INFECTIOUS DISEASE SIMULATION MODEL FOR ESTIMATION OF SPREADING

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ABSTRACT

Using simulation models for understanding social phenomena recently became popular and is especially useful in some phenomena that cannot be simulated or tested in the real world, such as the phenomena of spreading an infection. To manage risks of spreading an infection in the real world, making a model of spreading infections in the city is very important and using it as a tool for understanding and analyzing the effects of infections is also important. This paper provides both a simulation model of a virtual city that is based on real data of Izu-Oshima Island and an infection-spreading model. Simulation results show what will happen in the real world if an infection occurs. Proposals for future use of the concepts and model are offered.

INTRODUCTION

In recent years, research that uses multi agent systems become active and a lot of models were developed. These kinds of models are very useful for understanding and analyzing some social phenomena. Especially, in some social phenomena where human activities are very important or very influential, it is useful to make models by using multi agent systems and agent-based modeling because these approaches enable us to represent human activities in models (Epstain & Axtell, 1996; Gilbert & Troitzsch, 2005).

In 2009, the pandemic of swine flu happened all over the world and it is usually said that a new type of influenza will occur in the near future. Using simulation models is one solution to determining how to manage risks of future pandemics and to evaluate some policies. In our research, the main purpose is to make a simulation model that can simulate how an infection spreads in the city by evaluating and testing policies that are used to handle the influenza pandemic. In this paper, we present a simulation model that can simulate how influenza spreads. We will explain the concepts of our model, show some simulation results and discuss the possibilities of using our model for evaluating policies to handle future pandemics. We used SOARS, a social simulation language, for making our models.

ABSTRACT OF SOARS

SOARS is designed to describe agent activities under the roles of social and organizational structure. Role taking processes can be described in this language. SOARS is also designed to account for the theory of agent-based dynamic systems. Decomposition of multi-agent interaction is the most important characteristics in our framework. The notion of spot and stage offers special and temporal decomposition of interaction among agents (Ichikawa, Tanuma, Koyama, Deguchi, 2007). The latest information on SOARS is available at http://www.soars.jp.

TOTAL DESIGN OF MODEL

To make a social simulation model, usually a total model is designed first and a total model is made from start to finish. It is usually the same process to make a simulation model that targets a social phenomenon that occurs in the city. We call this kind of model an urban simulation model or a city simulation model. In making an urban/city simulation model, a virtual city model is made first and targeted social phenomenon are represented in it. This modeling style is a standard modeling style used in making an urban simulation model.

In this research, our purpose is to make a simulation model for simulating how infections spread in the city. To make this simulation model, we did not use a standard style of modeling, but used a separated modeling style. In the process of making our model, we first designed a virtual city model and designed an infection model later. By designing and also making a virtual city model and an infection model separately, we could concentrate on making each model and separate models enable us to reuse them in other models.

VIRTUAL CITY MODEL

Most of models that were aimed to model a town, a city, an area and so on use the geographic information, usually GIS (Geographic Information System), for modeling. Using this methodology is useful for modeling a very narrow area in the real world but it is difficult to model a very huge area, for example, a whole city, because data for modeling become very large and too complex. In our virtual city model, instead of using the geographic information, we decided to use the layer structure information for modeling. Several layers are represented in the virtual city model from real information of the layer structure of the targeted city. And the most important point is that spaces for human daily activities such as houses, offices, shops, schools and so on can be completely represented as different spaces in the virtual model (Ichikawa, Koyama, Deguchi, 2010). Spaces for human daily activities are very important for some social phenomena that contain interactions between "humans and humans" and "humans and spaces," such as having communications, spreading infections and so on. We choose Izu-Oshima Island as a target of our virtual city model and made Virtual Izu-Oshima Island based on statistical data.

IZU OSHIMA ISLAND

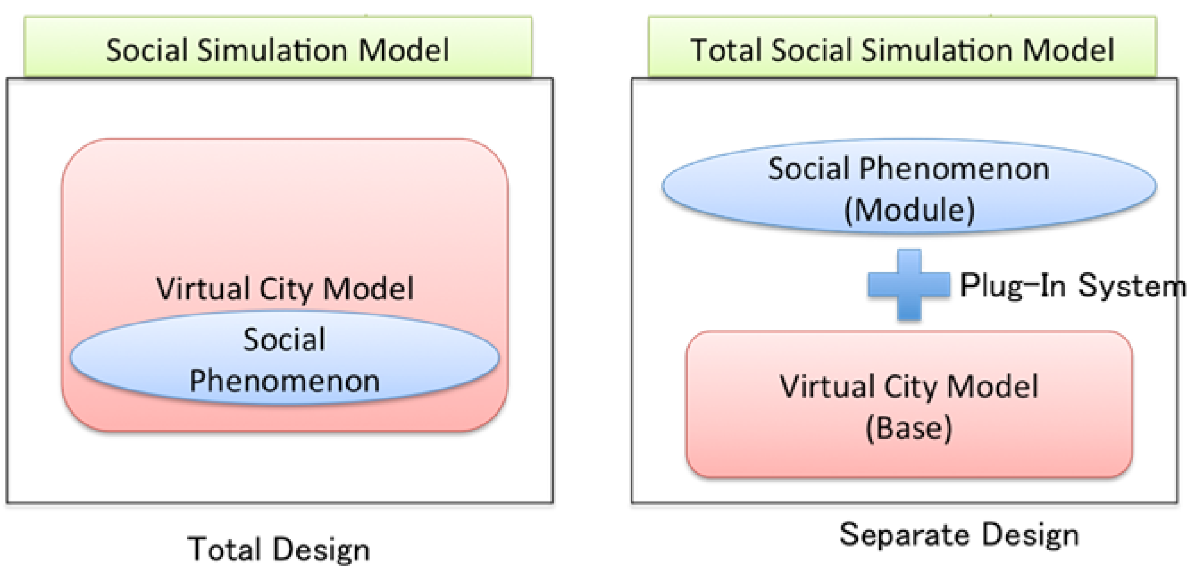
Izu-Oshima Island is located south of central Tokyo and it is 120km far from Tokyo. There are about 8000 people living in Izu-Oshima Island and there are about 5000 houses. There are also 6 elementary schools, 3 junior high schools and 2 high schools. And there are also some offices and shops. There are about 650 offices that include large offices that have more than 50 workers and small offices that have less than 10 workers, and about 200 shops in Izu-Oshima Island. Based these statistical data, we divided 5000 houses into 22 types which are based on people who live in each house. Some examples of these 22 types are a 3-people house with a father, a mother and a child, a 5-people house with a father, a mother, two children and a grandfather and so on. We also divided 650 offices into 7 types that are based on the number of workers in each office.

Regarding the geographical information of Izu-Oshima Island, there are 6 main areas in Izu-Oshima Island and each area consists of several small areas. The 6 main areas are "Motomachi", "Okata", "Sashikichi", "Habu", "Nomashi" and "Senzu". Totally, there are about 100 small areas in Izu-Oshima Island. We calculated the number of daily activity spaces in each small area from the above statistical data and we used this as input data of the virtual Izu-Oshima Island model that we made for this paper.

VIRTUAL IZU-OSHIMA ISLAND MODEL

As mentioned in the previous section, making a virtual city model is required as a first step in making a whole social simulation model to represent targeted social phenomena. We explain our virtual city model first.

Exhibit 1
Design of Total Model and Separated Models



The first layer in our model is the city layer and it shows a whole city. In this case, this layer shows whole Izu-Oshima Island. The second layer is the big area layer and 6 main areas of Izu-Oshima Island comprise this layer. This means that there are 6 elements in the second layer. The third layer is the small area layer and about 100 small areas make up this layer. The last fourth layer is the daily activity space layer and about 6000 elements are in this layer. Further, each element in a layer belongs to one of the elements in an upper layer. That is, for example, an element in the fourth layer shows one of activity spaces, such as houses, offices and so on, and it must belong to one of small areas in Izu-Oshima Island. This is the same between small areas and big areas as elements in the third area and elements in the second area. In our model, each element in a layer has a connection with an element in the upper layer and some connections with elements in the lower layer. This structure of our virtual city is similar to the tree structure.

The number of agents who are decision-making entities is about 8000 and they are living in this virtual Izu-Oshima Island. They belong to one of the houses and they have one of types that are defined based upon domestic roles in the home in the real world such as “father,” “mother,” “boy,” “girl,” “grandfather,” and “grandmother.” They also perform some simple actions to represent their daily activities based on their domestic role. For example, if an agent has “boy” as his domestic role, he will go to school in the daytime as his daily activity, and if an agent has “father,” he will go to office as his daily activity.

INFECTION MODULE

In this section, we explain about the infection module that can be used as a plug-in module for the virtual city model we explained in the previous section. As a social phenomenon module is plugged into a virtual city model, it can be used as a social simulation model of the targeted social phenomenon.

DISEASE STATE TRANSITION MODEL

We designed the disease state transition algorithm of the new influenza and constructed it as a plug-in module for our virtual city model.

In this disease state transition algorithm, agents who are not infected have “0” state. Once agents are infected, they change their state to “1” state from “0” state and this state lasts for three days. After three days in “1” state, there are two states which are “2” state and “2m” state. The difference between these two states is whether symptoms of this disease are shown or not. In the real world, most of the people who have diseases show some symptoms and they can be recognized by them. Usually, symptoms are a high fever, a chill, a cough, a rash and so on. However, some of people who have diseases do not show symptoms because symptoms are too light and they cannot recognize their diseases. These two types are represented as “2” state and “2m” state. “2” state means that symptoms are shown and “2m” state means that symptoms are not shown. In this disease state transition algorithm, 80% of

Exhibit 2
Image of Layer Structure of City

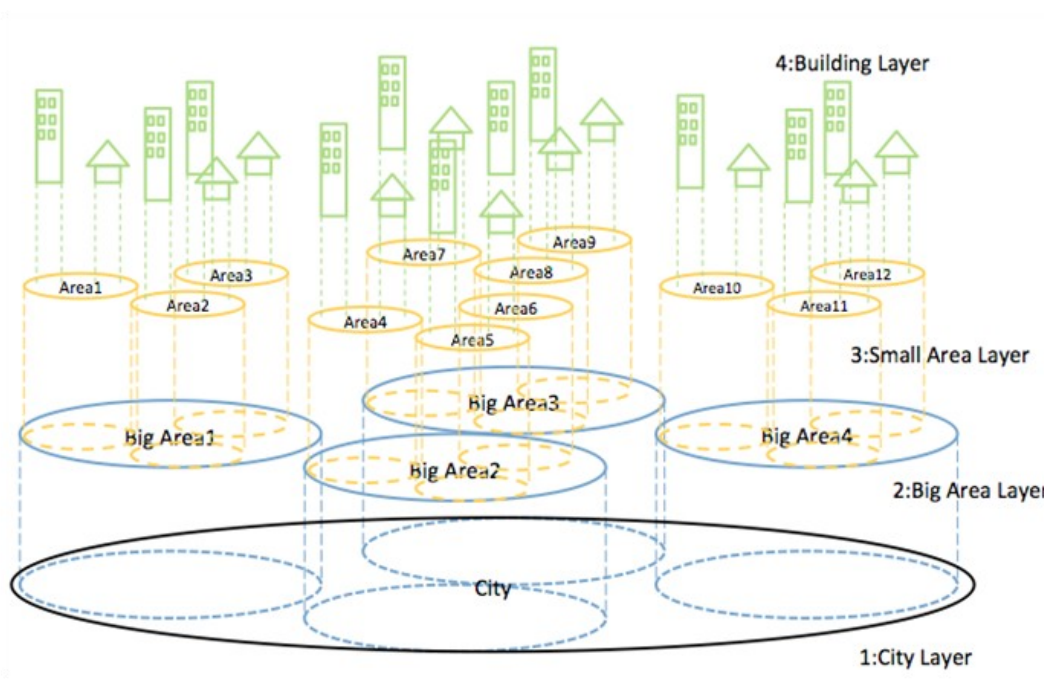


Exhibit 3
Example of Behavior

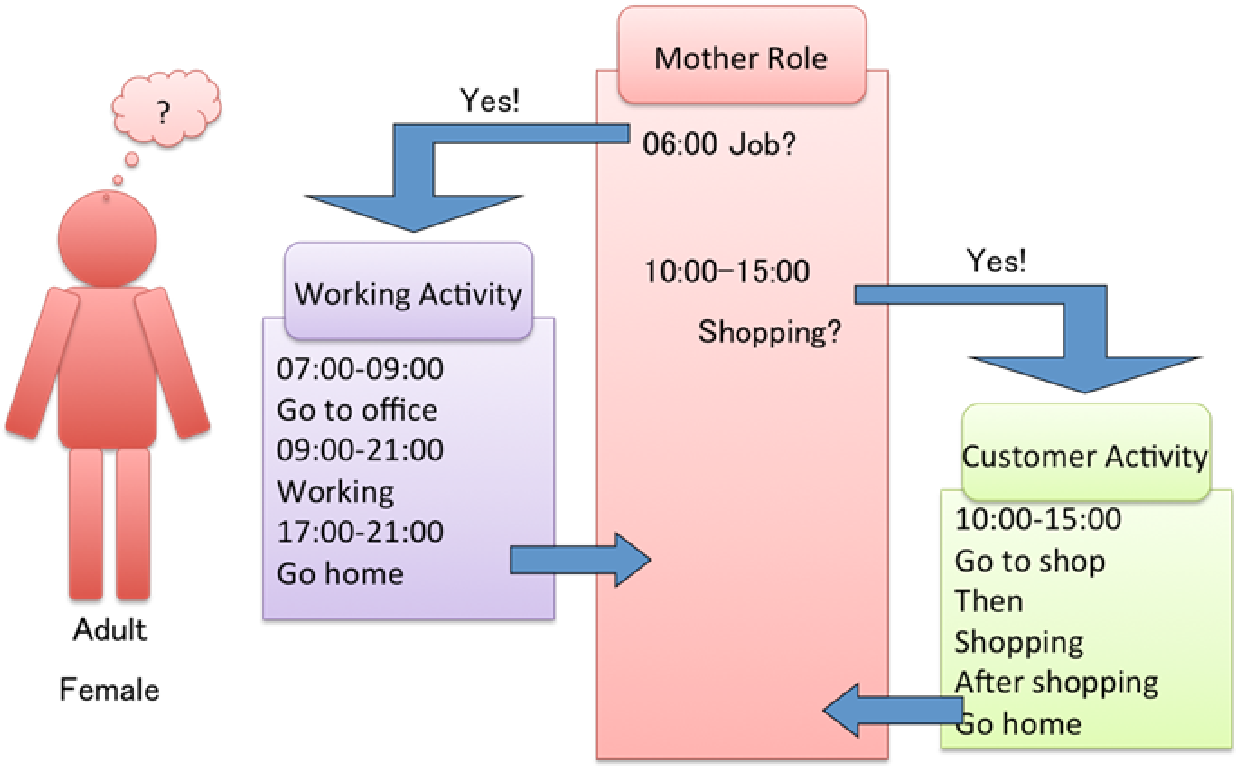
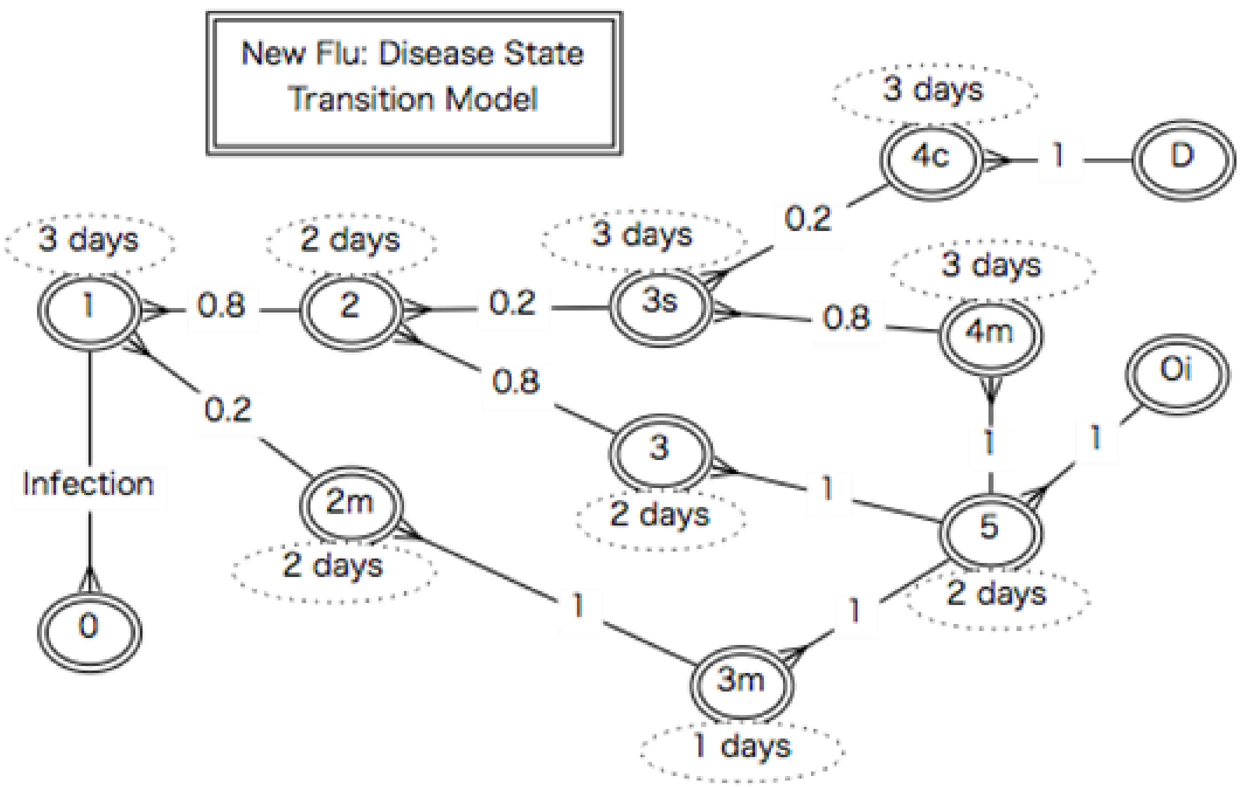


Exhibit 4
Disease State Transition Model



agents who are infected change their state to "2" and others change their state to "2m". Agents whose state is "2m" change their state to "3m" state from "2m" state after two days. And after a day, they change to "5" state. Agents who go through this process will perform their daily activities without going to a hospital and with spreading infections. This is because they do not recognize their diseases from symptoms. Agents whose state is "2" state change their state to "3s" state or "3" state after two days. "3" state means the normal process case and "3s" state means the heavy process case. In the normal process case, agents will not perform their daily activities and they just stay at home or go to a hospital. They change their state to "5" from "3" after a day. In the heavy process, there are also two states after "3s" state. One is death and the other is the process of recovery. After two days in state "5", agents will recover from the infection and change their states to "0i". This "0i" state means that agents have immunity to this infection and they will not be infected again.

TRANSMISSION MODEL

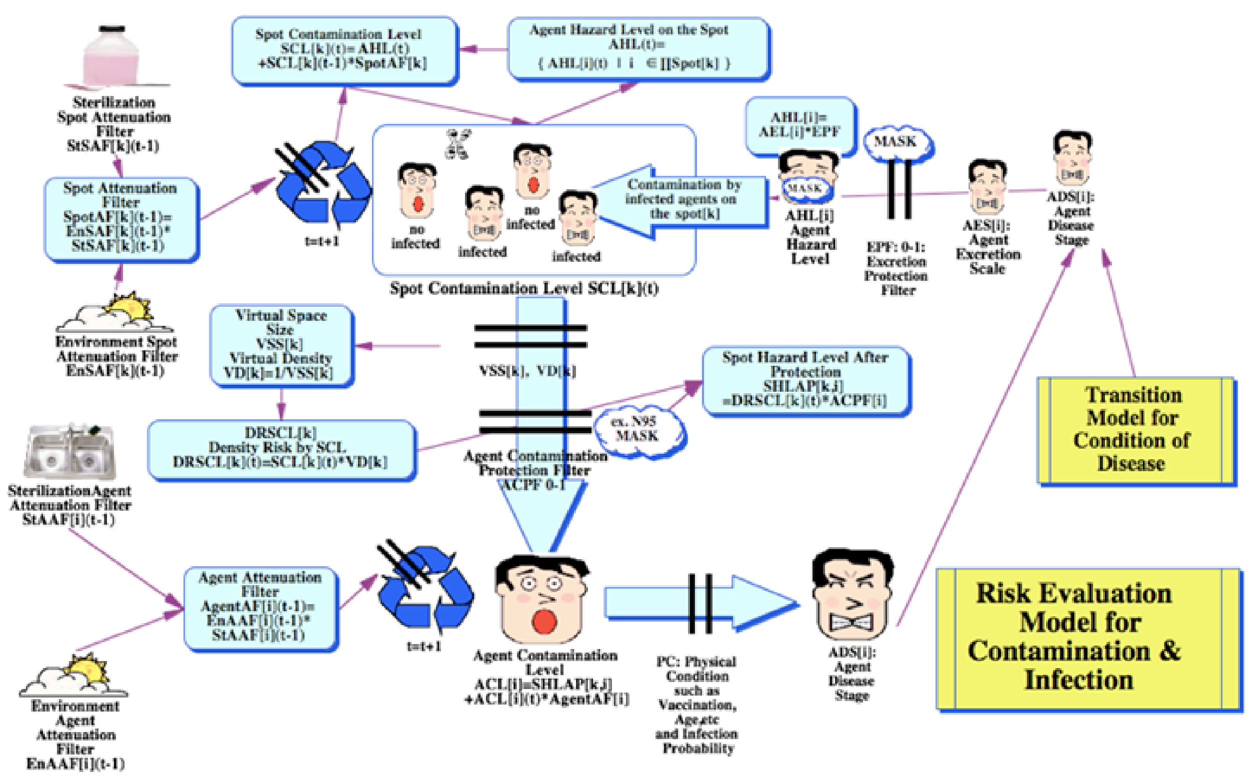
We also designed the transmission model and constructed it as a plug-in model for our virtual city based on this transition algorithm.

In this transmission model, the basic algorithm of spreading infection in the space, a place where agents act their daily activities, is as follows.

1. Both infected agents and non-infected agents move into the same activity space.
2. Infected agents spread their infection and they contaminate the space.
3. Non-infected agents may get an infection from the contaminated space.
4. Some of the non-infected agents will be infected.

The risk of getting an infection depends on the situation. If agents who have an infection have a mask, the risk of contaminating the space will be reduced. This is a process for preventing contamination of the space and it works well or poorly depending upon whether infected agents use a mask or not. This risk also depends on the size of the space and also upon the number of people who are infected. If the size of the space is huge and there are few agents who are infected, the risk of getting an infection will be reduced, but when the size of the space is small and there are many agents who are infected, the risk of getting an infection will be increased. Whether agents who do not have infection have a mask or not is also important to the rate of the infection spreading. If agents who have no infection have a mask, the risk of getting an infection will be reduced, but if they do not have a mask, the risk of it will be increased. There are several more important points in this transmission model and the probability of getting an infection will be determined by using these points.

Exhibit 5
Transmission Model



SIMULATION

In this section, we will show some results of simulating our infection model. The base model is the Virtual Izu-Oshima Island Model and Infection Module that we explained in the previous section and is plugged into the base model. We simulated two cases. One is the case that the five first-infected people live in the largest area in Izu-Oshima Island and the other is the case that five-first infected people live in the smallest area in Izu-Oshima Island.

CASE 1

In this case, the first five infected people live in the largest and most crowded area in the Izu-Ohima Island.

This figure shows the number of infected people in each area per day, in this case. The x-axis shows the day and the y-axis shows the number of infected people. In Motomachi area, the largest area in Izu-Oshima Island, most people are infected by the 20th day and the number of infected people reaches about 400. After spreading in Motomachi area, the infection starts to spread into the other five areas. Especially in Sashikichi area, the second largest area, the number of infected people reaches about 200 around the 35th day. In this case, the spreading of infection in this virtual city ends at about 90 days.

In this figure, the x-axis shows the day and the y-axis shows the rate of the number of people who are infected by one infected person. If the rate is 3, this means that one infected person infects three other people who were not infected. The highest rate is over 9 between the 10th day and 20th day and in these days, the infection spreads rapidly and widely in this virtual city. After the 45th day, the rate drops below 1 and this means that the infection is not spreading and is moving toward to the end. Around the 90th day, the rate is 0 and the spreading of the infection ends.

CASE 2

In this case, first five infected people live in the smallest area in the Izu-Oshima Island.

In this figure, the x-axis also shows the day and the y-axis shows the number of infected people. Results of this case are different from the previous case. It is the same since the largest occurrence happened in the Motomachi area, but the term is shorter than the previous case. In both the Habu area and Okata area, the peak number of infected people is higher than in the previous case and the bulk of the infection happened suddenly. In this case, the first five people infected spread their infection in their home area after which it began to move to the largest area. After spreading in this area, the occurrences will be begin in other areas.

From this figure, we can know that the prevalence of the infection ended after the 105th day, while between the 20th and 55th day most of the cases occurred in this virtual

Exhibit 6
Number of Infect Agents in Each Area in Case 1

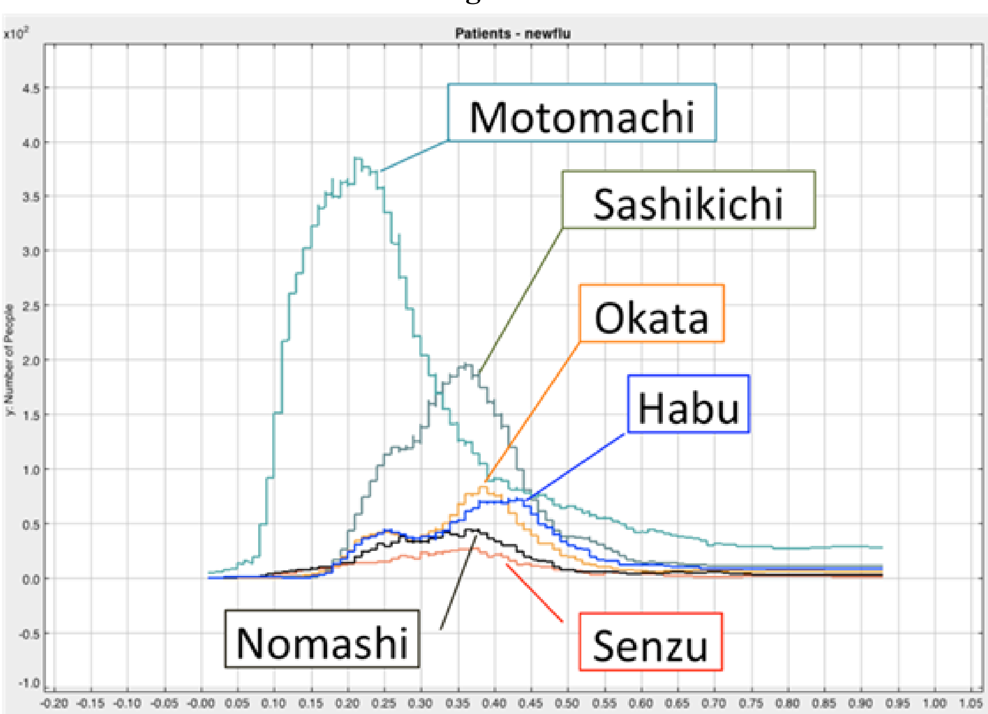


Exhibit 7
Infection Rate in Case 1

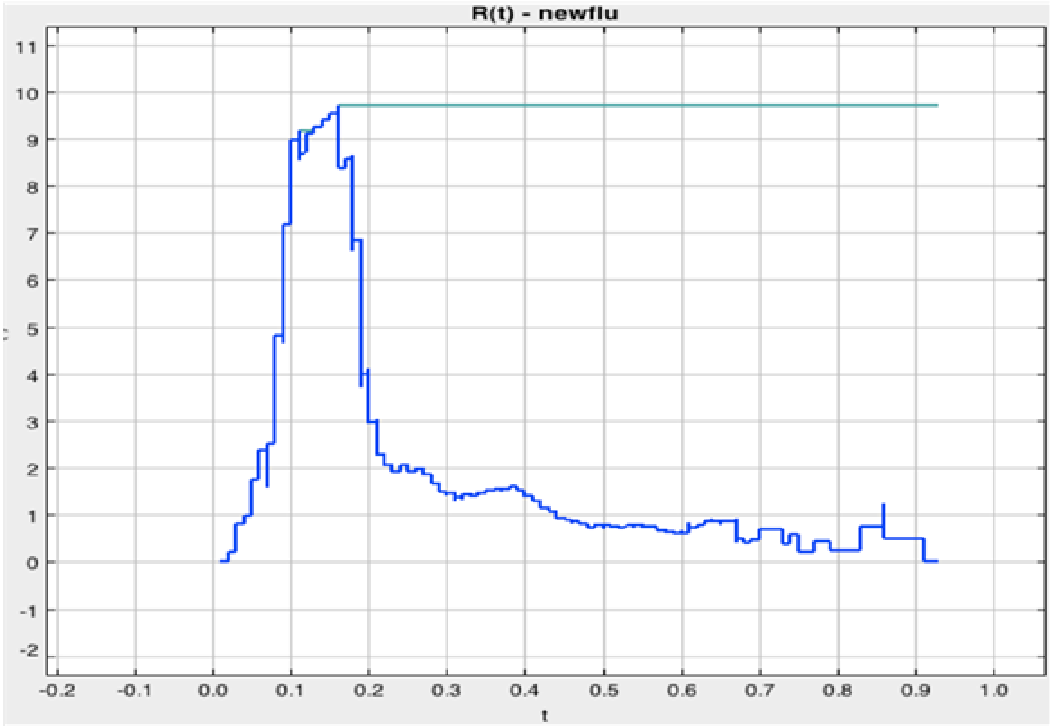
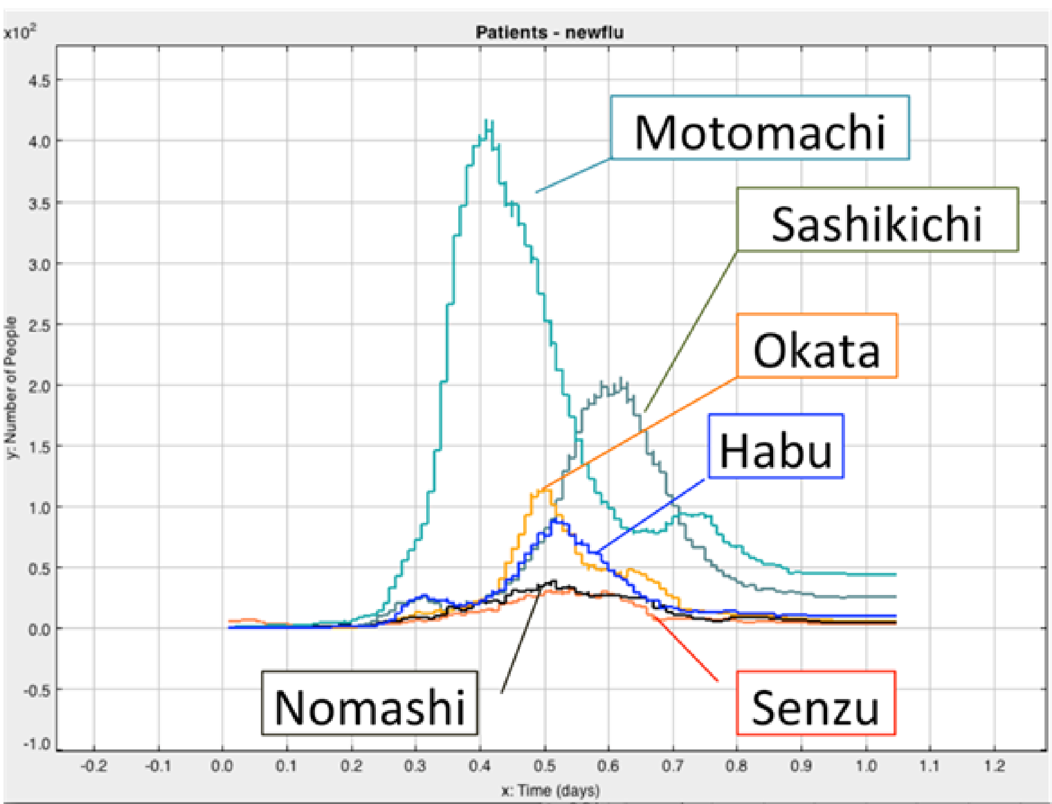


Exhibit 8
Number of Infect Agents in Each Area in Case 2



city. The highest rate is smaller than the previous case; the rate is about 5 in this case.

When we compare these two cases, the first shows that the prevalence of the infection results in an explosive epidemic. In case two it is a long-term epidemic. It takes about 90 days until the infection has ceased in the case one and two weeks longer in the case two.

CONCLUSION AND FUTURE WORK

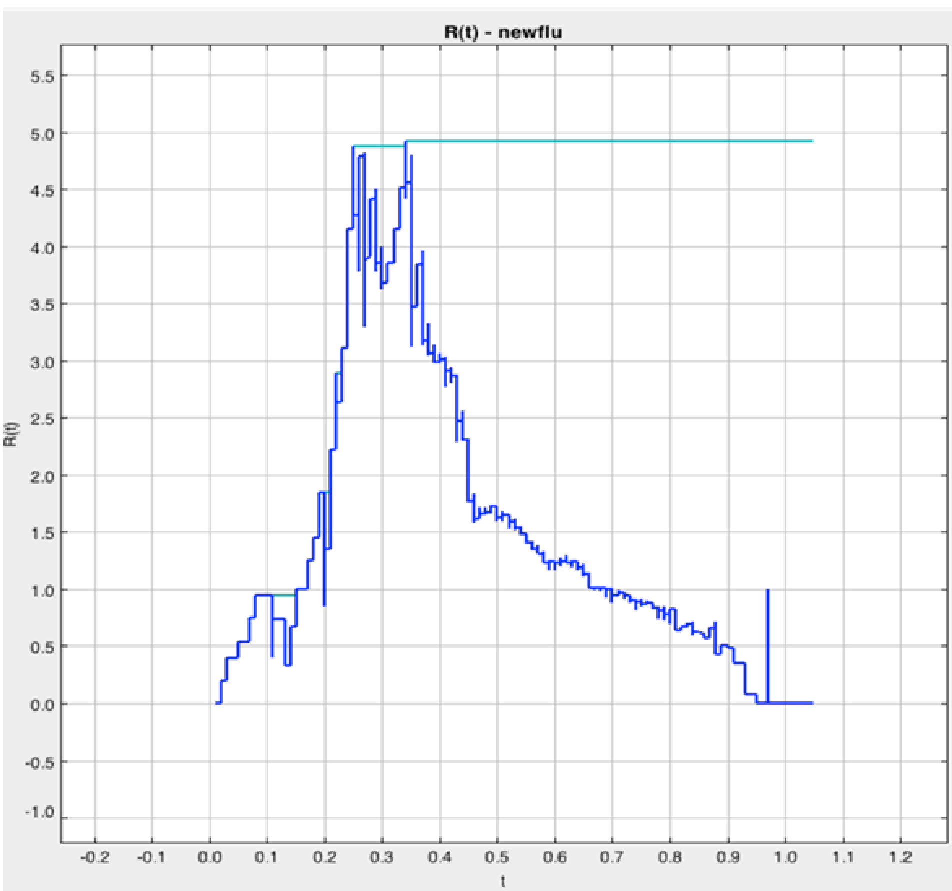
CONCLUSION

In this research, we made two important simulation models. The one is the virtual city model that we used as the base model of our total research model. In this base model, we made the virtual Izu-Oshima Island model that is based on the real data of statistics in the real Izu-Oshima Island. There about 8000 agents or people living in this virtual city among about 5000 houses, 300 offices, several shops and schools. These are places where people interact, such as at work, school, and shopping, which are important to the simulation

FUTURE WORK

There are several things that our model can do for this kind of infection we described in this paper. First of all, if we can get some statistical data of other cities, we can make some virtual city models based on their data. This means that our model enables us to test and simulate the infection-spreading phenomenon in several other cities (cases). We may find differences in the way infection spreads, which will be evidenced by the scale, type and other factors between simulated cities. Secondly, if we make another infection module based on another disease or infection, we can simulate other infection cases on the same virtual city. We will be able to find differences between several infections by comparing results of simulating a lot of models of several infections. Thirdly, we think this is the most important, if we make some policy modules for preventing the spread of infections and plug those into our model, the total model enables us to evaluate policies by simulating and analyzing simulation results. And also we can compare which policy is the best and which policy is the worst by simulation. It is true that a simulation model

Exhibit 9
Infection Rate in Case 2



is just a model, but simulation results may show one case that will really happen in the real world. We think that the basic model that we made in this research will become the risk management tool for infection management by solving these future challenges. Furthermore, our model can be used not only for infection spreading phenomena, but also for an urban economy, a rumor spreading phenomenon, urban planning and so on where phenomena are suitable to our model concept. We think that if a lot of social phenomenon modules are made, we will be able to simulate a lot of social phenomenon on a virtual city with variety of combinations of modules which will leads us to better understand and analyze our world.

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