INVOKING HOUSEHOLD COOPERATION IN CO2 EMISSION REDUCTION

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1 Introduction

1.1 “The tragedy of commons”

Hardin (1968) published an article on the dilemma of the commons. Commons refers to any resource (e.g. fish, water, forest, or clean air) shared by a group of people. Every member society has the right to take from and add to the commons pool for resources. To accumulate wealth, each member believes that he/she has to acquire one unit of resource or dump one unit of waste while distributing one unit of cost across all the members with whom the resources is shared. Thereby, the individual gain appears large and the cost very small. Ultimately, as population grows and greed runs rampant, the system collapses and ends in "the tragedy of the commons".

Human activities have changed the composition of the atmosphere, and are responsible for the excessive increase of CO2 in the air (Karl and Trenberth, 2003). Reduction of the CO2 emitted through human actions to an acceptable level is must be a global objective of the modern community (Kyoto Protocol, 1992). However, global objective and individual benefits may be contradictory. Reducing CO2 emission is then a type of the commons dilemma. Society shares the atmosphere, in which they freely emit CO2. In terms of households, the environmental load from one household is then multiplied by all the households in its area. Reduction of CO2 emissions would limit the household’s activity and could add additional cost to the family’s budget; those that do nothing for reducing CO2 emission pay nothing. Obviously, there is payoff from cooperative activity. According to game theory, the defector seems always to win in the game of commons dilemma (Yamamoto S, 2003). As a result of these circumstances, global warming is likely to reach damaging levels. The cost of controlling carbon emissions is high and there is always the mirage of a hydrogen dependent economy (Kennedy, 2003). According to Hardin (1968), there is no technical solution to the problem. Can the catastrophe not be redressed?

The payoff can be directly influenced through the cost/benefit relation of behaviors, for example via taxes and financial incentives. It must pay to behave in an environmentally-responsible way (Mosler, H.-J. 2001). This study considers introducing strategies which cause changes in payoff and support the cooperative activities.

To prohibit the defection behaviors, the strategy of levying maintenance charge for environment recovering is usually considered a legal solution. While in micro-economic, one of the most remarkable efforts is the creation of CO2 Emission Trading Scheme (CETS)

1.2 CO2 Emission Trading Scheme (CETS)

The restrictions concerning environmental problems include subsidy, deposit refund system, environmental tax, emissions trading, etc., which are solving the environmental problems by market-based mechanism.

The common attentions are attracted to environmental tax and CO2 Emissions Trading Scheme (CETS). Environmental tax is a kind of tax collected from polluters which can make the social cost internal by letting the polluters pay it. It's like having the government act like the owner of the resource, such as air or water and charge firms for using it. The main difficulty here is an information problem: how can the government determine the appropriate size of the tax? Normally, we rely on the market to tell us the cost of an activity or resource -- but the problem is precisely that no market exists for the resource in question, so we can't really know how much it's worth to people. And, energy using is allowed if the money is paid. So when economic recovery is carried out, its effect to an environmental improvement will become weaker.

CETS allows for the trading of CO2 Emission Allowance (CEA) among domestic companies. Due to its cost effectiveness, CETS has been implemented worldwide (Nishimura, 2004). It is a propose solution that the government would set some maximum quantity of the polluting activity, and then allow CEA to be sold and traded on the market. This proposal has the advantage of allocating the emission allowance to those who value it most. In the case of environmental tax, the government needs to discover the optimal tax rates. Conversely, it is unnecessary to determine the prices of CEA in the case of CETS. The government should just publish the quantity of emissions allowance corresponding to the amount of social optimal contamination. With this meaning, externality is effectively controllable with less information by CETS than by environmental tax. That yet not resolved in CETS is how to design the market which performs CEA trading.

If the enforcement expense of environmental regulation can be disregarded, the same effect is acquired either introduces the restriction of environmental tax or CETS (Ueda et al, 1992). The difference is, although environmental tax has the effect promoting the measure of energy saving, it is not the framework which can control the total amount of emissions.

The CO2 emissions from the Public Welfare Department are 28.7% of the total anthropogenic CO2 emission. 45% of that is from households (Ministry of Economy, Trade and Industry, 2004). The significant increase of CO2 emission from Public Welfare Department enhanced the importance to CO2 emission control at household level (Ministry of Environment, 2005). It seems promising to introducing CETS to households. However, the difficulty in estimating the CO2 emission from sources related to human behaviors is one of the obstacles (Nishimura 2004). With respect to individual households, in Chapter2, Household's Annual CO2 emission (HACO2) was defined as the sum of the life cycle CO2 emission from house construction and operation (LCCO2), the CO2 emission from commuter trips (CTCO2), and the CO2 emitted from energy usage in daily life (ELCO2). A managing instrument of given a constraint on HACO2 was proposed. Constraint on HACO2 led to the tradeoff between LCCO2, CTCO2 and ELCO2. Simulations in Chapter3 suggested the instrument could influence household activity.

A feasibility study showed the practicability of introducing CETS to households (Kondo et al., 2003). The study however, did not touch how to establish the CETS for households, and lacked the discussion on possibility of enforcement. Kimura & Orida (2002) developed a "Network CETS Experiment System", which imitated the CO2 emission trading in a multi-national market by Multi-Agent Simulator (MAS). It offered a method of making prior evaluations on the effects of CETS.

1.3 Purpose

The contradiction of global objective and individual benefits in reducing CO2 emission is regarded as a type of commons dilemma. This Chapter explores how to invoke the cooperation from individual household for achieving a global target of reducing HACO2 within a city. The payoff function of the commons links the household benefits to the number of cooperators in the city. 2 strategies: levying maintenance charge and CETS to households are introduced into the payoff function and supports the cooperators. The household in the city is treated as an agent in a multi-agent system (MAS). A Multi-Agent Simulator is applied for searching the relationship among the parameters in the payoff function and the social cooperation of households.

The following questions are addressed:

1) How the CETS for households be designed?
2) How do the strategies influence the payoff function and the household cooperation in reducing CO2 emission?
3) Is it possible to increase social cooperation by applying the strategies?

2 How the CETS for households be designed?

There are many types of emissions trading approaches; one of them is called "cap and trade", which is introduced in this paper. In a cap-and-trade system, the government sets the total amount of a pollutant that can be put into the environment by an entire industry or class of emitters. The government establishes emission allowances, which can be bought and sold among companies in the industry. At the end of the year, each company must hold a number of emission allowances equal to the amount of the pollutant they emitted. As industrial capacity, energy usage, and emissions grow over time, total emissions must still stay within the cap, which limits total pollution output while allowing industry some flexibility and predictability to meet their growing needs. Of course, the cap must be set low enough in the first place for the program to confer a true environmental benefit.

The international emission trading scheme have already initialized in many countries, especially into the manufacturing departments. The scheme is widely supported not only since it can control the total amount of energy consumption, but mostly since it helps in reducing emissions of greenhouse gasses in a cost efficient way. The mechanism of the cost efficiency of CETS for companies is shown in Figure.1 and Table 4-1 (made by author according to Nishimura 2004). Generally, the emission trading is happened between the companies that with different reduction cost (RC). For example, RC of company "A" is 10 (*monetary unit/kg-C*), and that of company "B" is 20 (*monetary unit/kg-C*). With CETS, both the companies can achieve the reduction target, and save the reduction cost as well (Table.1).

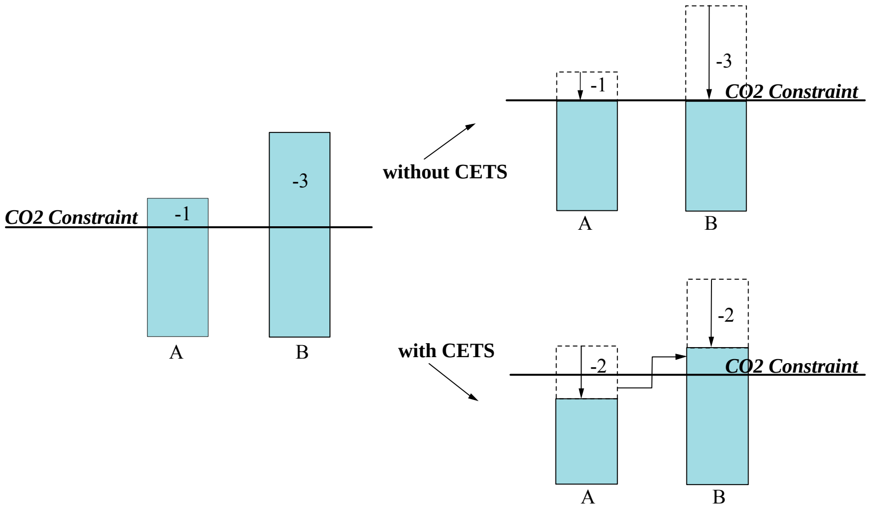

Figure.1CO2 Reduction Activities of Companies

Table.1 Changes in Company's Expense for CO2 Reduction without and with CETS

	Without CETS			With CETS		
	A	B	Total	A	B	Total
Reduction target(*kg-C*)	1	3	4	1	3	4
RC unit (*monetary unit/kg-C*)	10	20	-	10	20	-
CEA Trading Price(*monetary unit/kg-C*)	-	-	-	10	10	-
Amount of reduction (*kg-C*)	1	3	4	2	2	4
Amount of CEA purchase(*kg-C*)	-	-		1	1	
Reduction Cost(*monetary unit*)	10	60	60	20	40	40
Cost for purchase(*monetary unit*)	-	-	-	-15	15	0
Expense(*monetary unit/kg-C*)	10	60	70	5	55	60

CETS for households is designed according to the managing instrument of controlling HACO2, which is developed in Tang (2005). The trading is designed between the households with different CO2 emission allowance (CEA). CEA here, is the difference between HACO2 and the determined constraint on CO2 emission for each household (CO2 constraint). Figure.2 shows the framework of CETS. In case of without CETS, each household has to keep its HACO2 under the determined CO2 constraint. Household "A", has the allowance to consume the left over CO2 emission. Conversely, household "B", has to reduce all of the exceeded CO2 emission. While in case of with CETS, both "A" and "B" has several selections. For household "A", it can participate in the CEA trading, reduce CO2 emission, or do nothing. For household "B", it can decrease HACO2 by reducing CO2 emission, by buying CEA, or by using both of the two methods. Table.2 shows the changes of households' expenses for the same global reduction target with and without CETS (in case of with CETS, samples of 2 possibilities: P① and P② are offered). With CETS, the total expense of households is decreased. Household B costs lower than in the case of without CETS and household A obtains profits via emission trading.

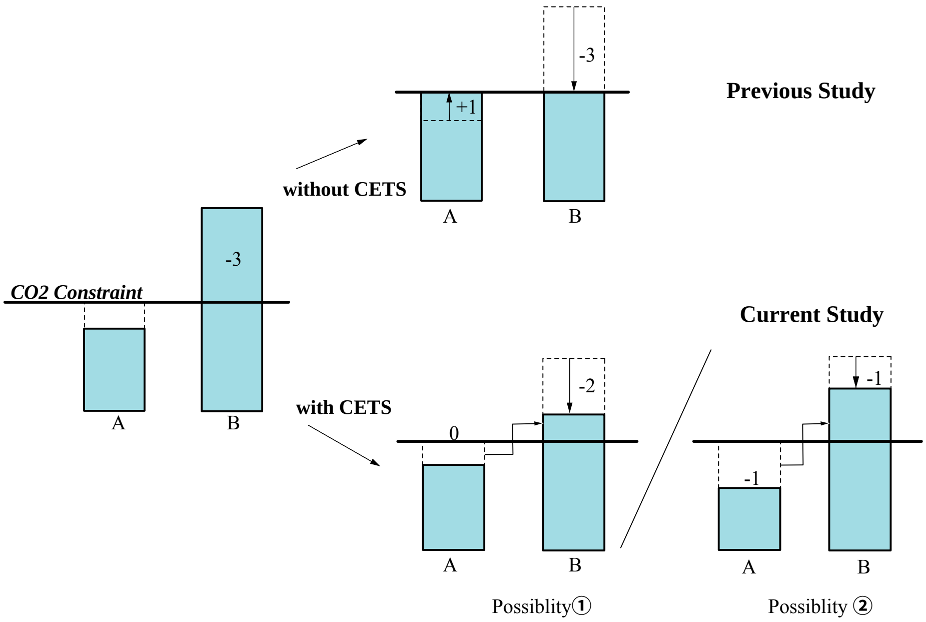

Figure.2 CO2 Reduction Activities of Households

Table.2 Changes in households' expenses for CO2 reduction without and with CETS

	Without CETS			With CETS-P①			With CETS-P②		
	A	B	Total	A	B	Total	A	B	Total
RC unit (*monetary unit/kg-C*)	20	20	-	20	20	-	20	20	-
CEA Trading Price(*monetary unit/kg-C*)	-	-	-	15	15	-	15	15	-
Amount of reduction (*kg-C*)	0	3	3	0	2	3	1	1	3
Amount of CEA purchase(*kg-C*)	-	-		-1	1		-2	2	
Reduction Cost(*monetary unit*)	0	60	60	0	40	40	20	20	40
Cost for purchase(*monetary unit*)	-	-	-	-15	15	0	-30	30	0
Expense(*monetary unit/kg-C*)	0	60	60	-15	55	40	-10	50	40

3 Method and Materials

3.1 MAS based model

A MAS is composed of several agents capable of reaching goals that are difficult to achieve (Weiss, 1999). All the agents have an identical internal structure, including goals, domain knowledge, possible actions, and decision procedures. This study adopted a multi-agent simulator to construct a model in which a household acts as an agent. Agents do not affect others directly, but because of physical proximity, the behaviors of one agent will change the sensory inputs of the others and thereby influence their behaviors.

Household as an agent in MAS

In this study, 'household' refers to a nuclear family belonging to the same social group. Family members were assumed to live in the same detached house, and one member was assumed to be a commuter working in the city. This research used a representative wooden standard house model (SHM) with a gross floor area of 125.9 m^2 (Figure.3). Annual CO_2 emission from the household ($HACO_2$ (kg-C/yr)) includes $LCCO_2$, $CTCO_2$, and $ELCO_2$, and can be expressed as

$$HACO_2 = LCCO_2 + CTCO_2 + ELCO_2 \; . \qquad (1)$$

The life cycle of a residential building includes several stages including material production, construction, occupation and repair, recycling and disposal, etc. $LCCO_2$ is the sum of CO_2 emissions during all stages; an approach proposed by Munemoto et al. (2002) can be used to estimate the $LCCO_2$ of a detached house.

In Japan, the average CO_2 emission resulting from household electric power consumption (four family members) was 2000 kg-CO_2/yr (545.0 kg-C/yr) in 2000Note [1]. This study used this value as the initial value of $ELCO_2$ for each household.

$CTCO_2$ relates to a vehicle and commuting distance using the following formula:

$$Tt_i = \sum E_j \times D_j \quad (2)$$

where Tt_i represents CTCO$_2$ (kg-C/yr), D_j represents the commuting distance by vehicle j (km), and E_j represents the CO_2 emission unit of vehicle j (kg-C/km.yr.p). Note [2]

Our previous study examined the effects of different vehicles on the energy-efficient housing arrangement (Tang et al., 2005). For simplicity, cars were the only mode of transportation considered.

In the MAS-based model, each agent was labeled cooperative (C) or defective (D) in reducing HACO$_2$ emission: a cooperative agent took action to reduce CO_2 emission (Agent-C) and a defective agent acted in no way to reduce emissions (Agent-D). An Agent-C could become an Agent-D if it changed its behavior, and vice versa.

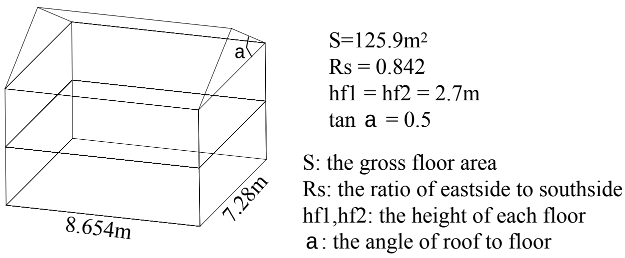

Figure.3 Definition of the Standard Housing Model.

Environment

Urban space served as the MAS-based model environment; houses were randomly located within this space (Figure.4). Commuting distances for each household did not exceed 50 km, and the number of households in the city was assumed to be constant. The city's management department gave each household a reasonable constraint on their CO_2 emissions within a designated period.

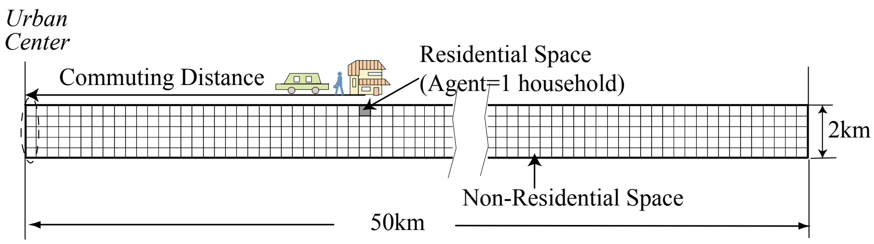

Figure.4 Urban Model

3.2 Payoff function

Reducing CO_2 emission involves additional expense to an agent. Defection, i.e., taking no action, involves no expense. A strategy of levying maintenance charges for environmental recovery was applied to prohibit defective behavior. If maintenance charges are related to the number of cooperators, the payoff function for each household can be expressed as

$$f(b, nC) = \begin{cases} -RC - (N - nC - 1) \times L & \text{if} \quad b = C \\ -(N - nC) \times L & \text{if} \quad b = D \end{cases}, \quad (3)$$

where f represents the expense to an agent (the payoff value), b represents either C or D behavior, RC represents the cost of reduction, N represents the number of households in the city (N = {1, 2, …, n}), nC represents the number of cooperators (nC = 0, 1, …, n – 1), and L represents the unit maintenance charge (monetary unit) ($L >= 0$).

The payoff function applies the following characteristics to represent the commons dilemma:

1) $f(C,nC) < f(D,nC)$. In the short term, payoff from cooperation is always lower than payoff from defection, if nC is neglected. As a result, the great number of Agent-Ds would never allow the global reduction target to be met.

2) $f(C,N - 1) > f(D,0)$. If all agents select C, the resulting payoff would be greater than if all agents select

D.

3) *f(C,nC)* is a monotone increase function of *nC*. In the long term, a greater *nC* would result in a greater payoff from C.

A cooperative household could reduce its $HACO_2$ to levels lower than the $HACO_2$ constraint for an individual household. CETS would allow remaining CEA to be sold via the trading market, and profits earned from selling CEA would encourage this cooperative behavior. After the introduction of CETS, the payoff function changes as follows:

if $HACO_2 > CO_2$ *constraint then*

$$f(b,nC)=\begin{cases}-RC-(N-nC-1)\times L & if \quad b=C\\ -(N-nC)\times L & if \quad b=D\end{cases}$$

if $HACO_2 < CO_2$ *constraint then*

$$f(b,nC)=\begin{cases}-RC-(N-nC-1)\times L+PS & if \quad b=C\\ -(N-nC)\times L & if \quad b=D\end{cases}$$

(3')

where *RC* represents the total cost of reduction (*monetary unit*), and *PS* represents profit from CEA selling (*monetary unit*)

$$RC^t = uRC \times iRT^t, \qquad (4)$$

where *t* represents the number order of the current stage, *uRC* represents the unit reduction cost (*monetary unit/kg-C*), and iRT^t represents the target reduction for an individual household at stage *t (kg-C)*

$$PS^t = uPT \times iRT^t, \qquad (5)$$

where *uPT* represents the price of unit CEA (*monetary unit/kg-C*).

If *PS* is greater than *RC*, Agent-C could receive a greater payoff than Agent-D. The greater the reduction in CO_2 emissions, the more profit Agent-C could earn. It is likely that this mechanism will invoke greater social cooperation toward reducing CO_2 emissions. In this study, the ratio of number of cooperators to total number of households ($R = nC/N$) is defined as an index of social cooperation. Payoff value is determined using parameters in the payoff function, such as unit reduction cost (*uRC*), cost of unit CEA (*uPT*), and unit maintenance charge (*L*). To simplify the relationship, *uRC* is assumed to be 1 (monetary unit), *L* is *p* times *RC* ($L = p \times RC^t (p >= 0)$), and *uPT* is *a* times *uRC* ($uPT = a \times uRC\ (a >= 0)$). The payoff function is thereby only a function of parameters *a* and *p*.

3.3 HACO2 reduction process

Reduction process of HACO2 is divided into several stages. The global reduction target is assigned to cut *m*% of the total HACO2 emitted from all of the households within a designed period. Figure.5 shows the flow of the reduction process.

At the initial stage, HACO2 from all of the households are summed up, and the global reduction target (gRT^0) is then obtained, based on formula (6).

$$gRT^0 = HC^0 \times m \qquad (6)$$

where,

HC^0: HACO2 from all households at the initial stage (*kg-C/yr*);

m: reduction rate (%).

At the 1st stage, the global reduction target gRT^0 is divided according to the total stage number (*T*) and household number (*N*). One part of that is the individual reduction target for a household at this stage (iRT^0). The reduction amount unachieved at this stage will be left to the next stage. The more the remained, the higher the reduction target is for next stage. The reduction target to an individual household at stage t (iRT^t) is then determined by the completion of the target at the previous stage. It is calculated from formula (7).

$$iRT^t = (gRT^0 - \sum F^{t-1})/(T-t)/N \qquad (7)$$

where

ΣF: reduced CO2 emission at the past stages (*kg-C*) (at 1st stage, $\Sigma F=0$);
t: number order of current stage;
T: number of total stages;
N: household number in the city.

The reduced amount of CO2 emission at stage t (F^t) is related to the cooperator number (nC^t) and the amount of reduction by each household (iF^t) (Formula (8)). iF^t is determined by the household behavior-selection for reduction. iF^t of a household with defective behavior is considered 0 or even minus. That of a household who shift closely to urban center is the difference of the CTCO2 before and after shifting.

$$F^t = iF^t \times nC^t \qquad (8)$$

where
F^t: total amount of reduction at stage *t (kg-C/yr)*;
nC^t: cooperator number at stage *t*.

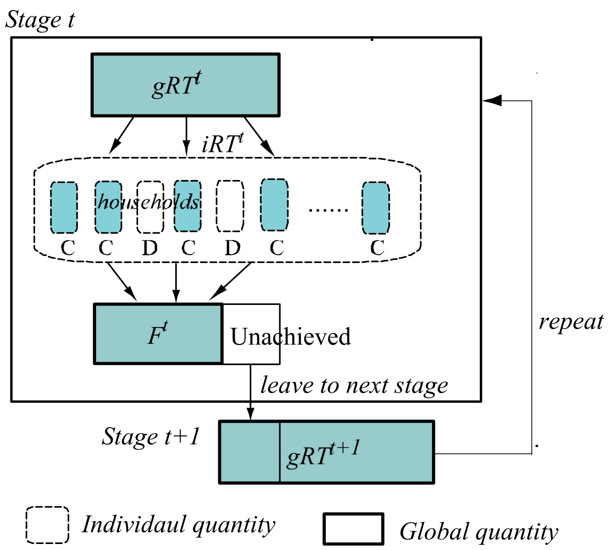

Figure.5 Reduction Process

3.4 Simulation

The initial condition, global target, and termination condition are given as follows.

Environmental initial condition: The number of Agent-C number is equal to that of Agent-D at initial stage. That is to say, the initial ratio of cooperation is 0.5 (R^0 =0.5).

Global reduction target: Cut 10% of initial CO2 emission within the designed period of 100 stages (*m =10%, T=100*). The values are arbitrarily set and can be changed.

Terminate condition: the iteration stops when the period is over or when the global reduction target is achieved.

Figure.6 shows the agents and their interactions with the environment. Each step is a reduction stage. At beginning of each stage, an agent calculates its HACO2 based on commuting distance, and judges if it is larger than the given CO2 constraint or not. Secondly, the agent inputs the assigned individual reduction target (iRT^t) and the cooperator number at the previous stage (nC^{t-1}). The environmental information is used to estimate the payoff of either Agent-C or Agent-D. Then, the agent selects either C or D activity, based on the payoff amount. The selection is based on the roulette strategy at a probability of the proportion to the payoff amount. The higher the payoff is, the higher the probability in selecting C would be. Agent-C turns to be Agent-D if it selects D, and vice versa.

If the agent decides to cooperate, it will go to the next step of the selection on the reduction behaviors. The behaviors and the relevant costs are shown in Figure.5 and Table.3. Generally, the agent reduces the assigned amount of CO2 emissions. In the case of "shift closely to urban center", the amount of reduction is the difference between the CTCO2 after and before moving. Else if the agent decides to defect, it needs not pay the reduction cost, but has to pay the maintenance charge. And the defectors are assumed discharging additional CO2 emission to the environment. Finally, the agents send the individual massages on the reduction to the environment. All the selections made by agents are based on the roulette strategy at the probability of the proportion to the magnitude of the payoff.

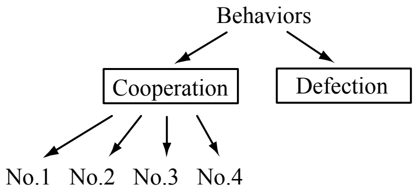

Figure.5 Behaviors Classification

Table 3.Reduction Behaviors and Related Cost

Behaviors		Losses (monetary unit /stage)		Profit (monetary unit /stage)	amount of reduced CO2 emission (kg-C)
		Lump sum (monetary unit)	Expenses (monetary unit/stage)		
No.1	Shift closely to urban center	for house-moving	-	from saved gasoline fee	△CTCO2
No.2	Decrease energy consumption	buy energy conservation electric appliance, etc	-	from saved electricity fee	iRT^t
No.3	Sell CER	-	-	uPT_sell×iRT^t	iRT^t
No.4	Buy CER	-	uPT_buy×iRT^t	-	iRT^t

At each stage, cooperator number is summed up and the global reduction target for next stage is set up, based on the outputs of the agents.

In order to clarify the effects resulted by the 2 strategies, simulations are performed in situation of $a=0$ (only levying maintenance charge) and $a>0$ (introduce both the 2 strategies).

In addition, to test the sensitivity of the defined input values, namely, the initial cooperation (R^0) and the global objective (m), to the resulted R value, simulation was made through changing m and R^0 individually while keeping α and p constantly.

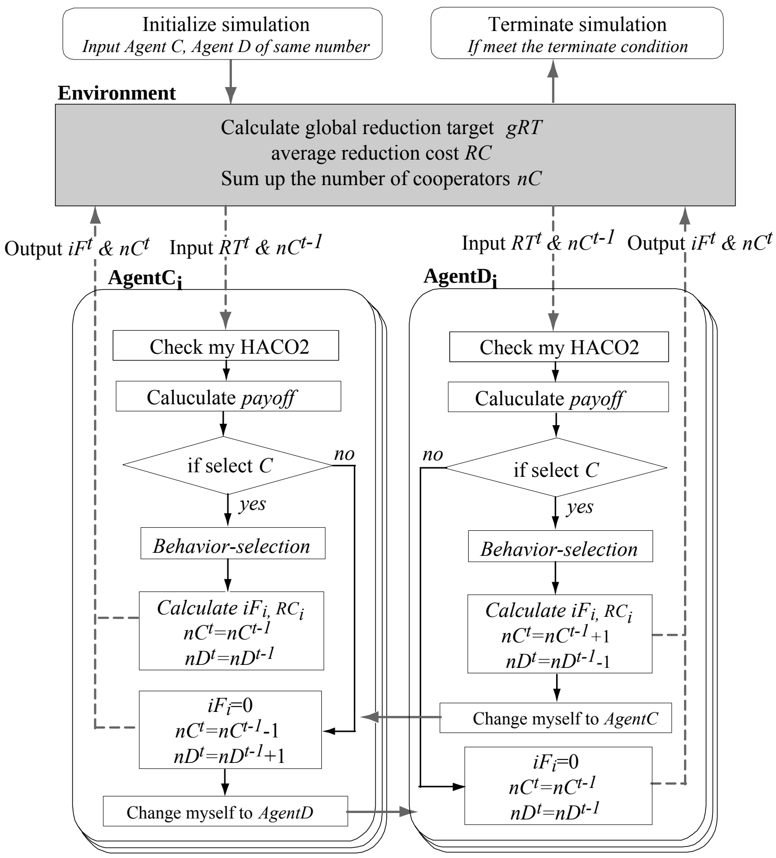

Figure.6 Simulation Flow

4 Result and Discussion

4.1 Results of Levying Maintenance Charge

Without CETS (*a=0*), simulations were made with *p* varying from 0 to an extremely large value. Figure.7 illustrates the relationship of R versus p, of which their values were averaged from 100 simulations. When *p=0*, it means the household need not pay maintenance charge. So, the payoff of Agent-D equals 0; that of Agent-C is equal to reduction cost (RC^t), which is minus. *R* is always 0 in such situation. The result indicates that, almost no household cooperates in CO2 emission reduction if there is no legal prohibition on defection or inducing household's behaviors. The environment would reach the damage situation and end in "the tragedy of the commons". When *p* is a little bit larger than 0 (such as *p=0.1*), *R* is relative stable at around 0.3. When *p=1*, *f(C,nC)=f(D,nC), R* is increased a little larger than 0.3. However, there is no obvious change in *R*, even if *p* continuously increases. This is because that, although *p* could be larger than 1, the difference between payoff of Agent-C and Agent-D is too small to encourage the cooperative behaviors. In this case, maintenance charge used to prohibit defection activities would fall to enhance the social cooperation. In addition, extremely expense may result in discouragement to both defector and cooperator.

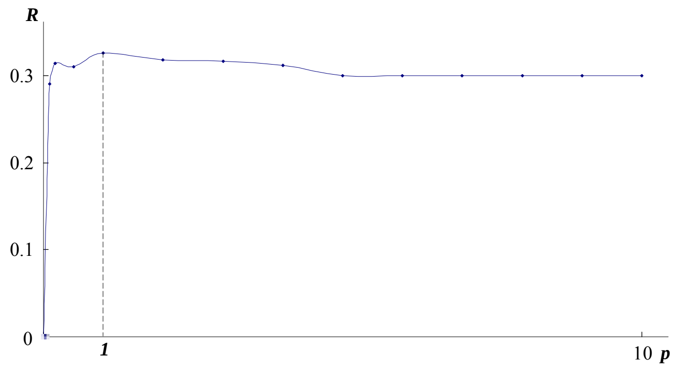

Figure.7 Relationship of Social Cooperation (*R)* Versus *p (in case of a=0)*

4.2 Results of Introducing CETS

Discussions on effects of CETS is firstly made when p=0, the situation of only introducing CETS to CO2 emission reduction. The payoff of Agent-C then equals *–RC* (*if HACO2> CO2 constraint*) or *–RC+PS* (*if HACO2<CO2 constraint*) (refer to formula 3'). When a>1, PS>RC, payoff of Agent-C with low HACO2 can be made larger than payoff of Agent-D. However, the purchase is not realized because there are only households selling CEA. So R is almost 0 although *a* turns to a very large value.

Secondly, the relationship of *R* versus *a* is analyzed by setting *p=1*. *uPT* is defined a times of *uRC (uPT=a×uRC (a>=0))*, *a* is therefore a right real number. But an extremely large *a*, relevant an extremely high price of selling CEA, is not reasonable. Figure.8 shows this relationship when *a* is ranged from 0 to 10. Under condition of *p=1*, the largest R value is obtained when *a=2*.

Finally, the simulations performed with CETS are made when *a* ranged from 0 to 3, and *p* ranged from 0.1 to 3*,* respectively. Figure.9 illustrates social cooperation (*R*) varying with *a* and *p*. One dot denotes a combination of a, p, and R. The dots with a low R gather at the locations at which a=0. It is clarified that, only introducing maintenance charge, is difficult to obtain the cooperation from more than 30% of households in the city. When a>0, which means introducing CETS to CO2 emission reduction, R values are relative stable at around 0.5. It is proved that, CETS is efficient on invoking the cooperation in the dilemma. The high social cooperation appears (*R*>0.6) appears and the highest *R (R=0.62)* is located where *a=2* and *p=1*. However, thousands of the simulations show it is impossible to obtain *R>0.65*.

Figure.10 shows the sensitivity of the initial cooperation (R^0) to the resulted R value. There is no obviously difference between *R* values produced from R^0=0, R^0=1. *R* is more dependent on *a* and *p*, and less on the initial input values.

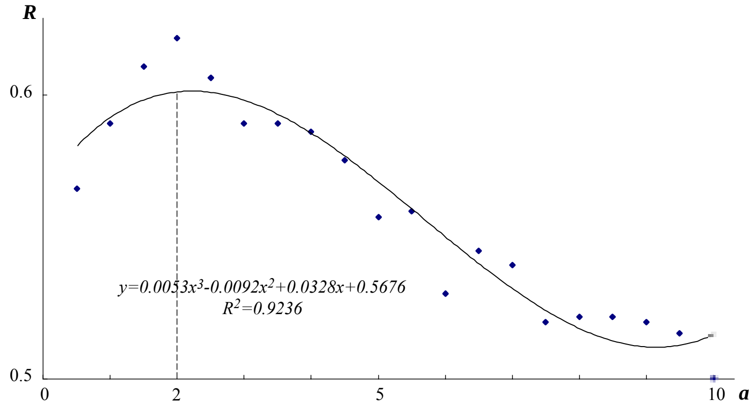

Figure.8 Relationship of Social Cooperation (*R*) Versus *a (p=1)*

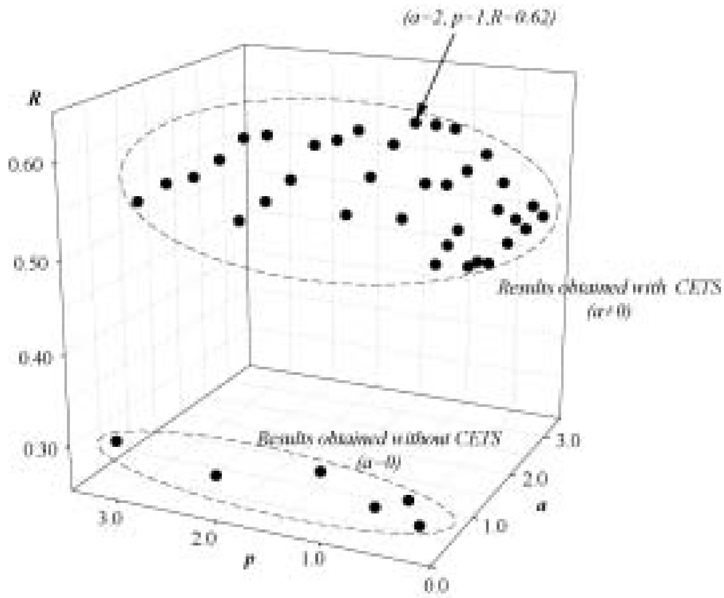

Figure.9 Change in Social Cooperation (*R*) with *a* and *p*

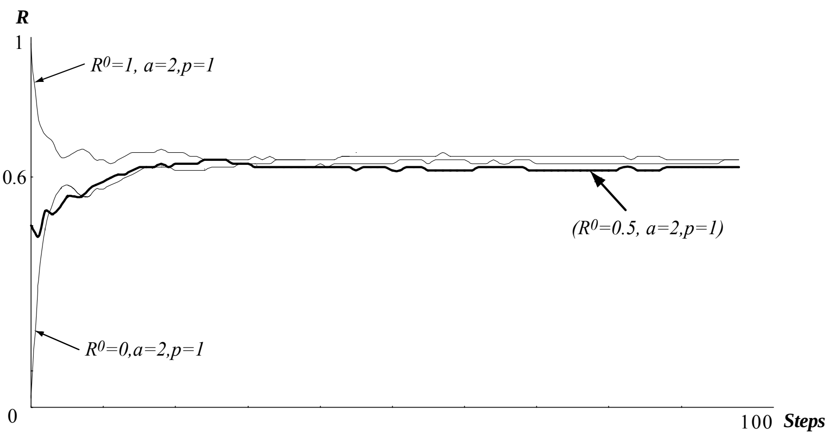

Figure.10 Sensitivity of Social Cooperation (*R*) to R^0

4.3 Housing arrangement and Household's Behavior-selections

The following results are from the situations performed by setting *a=2, p=1*, which is proved leading to the highest *R*.

Changes in housing arrangement and behavior-selections caused by the strategies are shown in

Figure.11. It turns compact. The average commuting distance is used to measure the degree of the compactness. In result of previous study, it is 10.9km (refer to Figure.12); in this study, it is 13.7km. The housing arrangement is obviously less compact than that of the previous study. The reason can be explained by the changes in household's behavior-selections.

The agents who do nothing or do harms to the urban environment are the defectors. Figure.13 illustrates where they locate, both in previous (left) and this study (right). By introducing the strategies, all the agents, even those locate closely to urban center are encouraged taking part in emission reduction. The cooperation of CO2 emission reduction is then increased.

Figure.14 shows the locations where the energy-saving behaviors happen. All of the agents, are taking part in the energy-saving, without considering if HACO2 has been made lower than CO2 constraint or not. The more the CO2 emission be reduced, the more profit it could obtain. Cooperative behaviors are supported by CETS, and the cooperation is invoked.

4.4 Completion of Reduction Target

The reduction target is not achieved in the previous study. But in this study, it is always achieved before reaching the reduction period. It is because that the completion of the global target is connecting with the household individual target (Figure.15).

In this study, each agent is assumed sufficient capability. It ensures the individual target at each stage is achieved without problem. In reality, it is difficult that each household can have such capability. So it may cost more times for achieving the target, or, the social cooperation is lower than the result in this study.

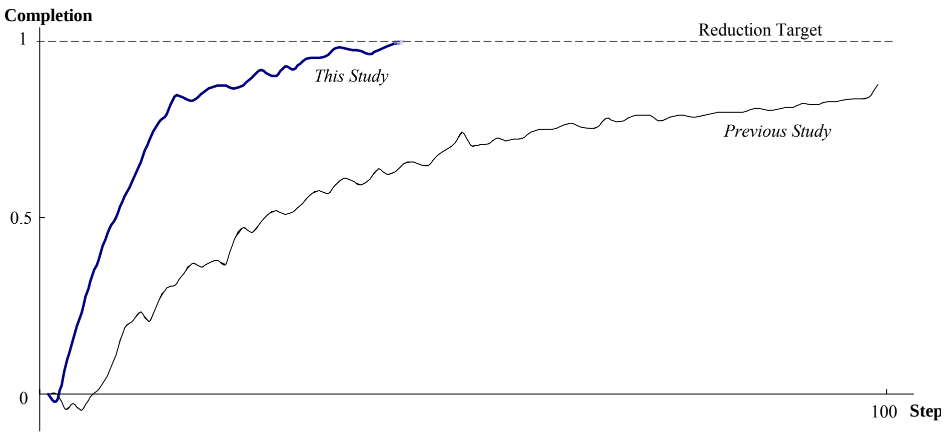

Figure.15 Completion of Reduction Target

5 Conclusions and perspectives

This study addressed how cooperation from individual households could be invoked for the purpose of achieving a global target of $HACO_2$ reduction in cities. Introducing a CETS to create a payoff function supports household cooperation towards $HACO_2$ reduction. It was impossible to gain cooperation from all households until opinions about resource use and reducing emissions were changed. The following points summarize our findings.

1) CETS is proved not only with cost-efficiency, but also promoting the process of CO2 emission reduction. If CEA is regard as a kind of resource, introducing CETS to households assures the optimal usage of the resources.

2) Levying only maintenance charges for households is ineffective to gaining the cooperation of more than 30% of the households in the city, and extremely high maintenance also discouraged cooperative behavior.

3) Higher cooperation can be obtained with the use of CETS than without CETS. While CETS is an efficient strategy to invoke cooperation, it is impossible to obtain cooperation from all households.

4) The strategies connect the global reduction target and the individual behavior-selection. The target is then achieved before the end of the period.

Payoff value can be influenced via financial incentives, such as a household CETS. This can help to reduce the total $HACO_2$ emissions in a city. Some parameters, such as the price of emission trading, are difficult to determine, but development of environmental policies could be aided by examining the combinations of parameters that this study found to be relevant to social cooperation.

This study illustrates the fact that it is impossible to obtain cooperation from all members of a community. Hardin's claim that "there is no technical solution for this problem" (1968) indicates that the problem of cooperation within the commons dilemma can only be ameliorated if opinions are changed; ideal solutions would include both structural and psychological strategies.

Notes

[1]. Unit of energy consumption of vehicles from EDMC (2000)

Vehicle	unit (kcal/p.km)
Train	50
Car	575
Bus	160

[2]. Data of statistics by METOCEAN Environment Inc. (2004)

Section	Age	CO2 emission from households with different number of families (kg-CO2)					
		1	2	3	4	5	6
Electric power consumption	2000	1090	1460	1840	2000*	2480	2910
	1990	779	1042	1314	1429	1771	2078

* the data used in this study.

[3]. Multi-Agent Simulator: software developed by Innovative Information Technology Dept. Kozo Keikaku Engineering Inc.

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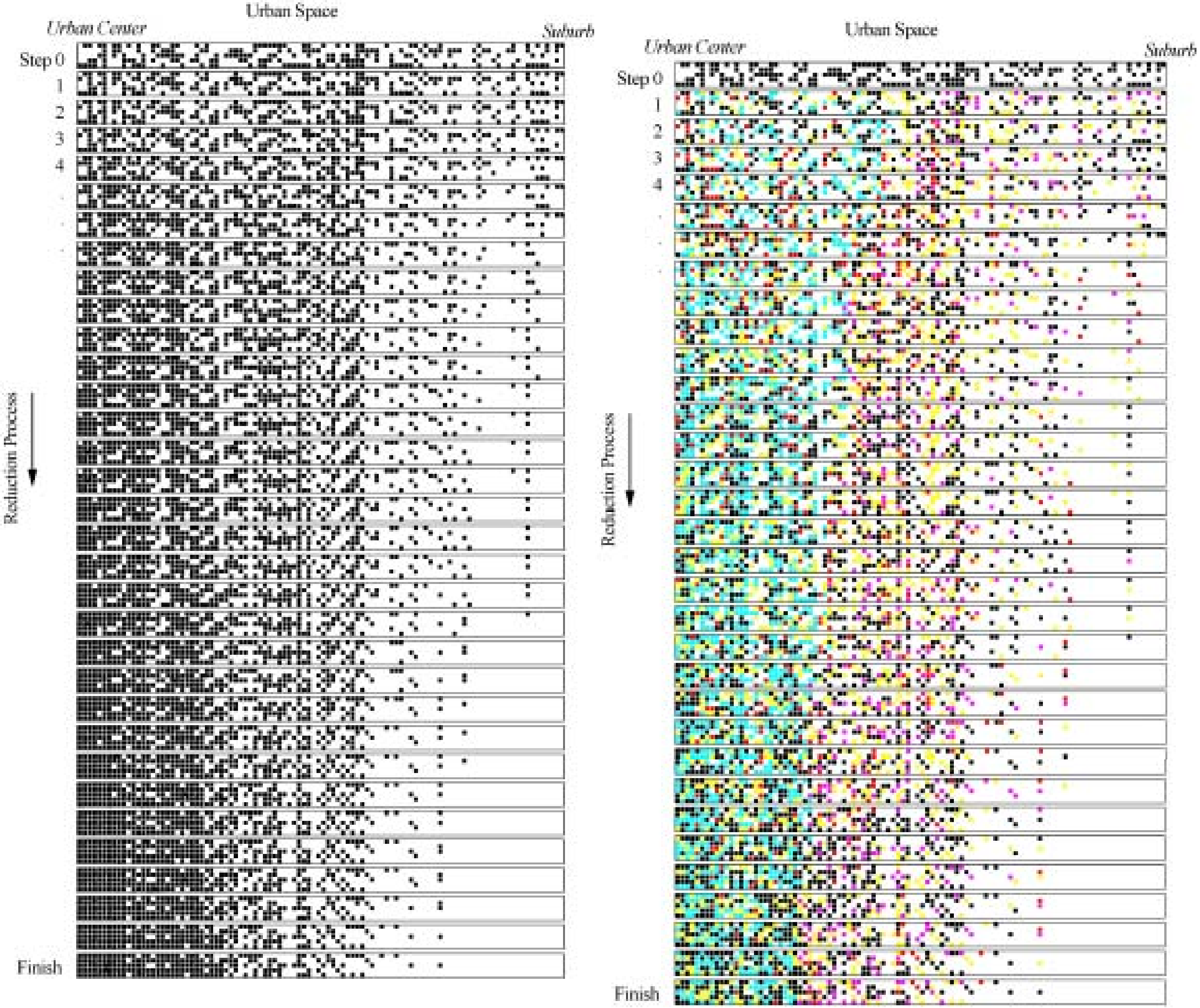
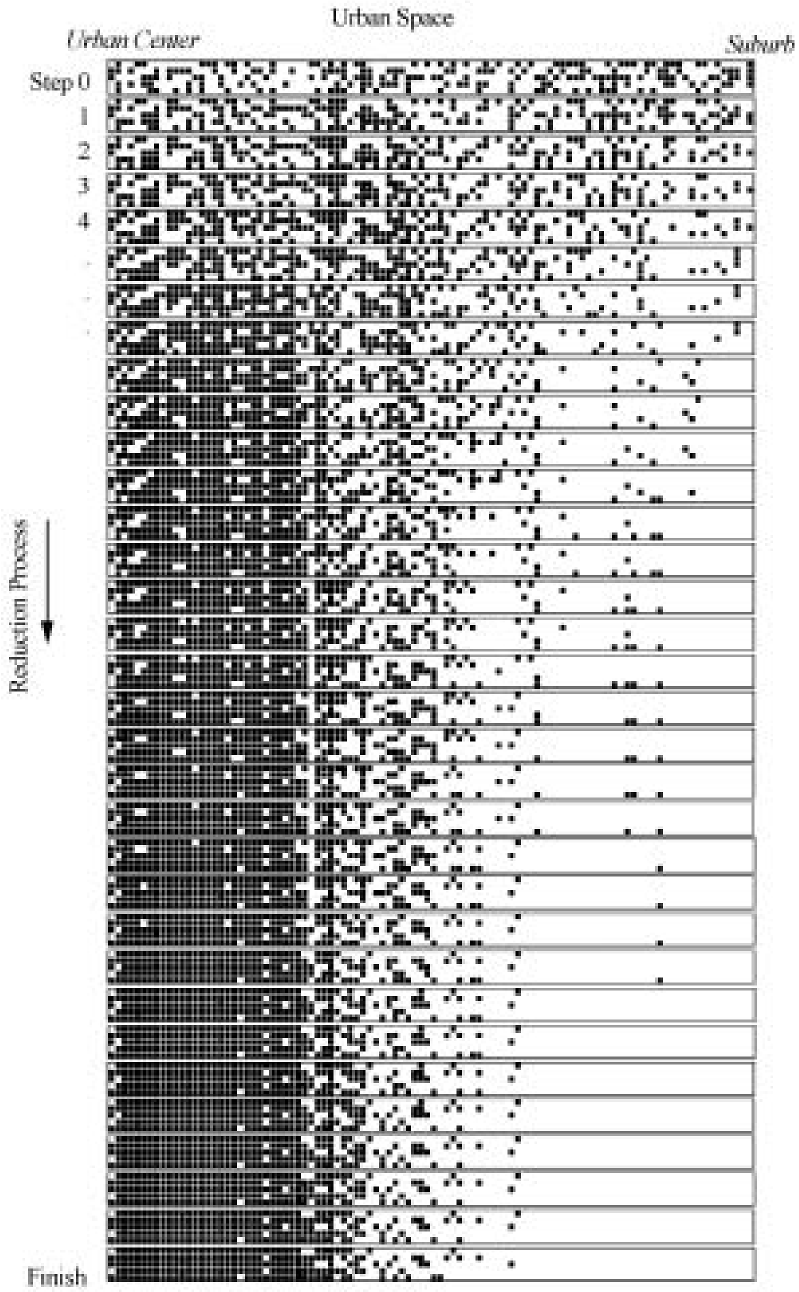


Figure.11 Housing Arrangement and Behavior-Selection resulted in this study



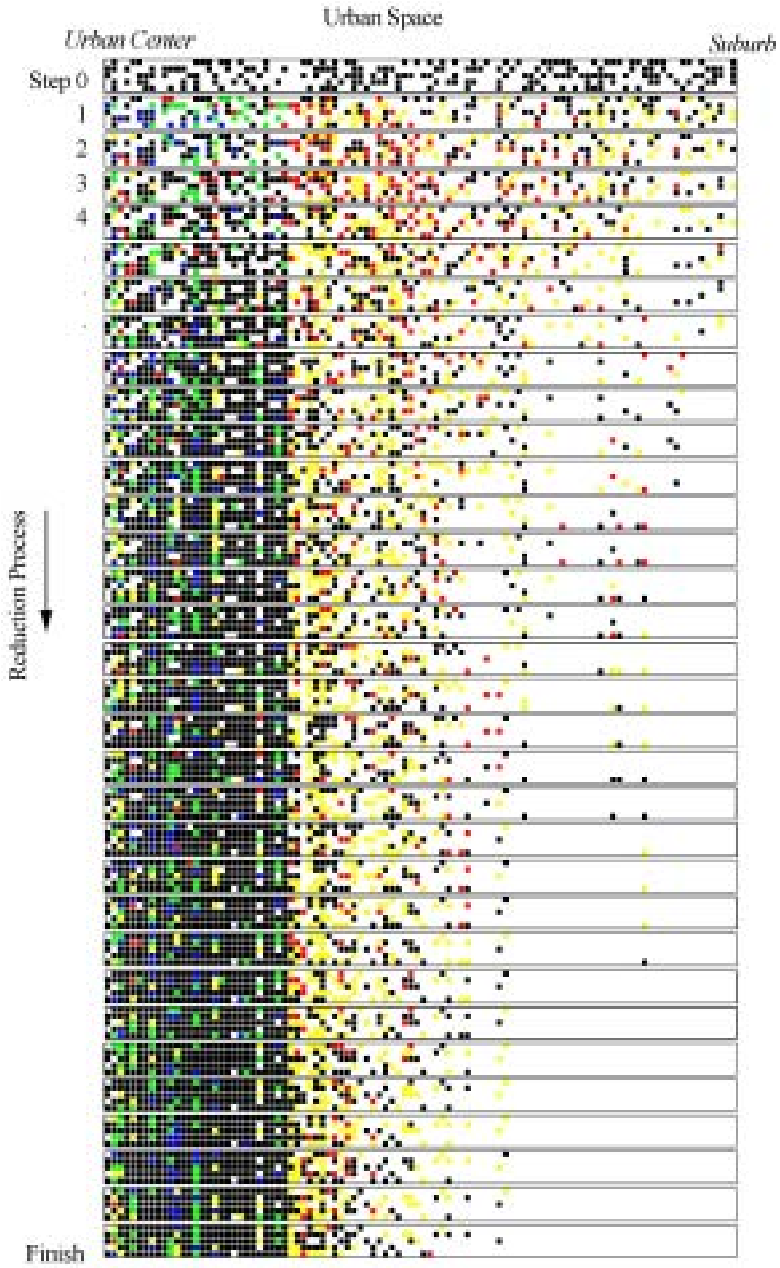


Figure.12 Housing Arrangement and Behavior-selection resulted in previous study

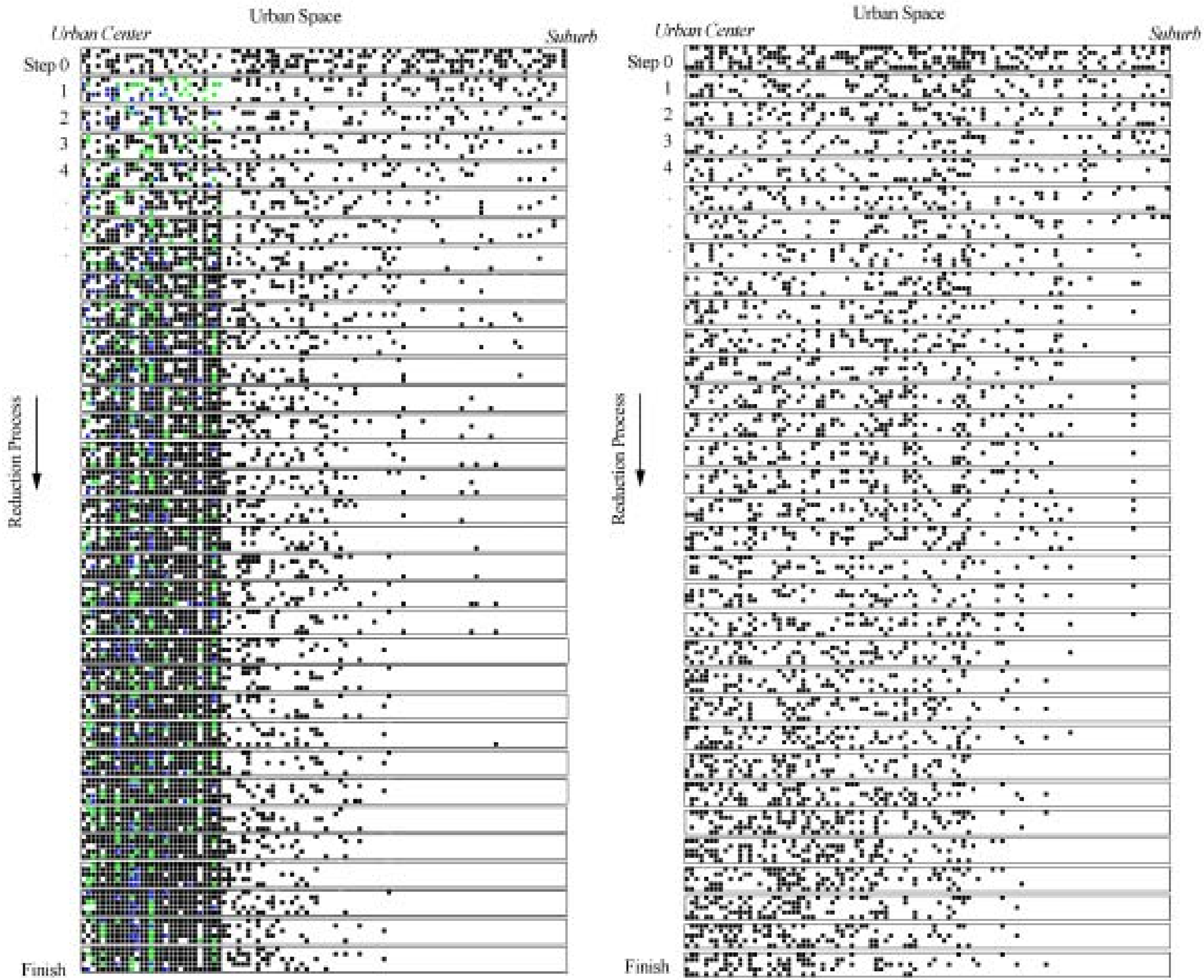


Fig.9. Distribution of Defective Behavior (Left: previous study; Right: current study)

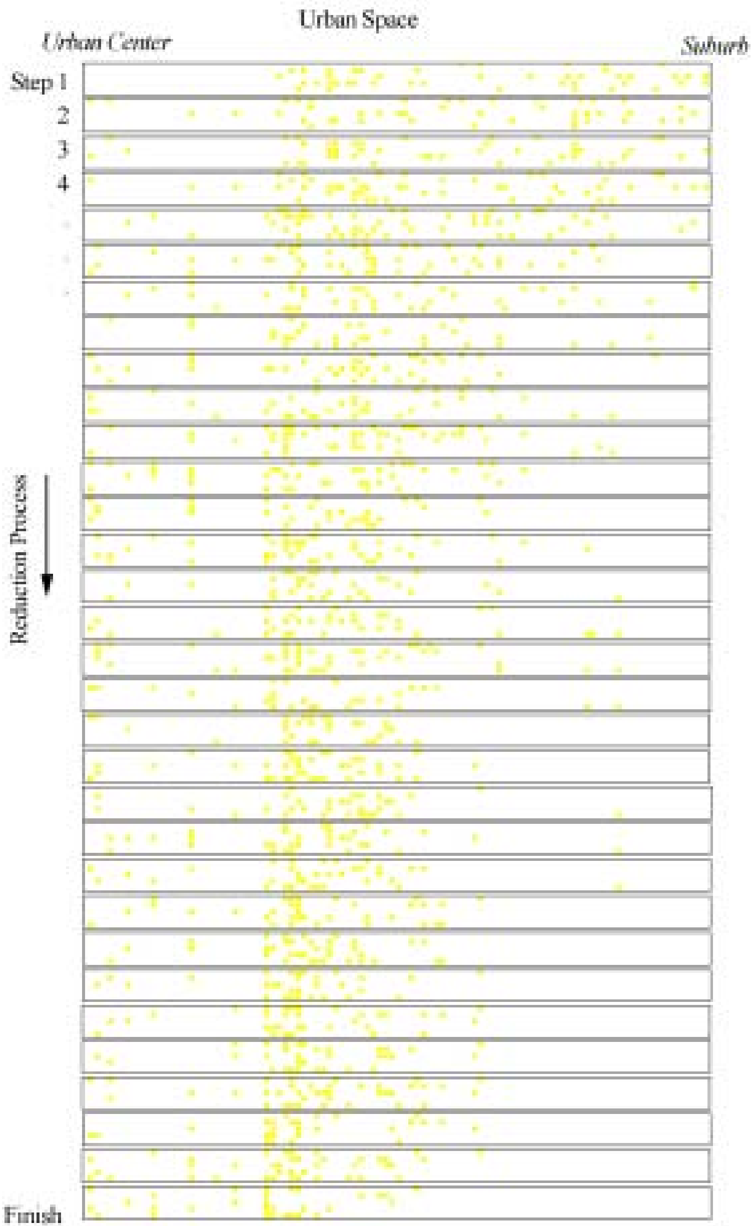


Fig 11 Distribution of Energy-saving (Left: previous study; Right: current study