# 19. An agent-based model for simulating locations of day care centers: A case study of Kanazawa City

## エージェントベースモデルを用いたディケアセンターの立地シミュレーションに関する研究 金沢市における事例研究

Shen Zhenjiang*, Nguyen Dinh Thanh**, Ma Yan**, Kawakami Mitsuhiko*
沈振江・グエン　ディン　タン・馬妍・川上光彦

日本において、高齢者福祉施設計画の計画政策が重要な課題である。本研究では、関連計画政策を検討するため、エージェントベースモデルを用いてディケアセンターの需要と立地をシミュレーションすることにより、高齢者とその施設利用の将来像を提示することを目的にしている。世帯とケアサービスの事業者をエージェントとし、高齢者の健康状態によって受けられるサービスの判定、ケアセンターの選択などの行為、ディケアセンターの立地選択と建設、運営の行為をモデル化し、シミュレーションに導入し、システムを構築した。まだ、金沢市の空間データ、例えば、都市計画の情報、世帯の空間分布をシミュレーション空間に導入した。さらに、2000 年から 2010 年の期間を対象に、シミュレーションの結果と実際のデータを比較することにより、シミュレーションの有効性を検証し、2030 年までの世帯変容、ケアセンターの需要と立地をシミュレーションによって予測を行った。
*Keywords*: Agent-based model, Day-care center, care level decision
エージェントベースモデル、ディケアセンター、ケアレベル認定

## 1. Introduction

In last few decades, the number of people aged 65 and older has been increased rapidly in Japan. According to statistic of population census, aging population increased from about 12.3 million in 1985 to 29.3 million people in 2010[1]. Along with the increase in elderly people, there are some laws and policies on welfare, health services, insurance for the aged people that were enacted, such as Old-age person's welfare law (1963), etc. and welfare facilities for elderly people, such as home care, day-care centers (hereafter, DC centers), etc. have been built more and more. In Kanazawa City, the number of elderly people made up 19.75% of total population in 2010 and number of elderly people who visited DC centers increased 2.3 times from 2000 to 2010 and these numbers suppose to increase in the future. In such situation, the government of Ishikawa prefecture issued a project to investigate current status in aging population, living environment for elderly people, facilities for elderly people's health care, etc. During the project, local government supposed to do predictions for elderly people's living environment, demand for health care facilities, etc in 2030. Therefore, a question arising is that how many facilities will be built in order to serve those elderly people and where these facilities should be located. From literature, there are some approaches for choosing locations. Location-allocation, for instance, is an optimal approach for determining an optimal location for one or more facilities that will service demand from a given set of points[2]. Besides that, Yang et al.[3] employed an ordered logit model for investigating potential factors that contribute to the hotel location choice. Agent-based models emerged as powerful models in exploring the complexity of urban systems. Moreover, it is also a popular means for representing decision-making processes, such as choosing locations for facilities or relocations, choosing facilities for commuting or shopping (Chen et al, 2006[4]; Vanhaverbeke et al, 2011[5]; Huang et al., 2011[6]; Shen et al , 2012[7]). In the agent-based models, agents that are individuals will be created and can receive necessary information from an environment where they are living and located. Then, the agents can also display their behaviors and interact with each other in the environment in order to achieve their goals. Furthermore, the simulation processes are designed based on those people do in the reality.

The purpose of this study is to develop an agent-based model for planners and policy-makers to consider planning strategies of DC centers through simulating how many DC centers should be built in urban area before making a plan regarding the locations of day-care centers. The simulation thus can provide very vivid visualization results of future age structure of population in research area and their demands for daycare centers. These kinds of simulation results can reflect the trend of population aging and the necessity of elderly people for daycare centers. From this viewpoint, this research can provide local government with visualized reference for considering the planning strategies before making a plan. As the advantages of agent-based simulation, our contribution to the existing literature is that we considered complex interactions between behavior and environment and gave rise to urban macro patterns in situations where decision-making are made under conditions of deep uncertainty. Moreover, unlike previous studies (Vanhaverbeke et al, 2011; Huang et al, 2011) that simulated locations of retails using the virtual world; this study simulated the whole framework of business operation of DC centers by using the real Kanazawa City. The framework that includes location choice of DC centers, care levels decision, DC choices of elderly people, and DC centers' operation is designed basing on the real situation. For example, we applied a procedure for deciding care levels for elderly people[8] that was issued by Japanese government.

* Member, Graduate school of nature & technology, Kanazawa University (正会員　金沢大学大学院自然科学研究科)
** Member, Graduate school of nature & technology, Kanazawa University (学生会員　金沢大学大学院自然科学研究科)

## 2. Method

We have collected and prepared datasets for simulating age structure of population and their demand for daycare centers as following:

- GIS datasets on household and population distribution, land use zones in 1985 for creating and locating household agents in our model
- Datasets on population from 1985 to 2010, data on number of elderly people who have visited DC centers and the number of DC centers from 1999 to 2010 in Kanazawa City for validating simulated results.
- A procedure for judging and deciding care levels issued by Japanese government[8)]

We used an agent-based model[9)] (*Macal and North, 2010*) to implement the simulation and employed Netlogo software *(Wilensky, 1999)* as a simulation platform. Our model will simulate behaviors of DC centers owners on choosing location for building DC centers and the DC center-choosing behavior of elderly people, etc. in Kanazawa City. In the former, we applied Logistic Regression[10)] *(Long et al, 2008)* for calculating the probability that indicates whether one cell will be chosen as a location of DC center or not.

## 3. Model design

### *3.1 Assumptions for the simulation*

Before running the simulation, we made some assumptions basing on the real situation of Kanazawa City as following:

1) Due to computing ability of computer and saving computing time, the number of household agents in this simulation is 6825 households who living in three areas: Downtown (CCA), Urbanization Promotion Area (UPA), Urbanization Control Area (UCA), which is the real number of households in the year of 2000 and makes up 3.8 % of the total 177,686 households in Kanazawa; 2) To make the simulation more reasonable, we will use the real data on population in 2000 as initial data on population and elderly people in our model and start the simulation from the year of 2000 with the real 6 existing DC centers.; 3) From statistic data in Kanazawa City issued on the Internet, the number of people who move in and move out is almost the same in each year during 2002-2011. Thus, we assume that the migration population is zero until 2030, which is the target year of the research project of Ishikawa Prefecture; Meanwhile the birth rate and death rate are assumed as the same with those during 2002-2011, which are 0.9% and 0.8% respectively; 4) DC centers can be built in all land use zones based on regulations on land use zones in Japan; 5) One simulation tick represents one year; 6) The elderly who want to visit DC centers tend to choose the nearest center to visit if the center is not full with other visitors; 7) There are three kinds of DC centers with different capacities that are set as 15, 20, 25 respectively (The numbers here indicate the maximum number of elderly people that a DC center can serve at the same time) and different prices. The more the capacity is, the higher the expenditure is; 8) For calculating the demand, the day-care center agents will consider the number of elderly people living in an area within a radius of 2.5 km, corresponding 50 cells, from a location they want to build a DC center.

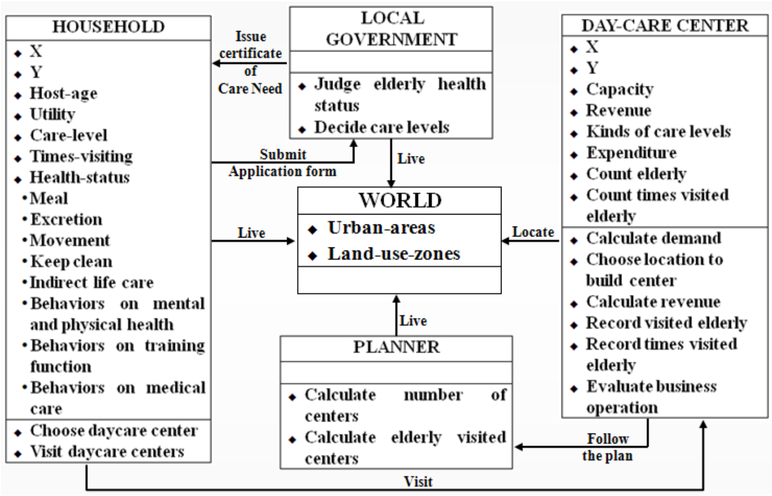


Figure-1 The agents and their interactions in the model

### *3.2 Description of the model*

In our model, we created 4 kinds of agents with different attributes and behaviors named planner agents, local government agents, day-care center agents and household agents that are living and located in urban space (figure 1). The urban space was divided into 3 areas: Downtown (CCA), Urbanization promotion area (UPA), Urbanization control area (UCA) (figure 6). The two formers are covered by 8 types of land use zones (figure 7). Moreover, the study area is a lattice with 468*752 cells in shape of square and each cell has a size in 50m*50m.

During the simulation, each agent displays its behaviors in order to obtain its objectives. Firstly, the DC center agents follow the plan of the planners and find suitable locations in CCA and UPA to build the DC centers. Next, to elderly agents who want to visit DC centers, they have to apply for a certificate of care need to local government. After that, the government agent judges the elderly people's health basing on 8 determinants, such as meal, excretion, movement, etc. and decides care levels for each elderly person. After receiving the certificate of care level, the elderly people visit a chosen DC center with a certain number of times per week. Finally, DC center agents count the elderly who visited their DC centers, calculate the revenue and compare the revenue with expenditure to make sure they could keep on their operations or not.

We divided our model into five modules that are described as following:

#### *3.2.1 Life cycle stage module*

This module displays a life cycle in which a person is born, grows up, gets married, gets old and passes away. To make the simulation more reasonable, we set the initial population according to the real population census data in 2000. And after each step, people will add one year to their ages.

*3.2.2 Location choice module*

According to procedure for opening a DC centers in Japan [11], the DC center agents will follow the decision tree shown in figure 2 to make a decision for building centers. To obtain its objective, A DC center agent has to specify locations of the elderly people who want to visit DC centers at each cell firstly. Then, it will calculate a demand for DC centers at each cell in CCA and UPA. The demand indicates the number of elderly people who want to visit DC centers in an area within a radius of certain maximum service distance. After that, the DC center agent compares the demand at each cell with a threshold in order to set that location as a potential site. The threshold indicates a minimum demand of 15 elderly people that the DC center agent can build a DC center at one cell for serving elderly people. The following equation was used for calculating the demand at one cell:

$$Dj = \sum_{i=1}^{n} a_i \times y_i \tag{1}$$

Subject to $y_i = 0$ if $d_{ij} > S_{\max}$

$y_i = 1$ if $d_{ij} < S_{\max}$

Where: $Dj$ : Demand at cell j; $a_i$ : Number of elderly people who want to visit a DC center at cell i; $d_{ij}$ : Distance between cell i and cell j; $S_{\max}$ : Maximum service distance.

Next, DC center agent will also evaluate the appropriateness that is governed by some factors, such as different land use zones, distance from hospital at each location. In another word, it calculates the probability that indicates whether one cell will be chosen for building a DC center or not. In this paper, we applied logistic regression[10] *(Long et al, 2008)* in order to calculate the probability that is represented as following equations:

$$\begin{aligned} S_{ij} = S_0 &+ \beta_1 \times f\_zone1 + \beta_2 \times f\_zone2 + \beta_3 \times f\_zone3 + \beta_4 \times f\_zone4 + \beta_5 \times f\_zone5 \\ &+ \beta_6 \times f\_zone6 + \beta_7 \times f\_zone7 + \beta_8 \times f\_zone8 + \beta_9 \times f\_center + \beta_{10} \times f\_hospital \end{aligned} \tag{2}$$

$$p_g^t = \frac{1}{1 + e^{[-S_{ij}^t - p_{av} \pm 1]}} \tag{3}$$

$$p_f = e^{a \times [-1 + (p_g / p_{g\max})]} \tag{4}$$

Where: $S_{ij}$ : suitability of cell (i;j) at time t; $S_0$: is constant that is one of [-3; 3]; $p_g^t$ : is initial probability at time t; $p_{g\max}^t$ : is maximum value of $p_g$ during each step; $\beta_1, \beta_2, \ldots$ : are coefficients in logistic regression; $f\_zone1, f\_zone2, \ldots$: are spatial features of cell (i;j); $a$ : is diffusion coefficient which is in the range of (1 – 10); $p_{av}$ : is the average probability between cell (i,j) and its four-cell neighbors; $p_f$ : is the final probability

Finally, the DC center agent will choose a potential site that has the highest value of probability as a location for DC center.

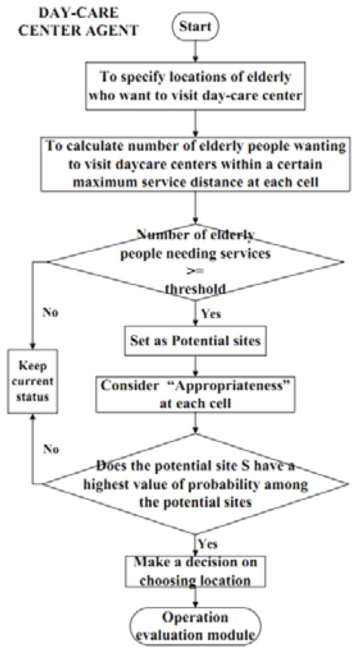


Figure-2 Decision tree for choosing locations of DC centers

*3.2.3 Care levels decision module*

The interactions between household agents and local government agent are represented in this module. Government agent makes a decision on specifying care levels for elderly agents basing on elderly people's health status (shown in figure 4).

**Meal (1)**
**1.1; 3.4; 5.0; 6.8; 7.5; 8.8; 10.1; 11.1; 11.2; 13.7; 15.4; 18.6; 21.6; 25.3; 34.2; 34.9; 45.4; 56.0; 65.9; 71.4**
**Excretion (2)**
**0.2; 2.0; 2.9; 4.7; 8.2; 8.3； 11.1; 11.6； 15.1； 16.1; 17.4; 18.4; 19.1; 19.7; 19.8; 20.1; 20.5; 20.8; 21.0; 21.5; 21.7; 22.1; 22.6; 22.9; 23.9; 24.0; 24.1; 24.5; 25.9; 28.0**
**Movement (3)**
**0.4; 2.0; 3.8; 4.1; 4.6; 4.7; 7.3; 7.6; 7.8; 8.2; 8.8; 10.2; 10.4; 11.1; 11.4; 12.6; 14.2; 14.6; 15.2; 16.3; 17.2; 17.6; 17.8; 19.0; 19.1; 19.2; 19.3; 20.5; 20.8; 21.4;**
**Keep clean (4)**
**1.2; 3.0; 3.9; 5.8; 6.0; 6.7; 7.6; 8.0; 9.8; 10.5; 10.8; 11.4; 11.6; 13.0; 13.6; 14.8; 15.1; 15.4; 15.5; 15.6; 15.8; 16.4; 17.1; 17.3; 17.5; 17.6; 17.7; 18.1; 18.5; 20.4; 20.5; 21.0; 23.1; 23.3; 24.3;**
**Indirect life care (5)**
**0.4； 1.3; 1.7; 2.2; 2.7; 2.8; 3.0; 3.2; 3.6; 4.2; 4.5; 4.6; 4.7; 4.9; 5.1; 5.4； 5.7; 5.8; 6.3; 6.4; 6.5; 6.7; 7.1; 7.2; 7.7; 7.8; 8.0; 8.2; 9.4; 10.9; 11.3;**
**Behaviors on mental and physical health (6)**
**5.8; 6.1; 6.2; 6.3; 6.4; 6.7; 7.5; 7.6; 8.1; 8.7; 9.0; 10.1; 10.5; 10.6; 10.8; 16.1; 21.2;**
**Behaviors on training function (7)**
**0.5; 1.1; 1.6; 1.9; 2.0; 2.2; 2.5; 3.2; 3.3; 3.9; 4.0; 4.1; 4.5; 4.6; 5.5; 5.7; 6.0; 6.1; 6.5; 7.0; 7.1; 7.6; 7.8; 8.9; 10.4; 10.5; 11.6; 15.4;**
**Behaviors on medical care (8)**
**1.0; 2.0; 2.6; 2.9; 3.0; 3.2; 3.3; 3.9; 5.3; 4.2; 4.4; 4.5; 5.1; 5.9; 6.0; 6.1; 6.5; 7.0; 7.4; 8.3; 9.2; 10.1; 14.8; 28.0; 29.0; 32.0; 33.7; 37.2;**

Figure-3 Determinants governing Elderly people's Health status

Firstly, each elderly agent who wants to visit the DC centers will choose one of scores from each determinant randomly (shown in figure 3). Then, the government agent calculates a health score for each elderly agent by summing all the scores that elderly people have chosen. Finally, the government agent will compare the health scores with a classification table of care levels (shown in table 1) in order to specify care levels for elderly people.

Table-1 Care levels classified by Japanese Government [8)]

| | Support 1 (S1) | Support 2 (S2) | Care 1 (C1) | Care 2 (C2) | Care 3 (C3) | Care 4 (C4) | Care 5 (C5) |
|---|---|---|---|---|---|---|---|
| T=1+…+8 | $25 \le T < 32$ | $32 \le T < 40$ | $40 \le T < 50$ | $50 \le T < 70$ | $70 \le T < 90$ | $90 \le T < 110$ | $T \ge 110$ |

*3.2.4 DC center choice module*

In this module, the elderly agents will follow a decision tree shown in figure 5 to display their behaviors on choosing the DC centers to visit. We assumed that a distance from an elderly agent's house to DC centers is considered as a single criterion for choosing a DC center to visit. In another word, they will choose the nearest center to visit with a certain number of times per week according to different care levels. However, they will be asked to move to another center randomly if the first chosen center is full of people. Besides that, this module also represents interactions between elderly agents. An elderly agent who has visited a DC center will introduce that center to his neighbors and ask them to visit the DC center with him. In our model, the elderly agents living in an area within a radius of 100 m, corresponding 2 cells in the model, from the houses of elderly agents visited DC centers are considered as neighbors of the elderly agents who visited DC centers. Furthermore, the probability for visiting DC centers that elderly people who will be asked to visit a DC center is set randomly.

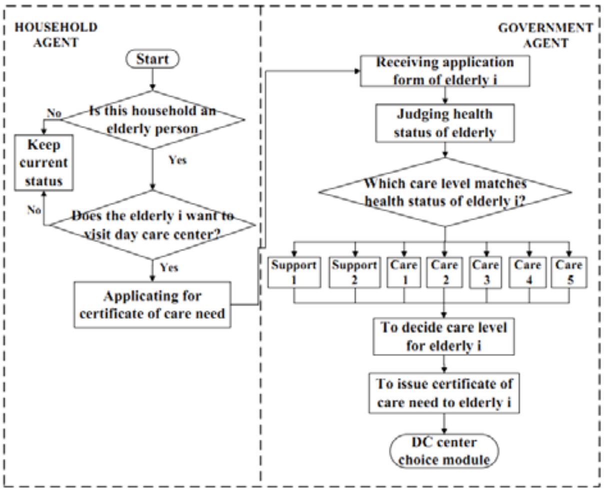


Figure-4 Decision tree for deciding care levels

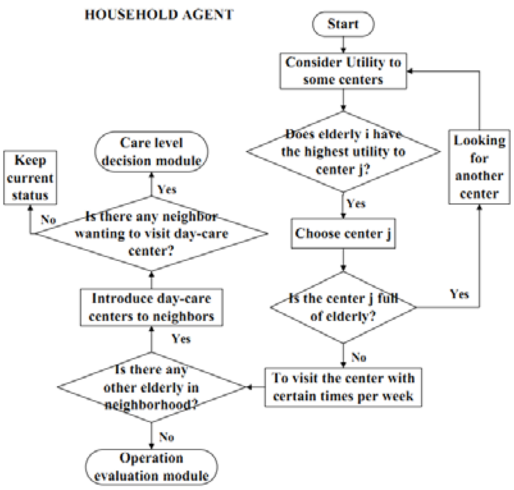


Figure-5 Decision tree for choosing DC centers

*3.2.5 Operation evaluation module*

The module shows the behaviors of DC center agents on recording number of elderly agents who have visited the DC centers according to different care levels. They also calculate their revenue for one year and compare the revenue to their expenditure in order to make sure the DC centers could keep on their operation or not. If the revenue of a DC center is lower than its expenditure, this center will go bankrupt and be eliminated from urban space. We also suggested an equation for calculating the revenue as following:

$$R = \sum_{i=1}^{7} N_i \times P_i \times F_i \times ra \times 52 \quad (5)$$

Where: $R$ : Revenue for one year; $N_i$ : Number of elderly people according to care levels has visited a DC center; $P_i$ : is the price that is different according to care levels; $F_i$ : is frequency indicating number of times elderly people visited a DC center ; 52 : means the number of weeks in a year; $ra$ : is the price ratio among three kinds of DC centers and ra has 3 different values, such as ra =1; ra =1.1; ra =1.5; i = [ 1; 7] corresponds to 7 care levels that are Support 1(S1), Support 2 (S2), Care 1 (C1), Care 2 (C2), Care 3 (C3), Care 4 (C4) and Care 5 (C5).

*3.3 Simulation process and simulated results*

*3.3.1 Data input*

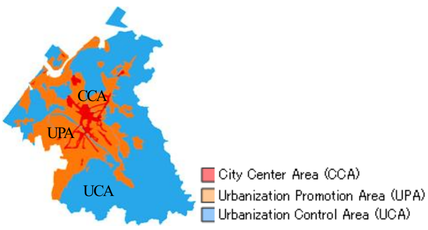


Figure-6 Urban planning area inputted in NetLogo in 1985

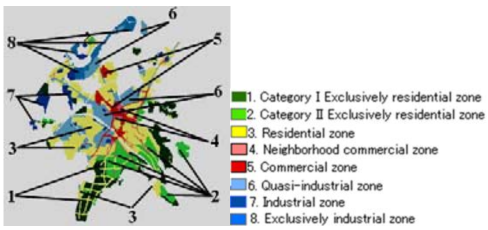


Figure-7 Land use zones inputted in NetLogo in 1985

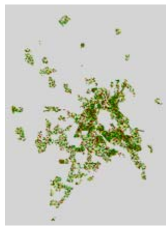

Figure-8 Distribution of 6285 households created in NetLogo

For data preparation, we used ArcGIS software to compile and convert some GIS data on household distribution, urban area, and land use zones from vector data to ASC files. Then, these ASC files were inputted into NetLogo software (figures 6, 7, and 8). We just considered 6825 households (figure 8) who live in Downtown (CCA), Urbanization Promotion Area (UPA), Urbanization Control Area (UCA) for running the simulation because it takes a lot of time if we use all number of households.

Besides that, to set the initial input data, we also used the same ratio of elderly agents comparing to total population and the same ratio of elderly people who visited the DC centers comparing to number of elderly people as those of the real data in 2000 that are 0.16 and 0.107 respectively. So, we have 1098 elderly agents including 117 elderly agents who visited the DC centers at the initial step.

Furthermore, we also suggested an equation to calculate number of new DC centers that will be built at each tick as follows:

$$N_{newDC} = \frac{N_{Visited-Elderly}}{Ca_{av}} - N_{exDC} \qquad (6)$$

Where: $N_{newDC}$: The number of new DC centers; $N_{Visited-Elderly}$ : The number of elderly agents who want to visit DC centers
$Ca_{av}$; The average capacity among DC centers; $N_{exDC}$ : The number of existing DC centers

Moreover, as mentioned in section 3.1, we divided the DC centers into 3 kinds with different capacities. Besides that, the expenditure of each DC center is different according to different capacities. In our case, we set the expenditures as 50% of revenue of a year that are calculated basing on an average price and average frequency among seven care levels. For more detail, DC centers with capacities of 15 (in color of blue), 20 (in color of yellow) and 25 (in color of red) have the expenditures as 637,200; 849,600 and 1,062,000 yen respectively.

*3.3.2 Simulated results*

We ran the simulation for 30 ticks that correspond 30 years from 2000 to 2030 and the simulation was repeated 30 times. It took 45 hours for 1 time and 1350 hours for obtaining all the simulation results. In this paper, we will represent the simulation results from the year of 2000 to 2010 firstly, and then validate the results by using the real census dataset in 2010. Finally, we will show some predictions on the locations and number of DC centers and number of elderly people who visited DC centers in 2030.

The figure 9 shows the simulation result on distribution of DC centers in 2010. Symbols with small houses indicate the existing DC centers that have the same coordinates with the real ones. And symbols with big houses represent the new DC centers. According to results from 30 times, there are 14 DC centers in average (figure 10) that include 12 centers, 86% located in residential areas (Re), one, 7% in commercial area (Co) and one, 7% in industrial areas(In) (figure 11), which are similar to real percentage 68%, 6% and 24% in those land use zones respectively in the entire Kanazawa city. Because we only focus UCA, UPA and CCA, the number of DC centers located in Industrial area is smaller than the real percentage.

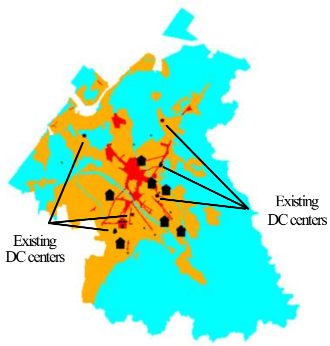

Figure-9 Distribution of DC centers in 2010

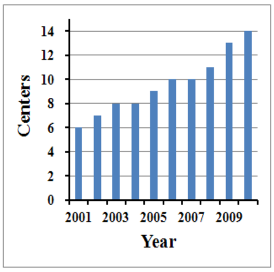

Figure-10 Average number of DC centers

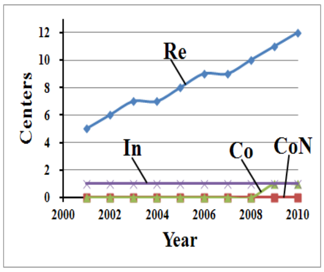

Figure-11 Number DC centers in different land use zones

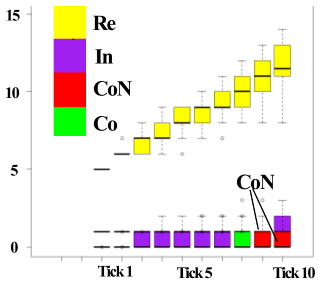

Figure-12 DC centers in different land use zones from 30 times of simulation

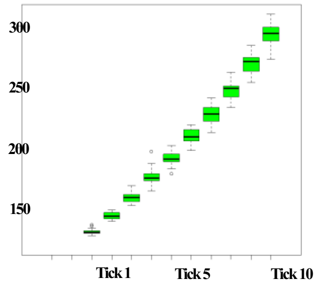

Figure-13 Elderly people visited DC centers from 30 times of simulation

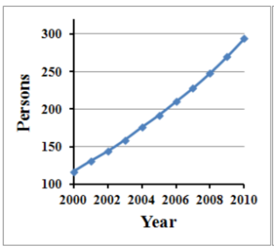

Figure-14 Elderly people visited DC centers

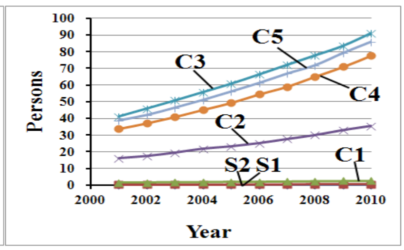

Figure-15 Elderly people visited DC centers with different care levels

Table-2 Comparing simulated results and real data

| | Living area | Number of elderly visited DC centers | | Increase in Elderly visited DC centers (times) |
|---|---|---|---|---|
| | | 2000 | 2010 | |
| Census data 177,686 households | Kanazawa City | 7795 | 18072 | 2.3 |
| Simulated data 6825 households | CCA, UPA, UCA | 117 | 294 | 2.5 |

Moreover, we also used R software to draw box-plot that represents the results from 30 times of simulation (figure 12, 13). And the number of DC centers from simulation results makes up about 10% of the real ones that are 138 centers in 2010[12].

Figures 14, 15, and 16 show the results on the number of elderly people who visited DC centers and number of elderly people who visited DC centers with different care levels. Moreover, the table 2 displays a comparison between the simulated results and the census data[13] on number of elderly agents who visited DC centers. The times of increase in number of elderly people who visited DC centers are nearly the same between real data and simulated results that are 2.3 and 2.5 respectively.

Furthermore, we also implemented simulation on the locations of DC centers and predicted number of visited elderly people in 2030 that are indicated as following figures 16-20. According to the simulated results, there are 60 DC centers and 1252 elderly agents who visited DC centers. Besides that, number of DC centers and number of elderly people who visited DC centers in 2030 increased 4.3 and 4.2 times respectively comparing to those in 2010. However, the number of elderly people with care levels of Support 1 (S1), Support (S2) and care level 1 (C1) are nearly zero as shown in the figures 15 and 19, which is because we have no dataset of health statues of elderly people and simulate the health status of each elderly person by a random process.

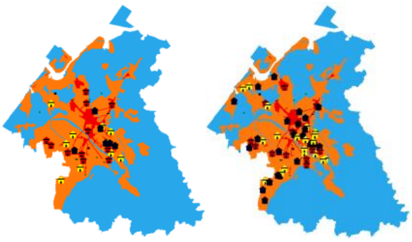

Figure-16 Distribution of DC centers in 2020 and 2030

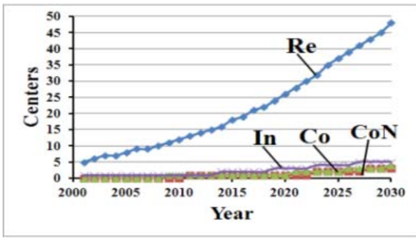


Figure-17 DC centers in different land use zones

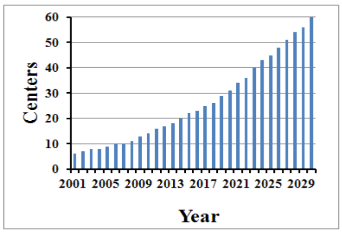


Figure-18 Number of DC centers until 2030

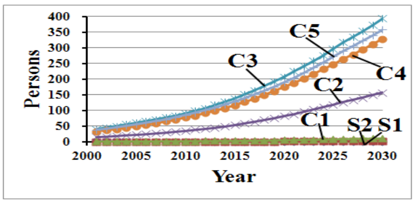


Figure-19 Elderly people visited DC centers with different care levels until 2030

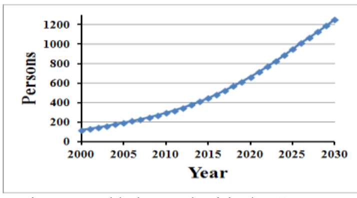


Figure-20 Elderly people visited DC centers until 2030

## 4. Discussion and further research

In this paper, an agent-based model for simulating locations of DC centers is developed and illustrated. The model integrated 5 different modules so that it can predict future age structure of population in Kanazawa city and its corresponded demand for daycare centers. Moreover, the distribution of these centers in different urban areas can also been simulated. From this viewpoint, comparing with traditional statistic analysis this research can provide planners who are making plans for daycare center with visualized reference. But in planning practice, to what extend this research can help planners and policy-makers to consider plan strategies for daycare centers is another topic we should consider in future.

However, our work still has limits that we have no dataset of health status of elderly people and simulation of the health status of each elderly person is conducted by a random process. In the future we should try to input real dataset of health status to predict the detailed demand of elderly people for different care levels. Furthermore, we should increase the accuracy of our model to parcel scale so that we can validate the location of DC centers by coordinates.

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