MULTIAGENT LEARNING SIMULATION FOR A SOCIAL DILEMMA OF COMMUTERS' MODE CHOICE*

By Yos Sunitiyoso** and Shoji MATSUMOTO***

1. Introduction

Most of models in transportation planning and analysis rely on the equation-based modeling. Agent-based approaches are still not as widely used as equation-based approaches. An agent-based model has the advantage of being validated at an individual level, since the behaviors encoded for each agent can be compared with local observations on the actual behavior of domain individuals. Understanding individual's behavior is important especially in studying effects of transportation policies.

Several works on route choice behavior by Nakayama et al.[8)-9)] are the examples of agent-based approaches in transportation modeling. Travelers are modeled to have bounded rationality, limited information and also capability to do cognitive learning. Klugl and Bazzan[7)] also studied route choice behavior by using a simple heuristic model. In travel mode choice, there are not so many works done by researchers. One of the inspiring works by Kitamura et al.[6)] is on travel mode choice by using a simple bi-modal transportation system and cellular automata.

Our study focuses on commuters' mode choice behavior. On the highway, all people have right of commuting by private car or public transport. As a common good, which is shared by people, a social dilemma[1)] situation may happen on the highway. Selfish behavior of people, who use cars based on their personal interest to minimize travel cost, creates traffic congestion, and furthermore increases travel cost for users both of car and public transit. By using a simple bi-modal transportation system, the social dilemma situation of travel mode choice is modeled. Travelers who use public transit, for example bus, are called as cooperative travelers, since they behave cooperatively for the sake of all people's benefit. Car users are defective travelers since they consider only their personal interests.

This study aims to provide an agent-based simulation model of travel mode choice in order to understand behavioral process of commuters on choosing travel mode. Interaction among travelers is one of factors that are predicted to influence choice behavior of travelers. A user equilibrium point may also be reached, but more important is the process to reach the point and the behavioral change of travelers during the process. By introducing evolutionary approaches into travelers' learning process, the model is expected to gain an insight into the way of solving social dilemmas.

2. Multiagent simulation model

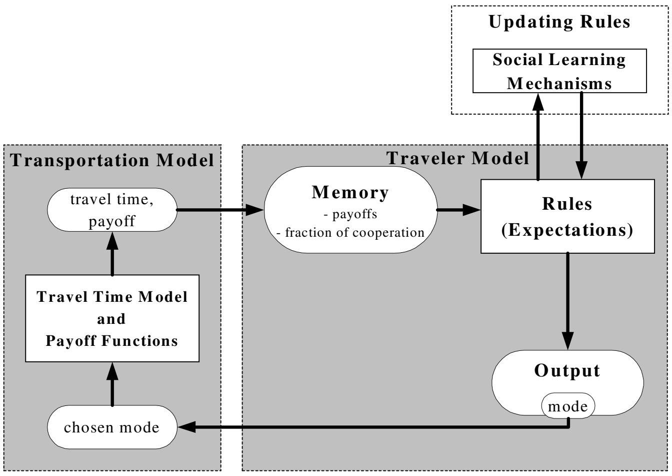

Figure 1: Multiagent simulation model

Travelers' commuting behavior can be represented by behavior of autonomous agents in a simulation model. Agents behave based on behavioral mechanisms updated by an evolutionary approach. The model is also used to represent interactions among travelers and complex decision-making processes by travelers.

Our model consists of two submodels (see Figure 1). In the traveler model, travelers decide mode based on the rules of expectations, which guide travelers on making decision. After all travelers decide the mode of commuting, then travel times are calculated in the transportation model. Generalized travel cost for each mode can be calculated and it returns to travelers as payoffs. Payoff value of each traveler depends on the mode he has chosen. These decision making processes are iterated 10 times for each generation. After that, there comes an evolutionary process to choose a type of expectations and to acquire adaptive behavior of travelers by means of simulating social learning mechanisms.

(1) Transportation model

A simple bi-modal transportation system, which comprises private car and bus as choices of commuting, is used as a transportation model. The two modes are assumed to be operated in the same lane so that there will be more interactions than if they are operated in exclusive lanes. This simple model is used in order to understand basic travel mode choice that represents social dilemma situation.

All travelers own cars so that they can easily change modes and they only know the cost of mode they choose. Private car users are assumed to be solo drivers. For public transport, bus operating frequencies and fare are adjusted so that bus passengers can pay the full cost of operating buses. Equations and their parameters of generalized travel costs for car and bus are derived from the work of Kitamura et al.[6)]

---

* Keywords: travel mode choice, social dilemma, agent-based approach, microsimulation
** Student Member of JSCE, Dept. of Civil and Environmental Systems Eng., Nagaoka Univ. of Technology (1603-1 Kamitomioka-machi, Nagaoka, Niigata, 940-2188 Japan, E-mail: yos@stn.nagaokaut.ac.jp)
*** Member of JSCE, Professor, Dept. of Civil and Environmental Systems Eng., Nagaoka Univ. of Technology (1603-1 Kamitomioka-machi, Nagaoka, Niigata, 940-2188 Japan, TEL 0258-47-9615, FAX 0258-47-9650, E-mail: shoji@nagaokaut.ac.jp)

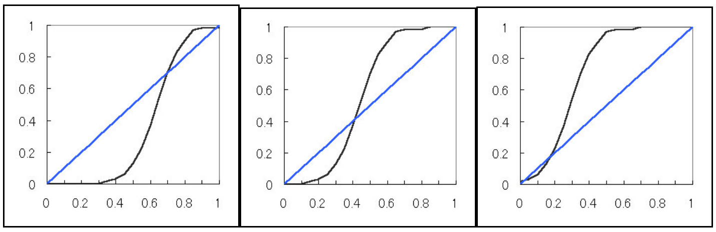

Figure 2: Types of bandwagon expectations curve
(from left to right; pessimistic, normal and optimistic.
x axis: fraction of cooperation, y axis: probability of cooperation)

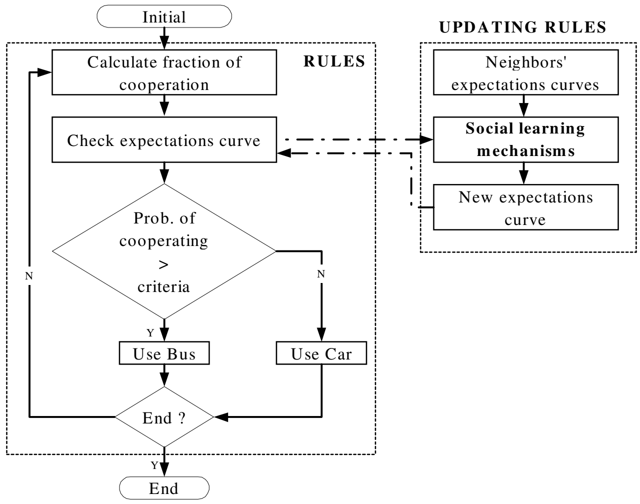

Figure 3: Decision making of a traveler

(2) Traveler model

a) Decision making rules: expectations' curve

Behavior of a traveler is represented by an expectations curve, which shows traveler's belief about the influence of his action on others[2)]. Two classes of beliefs were considered in the model: bandwagon expectations and opportunistic expectations[5)]. For each type, there are three types of curve that represent agents' level of expectations: pessimistic, normal and optimistic. In this paper, we deal with only the bandwagon expectations (see Figure 2). A probability of cooperating represents a degree of an individual's beliefs about the influences of his action on others; and a criteria, which lies on 45 degree of straight line and the value is equal to the fraction of cooperation, represents a base of beliefs.

Figure 3 shows decision making processes of a traveler. Initially, travelers are given a type of curve and a randomly chosen mode. Travelers make decision at an asynchronous time so that only 10% of them observe current level of cooperation and make a choice at the same time. Another 90% continue to use their current mode of commuting. Based on travel mode they chose, travelers receive payoffs and accumulate them. After 10 iterations, the accumulation of payoffs is used as the fitness of agents' type of curve.

b) Interaction among agents: group-based interaction

A possibility of incorporating employer-based TDM measures to solve a social dilemma of travel mode choice is studied by introducing a group-based interaction, where a group represents employees of a company. We also need this grouping to make travelers interact each other in order to acquire adaptive behavior by local interactions. A traveler interacts with travelers of the same company he works in a torus plane so that eight neighbors around him influence his choice of behavior. Each group is independent from others so that there is no interaction among members of different companies. Assuming limited information, a traveler knows only his own payoff information and types of expectations curve of eight surrounding neighbors.

c) Evolution of expectations by imitation

We apply an imitation game based on social learning mechanism in order to evolve expectations' curve of each traveler. Two kinds of mechanism are used: payoff-biased transmission and conformist transmission[3)]. The relative strength of each transmission depends on the strength of conformist (α) in a traveler's psychology[4)]. For each traveler, there are α probability to use conformist transmission and $(1 - \alpha)$ probability to use payoff-biased transmission.

3. Simulation Results and Discussions

A number of agents, exactly 4096, are assigned into 16 homogeneous groups with size 256. Each agent has a type of bandwagon expectations curve (pessimistic, normal or optimistic), which is assigned randomly giving the same proportion of agents for every type of expectations' curve. We run a simulation with various initial levels of cooperation, ranging from 0.2 to 0.8 with increment 0.1. The strength of conformist transmission (α) ranges from 0.0 to 0.4. Simulations are run up to 100 generations with 10 iterations per generation.

(1) Social learning mechanism by payoff-biased transmission ($\alpha = 0.0$)

The simulation resulted in an equilibrium point for initial level of cooperation from 0.2 to 0.7 (see Figure 4). According to the cost functions defined before, the number of bus users at the equilibrium point should be at 1222 or equal to 30% of travelers. High initial level of cooperation (0.8) resulted in full level of cooperation (all travelers chose bus) because for all types of curve, the probability of cooperating at a fraction of 0.8 was higher than the criteria (see Figure 2), so that all travelers suddenly cooperated.

Observing which kinds of type exist at the end of simulation, all three types of curve still exist as seen in Figure 5. Pessimistic type was chosen by the highest number of members, around 2500 travelers. Followed by normal type with around 1000 members and the rest is optimistic type.

(2) Dynamics within a group at $\alpha = 0.0$

Dynamics of behavioral change within a group can be seen in Figure 6, which is taken from a simulation run with initial level of cooperation 0.5. The number of bus users is taken from the average value of 10 iterations in one generation. Within Group 1, all members finally chose car. Pessimistic behavior dominates the group with around 200 agents. Small numbers of normal and optimistic agents could not increase the level of cooperation and furthermore they chose defection.

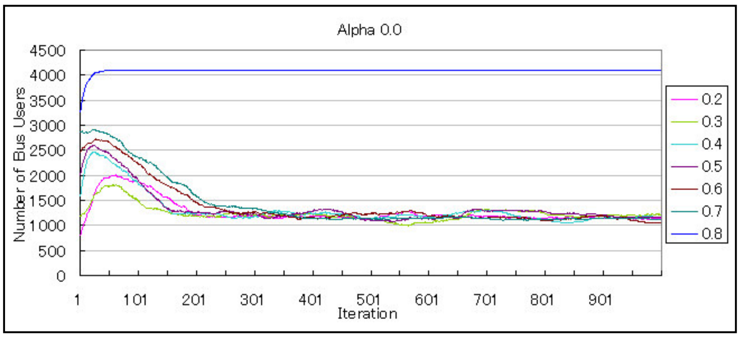

Figure 4: Dynamics of cooperation level (α = 0.0)

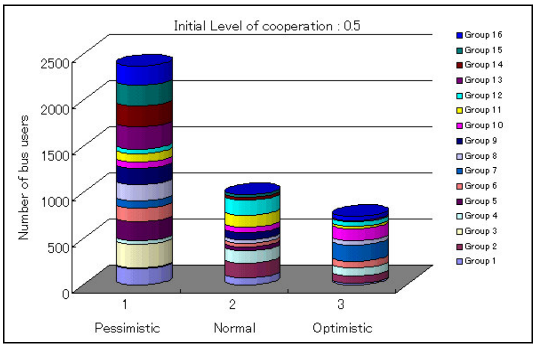

Figure 5: Type of curves at the end of simulation

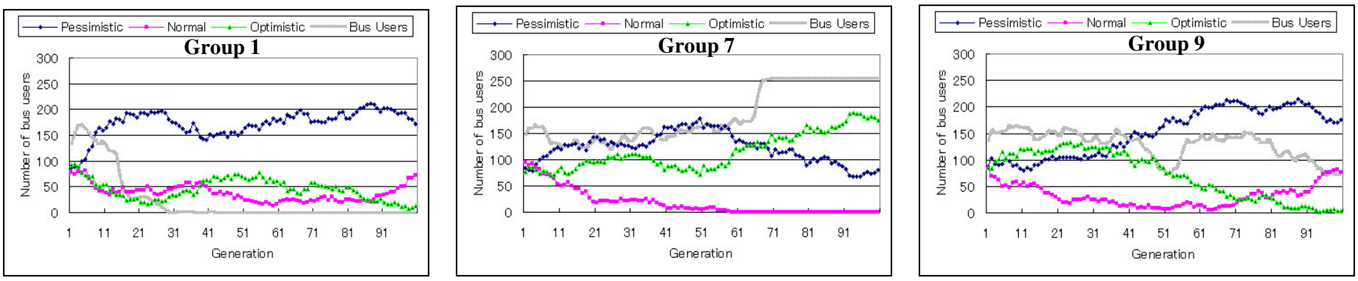

Figure 6: Dynamics of behaviors within a group (α = 0.0)

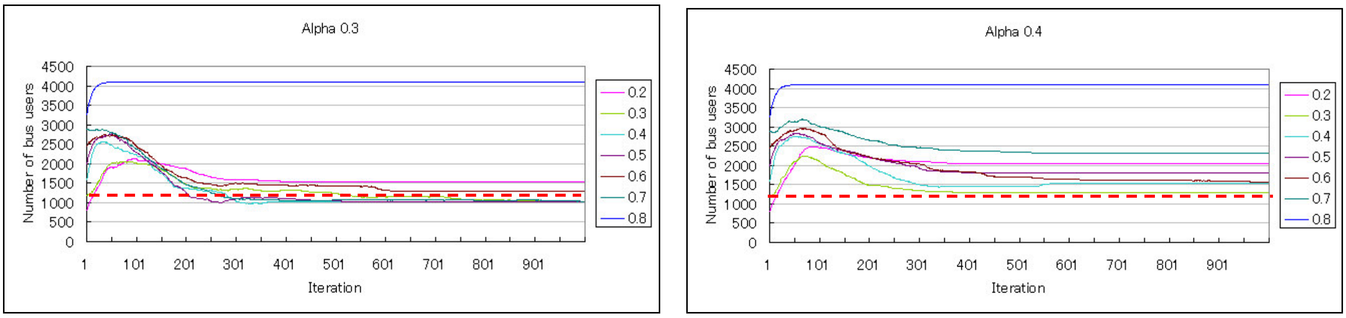

Figure 7: Dynamics of cooperation level (α= 0.3 and 0.4)

The situations between Group 7 and 9 are quite different. Group 7 shows the role of optimistic agents to elicit cooperation, since they acted alone as altruist agents following the fall of normal agents. They could maintain the level of cooperation and increased to the maximum level, after some pessimistic agents changed type to optimistic one. Group 9 has a different pattern. Almost the same numbers of pessimistic and optimistic agents dominate early 30 generations and maintain level of cooperation as high as the initial point. After generation 40's, the number of pessimistic agents increased and followed by decreasing level of cooperation. Although the cooperation level increased again during generation 60-80's, it was not stable and decreased gradually since there were not many optimistic or normal agents who could stabilize it.

(3) Combining payoff-biased transmission and conformist transmission (α=0.1 - 0.4)

The strength of conformist is represented by a value of α. High value means high probability of using conformist transmission for an agent. For α=0.1 and 0.2, the dynamics are only slightly different from α=0.0, so that we will focus on α=0.3 and 0.4 (see Figure 7). The dashed line is the user-equilibrium line. At α=0.3, conformist transmission could push the system to converge to a higher level of cooperation than the general equilibrium point for several cases only. But at α=0.4, higher level of cooperation could be reached for all initial levels of cooperation.

Low initial level of cooperation (0.2) gave a quite different behavior, because in the beginning the cost of bus was lower than car, so that most of users preferred bus to car. The level of cooperation suddenly increased and the conformist transmission spread cooperative behavior to other travelers. If the strength of conformist were strong enough then cooperative behaviors could spread fast to make all group members cooperate and stabilize cooperation within the group, without giving payoff-biased transmission a chance to push the global cooperation to the equilibrium point. It can be seen that low initial level of cooperation 0.2 gave higher convergence value than initial level 0.3, 0.4, 0.5, and 0.6.

Middle to high initial value of cooperation (0.4-0.7) had different processes. In that range, the higher the initial level, the higher is the convergence point. Let us focus on the case of α=0.4. In the beginning, cooperation increased suddenly because of the existence of optimistic agents who chose cooperation, since the initial fraction of cooperation was higher than the criteria of cooperation. They were followed by some normal agents who later also cooperated, after observing a certain level of cooperation which was higher than their criteria. Finally, payoff-biased transmission that has probability 0.6 (1-α), had pushed the cooperation level to lower state before the system converged. High initial level of cooperation (0.8) favored cooperation for all types of expectations so that full level of bus users was achieved.

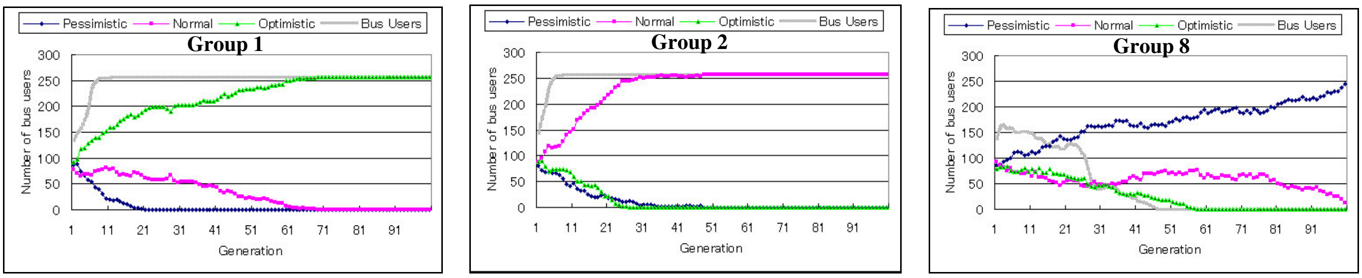

Figure 8: Dynamics of behaviors within a group (α = 0.4)

(4) Dynamics within a group at α = 0.4

Early dynamical processes within a group are complex and important to determine the succeeding processes and ending results of simulation (see Figure 8). Conformist transmission helped the spread of a type of expectations' curve and later the group would become homogeneous with an only type of curve. In some groups, optimistic expectations may dominate. But in some other groups, pessimistic or normal expectations may also dominate.

These results prove that the conformist transmission might be able to stabilize cooperation when it is strong enough compared with payoff-biased transmission. By using a complex process of interactions among agents, a combination of payoff-biased and conformist transmissions, and also other emergent components, high level of cooperation can be achieved.

4. Conclusion

A simulation model of multiagent learning for commuters' mode choice was built and applied to examining behavior of commuters. The same user equilibrium point as predicted by conventional analysis can be reached and stabilized, by interaction process among travelers and by behavioral-change process of each traveler. Outside the system, there is no central or external rule that organizes objective function of the system. The equilibrium is a result of self-organization and complex process among travelers.

Based on the phenomenon within a group, it could be inferred that cooperation level is highly related to the existence of type of expectations within a group. Domination of pessimistic agents would make a group converges to all defection and the appearance of optimistic agents is very important to pioneer cooperation within a group. This also shows that the global behavior of all agents may make the system converge to the equilibrium point, although local behaviors within a group converge to their own convergent point.

When the strength of conformist transmission is relatively high (0.4), once a type of expectations becomes common then it will quickly dominate and homogenize a group. Within a group, if optimistic agents were quite common and the conformist transmission were strong enough, then optimistic type would spread through all group members and the maximum level of cooperation could be achieved. The only chance for 'cooperative type', like optimistic type, to spread is by dominating the group as fast as possible, without giving a chance for 'selfish type', like pessimistic type, to spread with the help of payoff-biased transmission. Once a type spreads widely enough then it will dominate the group.

There are three conditions that produce cooperation as a possible outcome. The first is beliefs and expectations. This study assumes that travelers have bounded rationality since they do not directly choose mode based on payoff they receive, but based on the expectation of their actions to affect others. The second is limited information. Grouping among travelers, as a way to represent employer-based interactions, limits travelers' knowledge about behaviors of other groups' members. They can observe the behavior of all their close neighbors, instead of all group members. The third is the conformist transmission. When travelers do not feel economic rationality as a must, they should observe other kinds of learning process such as conformist transmission, which is formed as a motivation to copy majority behavior of a group.

References

1) Dawes, R.: Social dilemmas, Annual Review of Psychology, Vol.31, pp.169-193, 1980.
2) Glance, N., Huberman, B.: The outbreak of cooperation, Journal of Mathematical Sociology, Vol.17(4), pp.281-302, 1993.
3) Henrich, J.: Cultural group selection, coevolutionary processes and large-scale cooperation, Journal of Economic Behavior and Organization, Vol. 53, pp.3-35, 2004.
4) Henrich, J., Boyd, R.: Why people punish defectors: weak conformist transmission can stabilize costly enforcement of norms in cooperative dilemmas, Journal of Theoretical Biology, Vol.208, pp.79-89, 2001.
5) Huberman, B., Glance, N.: Beliefs and cooperation, Paper at Chaos and Society's International Conference, 1994.
6) Kitamura, R., Nakayama, S., Yamamoto, T.: Self -reinforcing motorization: can travel demand management take us out of the social trap?, Transport Policy, Vol.6, pp.135-145, 1999.
7) Klugl, F., Bazzan, A.: Route decision behaviour in a commuting scenario: simple heuristics adaptation and effect of traffic forecast, Journal of Artificial Societies and Social Simulation, Vol.7, No.1(online at http://jass.soc.surrey.ac.uk).
8) Nakayama, S., Kitamura, R., Fujii, S.,: Drivers' learning and network behavior: dynamic analysis of the driver-network system as a complex system, TRR 1676, pp.30-36, 1999.
9) Nakayama, S., Kitamura, R.: Route choice model with inductive learning. TRR 1725, pp.63-70, 2000.