 in dispersed city scenario and *471* tCO_2 in compact city scenario.

In addition, we can observe different characteristics of traffic volume distribution over roads with two scenarios, for example, that the frequency of higher traffic roads diminishes rather rapidly in a dispersed city scenario which may indicate that vehicles are more distributed in the dispersed city. However, there are more roads with the largest edges in dispersed city scenario which may result in more traffic jams. On average, the frequency of higher traffic volume is larger in compact city scenario, which causes larger emissions.

For these simulations, we only used very simple road information without signals and speed limit variation. In future works, we plan to utilize more road information for higher accuracy and validate detailed analysis results with real city data from our collaboration with the city planners.

As shown in this analysis, we can investigate both possible traffic volumes and emissions for each given scenario and road design which can support decision making for city planners.

12.6 Network and Organization Sciences

In this section, we consider a slightly different but related topic, complex networks that can be used to analyze interactions in service systems.

Two essential elements of agent-based simulations (ABS) are the nature of the agents and their interactions. Hence it is natural for ABS researchers to have interests in network and organization theory. In parallel, these traditional topics in social science have experienced a new trend because of insights from complexity scientists and physicists. Today, Computational Organization Theory (Carley and Krackhardt 1998) investigates communities from the viewpoint of agents and network. Duncan Watts (1999) has constructed a new simple network which has characteristic of small world phenomena that are famous by Milgram's early experiments as Six Degrees of Separation (Milgram 1967). Furthermore, Barabási's works and popular book (Barabasi 2001) on the scale-free network explosively attract interests in the emerging complex network science. Complex network science has similarity with EconoPhysics and fractals in the way that power distributions appear universally. Many ABS researchers have also found that complex networks fit with their research.

We also have an interest in organizational networks from the viewpoint of businesses as networks. In this section, we introduce our project on communication networks in enterprise organization.

Observing enterprises from a viewpoint of social human relationship, we notice there are coexisting networks. These networks are mutually affected and important for business and personal activities in the enterprise. Traditionally, to perform business activities strategically with strong leadership, there is a definite organizational hierarchy within an enterprise. The organizational hierarchy starts from the top node which consists of board of directors and CEO, going through several levels of managers, and arrives at employees. Such an organizational structure can also be observed in most government and military organizations. Organization studies are motivated to achieve business goals efficiently with strategic design and transformation of organization along with management policies, enterprise cultures, and business environments. On the other hand, employees' benefit from a good climate for bottom-up innovation with flexible collaboration encouraged across organizational boundaries, especially in service businesses with R&D groups.

For business collaboration, we can use various kinds of communication methods from traditional face-to-face meeting and telephone to computational email, instant messaging and groupware. It is still difficult to document all these types of activities. In this project, we consider the transactions obtained from email send/receive log files. Together with the organizational network, we can analyze the communications network in enterprises.

In traditional social sciences, researchers have to investigate various communications among examinees by direct interviews or questionnaires. Such a human survey is so troublesome and time-consuming that available data are small. By using email transaction log which is automatically stored on email servers, we can obtain enormous communication data more easily.

We introduced a survey in one enterprise before and after a strategic organization change. With business activities, it is important to take into account positions in the strategic enterprise structure. We have analyzed large email communications as described above. From a viewpoint of privacy, we aggregated the transaction data as the communications flow between departments so that a particular employee cannot be traced.

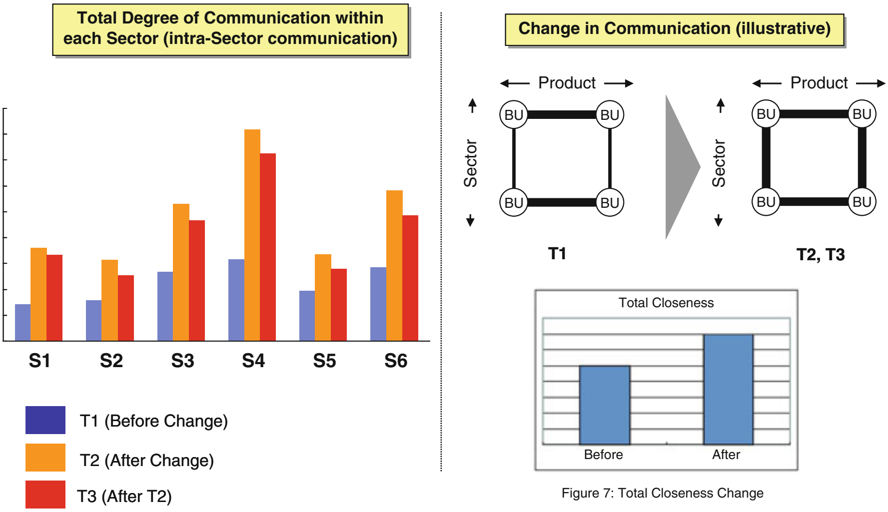

Fig. 12.10 Communications network patterns and organizational change

We developed a tool to aggregate the communications flow and to calculate network indices. As the preprocess, the tool aggregates email transaction data between lowest-level departments (units) to link information between strategic groups (nodes) which we want to investigate.

We briefly introduce an example of our survey on communications network before and after organization changes. We investigated one company with consultants (IBM Global Business Services) using communication and organization data and tools described in the previous section. Especially, we examine recent strategic organizational changes. We made an analysis with a node definition created for this purpose and observed changes appeared in the communications network.

The organizational structure can be represented by two-dimensional matrix (product groups in rows and client sector groups in columns). Before the organizational change, the matrix structure was not balanced. Because relationship within a product group was dominant, customer had to contact separate product groups. The purpose of the organizational change was intended to strengthen another direction (client sector relationships) to balance the matrix structure and to provide "one-face" services.

We investigated changes in Degrees of the communication network along these two directions. Results are shown in Fig. 12.10. We can observe a significant increase of the communication along sector from the graph (Fig. 12.10). On the other hand, this change does not cause an undesirable side effect on the communication along product. In addition, we analyzed changes in the total closeness. This result shows that the whole organizational network becomes more condensed.

Furthermore, Mizuta and Nakamura (2005) consider a prototype agent model and simulation of dynamic communications on enterprise structure. The results reproduced a power-law distribution of Degree similar to the observed data in a real enterprise. It is important to utilize this universal characteristic to verify the plausibility of a model.

12.7 Agent-Based Simulation as an Academic Discipline

Before the applications of complex adaptive systems and artificial markets became popular, the mainstream of agent research in Japan focused on the study of collaborative work by multiple agents. Researchers developed standards for communication protocols, frameworks, and mature communities for multi-agent systems. Their concepts and tools have similarities with ABS systems. Some of the early applications of ABS were developed using multi-agent frameworks (for example, mobile agent platform, Aglets (Lange and Oshima 1998)). However, these tools have many powerful functions for multi-agent studies that are not necessary for ABS and these features slow the simulations and complicate their programming environments.

Researchers looking at newer applications of agents for agent-based simulations of complex adaptive systems and artificial markets need new communities and conferences so they can develop an independent discipline and create new standards. An early attempt to create such a community involved the IPSJ (Information Processing Society of Japan), which gathered many researchers in a study group called SIGICS.

In 2001, AESCS (Agent-based Approaches in Economic and Social Complex Systems) was held as the first international workshop on ABS studies in Japan. With a close relationship with AESCS, the Pacific-Asian Association for Agent-based Approaches in Social Systems Sciences (PAAA) was soon created. Building on the successes of AESCS and PAAA, there are now large communities for ABS researchers in Japan and ASIA.

We hope that the research communities of ABS and SSME will continue working together to evolve their interrelated disciplines.

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