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Agent-based Modelling for Planning Support of Local Residential Policy in Kanazawa City, Japan

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Abstract—The new contribution of this paper is that we proposed an agent-based Household Residential Relocation Model (HRRM) for planning support in Kanazawa city, Japan. This model is built on household interaction through lifecycle stage and policy response to simulate household relocation accelerated by a new local policy of allowance support for households remove to downtown. The simulation is targeted to evaluate the effectiveness of this policy and hereafter, helps local government make a decision.

Keywords—household relocation; downtown decline; agent-based model; compact city; planning support

I. INTRODUCTION

In this paper, an Agent-Based Model (ABM) for household residential relocation from suburban to downtown will be built for a policy evaluation in Kanazawa city, Japan. Within this model a lifecycle stage principle has been imported to conduct household interaction.

For a number of decades, urban issues such as urbanization and sprawling settlements dominated housing markets and residential mobility [1-3]. While urban shrinkage is currently a hot topic among urban planners [4]. Urban shrinkage is a complex phenomenon resulting from de-industrialization, out-migration and meanwhile, population decline [5]. The same as many developed countries, Japanese government now is being nagged by this problem. Experienced urban shrinkage over the past decades, many Japanese cities have to face the problems like downtown decline, low residential rate and population density in urban center and low utilization rate of city facilities. Especially since the increase of commuting distance has been proved won't result to obviously increase in commuting time [6], more people are moving to suburban. This phenomenon partly accelerated downtown decline.

How to make downtown more active is now a new concern of governments and urban planners. In most Western societies today, policy prescription has increasingly favoured a compact city approach to mounting environmental problems [7]. While the benefits of compact city will not just limited on environmental level, it can also make downtown more active and social resources more efficiently be utilized, hereafter makes our city develop in a more sustainable way. One of such kind policy is argued by local government in Kanazawa city, Japan. The main strategy of this policy is

applying the residents who would like removing to downtown with allowances for their residential relocation.

The aim of this paper is to evaluate the effectiveness of this policy. As proved by exist research, ABM is expected to contribute significantly to the study of behavior-environment interactions, and to provide a valuable tool for exploring the effectiveness of policy measures in complex environments [8]. Some researchers in this filed focus on assessment of future socio-ecological consequences resulting from land-use policies [9]. And some others focus on using multi-agent simulation for development of policies [10]. While our focus is mostly from the aspect of planning support, for which the basic principle can be explained as evaluation of policy effectiveness and hereby, support government make a decision. Utilize ABM to simulate household residential location is now a very hot work in urban housing market [11, 12]. Influenced by urban growth and settlement sprawl, ABM also has been utilized to simulate local landscape pressure influenced by residential location [13, 14].

Anyway, existed researches proved that ABM shows great potential and advantage in simulation and representation of entity choices and activities. This characteristic of ABM makes it a practical approach for simulation of policy and meanwhile, revealing the effectiveness of policy. In the following we will introduce how our HRRM is built and how it works.

II. AN AGENT-BASED SIMULATION FOR PLANNING SUPPORT OF LOCAL RESIDENTIAL POLICY

Local government of Kanazawa city argued a new residential policy to attract households remove to downtown. This policy targets to release the situation of downtown decline in Kanazawa city, Japan. While would this policy useful and to what extend can this policy pull local city out of the embarrassment of downtown decline still needs further discussion. In this paper an agent-based HRRM model will be built to represent the possible effects of implementation of this policy and hereafter, support local government make a decision on this new residential policy.

Within HRRM there are three modules for simulation on household residential relocation. They are household lifecycle stage module, evaluation module for household relocation desire and household relocation choice module. As most agent-based models do, in HRRM there will be pre-

determined rules for agent interactions. In this work, the interactions will take place on two levels, one is between agents and the other one is between agent and land parcels. Regarding to the former, a lifecycle stage principle that covers the whole life of a person since birth to death will be inputted in our model to determine when agents would like to do residential relocation. Within this process, we propose that household would like to do residential relocation only when their lifecycle stages happen change or they are unsatisfied with their current locations. This is also the main function of first module that practice household interaction and recognizing possible occasions for household residential relocation.

Then, the interaction will take place between agent and land parcels. In HRRM each residential location as different land parcel will be further defined by a series of special attributes. Agent will make decision on new location based on their affordability and the utility of that location. Before doing a new location, household will firstly evaluation on the utility of current location. This process will produce a satisfaction survey result of households on current locations and hereby, reveal their relocation desire. This function can be fulfilled by the second module in HRRM. After the second process households who want to do a new location will find a new house in somewhere within the urban. We utilize utility theory to build the third module in HRRM. This location module will help households compare the utility of residential locations in different urban area and finally make households choose the location with biggest utility.

Through the works above a complete household residential relocation model can be finished. Through model validation we can observe the different relocation choices of agents and finally gain a result about how many agents would remove to downtown. Thus, the effectiveness of residential policy in Kanazawa city can be easily represented.

III. DESCRIPTION OF HRRM

A. Lifecycle Stage Model of Household Agent

In HRRM, the real persons in kawakawa city are not seemed as individuals but members of a household. A household is a coherent unit of analysis in our model and it can make decision as a single entity on the property within which it is located (comprising single person or groups of persons). Location decisions are affected by the household attributes (the number of persons, their age, their transportation means, their desires for location, etc). These attributes will influence on household decision-making of relocation to downtown. While here a question emerged that if we want to do a location simulation we should firstly know when household would like to move. Some existed researches focused on resolving this problem through analyzing life status change of households. The life status within a household's whole life was defined as lifecycle stage by some researchers [14].

In HRRM the main interaction between households to determine when to do a new location that means relocation here is determined by their lifecycle stage changes. In HRRM we divided the whole life of a household to 4 stages, which are respectively independent from original family (we called independent in following), get married (called marriage in following), give birth to new household members and raise up them (shortly called grow up children), and finally dead

(Fig. 1). We propose that once when coupled households get married, except they give birth to babies, they would probably not do a new location till they die. Furthermore, we suppose that when households get married they won't divorce. Thus, as showed in Fig. 1 after the lifecycle stage of marriage we have not considered the stage of retirement and just skipped to death.

As shown in Fig. 1, at first stage an independent household is created and after several years' single and independent life, this household meets someone and decided to get married. So in the second stage he and she find a bigger house and became a new household (here we define the households more than 36 years old will get married based on local coupling rate). While as indicated by the dashed line, some households won't marry till they die. When coupled households are created we suppose they would not consider moving again till their fourth lifecycle stage (a death rate here is utilized to eliminate household agents). While in the other side some coupled households will pregnant and become to their third lifecycle stage (we define households less than 45 years old can give birth to new generation of households according to local birth rate). In the third stage these couples find that their current houses are too full for the coming kids or too far away from local schools so they probably decided to move again for their babies. In this stage a new generation of households is created and just as showed by another dashed line when he one day grow up, he will independent from his original household (go to college or get a job according to local employee rate) and probably find a new residential location for himself to begin his first lifecycle stage. During this process, the old household who gave birth to this new household will continues their life and finally go to their last lifecycle stage.

Figure 1. Diagram of household lifecycle stage in HRRM.

B. Evaluation Module of Household Relocation Desire

1) Decision tree for household relocation desire

We suppose that when the lifecycle stage of household happen changes, household will face to a demand of residential relocation. Within HRRM an evaluation module of household relocation desire will be built to support whether households will indeed do residential relocations.

The decision tree for household decision-making on residential relocation is showed in Fig. 2. As showed in this figure household's satisfaction with current location will be firstly calculated to judge whether household i has a potential

to move to a new location. If the result shows that his satisfaction of current residential S_i is below the threshold $S_{threshold}$ that he pursuits, household i will consider doing a new location. Then is the turn for household predicting the possible costs of the coming relocation and compare it with his deposit. If the deposit can afford the relocation cost, he will do a new location and following is the job of relocation module.

Figure 2. Decision tree for household relocation desire.

2) Evaluation on household satisfaction with current location

In our work we seem that household's desire for new location depends on whether he is satisfied by current location. If current location can meet his utility pursuit of residential location, he will be satisfied. Otherwise, he is unsatisfied and will show a desire for relocation. In HRRM the utility of different residential locations can be calculated by the attribute variables of residential land parcels. As we introduced before, each land parcel in HRRM has a series of predefined spatial attribute variables. These variables will be utilized here to evaluate utility of residential locations. The variables chose for utility evaluation are showed as following:

TABLE I. VARIABLES FOR EVALUATION ON THE UTILITY OF RESIDENTIAL LOCATION

① Building size	② Building security from earthquake and typhoon
③ Building security from fire	④ Building impairment
⑤ Barrier-free structures for old people	⑥ Comprehensive evaluation on building quality
⑦ Surrounding safety equipments	⑧ Safety while walking on surrounding pavement
⑨ Crime rate	⑩ Air or noise pollution
⑪ Accessibility for work or school	⑫ Shopping convenience
⑬ Distance from community hospital	⑭ Cultural facilities (e.g. Distance from library)
⑮ Park or playing ground for children	⑯ Green space
⑰ The areas of out space	⑱ Street landscape
⑲ Communication feasibility with neighbors	⑳ Comprehensive evaluation on building's surrounding environment

During simulation these variables can be assigned by values for calculating the utility of residential locations. The mathematic model for this calculation process is based on the

utility theory, which can be represented by following equations:

$$S_i = \frac{\sum_{j=1}^n (a_j \times x_{ij}) + \varepsilon_i}{n} \quad (n=1, \dots, 20). \quad (1)$$

$$-2 \leq S_{threshold} \leq 2. \quad (2)$$

$$S_i > S_{threshold} \quad (\text{Satisfied by current location}). \quad (3)$$

$$S_i \leq S_{threshold} \quad (\text{Unsatisfied by current location}). \quad (4)$$

As showed by the equations above, variable S_i stands for the satisfaction of household i 's current residential location. a_j is the value of variable number j , which obeys the order in TABLE I (e.g. a_1 means the value of first variable, building size). During simulation this value will be randomly assigned to obey the uniform distribution in the range of $(-1, 1)$. Additionally, X_{ij} as the utility of variable number j for household i will be given as a random in the range of $[-2, 2]$ that determined by an investigation of residential satisfaction in Kanazawa during Dec 2009 to Jan 2010. The investigation contents covered the variables in TABLE I except number 6 and 20. Satisfaction degree was divided into 2, 1, -1 and -2 four levels, which represented satisfied very much, satisfied, unsatisfied and extremely unsatisfied. Meanwhile, according to some existed researches of household satisfaction with residential location we set the satisfaction threshold as 0.1 [15, 16].

C. Household Relocation Module

1) Decision tree for household relocation choice

In this part a relocation model based on utility theory will be developed to simulate household decision-making on their new locations.

Figure 3. Decision tree for household relocation choice.

We propose that households who have desire to do a new location will follow the decision-making flow showed in Fig. 3. As represented by this figure when households do a new location they will compare the utility of residential locations between different urban areas, which are respectively urban center area, urban planning area and urban control area.

Based on the comparison they will finally choose the one with biggest utility for themselves.

2) Utility calculation of residential locations in different urban area

Household makes decision on a new residential location basing on the utility offered at and around the location. Different from traditional means, the utility model here for presenting subjective difference between agent's choices is represented by (6). As showed by it, a component ϵ_{is} has been used to reflect the unobserved random contribution to utility. This random element follows a Gumble distribution and can be generated by (7), in which r is a random following uniform distribution, μ and β are constants, respectively set as 0.5 and 2.

$$V_{is} = \sum_{j=1}^m a_{sj} \times x_{isj}, \quad (m = 1, 2, 3, 4, 5). \quad (5)$$

$$U_{is} = V_{is} + \epsilon_{is}. \quad (6)$$

$$\epsilon_{is} = \mu - \beta \ln(-\ln r) \quad (\beta > 0), (0 < r < 1). \quad (7)$$

$$Q_{is} = \frac{e^{V_{is}}}{\sum_{m=1}^5 e^{V_{is}}}. \quad (8)$$

Finally the probability for household i choosing location s follows a logistic function showed in (8). Q_{is} means the probability of household i choose location s , which will further be influenced by the utility offered by location s and without considering the unobserved random influences. This utility V_{is} can be calculated by (5). X_{isj} here means a vector of observable explanatory variable j describing attributes of household i and location s , in which j covers commuting distance, floor area, satisfaction, neighbors and policy influences. Additionally, a_{sj} is a vector of retrospective coefficients to variable j .

The values of the five variables we talked above can be gained through:

a) *Commuting distance* (X_{is1}): Commuting distance from current location to work $\text{Commuting}_{\text{now}}$ divided by commuting distance from next location to work $\text{Commuting}_{\text{next}}$.

b) *Floor area* (X_{is2}): Current floor area $\text{Location}_{\text{now}}$ divided by floor area of next location $\text{Location}_{\text{next}}$.

c) *Satisfaction* (X_{is3}): Satisfaction produced by current location S_{now} divided by expected satisfaction by next location S_{next} .

d) *Residential aggregation* (X_{is4}): Current neighbor numbers N_{now} divided by possible neighbor numbers by new location N_{next} .

e) *Policy influence* (X_{is5}): Three detailed factors are used here. Affordability, quantified as household income divided by the number of household members; Global acceptance of policy, quantified as the number of households move to CA N_{ca} divided by all moved households N_{all} ; Children needs, quantified as children numbers of a household N_{chi} divided by all members of that household N_{fam} .

IV. VALIDATION OF LOCAL RESIDENTIAL POLICY BY HRRM

A. Hypothetical Urban Space and Household for Policy Simulation

Preparing for simulation two types of virtual data, namely spatial data and agent data are respectively created. Within them, as the second picture showed in Fig. 4, a virtual urban space has been created for representing land use zoning in local city. The land use zoning is based on the division of urban region that showed by the left picture in Fig. 4. Another item here worth figuring out is that each parcel in the virtual space stands for 1 km² urban area and the following simulation will start from 1985, each simulation loop stands for 5 years.

According to the Japanese Consensus Survey in 2005, household data is created for reflecting household attributes in Kanazawa city. It contains like household income, car ownership, age, current residential location, etc. As shown in the right of Fig. 4, these agents are further divided into three income groups that stand for poor households, middle-income households and rich households in real society. Furthermore, the number of real households in 1 km² will be defined as household density in the virtual data (third picture in Fig. 4). Therefore, agent numbers can be gained as one agent stands for 300 households in real city.

Figure 4. The virtual Kanazawa city for accommodating household agents.

B. Model Behavior Test

HRRM will be tested in the platform of Netlogo, which is authored by Uri Wilensky in 1999. There will be two scenarios for our model test. The first one will purely focus on testing the model behavior of household residential relocation by ignoring the policy influences. The other one will input the policy influences in the simulation to conduct the interaction between policy implementation and household responses.

1) Scenario one

When we simulation, the virtual data has to be firstly updated. Through this process the household information, such as how many households desire to move and finally moved will be evaluated by the second module we introduced before. Meanwhile, some other information as how many households get married and have children, and how many children are younger than 18 will also be calculated according to the coupling rate and birth rate we set. This information will be utilized to the simulation of household relocation without considering the policy influences on household residential relocation. As showed by Fig. 5, there are 1500 households desire to move. While only

936 households within them finally practiced this desire. There would be many reasons for this result, as our investigation showed, many of them have no enough money to buy a new house or pay for the rent of new location and some. After data updating, the simulation can be conducted by the parameter settings showed in Fig. 6.

total households	population	Hnum desire move	Hnum moved
1500	4038	1500	936
Hnum married	Hnum single	Hnum no children	poor
1357	143	669	292
Hnum age below20	Hnum age 30	Hnum has children	middle
0	0	831	899
Hnum age 40~50	Hnum older than 60	Nchild below 18 age	rich
0	0	1181	309

Household number in different urban area		
households in UCA	households in UPA	households in CA
621	653	226

Figure 5. Initial household information.

Figure 6. Parameter settings for the simulation of first scenario.

Figure 7. Simulation result of the first scenario.

We suppose that all the job locations are centralized in city center area. Additional to, we also assume that the birth rate, death rate and coupling rate are respectively 10%, 3% and 50%. As showed by Fig. 7 above, experienced the three steps of model function, which are life stage modeling, relocation desire modeling and relocation modeling, there are 161 households moved to new locations. While although

relocations are happening most households still choose aggregating to urban control area. The number of households live in city center is just 340, only less than half of the figure in urban control area (suburban). Especially that the households live in urban control area is rising obviously. It is thus evident that without special intervention, down decline cannot be practically changed.

2) Scenario two

In this scenario we will input the policy factors in the simulation model. The basic principle of this process is reflect the policy affects by seeming it as determined parameters, like cash allowances, policy propaganda and household responses (remove with allowance). These factors are noted as a2-5-1, a2-5-2 and a2-5-3 in Fig. 6.

Figure 8. Simulation results of the second scenario.

Within them a2-5-1 reflects the income's influence on household decision-making of relocation. During simulation the allowance will be add to household income for the agents who cannot afford new location but show a desire bigger than the threshold. a2-5-2 stands for the influences from public. The basic idea for quantization of this factor is that when the value of a2-5-2 becomes bigger means the households moved to CA took a bigger percentage of all the households who did relocations. Thereby, it represents a well acceptance of local residential relocation policy by households and also a positive influence on households removing to CA.

The last factor related to policy influence is a2-5-3, which reflects the household decision-making influenced by their children numbers. The reason of why children number is considered is that when the households who have more than one child, means they need more floor areas. These agents will show more positive and stronger desire for relocations. Thus, they would be more interested in local residential policy and easier to show positive responses to the policy.

Simulation results of this scenario are showed in Fig. 8, within which two types of policy parameters are simulated. Compared with first scenario we can easily observe that households live in CA or do relocation to CA are increasing obviously. This phenomenon becomes more and more positive since we increase the values of policy parameters. Apparently implementation of this residential policy can accelerate households remove to downtown.

C. Model Validation by the Real Data of Kawakawa City

As tested by the virtual data, HRRM works well and can reflect the number changes of households in different urban areas through adjusting the parameters. While to validate HRRM accuracy it is still necessary to test the model by real data in local city. We conducted the simulation of household residential relocation from year 1985 to 2000. In order to prove the validation of HRRM we will compare the simulation results with local statistic data by converting the simulation results into household ratios in different urban areas.

The comparison are showed by TABLE II, as showed by local consensus survey in 1985 the household ratios in CA is 33.9% and 66.1% in UPA and UCA, up to these two indexes the simulation results are respectively 32% and 68%. Obviously the simulation results are quite near to the real data. This situation keeps the same in 1990 and 1995 but changed in 2000, in which year the simulation results shows big differences from the real data. This situation should belong to the affects of policy parameters in our model. Until this stage, a conclusion can be gained that our model can simulate household residential relocation within different areas in a very realistic way.

TABLE II. COMPARISON OF HOUSEHOLD RATIOS IN DIFFERENT URBAN AREAS BETWEEN REAL DATA AND SIMULATION RESULTS

Years	Real dataset		Simulated results	
	CA	UPA+UCA	CA	UPA+UCA
1985	33.90%	66.10%	32.00%	68.00%
1990	31.90%	68.10%	28.60%	71.40%
1995	29.00%	71.00%	30.40%	69.60%
2000	26.60%	73.40%	33.90%	66.10%

V. CONCLUSIONS

The HRRM integrated three modules, which can thereby mimic the whole process of household decision-making on residential relocation from they firstly show relocation desire because of the changes of their lifecycle stage to finally make a location choice based on location's utility. The model contents abundant theory and reasonable basis and hereby, can be employed to planning support.

As introduced by model behavior test, comparing with the simulation results in first scenario, the number of households moved to downtown (CA area) is increasing evidently when the policy parameters are updated. It means that local downtown decline probably can be relieved by implementation of this new residential policy. To further validate HRRM, model validation has been implemented by real data in Kanazawa city. The results show that the simulation results of household residential relocation are quite similar to the real statistic results of households'

choices of residential location in the past 20 years. Thus, as an attempt of planning support our HRRM can sufficiently visualize the results of policy implementation and hereafter, predict the possible effectiveness of the residential policy for revitalization of city center in Kanazawa city, Japan.

REFERENCES

- [1] D. Haase, S. Lautenbach, and R. Seppelt, "Modeling and simulating residential mobility in a shrinking city using an agent-based approach," *Environmental Modelling & Software*, vol. 25, 2010, pp. 1225-1240.
- [2] M. Antrop, "Landscape change and the urbanization process in Europe," *Landscape and Urban Planning*, vol. 67, 2004, pp. 9-26.
- [3] Y. Kazepov, *Cities of Europe. Changing Contexts, Local Arrangements, and the Challenge to Urban Cohesion*. UK: Blackwell Publishing Ltd, 2005.
- [4] T. Rieniets, "Urban shrinkage," in *Atlas of Shrinking Cities*, P. Oswalt and T. Rieniets, Eds. German: Hatje, Ostfildern, 2006, pp. 30.
- [5] T. Rieniets, "Shrinking cities: causes and effects of urban population losses in the twentieth century," *Nature and Culture*, vol. 4(3), 2009, pp. 231-254.
- [6] K. R. Ma and E. T. Kang, "Time-space convergence and urban decentralisation," *Journal of Transport Geography*, 2010, in press.
- [7] P. Howley, M. Scott, and D. Redmond, "An examination of residential preferences for less sustainable housing: Exploring future mobility among Dublin central city residents," *Cities*, vol. 26, 2009, pp. 1-8.
- [8] W. Jager and H. J. Mosler, "Simulating Human Behavior for Understanding and Managing Environmental Resource Use," *Social Issues*, vol. 63(1), 2007, pp. 97-116.
- [9] Q. B. Lee, S. J. Park, and P. L. G. Vlek, "Land Use Dynamic Simulator (LUDAS): A multi-agent system model for simulating spatio-temporal dynamics of coupled human-landscape system: 2. Scenario-based application for impact assessment of land-use policies," *Ecological Informatics*, vol. 5(3), 2010, pp. 203-221.
- [10] T. Berger, P. Schreinemachers, and J. Woelcke, "Multi-agent simulation for the targeting of development policies in less-favored areas," *Agricultural Systems*, vol. 88(1), 2006, pp. 28-43.
- [11] D. Ettema, "A multi-agent model of urban processes: Modelling relocation processes and price setting in housing markets," *Computers, Environment and Urban Systems*, vol. 35, 2011, pp. 1-11.
- [12] C. P. Dawn and T. Filatova, "A conceptual design for a bilateral agent-based land market with heterogeneous economic agents," *Computers, Environment and Urban Systems*, vol. 32, 2008, pp. 454-463.
- [13] D. C. Parker, S. M. Manson, M. A. Janssen, M. J. Hoffmann, and P. Deadman, "Multi- agent systems for the simulation of land use and land cover change: a review," *Annals of the Association of American Geographers*, vol. 93(2), 2003, pp. 314-337.
- [14] C. M. Fontaine and M. D. A. Rounsevell, "An agent-based approach to model future residential pressure on a regional landscape," *Landscape Ecological*, vol. 24, 2009, pp.1237-1254.
- [15] M. Kawakam and C. Takayama, "Investigation research on households' choices of residential relocation: a case study in Kanazawa City," *Architecture Institute of Japan*, vol. 13, 1978, pp. 67-72.
- [16] Y. Kikuchi and S. Nojima, "Resident's Mind about Residence Selection in Suburban Housing Estates : Case study of 4 suburban estates in Fukui City," *City planning review: Special issue on city planning*, vol. 42(3), 2007, pp. 217-222.