論文 / 著書情報
Article / Book Information

題目(和文)	ソーシャルネットワークにおける予防接種モデル
Title(English)	A Pandemic Immunization Simulation based on Population-wide Social Network Model
著者(和文)	薛キョウ
Author(English)	Jiao Xue
出典(和文)	学位:博士（工学）, 学位授与機関:東京工業大学, 報告番号:甲第10347号, 授与年月日:2016年9月20日, 学位の種別:課程博士, 審査員:出口 弘,金谷 泰宏,寺野 隆雄,新田 克己,三宅 美博,小野 功
Citation(English)	Degree:, Conferring organization: Tokyo Institute of Technology, Report number:甲第10347号, Conferred date:2016/9/20, Degree Type:Course doctor, Examiner:,,,,,
学位種別(和文)	博士論文
Type(English)	Doctoral Thesis

TOKYO INSTITUTE OF TECHNOLOGY

DOCTORAL THESIS

A Pandemic Immunization Simulation based on Population-wide Social Network Model

Author:

Jiao XUE

Supervisor:

Hiroshi DEGUCHI &

Yasuhiro KANATANI

A thesis submitted in fulfillment of the requirements

for the degree of Doctor of Engineering

in the

Deguchi Laboratory

Department of Computational Intelligence and Systems

TOKYO INSTITUTE OF TECHNOLOGY

Abstract

Interdisciplinary Graduate School of Science and Engineering

Department of Computational Intelligence and Systems

Doctor of Engineering

A Pandemic Immunization Simulation based on Population-wide Social Network Model

by Jiao XUE

Immunizations are the most effective method of preventing and ameliorating morbidity from infectious disease in the population-wide community. Personal vaccination behavior, which constitutes to the whole immunization system, are viewed as a prophylactic and active immunoprophylaxis measure taken in order to protect vaccinator himself or herself and prevent the spreading of infectious diseases for the susceptible groups around the vaccinator. Relative prognostic importance of the various factors predisposing to vaccination behavior modification of individuals is determined by personal values, health beliefs, and influence from interpersonal relationships within population-wide social network during the process of immunization decision modification. In order to determine the relative prognostic importance of the various factors predisposing to personal vaccination behavior modification and analyze the influence of immunization awareness diffusion on overall social network architecture, this thesis carries out an agent-based simulation method to construct a pandemic immunization model and analyze the influence of immunization decision-making process in self-awareness and attitudes toward vaccination during social interaction.

During the past decades, experimentation, controlled observation and questionnaires are primary ways that gave us a valuable insight into vaccination decision-making, awareness diffusion in social networks and mechanism of in immunization system. Comparing with the most of the previous researches, this work use an agent-based simulation approach, which is better to consider aspects usually ignored in most of previous models: interactions among individuals, activities of daily living, and in particular individual decision-making adapting to the individual ’s changing internal behavior intention and external social environment. In this thesis, all individuals in the community are viewed as independent agents. All agents and their personal relationship networks constitute a population-wide social network and their vaccination behavior is component of an immunization system. On social interaction side, we focus on the universality and intimacy existing in agents ’ personal networks, which are embedded in a population-wide network structure in reality, as well as structure and influence of a social network on agents ’ personal behavior. This work purposes to provide a specific method to generate a population-wide social network in community. Firstly, we predicts the features (such as intimacy between social interaction, personal leadership, etc.) inside a real social network through the analysis of all types of personal relationship networks in the real world based on Japanese General Social Survey data. Then, we carries out an agent-based simulation method to generate a realistic spatial social network based on a virtual city model by achieving the real geographic information of a specific city area and applying data analysis results as a contribution to intimacy between agents. The constructed social network consists of all personal relationship networks of agents and indicates the ways in which agents are connected through various social familiarities ranging from casual acquaintance to close familial bonds. In this thesis, by specifying the personal information (age, sex, job, etc.), geographic location, social interaction, and a series of entity rules of behaviors for each human agent, we have generated a population-wide social network model of Oshima city using computer simulation.

On vaccinator side, the focuses of our research concentrate on personal voluntary vaccination decision-making and its relationship with the personal relationship networks. In this work, Theory of Reasoned Action (TRA), which is a typical paradigm of behavior modification in the field of social psychology, is supposed to be a potential mechanism for improving vaccination decision-making performance for every human agent living in the community. In order to determine the relative prognostic importance of the various factors predisposing to vaccination behavior modification of individuals, we have figured out prospective factors in vaccination behavior modification and evaluated degree of the influence from the factors for each individual by applying the variables of TRA to distinguish inoculation program participants from nonparticipants. Besides, considering infectious risk, kinds of vaccination, inoculation pattern vary in a big way for different pandemic, this research focuses on vaccination behavior towards seasonal influenza vaccine.

The constructed simulation model with agent-based approach links micro-level individual vaccination intention analysis to macro-level immunization phenomena by making an insight of the properties of individual agents. Therefore, this thesis has analyzed the simulation results in a more comprehensive manner from both macro-level and micro-level perspectives. Macro-level characteristics of the immunization system in influenza season are analyzed from the viewpoints of the relationship among immunization coverage, epidemic period and infection number, while micro-level simulation result analysis explains the internal decision-making process and discuss immunization intention under social norms in the social network. Furthermore, the constructed simulation model is viewed as a tool for predicting the variation patterns of the reality. In order to support vaccination policy decision-making, several policies which including herd immunity, delay of countermeasure, range of vaccination targets, etc. are systematically studied. As a result, the simulation suggests that reasonable vaccination policies tend to promote vaccination behavior modification and gives decision support to assess the relative impact of public health services for pandemic control.

Acknowledgements

My deepest gratitude goes first and foremost to Prof. Hiroshi Deguchi, my supervisor, for his constant encouragement and guidance. He has ever taught me throughout more than 5 years of my graduate student life. Without his consistent and illuminating instruction, this thesis could not have reached its present form and I would not have acquired the knowledge needed for this academic task.

My heatfelt gratitude also goes to Mr. Manabu Ichikawa and Mr. Yasuhiro Kanatani, who are from National Institute of Public Health. I am deeply inspired by their pioneering and insightful thought and work on healthcare research field. They have instructed me. in detail, how to make the research paper preparation and compilation. Their insightful guidance and enthusiastic encouragement in the course of my shaping this thesis definitely gain my deepest gratitude.

I am particularly indebted to Mr. Saito from National Institute of Public Health and Prof. Fujimoto from Tokai University. They have given me a lot of guidance, assistance and concern, and imparted to me so much valuable knowledge about epidemic simulation.

I also want to take this opportunity to express my gratitude to Prof. Il-Chul Moon from Korea Advanced Institute of Science and Technology. Thanks for him accepting me to Applied Artificial Intelligence Laboratory as a exchange student. He has instructed me a lot in network research field. Owing to his insightful guidance and comments on my research, the completion of this research is made possible.

I am also grateful to my thesis committee, Prof. Terano, Prof. Miyake, Prof. Niita, and Prof. Ono, for their critiques during my oral defense, precious advices and comments on my dissertation and insightful suggestions for my future research.

Especially I would like to thank Mr. Kurada and all members from PieCake, Inc. for giving me constructive advices on programming language and developing SOARS and Falconseed, which are used to construct the model in this thesis.

No less gratitude should be given to my beloved family for their loving considerations and great confidence in me all through these years. I also owe my sincere gratitude to my dear friends and laboratory members, who have accompanied me throughout the five years at the graduate school, sharing sadness and happiness with me and teaching me a lot about Japanese. Especially, I want to give my hearty thanks to Ms. Hayashibara for all the paperwork and kind help during my study at Deguchi lab. Our friendship is always a treasure and a driving force to me.

Finally, my deepest gratitude goes foremost to JGSS project, who provide the data resource for this research. The Japanese General Social Surveys (JGSS) are designed and carried out at the Institute of Regional Studies at Osaka University of Commerce in collaboration with the Institute of Social Science at the University of Tokyo under the direction of Ichiro TANIOKA, Michio NITTA, Hiroki SATO and Noriko IWAI with Project Manager, Minae OSAWA. The project is financially assisted by Gakujutsu Frontier Grant from the Japanese Ministry of Education, Culture, Sports, Science and Technology for 1999-2003 academic years, and the datasets are compiled with cooperation from the SSJ Data Archive, Information Center for Social Science Research on Japan, Institute of Social Science, The University of Tokyo.

Contents

List of Figures

List of Tables

List of Abbreviations

HBM **H**ealth **B**elief **M**odel

TRA **T**heory of **R**easoned **B**ehavior

JGSS **J**apanese **G**eneral **S**ocial **S**urvey

GIS **G**eographic **I**nformation **S**ystem

ABM **A**gent **B**ased **M**odelling

Chapter 1

Introduction

1.1 Motivation

Immunizations are the most effective method of preventing and ameliorating morbidity from infectious disease. Preventive vaccines have an indirect herd-protective effect by reducing inter-individual transmission and thereby lowing the risk of infection among unvaccinated persons. Since British physician Dr Edward Jenner developed and implemented the vaccine against smallpox in its modern form and proved to the scientific community that it worked from the 18th century, immunizations have been an essential part of preventive medicine against infections, such as smallpox, diphtheria, polio, Seasonal Influenza, Mumps, Rotavirus, etc. In the history, vaccines have saved millions of lives and have prevented crippling disabilities caused by many of these diseases in consequence. According to the claim from WHO [1](World Health Organization), immunization is a proven tool for controlling and eliminating life-threatening infectious diseases and is estimated to avert between 2 and 3 million deaths each year.

Nowadays, more and more types of vaccines are being exploited and immunizations are spreading across the globe, so that vaccines have been very effective in improving health worldwide. Because vaccines are successful at preventing diseases, the public often takes them for granted. In U.S., Vaccines & Immunizations

[1] World Health Organization http://www.who.int/topics/immunization/en/

is one of the main administrative categories for CDC [2](Centers for Disease Control and Prevention). Vaccines Tracking Systems (VTrckS), Vaccines for Children Program (VFC), Vaccine Management Business Improvement Project (VMBIP) is being conducted for the purpose of improving the whole immunization system. In developing countries, China is enforcing National Immunization Program, in which group one vaccines under the Chinese national immunization scheme are supplied free of charge the government. Besides, a lot of efforts is being made to explore optimal immunization schedules and possible synchronization with national immunization programs, and to evaluate the need for booster injections in many other counties in the world. Because of all immunization programs and efforts from the governments and CDC, in communities and countries where vaccines are widely used, many diseases that were once common or fatal are now rare or under control.

The concept of immunization was started in Japan in 1849 when Jenner 's cowpox vaccine seed was introduced, and the current immunization law was stipulated in 1948**(Nakayama**; **2013)** . There are two categories of vaccination: one is routine vaccination designated by immunization law, the other is voluntary vaccination. Routine vaccinations, which include Pneumococcal Conjugate vaccine, Chickenpox, etc., are all free of charge if you have coupons provided from municipal health centers. The group of people, who reach a specific age, will get the coupons from the local municipal health center at the right age and is available to make an appointment with designated local pediatrics to have shots. In contrast, voluntary vaccinations, which include seasonal influenza, rotavirus vaccine, etc., are not free and costs vary depending on the shot. Humans need to contact pediatrics or private clinics to have these shots.

Though different diseases have different thresholds for voluntary vaccinations, routine vaccinations always hold a higher vaccination coverage than voluntary vaccination, for example, for measles, a highly contagious disease,the threshold for

[2] Centers for Disease Control and Prevention http://www.cdc.gov/vaccines/

measles vaccination is 95 percent community immunity. Whereas, influenza vaccination coverage is 38.6% in 2010/2011 season**(Nobuhara**; **Watanabe and Miura**; **2013)** The topic of this paper mainly focuses on voluntary vaccinations.

Immunization awareness reflects the psychology of consciousness towards voluntary vaccination and controls inoculation action. There are a series of questionnaires trying to make an investigation into the deep reason of vaccination psychology. For example, according to the questionnaire [3] about the degree of recognition towards immunization by Banyu Pharmaceutical co.ltd. in April.2010. About 70% respondents pointed out that the barrier of immunization was the high immunization fee. Besides, for the seasonal influenza vaccination, which is one type of voluntary vaccinations, QLife(November.2010) [4] and **Ono and Numazaki**; **(2010)** surveyed the normal attitude and guardian attitude on influenza voluntary vaccines. Depending on the questionnaires, the most reason of vaccination is [the fear of pandemic influenza], another reasons include [the recommendation from family or friends], [immunization with justice], etc. Conversely, people refuse to inoculate because of [the fear of side effect], [the self-belief towards infectious], [the high price], etc.

According to these surveys, we found that subsidies or another state measures toward voluntary vaccinations play an essential role to affecting immunization awareness of residents. As researchers from a number of European universities wrote in the scientific journal Eurosurveillance**(Haverkate**; **M.**; **et al. 2012)** :"a national healthcare system should promote and actively offer those vaccines that have been proven to be safe, effective, and with a positive public health impact. In a world where people trust health authorities, more compliance with national recommendations can be established. " In other words, the state measures toward voluntary vaccinations that is both accessible and trustworthy is a key factor in ensuring widespread recommended vaccination. Immunization programs often organize subsidies and public relations in order to obtain high vaccination uptake rates and

[3] Japanese Immunization Awareness Investigation by Banyu Pharmaceutical co.ltd (April. 2010). http://www.msd.co.jp/newsroom/banyu-archive/pdf/product/product_news_0520.pdf/

[4] Cost of "Influenza Vaccination " Investigation by Qlife http://www.qlife.co.jp/news/081211qlife_news.pdf/

coverage. That is not only because a universally accessible healthcare system would make vaccines readily available to all people, but also because frustration with expensive and unreliable healthcare contributes to the kind of mistrust that makes people suspicious of vaccines themselves.

One example**(Ohkusa**; **Yasushi**; **et al. 2010)** of the great impact of vaccination subsidy is the control of varicella. From May 1st 2007 to March 31st 2008, Mitoyo and Kanonji cities in Kagawa prefecture began a varicella vaccination subsidy for residents under 5 years old. According to the subsidy, vaccination copayment would be cut by 4500 yen (US$ 46.75) per dose. As a result, subsidy vaccination coverage at 1 years old rose from 8.0% to 17.2% in Mitoyo and from 13.0% to 28.9% in Kanonji. The increase of immunization coverage also resulted in infection prevention and a decrease in medical costs. It was estimated that 455,000 yen (US$ 4568.23) in direct medical cost on average were saved by the subsidy. Therefore, that rational vaccination subsidy policies contribute to control transmission of the disease and save money has been proved.

In Japan, though seasonal influenza outbreaks every year and infect a large proportion of the people, the residents are not obligated to accept seasonal influenza vaccination. In Japan, MHLW(Ministry of Health, Labor and Welfare)[5] has enforced a subsidy of influenza vaccination for the elderly from November 2001. This subsidy focuses on vaccination of the elderly (65 years and over). Since it has achieved great progress in reducing both the incidence of influenza and mortality attributable to influenza among older persons. The cities tried to expand the subsidy and apply it into the vaccination of special group at high risk. For example, in 2012 ˜ 2013, Ishinomaki city, Miyagi Prefecture planed to cut 2000 yen(US$ 20.08) off for vaccination payment for the residents from 3 ˜ 13 years old. On the other hand, Iwanuma city, which also belongs to the same Miyagi Prefecture provided free influenza vaccine to the children younger than 13 years old.

[5]Ministry of Health, Labor and Welfare http://www.mhlw.go.jp/

Furthermore, although a number of vaccine policies had met with success in increasing the supply and demand for vaccines, unbalanced supply and demand on vaccination market led to massive waste especially in recent years. For example, waste of 16.6 million doses in the value of 21.4 billion yen(US$ 223 million) was claimed in 2010[2]. To solve such problem, vaccination subsidy strives to provide income support to a group of susceptible population and contributes to the improvement of vaccination coverage by enhancing their immunization awareness.

In conclusion, available vaccine subsidy gives rise to increase in voluntary vaccinations rates, and the changes in willingness towards immunization of individual resulting from effectiveness of the subsidy. In this research, we aim to investigate the relationships between vaccine policies, vaccination intention and behavior, and then estimate the possible effect from the vaccine policies.

Moreover, according to an investigation about the degree of recognition towards immunization, [the recommendation from family or friends] is one of the main reasons, which affect the immunization awareness of humans. Therefore we are able to suppose that pandemic immunization campaigns encourage a group of vulnerable population to get vaccination firstly and expect vaccinators making publicity for immunization campaign to the other people in their personal social networks. which implies that groups who support vaccines in higher numbers tend to cluster together means that there are pockets of stimulation repercuss throughout the community that are a motivation to people who want to be inoculated due to illness. Such phenomenon occurs because that people are likely to be influenced by suggestion from their acquaintances. The phenomenon is also called " Subjective Norms " in psychology. Therefore, it is essential to take a consideration of social network structure and especially all personal networks of each human in the whole society when establish a state immunization program in healthcare system.

Owing to the immunization psychology survey towards voluntary vaccinations, in this section, we suppose to see through the essence of vaccination behavior modification and find out how immunization subsidies obtain high vaccination uptake rates and coverage by getting hold of vaccination psychology of human beings. Simultaneously, public relationships inside population-wide social network and its influence on the whole immunization system will be discussed.

1.1.1 Individual Vaccination Behavior

In Japan, Low voluntary vaccination coverage rates and high target disease incidence are assumed to be a consequence of voluntary vaccination **(Aiko and Kondo**; **2015)** . This section focuses on voluntary vaccination decision-making behavior and characterize the effect of personal values, health beliefs, and influence from interpersonal relationships within population-wide social network during the process of vaccination behavior modification.

Vaccination behavior is viewed as a prophylactic and active immunoprophylaxis measure taken in order to protect vaccinator himself and prevent the spreading of infectious diseases for the susceptible groups around the vaccinator. Personal vaccination behavior is associated with individual differences in age, health state, social circumstance, relationship network, etc. Impediments to modifying individual vaccination behavior is the basis for persuasion models of psychology, intended to characterize and modify behavior optimally. Relative prognostic importance of the various factors predisposing to vaccination behavior modification of individuals is determined by personal values, health beliefs, and influence from interpersonal relationships within population-wide social network during the process of immunization decision modification. There are a lot of evidences that application of behavioral modification paradigms to public health and clinical goals can be effective**(Kelly**; **Robert B**; **1991)**

In literature, obtaining vaccination against infectious diseases represents precisely the kind of preventive health behavior toward which the archetypical Health belief Model(HBM) was directed **(Janz**; **Nancy K**; **and Marshall H. Becker**; **1984)** .

Yoko Kobayashi (2015) surveyed the human papilloma virus (HPV) vaccines status of 2216 female high-school students as investigation object. A 23-item interview schedule elicited respondents's beliefs along all of the major HBM dimensions and 8 factors related with personal immunization awareness was be proposed including family vaccination awareness, frequency of accessing to the immunization or immunization-related topics, etc. Another types of vaccination concerned Swine Flu**(Aho WR**; **1979)(Cummings KM**; **et al**; **1979)(Rundall TG**; **Wheeler JRC**; **1979)** and dealt with influenza**(Larson EB**; **et al**; **1979)** were also applied the HBM in attempts to understand vaccination behavior. Although HBM succeed to explain the mechanism of inoculation behavior from the social psychology point of view qualitatively, quantitative analysis concerned with individual decision-making process cannot be estimated.

Other expressive associated research**(Yasushi Ohkusa**; **2003)** which is relatively new, conjointly analyzed inoculation behavior and virtual scenarios for individuals over 65 years old in the context of receipt of influenza vaccine by persons thought to be at high risk for serious complications from influenza infection. However, personal immunization motivation dealt with effect from individual's relationship network was not taken into consideration.

Differing from previous researches, the focuses of this paper concentrate on personal voluntary vaccination decision-making behavior and its relationship with the personal networks, which are embedded in a population-wide network structure in reality, as well as the structure and influence of a social network on individual behaviors.

As a kind of preventive health behavior, vaccination behavior is adapted to traditional behavior modification theories, such as Theory of Planned Behavior, Precaution Adoption Process Model, etc. However, most of traditional behavior modification theories focus on the individuals' psychological factors concerned with the purpose of preventing disease rather than social norms and community enforcement. Conversely Fishbein & Ajzen**(Fishbein**; **M.**; **Ajzen**; **I. 1975**; **1980)** provided a critical review of Behavior Modification investigations and proposed the Theory of Reasoned Action(TRA). This research purposes to apply the variables of TRA to explain the mechanism of personal immunization decision-making and figure out prospective factors in vaccination behavior modification.

In order to determine the relative prognostic importance of the various factors predisposing to vaccination behavior modification of individuals, this paper attempts to simulate the individual vaccination behavior modification process and analyzes the influence of immunizations decision-making process in self-awareness and attitudes toward vaccination during social interaction. In the pandemic immunization system, all individuals compose a whole pandemic immunization community, which is based on a realistic spatial model by utilizing real geographic information about a specific city area and considering geographical closeness as a contribution to intimacy between the humans in the whole pandemic immunization system The Theory of Reasoned Action(TRA), which is a typical paradigm of behavior modification in the field of social psychology, is supposed to be a potential mechanism for improving vaccination decision-making performance for every individual living in the community. By applying the variables of TRA to distinguish inoculation program participants from nonparticipants, we aims to figure out prospective factors in vaccination behavior modification and evaluate degree of the influence from the factors for each individual.

1.1.2 Immunization System and Population-wide Social Network

According to World Health Organization, a whole immunization system should include a shared responsibility of governments, legislators, health care providers, caregivers, the pharmaceutical industry and other stakeholders. In this research, we simplify the supply in vaccination resource from health care providers, which means the conflict between immunization behavior and behavioral intention is ignored. Meanwhile, we focus on legislators from government and the immunization decision-making of individual. On the one hand, government and resident in the community are the main factors in the whole immunization system. Government is in charge of establishing the subsidy and organizing the amount of vaccine supply, deadline for Vaccination, delay of countermeasure, range of vaccination targets, etc. On the other hand, immunization decision-making and vaccination behavior modification of all human beings in the whole community are included in the immunization system.

Social norms exist in immunization system and refer to a combination of perceived expectations from relevant individuals or groups along with intentions to comply with these expectations. In other words, if referents in personal network of individual are vaccinated or recommend the vaccination, behavioral intentions of the individual are likely to be influenced. The potential referents include family members, friends, and all the people involved in personal network of the individual.

In this thesis, personal networks are representations of the relationships between an individual and others, that individual would expect to interact with friends, family, acquaintances, work colleagues, etc. Large populations and their personal networks compose a population-wide social network. Such social network consists of individuals or organizations and indicates the ways in which they are connected through various social familiarities ranging from casual acquaintance to close familial bonds.

Social network analysis was introduced by Moreno in 1934 **(Moreno; et al;1938)** . Original researches about social network aimed to explore the ways in which people ’s group relations serve as both limitations and opportunities for their actions and, therefore for their personal psychological development with statistical method. In 1969, **J. A. Barnes and John A (1969)** pointed out that the study of social networks was based on the basic notions of graph theory, as has the identification and analysis of social cliques. Moreover, with development of computational sociology, **Lynne Hamill and Nigel Gilbert (2010)** designed a social circle model, which fitted well with the sociological observations of real social networks. Nowadays, social network research has become a prominent research field in sociology, anthropology, social psychology and other branches of science. Particularly, the importance of social networks for understanding and predicting human interaction and behavior is generally acknowledged **(Fowler; James H.; and Nicholas A. Christakis; 1938)** .

In the immunization system, the phenomena of immunization awareness diffusion in the population-wide social network scale result in a herd immunity, or mass community immunity. In healthcare on communication network research field, collective behavior, formation of social opinion and intention delivery have been improved from the last century. However, It is noteworthy that seldom research only focus on the typical immunization case or immunization system case. For these reasons, this research focus on Immunization decision making mechanism and diffusion phenomena on social network.

In the methodology, this research attempts to construct an intimacy based population-wide social network model through the analysis of all types of personal relationship networks in the real world based on Japanese General Social Survey(JGSS) [6] ,which is an open sociology 's data sources proposed to add network survey items from 1984, and apply the network model in immunization system. We carry out an agent-based simulation to build up this social network based on a virtual city model, which can be achieved from geographic information system and census. Furthermore, as one of the social phenomena simulation, immunization awareness diffusion in the constructed social network is shown in the immunization system.

1.2 Contribution Statements

As discussed above, this research aims to generate a pandemic immunization model and analyze the influence of immunization awareness diffusion on an overall social network architecture. We attempt to combine the personal relationship based social network with geography based virtual city model, and apply pandemic immunization module into the social network. Specifically, for one thing, we construct an

[6] JGSS Research Center, http://jgss.daishodai.ac.jp/english/index.html

intimacy-based social network model by the analysis of all types of personal relationship networks in the real world based on the JGSS data. for another, we introduce an pandemic immunization model to evaluate the vaccination awareness of individuals in the network by considering risk cognition, and subjective norms in a comprehensive manner. As a result, immunization awareness diffusion phenomena in the constructed population-wide social network will be exhibited in the immunization system simulation model.

Besides, considering infectious risk, kinds of vaccination, inoculation pattern vary in a big way for different pandemic, though the vaccination behavior modification mechanism is applicable for all voluntary vaccinations, this research focuses on a typical study object: seasonal influenza vaccination. By applying the method to a specific city, we aim to figure out prospective factors in seasonal influenza vaccination behavior modification and verify that policies toward seasonal influenza vaccination from legislators side in the city can contribute to the increase of immunization coverage.

The objectives of this thesis are stated as follows:

- Firstly, we purpose to construct an agent-based social network model by analyzing all types of personal relationship networks in the real world from JGSS data. Immunization system should be presented on the population wide social network model. Ordinarily, personal relationship networks hold particular characteristics deriving from distinct person so that the aggregation of the personal networks is always complicated. During the past decades, experimentation, controlled observation and questionnaires were primary ways that gave us a valuable insight into mechanism of personal network structure. As one of the typical questionnaires, JGSS data focus on the universality and intimacy existing in the personal networks, which are embedded in a population-wide network structure in reality, as well as structure and influence of a social network on individual behaviors.

- Secondly, we aim to determine the relative prognostic importance of the various factors predisposing to vaccination behavior modification of individuals. Since the immunization system is based on the constructed population wide social network, which is composed of all personal relationship networks of individuals in the community, we are able to analyze vaccination behaviors change interaction of individuals in their personal relationship networks. Especially, by applying the variables of TRA, which is a typical paradigm of behavior modification in the field of social psychology, to distinguish inoculation program participants from nonparticipants, we purpose to figure out prospective factors in vaccination behavior modification and evaluate degree of the influence from the factors for each individual.

- Thirdly, after analyzing the JGSS data and applying the result to social network model, we aim to simulate the pandemic immunization awareness diffusion phenomena under the constructed population wide social network of the community. The diffusion of immunization awareness concepts assist the evaluation of policy diffusion. Through measuring the association between state characteristics and the diffusion of voluntary vaccine policy across states a policy diffusion trend may emerge. The propagation path of immunization awareness inside the community will be reviewed in depth in the simulation result.

- Finally, considering simulation is viewed as a tool for predicting the variation patterns of the reality, in order to support vaccination policy decision-making, we purpose to evaluate the possible effectivity from vaccination strategies. As is known to all that vaccination subsidy strives to provide income support to a group of susceptible population and contributes to the improvement of vaccination coverage by enhancing their immunization awareness. In this research, we plan to prove available vaccine subsidy gives rise to increase in immunization rates, and then analyze the changes in willingness towards immunization of individual resulting from effectiveness of the subsidy.

1.3 Overall Perspective

In order to determine the relative prognostic importance of the various factors predisposing to vaccination behavior modification of individuals, this research carries out an agent-based simulation method to construct a population-wide social network based pandemic immunization model. Ordinarily, the whole immunization system include two parts: vaccination administrator-side and vaccination accepter-side, which is composed of all individuals living in the community. We construct the whole immunization system by modeling both two parts and breaking down each parts into several items hierarchically.

For one thing, in the vaccination administrator-side, various vaccination strategies are taken into consideration. By determining possible policy direction, which including herd immunity, delay of countermeasure, range of vaccination targets, etc. simulation is viewed as a tool to predict the effectiveness of each policy. For example, as is know to all that pandemic immunization campaign strives to provide financial support to a group of vulnerable population, which contributes to the improvement of healthy awareness diffusion in the personal social networks of vaccinators. we are able to implement subsidy policies into the model and verify the practical significance from subsidy.

For another, vaccination accepter-side modeling concerned with immunization behavior modification of all individuals living in the immunization system. As we have mentioned before, we will use TRA to explain the immunization behavior modification. According to the original paradigm of TRA, a kind of personal action can be deduced from two elements: risk cognitive and social norms. We apply TRA to immunization and find that risk cognitive represent the self- reference of individual himself in social psychological field, whereas social norms are symbolic of social-reference**(Holyoak**; **Keith J.**; **and Peter C. Gordon**; **1983)** . We hierarchically organize the each module as Figure 1.1 .

From the overall perspective, on the one hand, geography based virtual city model

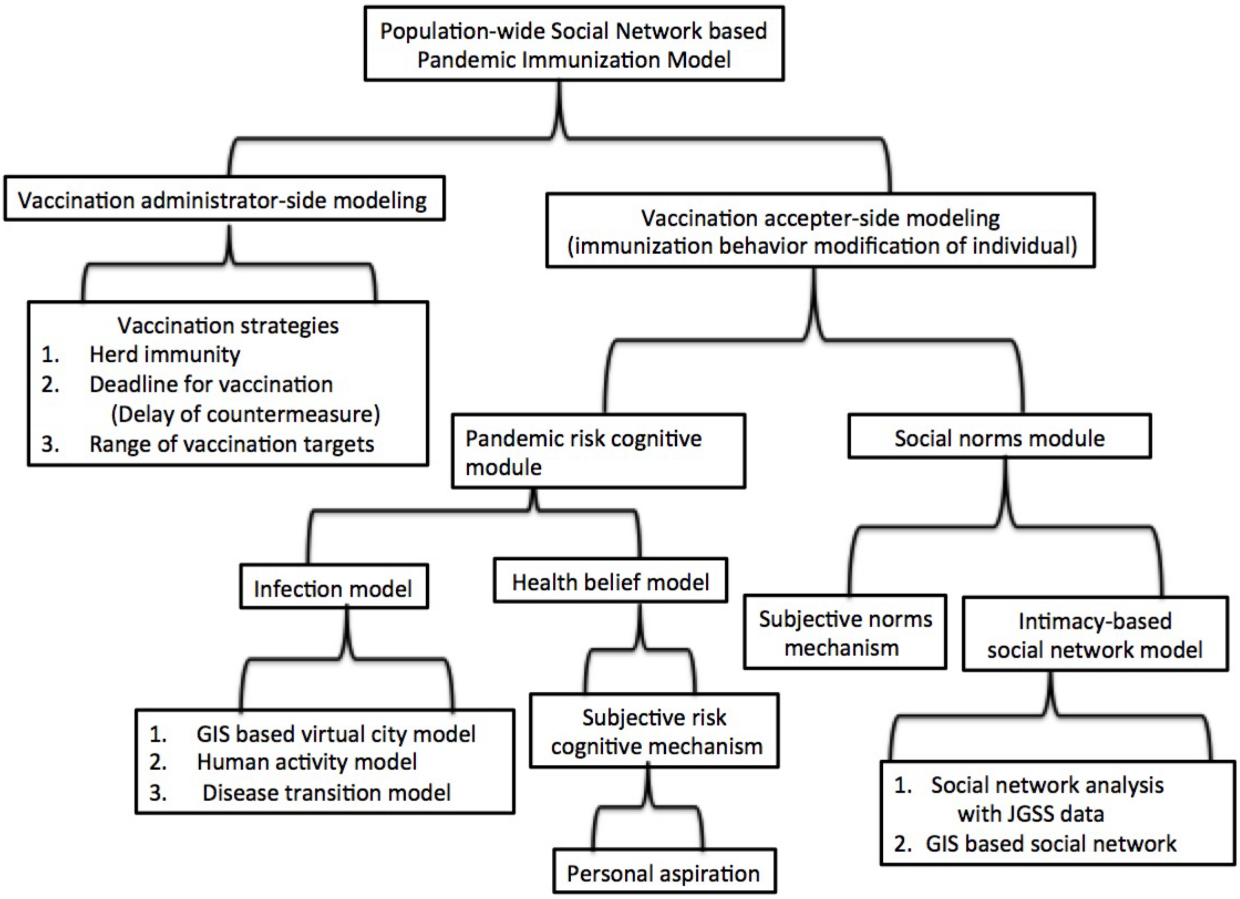


FIGURE 1.1: Figure of overall perspective

provides a groundwork for infectious disease transmission. By implementing the disease transition mechanism into the virtual city model, we are able to predict the pandemic risk of each individual in the community. The construction of the infection model will be introduced in Section 2.2.1 and Section 2.2.2 . Besides, considering this risk calculated from the infectious model is an objective factor, incidentally there is a disparity between objective risk and subjective risk recognition, we use amendatory values with subjective performance instead of objective parameters in this paper. The subjective risk cognitive mechanism is inherited by health belief model. Personal aspiration level subjective cognitive will be discussed in Section 4.1.3 .

On the other hand, we evaluate the subjective norms similarly. Social relationship, in other words, intimacy-based social network contributes to the improvement of healthy awareness diffusion in the personal social networks of vaccinators. We will construct the intimacy-based social network concerned with a population wide scale. The whole Chapter 3 will introduce the way how to construct such population-wide social network with JGSS data and geographic information of the community. Based on the constructed social network, subjective norms mechanism will be illustrated in Section 4.1.4 .

1.4 Outline of the Thesis

The structure of the paper is organized as follows: we will review the relevant literature on vaccination decision making, awareness diffusion in social networks and immunization system simulation from both methodological and theoretical perspectives in Chapter 2. A review on agent-based simulation approach and its application on epidemic model will be provided as well. In Chapter 3, the population-wide social network model, which not only includes the geographic composition of society, but also contains population-wide network, which is constituted of personal relationship networks of all individuals in the society, will be introduced. The details of pandemic immunization model will be shown in Chapter 4. Vaccination behavior modification mechanism will be applied in the constructed population-wide social network model. Resulted simulation data analysis will be conducted in both macro-level and micro-level in Chapter 5. Immunization awareness diffusion phenomena and vaccination behavior change interaction in the personal networks will be shown in this chapter as well. As an application of the population-wide social network based pandemic immunization model, Chapter 6 attempt to estimate the effect of vaccination policies. In the final Chapter 7 of this paper, conclusion and implications are proposed.

The overall structure is as illustrated in the following Figure 1.2 .

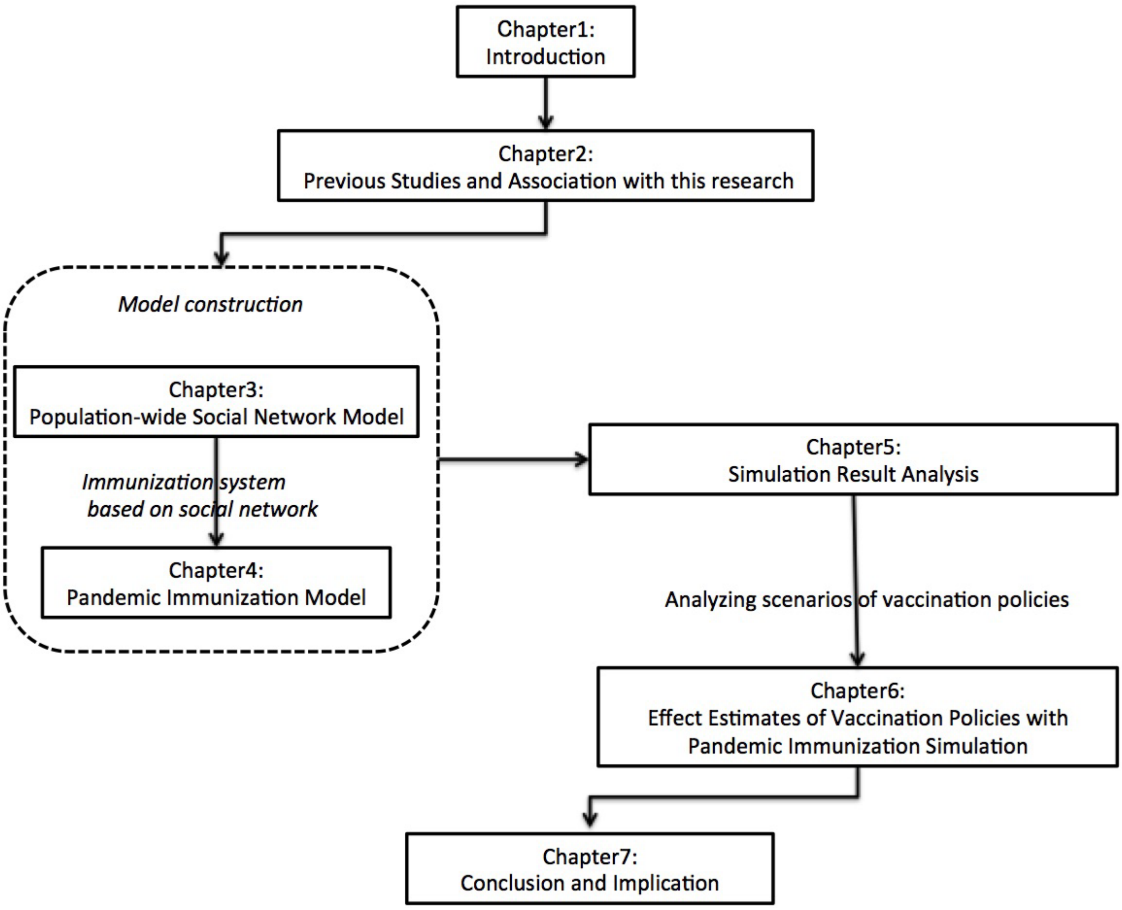


FIGURE 1.2: Thesis structure

Chapter 2

Previous Studies and Association with this Research

This chapter contains a review of the previous literature concerning the pandemic immunization researches, which include vaccination decision making, awareness diffusion in social networks and immunization system simulation. In addition, agent-based approach and especially the previous studies about epidemic transmission on geography based virtual city model will be discussed. As is shown in the overall perspective, infectious model will be applied in our immunization system. At the end of this chapter, we will discuss the association between previous studies and this work. Comparative studies and case studies on description requirements, novelty and inventive step will be conducted as well.

2.1 Literature Review

There are 3 key perspectives in this work: vaccination decision making, immunization awareness diffusion, and immunization system. Previous researchers try to study the pandemic immunization phenomena from various points of view. We summarize the features from literature and list some of them for comparing with this work.

2.1.1 Vaccination Decision Making

Theories about medical decision making goes back to 1988. **Sox**; **Harold C** and **Michael C** pointed out the uncertainty and probability in medicine and listed many medical situations where decision should be made reliably and effectively. In their theories, they mainly made use of probability theory, which is a system of axiomatic relationships, for quantifying and expressing uncertainty so that people can estimate the probability-weighted average of the risk following with forming medical decision. However, the physician is alert for unusual characteristics of the individuals that put the himself at higher or lower risk than the average. This is attributed to the subjective thinking at the individual level.

Decision tree is also an ordinary methodology, which is always used in medicine and especially in vaccination. **Podgorelec**; **Vili**; **et al. (2002)** presented an overview of decision trees with the emphasis on variety of different induction methods available and claimed that "decision tree are a reliable and effective decision making technique that provide high classification accuracy with a simple representation of gathered knowledge and they have been used in different areas of medical decision making". There is no doubt that decision tree is one of the effective and reliable decision making method and appropriate to support decision making process in medicine and vaccination. Numerous researchers have applied decision tree technology in vaccination decision making. Meanwhile, the process of forming an opinion is very complicated especially in medical related cases. Decision tree performs very well for one case nevertheless result poorly for some others. In this manner, instead of decision making research field. we tend to find a specific decision making mechanism, which is much more appropriate for medical tasks especially immunization cases.

Health belief model (HBM) is one of the most widely used socio-psychologic approaches to explaining health-related behavior. Originally the HBM is developed as an attempt to explain an individual's decision regarding obtaining preventive health care **(Champion et al; 2008)** . By classifying the health behavior into 4 dimensions: Susceptibility, Severity, Benefits and Costs, HBM provides a theoretical framework for measuring the probability that an individual take health-related action by establishing the validity of all dimensions. According to HBM, an individual will take action to avoid disease if an individual subjectively believe that 1) he or she is susceptible to illness; 2) he or she feels concerning the seriousness of contracting an illness or of leaving it untreated; 3) accepting any recommended health action will in fact be beneficial by reducing his or her susceptibility to the condition; 4) the potential negative aspects of a particular health action may act as impediments, for example, the vaccination may be expensive, dangerous, pain, embarrassment, etc.

In literature, another previous researches have already evaluated decision on vaccination based on HBM. **Nexoe et al (1999)** analyzed a questionnaire to explain the individual decision making on influenza vaccination among the elderly , As a result, influenza vaccination behavior was found to be consistent with the Health Belief Model.

In this paper, HBM is viewed as one of social cognition models for explaining health behavior change and psychological model. It has been used for studying and promoting the uptake of health services. The HBM suggests that your belief in a personal threat together with your belief in the effectiveness of the proposed behavior will predict the likelihood of that behavior, like immunization, there is no doubt that vaccination is seen as a general health behaviors.

Though HBM takes advantage in personal risk cognition towards vaccination and is successfully suggests the impact of self-reference during immunization decision making, HBM ignores the social reference part. We have to admit that social norms is an essential factor exciting in human decision making. Therefore, this paper apply HBM in pandemic risk cognitive module, which is independence with social norms module. The details of HBM and its application will be introduced in Section 4.1.3 .

2.1.2 Awareness Diffusion in Social Networks

Ordinarily, we are likely influenced by family members , friends or colleagues when we need to make a decision. Decisions in of our lives are strongly affected by a process known as social diffusion, which focuses on the process of change in public norms and results in behavior change among social groups. Such social diffusion theory has been studied and applied extensively in fields such as public health, social media, etc. Especially most population-wide public health interventions targeting behavior of individual can expect gradual changes **(Doner**; **Lynne; 1998)** .

Therefore, awareness diffusion in social network can be explained as a social diffusion phenomenon in population-wide public health field. This work presents a key to understanding how immunization awareness or vaccination behavior of individual in the community take off and spread throughout society referred to as the social diffusion. Moreover, by using simulation approach, the work aims to provide a means to estimate the diffusion path in the population-wide social network.

Similarly to our purpose, one of the network models of the social diffusion gave a definition about social network. According to **Valente**; **Thomas W.(1995)** , the diffusion of innovations occurs among individuals in a social system, and the pattern of communications among these individuals is social network. That research analyzed how social networks structure affect the social diffusion, which provide us the rationale of a policy for making connection between awareness diffusion and social network structure in the community. Though we can not generally use the theory from **Valente**; **Thomas W.** because of the different study object and social network strcture.

Besides, another prior researches also claimed that interactions inside social network establish and maintain privacy awareness. In 2015, **Artemis D. Avgerou** and **Yannis C. Stamatiou** introduced game theory and an innovative diffusion model show that privacy awareness can be spread to large populations by taking advantage of individuals' social-network connections. **Cain**; **Mary**; **and Robert Mittman** pointed out that choose the right social network and a group with appropriate norms can maximize the pace of diffusion. All prior researches provided us numerous rationales. However, the awareness diffusion in social networks should depend on the specific subject and a defined network structure. Owing to this the construction of social network should be proposed in immunization awareness diffusion field.

Comparing with priors works, we present an analytic immunization model for the social diffusion dynamics of spreading network patterns. Our proposed method is based on subjective social norms models, and is capable of predicting future trends based on the analysis of past social interactions between the community 's members in this paper. Specifically, this work will present individual relationship network models of diffusion which posit that individuals adopt vaccination based on their direct relations with others in their social system. The next chapter provides structural population-wide social network models. Furthermore, subjective social norms will be illustrated in Section 4.1.4 through the well-defined network structure.

2.1.3 Immunization System Simulation

Because of the complex nature of the epidemic system and immunization system corresponding to epidemic transmission phase, simulation is viewed as the most appropriate modeling technique for revival of the real situations about vaccination behavior of individuals and the realistic immunization system.

In 2004, **Gaba**; **David M** has already emphasized that "simulation is a technique to replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner". In his work, diverse applications of simulation in health care can be categorized by 11 dimensions. Unit of participation, behaviors addressed and method of feedback used are the essential dimensions in healthcare system. In population-wide social network based pandemic immunization simulation, participation is viewed as the individuals in the community, all vaccination behavior and the psychological process will be recorded in the simulation and estimation of vaccination policies belongs to feedback used dimension.

In health care research field, most of prior researches used simulation models and published estimates of age and sex specific risks for infectious incidence, and vaccine effectiveness for assessing the effect of immunization. Clearly simulation modeling has the potential to play a role in health care decision making at all levels. All simulation models can be divided into 2 categories: mathematic modeling and agent-based modeling.

System dynamics is one of the most widely used methodology and mathematical modeling technique to frame, understand, and discuss complex issues and problems. A typical research **(Rwashana**; **et al; 2008)** , which applied system dynamic modeling to research immunization health care problems and to generate insights that may increase the immunization coverage effectiveness, was advanced by studying the Ugandan. The model of that research successfully demonstrated the need to upgrade the health system in proportion to the growing population and such efforts could lead to improved immunization coverage rates. Another prior research **(Arman Kussainov**; **2015)** used system dynamics simulation in modeling and analysis of vaccine supply chain management. Although system dynamics models in heal care situation have been developed for a long time, they has not been widely applied at the regional and national health systems level where integrated policies can be effectively modeled for dramatic health system improvements. **(Koelling**; **Patrick**; **and Michael J. Schwandt**; **2005)** Mathematical modeling are effectively used for health care application, whereas should not always be the tools of choice at the regional and national health systems level. To conquer such barriers, other very useful tools, such as optimization and discrete-event simulation, are also effectively used for health care application.

Agent-based simulation approach is the other research technique in the wider area of immunization system simulation. Agent-based modeling has already made a great progress in immunization coverage investigation **(Liu**; **Fengchen**; **et al; 2015)** . Comparing with mathematic simulation, in which estimates are based on models with relatively simple assumptions about contacts among individuals in the population, agent-based simulation consider individual-level heterogeneous contact patterns and generate a population-level disease dynamics and immunization diffusion in the human network. The simulation results from **Liu**; **Fengchen**; **et al.** developed an agent-based simulation model of measles transmission after the introduction of one index case into a population in order to study the effects of contact tracing and public health interventions on the occurrence of measles epidemics. The simulation results demonstrated the importance of vaccination coverage, clustering of immunity, and contact investigations in preventing uncontrolled measles outbreaks from a macro level.

Similarly, in this work, we will generate an agent-based model of epidemic transmission model by inheriting the frame work from **Ichikawa and Deguchi** and study the public health intervention from the social immunization system in the community. Except the research subject is different with the work from **Liu**; **Fengchen**; **et al.** , there are still another points of difference between our research and another agent-based researches. Firstly, we focus on voluntary vaccination instead of all kinds of vaccination. In general, classification of vaccination depends on each nation. In most counties, there is not a clear boundary between voluntary vaccination and routine vaccination. Secondly, though the effects of contact tracing in our research is taken into consideration in epidemic transmission, mental contact is much more important in individual-level vaccination and population-wide immunization awareness diffusion. this research will generate an intimacy degree based population-wide social network and simulate the occurrence of inoculation related behaviors for all individuals. Finally, since agent-based simulation method takes advantage of making insight of individual behavior and personal modification. This work will conduct a micro level analysis to demonstrate the vaccination coverage in preventing uncontrolled epidemic outbreaks and reveal the vaccination behavior of individuals in the constructed social network.

2.2 Agent-based Simulation

Agent-based simulation is one of the computer simulation methods to analyze complex system **(Deguchi; 1998)** . In this work, immunization system is treated as a realistic complex system existing in our social life. The research approach corresponds to the simulation of social phenomena on computers in terms of agent-based simulation technique.

The simulation model by using agent-based approach, which sometimes is called individual based model, focuses on description of autonomous individual organisms. It is an useful tool to study how system level properties emerge from the adaptive behavior of individuals as well as how, on the other hand, the system affects individuals **(Strand et al.; 2002)** . Agent-based approach is essential both for theory and management because they allow researchers to consider aspects usually ignored in analytical models: variability among individuals, local interactions, complete life cycles, and in particular individual behavior adapting to the individual's changing internal and external environment **(Grimm**; **Volker**; **et al.; 2006)** . Considering such kinds of features in agent-based approach, individual vaccination behavior and individual interaction are the research subject so that all individuals in the community are viewed as independent agents in this work.

According to the review of literatures in the previous section in this chapter, this work will construct an agent-based population-wide social network and simulate the individual vaccination behavior in the constructed social network. Since the social network is developed based on the framework about the geography based virtual city from previous research **(Ichikawa et al.; 2010)** Besides, owing to the relationship between immunization system and epidemic transmission system, agent-based infectious disease simulation is a significant part in the whole immunization system. Therefore, previous epidemic model from **Deguchi et al. (2007)** and

Ichikawa et al. (2010) with agent-based approach will be introduced at this section.

2.2.1 Geography based Virtual City Model

" Virtual city model is a base tool for simulating a social phenomenon that will occur in a city." as claimed by **Ichikawa et al.(2010)** They argued that by plugging social phenomenon module in virtual city model, the social phenomenon can be revealed in the computer simulation. In the previous work, Ichikawa constructed a virtual city model, in which people were related by social structure estimation from Geographic Information System (GIS) and Japan Census from E-STAT [1]. The content of the virtual city model is shown in Figure 2.1 .

There were almost 2 kinds of elements in the virtual city model: human agents, and spots. Human agents represented people living in the city. Spots included homes, schools, workplaces, etc. In the virtual city model, all human agents were built up with a series of individual properties, such as age, sex, household structure, social role, etc. Behaviors of human agents depended on a bundle of rules that agents have. For example, a 6 year-old child agent had a family with his father, mother, and a 1 year-old brother. On weekdays, he went to primary school, which was nearby his home, at 8:00. At school, he communicates with another students. On 3:00, he went back to home. According to previous work, we are able to presume the population-by-age composition and the household composition of the city based on city survey, geographic information and census data of a specific city.

Specifically, according to previous work, we are able to construct a virtual city model for a specific area: Izu-oshima Island **(Ichikawa et al. 2014; Inamasu at al. 2012)** , which is a city under the administration of Tokyo. The information about virtual Izu-oshima model is shown in Table. 2.1. Since it is possible to achieve the information about household composition, population-by-age composition, location of institutions and a lot of information by accessing to the community survey about

[1] Portal Site of Official Statistics of Japan https://www.e-stat.go.jp/

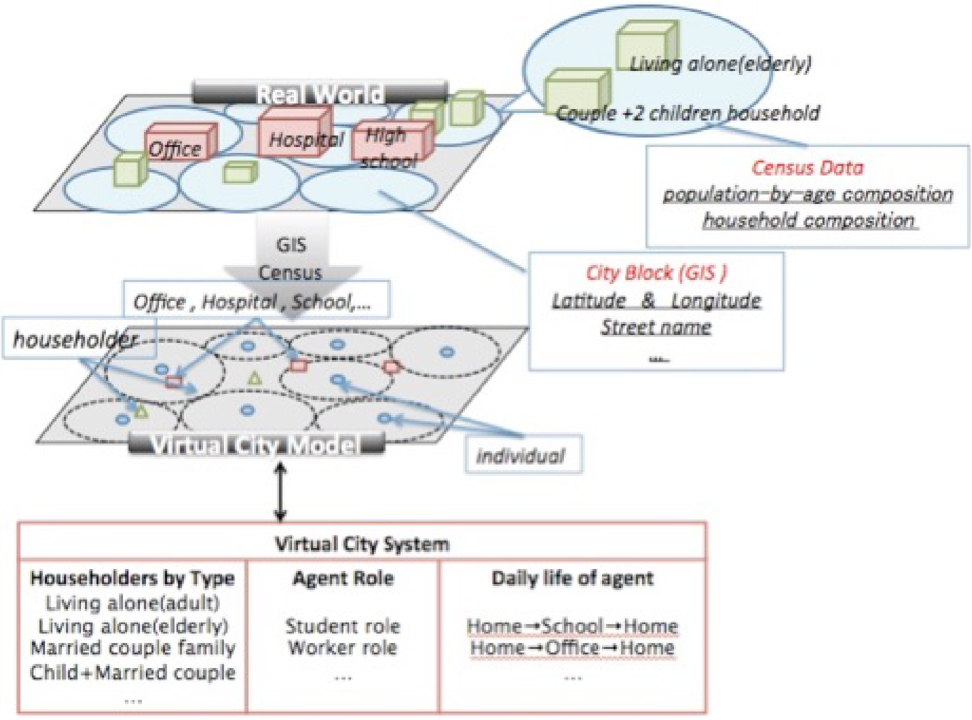


FIGURE 2.1: Virtual city model

any city in Japan from Japanese Census, we can generate any geography-based virtual city in Japan.

Though the previous virtual city model considered the geographic social structure so that the constructed model was similar to the real world, and also virtual city model took an agent-based simulation to reflect the domestic activities and social activities of human beings, it was not enough for representing the real social network because of ignoring of the intimacy between human agents. Considering each agent in a virtual system composes the whole social network, each referent has some connection essentially. All agents should be affected from their relevant people in their personal social network. In real world, such network not only depends on geography, but also relies on each agent himself. Therefore, we aim to generate a spatial social network based on previous geography-based virtual city model. Especially, intimacy in the social network is estimated by the JGSS data analysis results.

TABLE 2.1: Details of geography-based virtual izu-oshima city model

<table>
<tr><th>City Composition</th><th colspan="2">Parameter</th><th>Value</th></tr>
<tr><td rowspan="3">Human Agent
(Number: 7584)</td><td colspan="2">Age, Gender, Household,
Job, Married status</td><td>Fixed from Census
from E-STAT</td></tr>
<tr><td colspan="2">Location of workplace/school
location of home</td><td>Population location is deduced
from Census mapping with GIS
from E-STAT</td></tr>
<tr><td colspan="2">Parameters associated
with Daily Action</td><td>Refer to Comprehensive
Survey of Living Conditions.
(Ex: Home(8:00) → Primary
school(16:00) → Home →⋯)</td></tr>
<tr><td rowspan="12">Spot (Place)
in the virtual city</td><td>Household (home)
(Number: 4098)</td><td>9 types:
Single
(over 65 years old);
Couple+1 child;
Couple +2 children
⋯</td><td rowspan="12">Latitude and longitude of
the spot is fixed from GIS

Location of spots decides
the home, school,
workplace location
of human agents

Scale and structure of spots
is from city survey</td></tr>
<tr><td rowspan="6">Factory
office
enterprise
(Number: 1620)</td><td>Staff number:
1∼ 4
(Number:1182)</td></tr>
<tr><td>Staff number:
5∼ 9
(Number:228)</td></tr>
<tr><td>Staff number:
10∼ 19
(Number:136)</td></tr>
<tr><td>Staff number:
20∼ 29
(Number:30)</td></tr>
<tr><td>Staff number:
30∼
(Number:40)</td></tr>
<tr><td>Another
(Number:4)</td></tr>
<tr><td>Kindergarten
(Number:5)</td><td rowspan="4">Students number
in each school
can be achieved
from city survey</td></tr>
<tr><td>Primary school
(Number:3)</td></tr>
<tr><td>Middle school
(Number:3)</td></tr>
<tr><td>High school
(Number:2)</td></tr>
<tr><td colspan="2">Retirement home（Number:20）
Long stay (3) Others: (17)</td></tr>
</table>

2.2.2 Epidemic Model with Agent-based Approach

Since the virtual city model has provided an available tool for simulating social phenomena, for the purpose of make the tool available in universal use, the spread of epidemic virus as a social phenomenon was reflected in the virtual city by implementing the pathological transition model**(Deguchi et al. 2007) (Inamasu et al. 2012) (Ichikawa et al. 2010; 2014)** .

In general, such kind of the previous researches focused on a modular type of agent based simulation model for pandemic protection. The epidemic model of agent based modeling introduced the concept of spot that is a place on which agents interact. The combination of all spots constitute the community or the city. By plugging the disease state transition module of epidemic into the virtual city model, the previous researches simulated the epidemic transmission phenomenon by reveal the spreading infection in the every spot, where human agents act their daily activities. Inside their models, if infected human agents and susceptible human agents move into a same activity spot, infected agents would spread the virus and contaminate the space so that susceptible agents have a high probability to be infected from the contaminated space.

Excepting the disease state transition module, individual pathological transition module is the other part of the whole epidemic module. Since every epidemic has different transition pattern, such as droplet infection, contagious infection and blood infection, and the features about a specific epidemic vary in a big way. **Deguchi et al. (2011)** proposed a pathological transition module for categorizing infection levels into several states, and utilizing a model, which is defined by the number of days spent that each state endures and the probability of transition between states. The pathological transition module has applied it to smallpox**(Deguchi et al. 2011)** mutated H5N1 bird influenza **(Deguchi et al. 2007)** and influenza**(Inamasu at al. 2012) (Deguchi et al. 2011)** .

The conceptual graph of the agent-based epidemic model inside the geography based virtual city is shown as Figure 2.2

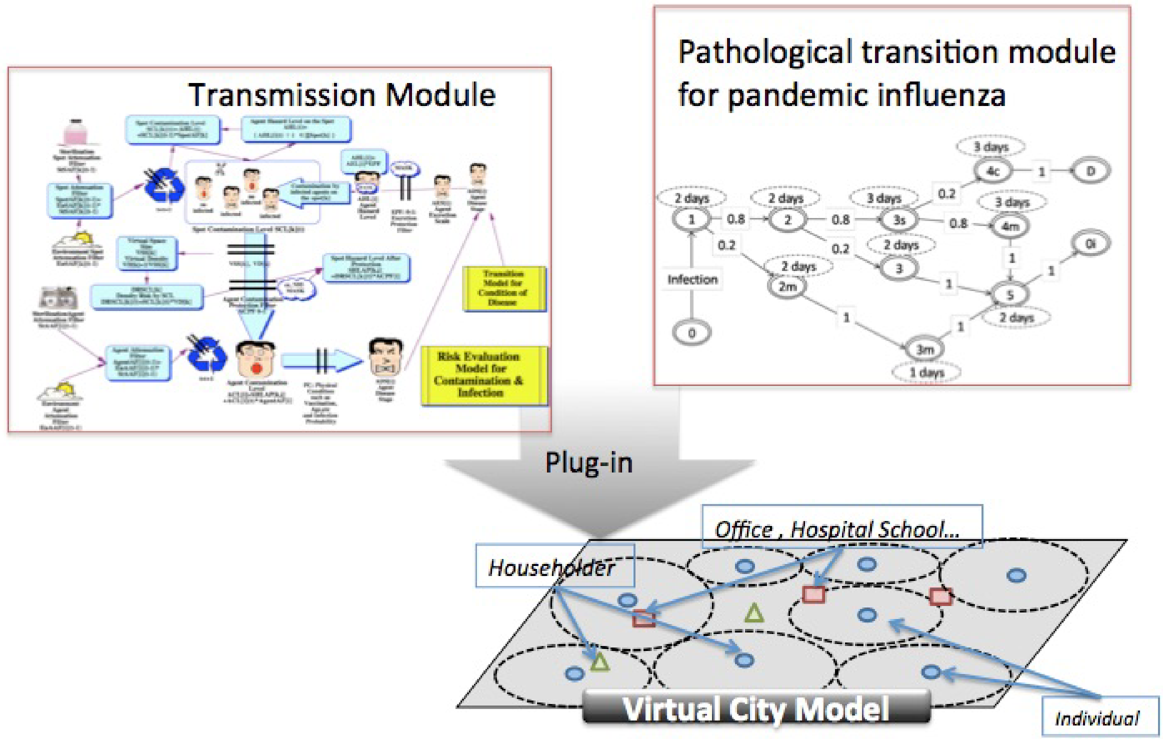


FIGURE 2.2: Epidemic Model
(adopted from **Ichikawa M. et al. (2014)\& Kanatani Y. et al.(2008)**

Considering the vaccination in this work depends on the type of epidemic, this research focuses the seasonal pandemic influenza.

2.3 Contribution of this research

In the previous sections in this chapter, we reviewed numerous literatures about immunization system and gave a brief introduction about ABM and its application on geography based epidemic model, which we inherit some knowledges and apply them into the population-wide social network based immunization system.

On the one hand, differing from prior literatures, the focuses of our research concentrate on personal voluntary vaccination decision-making behavior and its relationship with the personal networks, which are embedded in a population-wide network structure in reality, as well as the structure and influence of a social network on individual behaviors. By applying the variables of TRA to distinguish inoculation program participants from nonparticipants, we aims to figure out prospective factors in vaccination behavior modification and evaluate degree of the influence from the factors for each individual.

On the other hand, the previous researches about epidemic model also designed a series of infection control measures, such as school shutdown, mask use, mandatory vaccination, etc. as a purpose of analyzing diffusion prevention, protection, diagnosis and treatment of infectious diseases. However, though they formulated a series of vaccination scenarios through programming aiming to find a proper way for disease control, immunization system and vaccination action of individual level is still awaiting solution. To improve this part, we consider constructing an immunization model as the internal of infection transmission system model to simulate the vaccination phenomenon. In this research, we deeply explore the part of vaccination and expand the immunization part from precedent studies which reflect the spread of influenza in the virtual city system with agent-based simulation approach.

Since immunization system deeply relies on epidemic transmission in the community, we will inherit the previous epidemic model **(Ichikawa et al. 2014)** and build up an immunization system onto the epidemic model. Differing with the epidemic model, which is based on the contact and interaction among geographically clustered populations, immunization system should based on intimacy degree based social network. Though the network is separated with geography based virtual city, there are still some connections between the intimacy degree based social network and the geography based network inside the community. We will discuss the connection in the next chapter in detail.

Chapter 3

Population-wide Social Network Model

This chapter aims to construct an intimacy based social network model through the analysis of all types of personal relationship networks in the real world based on Japanese General Social Survey(JGSS) and apply the network model in social phenomena simulation.

The definition of population-wide social network and literature reviews about previous social network researches will be introduced as first. Then, we will give a brief insight of the JGSS data and the way we analyze the data with the use of statistical techniques. Besides, in this work, we carry out an agent-based simulation to build up this social network based on a virtual city model, which can be achieved from geographic information system and census. The construction of the virtual city model is inherited from **Ichikawa et al.** , which has been introduced in the last chapter. The details about the agent-based social network model of construction will be illustrated at the final section in this chapter.

Since this paper mainly focus on making use of the structure of social network model to simulate immunization awareness diffusion, which is a specific social phenomena. Besides this example, the generated social network is potential to be used in another sociological studies as well. Another kinds of applications (ex: information spreading, diffusion of innovation, communication, etc.) of the social network model in social simulation area with agent-based simulation method can also be taken into consideration by expanding the application of the social network model more widely in social simulation research field. Meanwhile, we will not discuss another application in this paper.

3.1 Personal Network and Population-wide Social Network

Personal networks are representations of the relationships between an individual and others, that individual would expect to interact with friends, family, acquaintances, work colleagues, etc. Large populations and their personal networks compose a population-wide social network. Such social network consists of individuals or organizations and indicates the ways in which they are connected through various social familiarities ranging from casual acquaintance to close familial bonds.

In literature, on one hand, traditional social network generation models focused on reproducing the global characteristics of social networks, such as path length, clustering coefficient and degree distribution without the intention to model choice behavior of actors explicitly **(Wasserman**; **Stanley**; **and Garry Robins; 2005)** . There were 6 representative topological social network generation algorithms concerning with traditional social network generation models: Ring Lattice, Small World, Erdos Random, Core Periphery, Scale Free and Cellular**(Airoldi**; **Edoardo M. et al; 2005)** . Since the mid-twentieth century, many social network models created by random linking were based on these algorithms. However, there is a problem cannot be ignored in these random linking social network models. All people in these models choose their partners according to a same algorithm without considering their personality and social characters. Some kinds of people (infant, unemployed person, etc.) may do not necessarily to have a lot of links in reality. Unlike these models, our research attempt to generate a social network by considering the features in terms of personal relationship network at the individual level with a statistical approach according to analysis of statistic data from Japanese General Social Survey (JGSS), which provides us with the basis of reality about existing personal networks. In our model, all individuals in the population and their personal networks are connected to a whole social network.

On the other hand, similar to our purpose, one of the most famous previous statistical approaches to modeling social networks was the Exponential Random Graph Models (ERGMs) **(Lusher et al; 2012)** , in which they accounted for the presence and absence of network ties and provided a model for network structure. In case of ERGMs, the focus was not on modeling the choice behavior of humans but rather on more direct modeling the social structures this choice behavior might produce. More recently, researches about geographical distribution of personal networks with survey method were introduced for the purpose of revealing geographic and mobility aspects of social networks and social interactions **(Molina; 2012) (Axhausen**; **Kay W; 2008) (Van den Berg et al. ; 209)** . Considering collecting data at a social level was relatively difficult because of the high project cost and technical limitations about survey strategy, most of studies in this field used a small-scale survey. Personal networks and respondents in these studies were always selected indiscriminately. Conversely the data we used in this research are from a sophisticatedly sociological survey belonging to global General Social Survey group, which is a longest running project from 1972. The strict survey data bring on a more convincible social network model in this research.

Moreover, although research about social network generation with topological graph theory has made decisive progress and commonly found in literature, research into social network from an agent-based simulation perspective is relatively new. Most of previous researches focused on agent-based social network models for simulating several specific situations, such as recommendation system **(Battoston B. et al; 2006) (Yang H. et al; 2007)** , individuals 'travel behavior and traffic system **(Arentze Theo**; **and Harry Timmermans; 2008)** , instead of social network generation. The premier researches in agent-based network filed, which were developed by Los Alamos National Laboratory in 2004 **(Eubank; Stephen and Kumar; V. S. et al; 2004) (Eubank; Stephen and Guclu; H. et al; 2004)** , studied the algorithmic and structural properties of a very large, realistic social contact network and applied the result on social network for the city of Portland, Oregon, USA. Although these researches considered the heterogeneity of human and combined realistic estimates of population mobility as well as ours, social network they generated was a social-contact network, which didn 't consider the intimacy between humans in the network. Another expressive associated researches **(Hamill; Lynne; and Nigel Gilbert; 2010) (Arentze T A. et al; 2012)** , which were relatively new, created large social networks in agent-based models by incorporating different sizes of personal networks, high clustering and another key aspects of the large social networks, though the initial number of human agents in the social network varied due to the randomness. Differing with the previous agent-based social network researches, we attempt to construct a much more realistic spatial model by achieving the real geography information about a specific city area and considering geographical close as a contribution to intimacy between the human agents in the model.

In this paper, our research interests focus on the universality and intimacy existing in the personal networks, which are embedded in a population-wide network structure in reality, as well as structure and influence of a social network on individual behaviors. Ordinarily, personal networks hold particular characteristics deriving from distinct person so that the aggregation of the personal networks is always complicated. During the past decades, experimentation, controlled observation and questionnaires were primary ways that gave us a valuable insight into mechanism of personal network structure. As one of the typical questionnaires, General Social Survey is an open sociology 's data sources, which was proposed to add network survey items from 1984 **(Burt; Ronald S; 1984)** . In this research, we purpose to construct an agent-based social network model by analyzing all types of personal relationship networks in the real world from Japanese General Social Survey.

3.2 Social Network Analysis of JGSS Data

This research attempts to analyze Japanese General Social Survey in 2003<JGSS-2003>, which is conducted about 7000 men and women 20-89 years of age living in Japan from late October to min-November 2003 by Institute of Regional Studies at Osaka University of Commerce and Institute of Social Science at the University of Tokyo. The details of data analysis will be dealt in this section.

3.2.1 Data Construction of JGSS

JGSS-2003 uses both interviews and a self-administered method for each respondent. The interview questionnaire records fundamental personal information about each respondent. The self-administered questionnaire B consists of some core questions about the personal network of respondents. Two kinds of questions are listed in the questionnaire B: questions about name generator **(Lin; Nan; and Mary Dumin; 1986)** and questions about position generator**(J.Shettyand J.Adibi; 2005)** Name generator elicits the names of persons and characteristics of these persons with whom the respondent discussed personal matters during the last six months. In contrast, position generator uses the samples of structural positions salient in a society (occupations, authorities, work, units, class, or sector). Furthermore, relationships between ego and contact for each position can be identified. Name generator focuses on the intimacy between humans, while position generator certificates the diversity of personal contacts within the network of acquaintances.

On one hand, in the name generator part, respondents are asked 3 main questions: ‘ people with whom you discuss matters important to you or those in whom you confide ’;‘ people with whom you discuss Japanese politics, elections or politicians. You may include people with whom you occasionally talk about the above topics ’; and ‘ people with whom you consult about your job or whom you ask for advice concerning your job ’. Every respondent should name up to maximum four actual persons for each question. Respondents should write down full names, initials or nicknames in their answer sheet so that interviewers can identify them afterwards. Besides, respondents can write same names in different questions. Respondents are also asked to point out the relationships between the persons, whose names are mentioned in their answer sheet. On the other hand, since position generation purposes to investigate the diversity of personal contacts, in position generator part, respondents are asked several additional questions about information of the persons they have mentioned (such as: age, sex, job, relationship, background, etc.). Such personal information is directly related to the personal network diversity of respondents so that we can assume what kind of acquaintances the respondents are willing to be on intimate terms with.

The survey data of JGSS-2003 conducted a two-stage stratified random sampling approach and stratified by regional block and population size. The coverage of the JGSS contain a nationwide scale. All survey data include 962 items. We exclude the unnecessary questionnaire and select 239 items from the data as our analysis subjects. In addition, there are 1706 valid respondents in self-administered questionnaire B.

For one thing, we collect fundamental information about these 1706 respondents from interview data JGSS-2003. Depending on the personal information, we classify all respondents under 270 types. For another, we analyze the personal social networks of the respondents according to their answers in self-administered questionnaire B, and then calculate leadership degree of them in their personal social networks. Furthermore, we compare the individual type and characteristics in the personal social network of each respondent. Depending on such comparisons, we aim to find the mechanism about the relevance between individual type and personal social network. Finally, after introducing our data analysis result into a city model, and substituting characteristics of personal social network for every people in city model, we are able to generate a whole social network model.

In this research, we divide all respondents into several types. Considering that JGSS chooses respondents with their special standards so that all answers have universal meaning, we are able to be sure that all individual types existing in the real world are included in the survey data and every type of individuals can represent a general group of people in society.

We exact 5 kinds of the necessary information (sex, age, married status, job and household type) from the interview data, and then use the information to give a definition of human type as Table 3.1.

TABLE 3.1: Definition of human type

Sex	male: sexx=1, female: sexx=2;
Age	twenties: agee=2 thirties: agee=3 forties: agee=4 fifties: agee=5 sixties: agee=6 beyond seventies: agee=7
Marital Status	married: marryy=1 unmarried: marryy=2
Job	worker: jobb=1 retired: jobb=2 student: jobb=3 house worker (housewife): jobb=4 others: jobb=5
Household type	one-person household:householdd=1, two-person household:householdd=2, three-person household:householdd=3, four-person household:householdd=4, five-person household: householdd=5, more than six-person household: householdd=6

According to the definition of human type. Any type of human in the reality can be indicated as Human(sexx, agee, marryy, jobb, householdd). For example, Human(1, 2, 1, 1, 2) represents a group of people, who are men, between 20 and 30 years old, married, worker and living with their wife together.

Originally, depending on these 5 kinds of indexes we defined in Table.1, all respondents should be classified under 720 (2*6*2*5*6) types. However, some kinds of the types cannot exist objectively in reality because of the contradiction between conditions (for example, over 60 years old & student). So we strike the impossible types off the 720 types list. As a result, there are 270 types being remained.

3.2.2 Assessment of Intimacy in Personal Social Networks

Considering the answers of respondents can be repeated in different questions according to the questionnaire setting, we assume that if a same name is written many times in different questions, then the respondent will have a deep relationship with the name holder. To evaluate the degree of intimacy between respondents and the acquaintances, whose names are appeared in the answer sheet, we count number of the occurrences of each name. We define that number of the occurrences of a name equals to intimacy degree between the respondent and the name holder. (Depending on the answer sheet, each name enables to occur maximum 3 times.) Besides, we can also calculate the intimacy degree between the acquaintances themselves as the same way. By combining the intimacy between the respondent and his acquaintances and intimacy between the acquaintances themselves, we can achieve a personal network of the respondent.

According to JGSS, we construct 1706 personal networks for each valid respondent. Figure 3.1 shows an example about the personal relationship network of a respondent in JGSS-2003. The person in the centre of the network graph stands for this respondent. His answer sheet is shown as the left one. ‘ B ’ and ‘ E ’ are the same person whose name is ‘ NAME2 ’, so the intimacy degree between respondent and ‘ B ’(or‘ E ’) is 2. Besides,‘ NAME2 ’knows‘ NAME3 ’and‘ NAME4 ’, who are also included in personal social network of the respondent. Moreover, according to the survey about position generator in questionnaire B, we found‘ NAME2 ’is the wife of the respondent in reality. Similarly, we are able to know relationship between the respondent and everyone existing in his personal network and calculate intimacy degree between any two individuals in this network.

To establish the connection between fundamental properties of respondents and their corresponding personal network, we collect the statistics about each type of people and their corresponding personal relationship network. According to the survey, there are 10 types of relationship between humans. Type1∼Type3 refer to

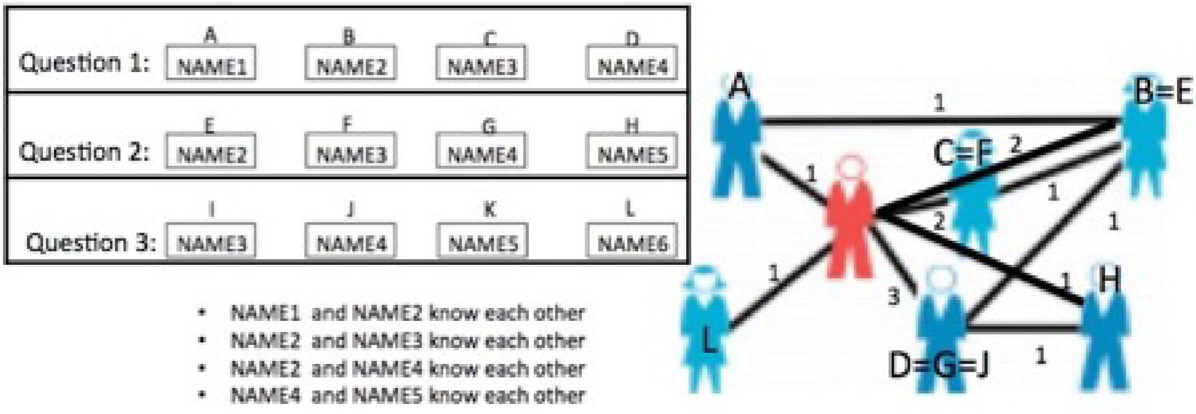


FIGURE 3.1: An example of a personal relationship network

relationship within family members: Type1: spouse (husband or wife); Type2: parent or child; Type3: brother sister, other family member or relative. Type4∼Type6 are human relations with relevant in workplace: Type4: superior or subordinate at my workplace; Type5: coworker (except superiors or subordinates); Type6: other business associate. Type7∼Type10 stand for other types of relationship, such as neighbor, friend, etc. Here we will show an intimacy characters of one type of human: ' Human(1,5,1,1,4) ', who is a group of men, 50∼60 years old, married, worker, household including 4 people. We summarize all ratio of relationship in personal networks of Human(1,5,1,1,4) for each relation type (Table.2). According to the statistics, workmates (Type4∼6) occupy 43.860% of relation networks for ' Human(1,5,1,1,4) ' averagely, which suggests that workmates are the main personal contacts for worker over 50s. In addition, although type ' Human(1,5,1,1,4) ' has a much more huge number of relevant people in workplace rather than in home, only 6.667% workmates have a very good relationship (intimacy degree=3) with ' Human(1,5,1,1,4) '. Conversely, 31.25% people from type ' Human(1,5,1,1,4) ' claim that their wives are the persons they most nearly concerned. We summarize all ratio of relationship in personal relationship network of ' Human(1,5,1,1,4)' (Table. 3.2). In the Table. 3.2, Relation Type 1: Spouse (husband or wife); Type 2:Parent or child; Type 3:Brother sister, other family member or relative; Type 4∼6: relevant in workplace; Type 7∼10: Others(friends, etc.)

TABLE 3.2: Statistic of relationship degree and relationship type in personal relationship network of ‘ Human(1,5,1,1,4)’

Ratio / Intimacy Degree / Relationship Type	1	2	3	Ratio of each type
Type1	34.375%	34.375 %	31.25%	18.713%
Type2	71.429%	23.81%	4.762%	12.281%
Type3	69.23%	30.769 %	0	7.602%
Type4, Type5, Type6	73.333%	20 %	6.667%	43.86%
Type7∼Type10	63.333%	33.333 %	3.333%	17.544%

3.2.3 Leadership Degree of Individuals in Personal Social Network

Based on the personal social network of each respondent, we can also calculate the leadership degree of each respondent in his own personal social network with graph entropy method **(Lusher. et al; 2012)** . We define leadership degree of the respondent ‘ i ’ is L_i. and calculate the graph entropy as following equation:

$$Graph \quad entropy \quad E_{all}: \quad E_{all} = \sum_{i,j} p_{i,j} log(\frac{1}{p_{i,j}}); \tag{3.1}$$

$$p_{i,j} = \frac{w_{i,j}}{\sum\limits_{i,j} w_{i,j}}; \tag{3.2}$$

$w_{i,j}$is the weight between i and his relevant people j, which is also intimacy degree between i and j. $p_{i,j}$ is the ratio in whole network. Edge entropy belongs to respondent i:

$$E_i = \sum_j p_{i,j} log(\frac{1}{p_{i,j}}) + \sum_j p_{j,i} log(\frac{1}{p_{j,i}}); \tag{3.3}$$

$\overline{E_i}$ is the graph entropy, when the graph delete respondent i and all his edges.

$$Leadership \quad degree \quad of \quad i: \qquad L_i = \frac{\overline{E_i}}{log(\frac{E_{all}}{E_i})}; \tag{3.4}$$

We use graph entropy method to calculate the leadership degree of all respondents in JGSS, the statistic result is show as Figure 3.2 .

Leadership degree	
N(L_i>0)	1274
L_i=0	432
Average	3.03
Median	3.07
Standard Deviation	0.69
Minimum	1.55
Maximum	4.98

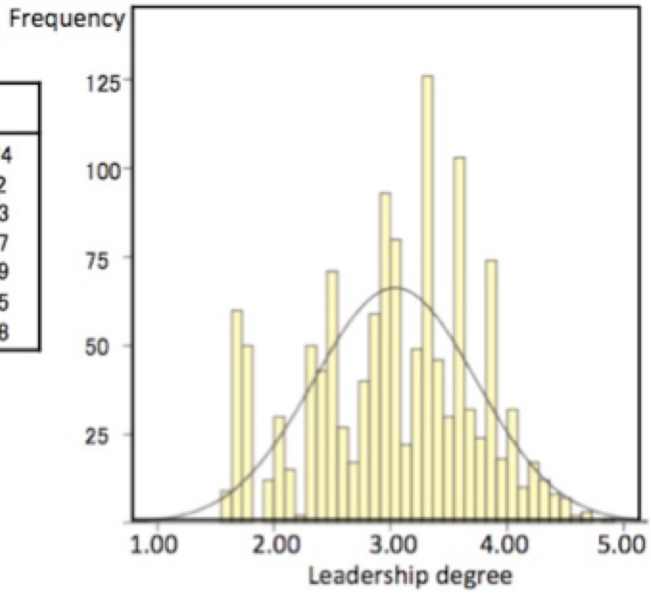


FIGURE 3.2: Statistics about leadership degree

Moreover, we compare the leadership degree result with each index of respondents and find that relations between leadership degree and sex, marital status, household type are not remarkable. Conversely, the leadership degree of respondents is obviously related with their job status. A statistical chart about respondents ' job status and their leadership degree is shown as Figure 3.3. The mean value or variability of the leadership degree among workers is marked higher than another types of job as for the overall trends. Particularly, almost all respondents, whose leadership degrees are beyond 4.00, are workers. Besides, considering only few of students are chosen as respondents, number of student sample is less than another job types.

Besides, we can also achieve the features from statistics about leadership degree of the ' Human(1,5,1,1,4) ' (Figure 3.4). Depending on the statistics, average leadership degree of ' Human(1,5,1,1,4) ' is bigger than the total average leadership degree. Therefore, we can presume that leadership degree of 50s years old workers is always higher than average standard in reality. Similarly, we can also analyze characteristics of the personal social network for all 270 types respondents.

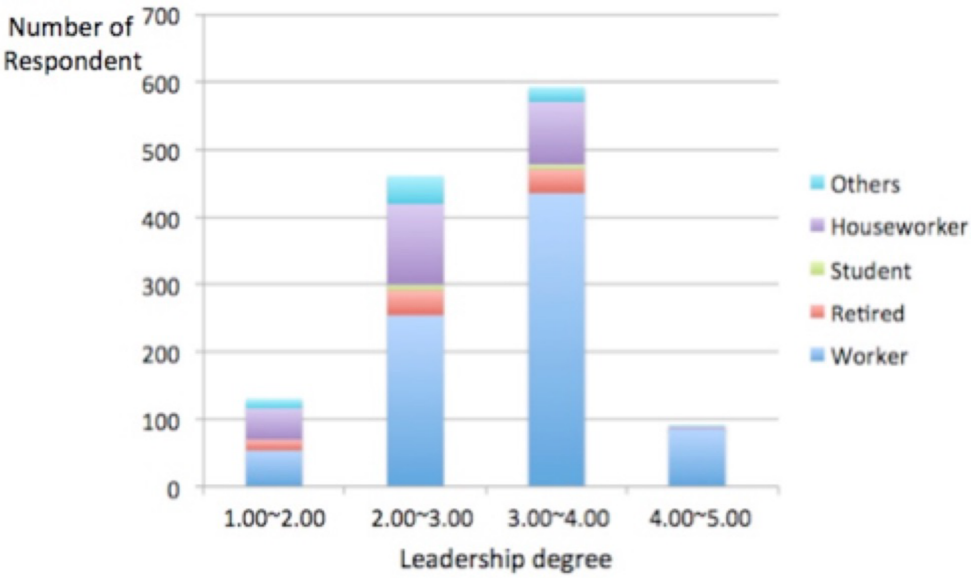


FIGURE 3.3: Statistical chart about job status of the respondents and their leadership degree

Leadership degree of Human(1,5,1,1,4)	
N	44
Average	3.22
Standard Deviation	0.40

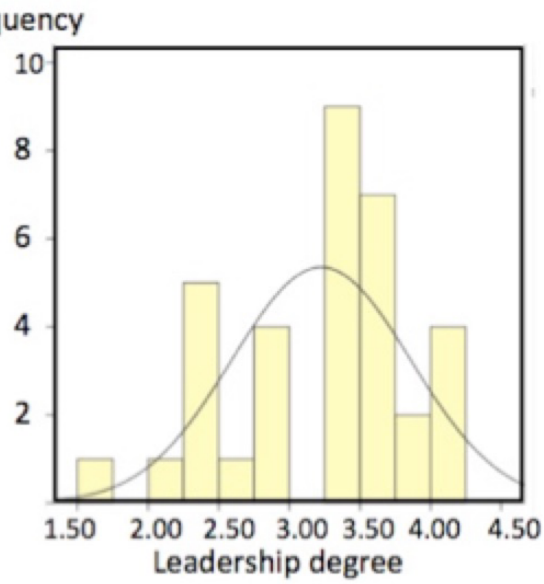


FIGURE 3.4: Statistics about leadership degree of ' Human(1,5,1,1,4) '

As has been noted, in this research, we attempt to analyze features in terms of personal social network at the individual level from Japanese General Social Survey for the purpose of generating an agent-based social network model. The application of the data analysis result and the method of social network model construction will be introduced in the next section.

3.3 Agent-based Social Network Model of Construction

The social network model, which not only includes the geographic composition of society, but also contains population-wide network, which is constituted of personal relationship networks of all individuals in the society, will be introduced in this section.

In this research, we carry out an agent-based simulation method to generate a realistic spatial social network based on a virtual city model by achieving the real geographic information of a specific city area and considering geographical close as a contribution to intimacy between humans.

This model is developed with the agent-based simulation language: SOARS[1] (Spot Oriented Agent Role Simulator) **(Ichikawa M et al; 2007)** **(Tanuma H et al; 2007)** , which is a Java based simulation tool. The details of the model are introduced in the following.

3.3.1 Geography based Virtual City Model and Social Network

According to previous work, we are able to construct a virtual city model for a specific area: Izu-oshima Island **(Ichikawa M et al; 2014)** **(Inamasu; T. et al; 2012)** which is a city under the administration of Tokyo. The information about virtual Izu-oshima model is shown in Table. 3.3. Since it is possible to achieve the information about household composition, population-by-age composition, location of

[1] SOARS Project: http://www.soars.jp/

institutions and a lot of information by accessing to the community survey about any city in Japan from Japanese Census, we can generate any geography-based virtual city in Japan.

Though the previous virtual city model considered the geographic social structure so that the constructed model was similar to the real world, and also virtual city model took an agent-based simulation to reflect the domestic activities and social activities of human beings, it was not enough for representing the real social network because of ignoring of the intimacy between human agents. Considering each agent in a virtual system composes the whole social network, each referent has some connection essentially. All agents should be affected from their relevant people in their personal social network. In real world, such network not only depends on geography, but also relies on each agent himself. Therefore, we aim to generate a spatial social network based on previous geography-based virtual city model. Especially, intimacy in the social network is estimated by the JGSS data analysis results.

TABLE 3.3: Statistic of relationship degree and relationship type in personal relationship network of ' Human(1,5,1,1,4)'

Ratio / Intimacy Degree / Relationship Type	1	2	3	Ratio of each type
Type1	34.375%	34.375 %	31.25%	18.713%
Type2	71.429%	23.81%	4.762%	12.281%
Type3	69.23%	30.769 %	0	7.602%
Type4, Type5, Type6	73.333%	20 %	6.667%	43.86%
Type7∼Type10	63.333%	33.333 %	3.333%	17.544%

3.3.2 Application of JGSS Data Analysis Results

In this part, we purpose to introduce our data analysis result into virtual city model and construct a whole social network based on the geography-based virtual city. In this social network, all leadership degree and relationship intimacy degree of each person are based on JGSS data analysis results.

To realize our purpose, firstly, we construct a geography-based virtual city. Families 'information (including family numbers, their social role, their family role) and information about workplaces (human agents who work in the same workplace) are included in the original geography-based virtual city. Then we put the value ('1', '2', '3') of relationship intimacy degree to each people in his personal network. The selection of value is based on the ratio of relationship in this type of people 's personal relationship network for each relation type. Similarly, we choose a human agent from type Human(1,5,1,1,4) as an example. The setting of intimacy degree with another relations in his personal network is shown as Figure 3.5.

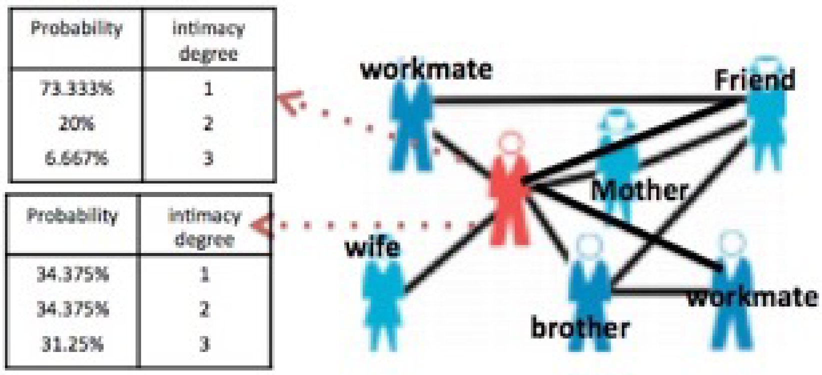


FIGURE 3.5: Model setting about intimacy degree for a 'Human(1,5,1,1,4)'

3.3.3 Agent-based Social Network Model

By applying data analysis result to the virtual city model, we are able to generate a whole agent-based population-wide social network. In this research, we construct a social network model about Oshima Island. The process of social network generation can be organized as follows: To begin with, we classify all agents into 270 types according to their age, sex, marital status, job and householder type. The statistic of human type in Oshima is attached in Appendix A.

Secondly, through applying the JGSS analysis result into the virtual city model, we calculate the relationship intimacy degree for each type of the human agents in the model. Finally, by building all personal networks for all human agents, we generate

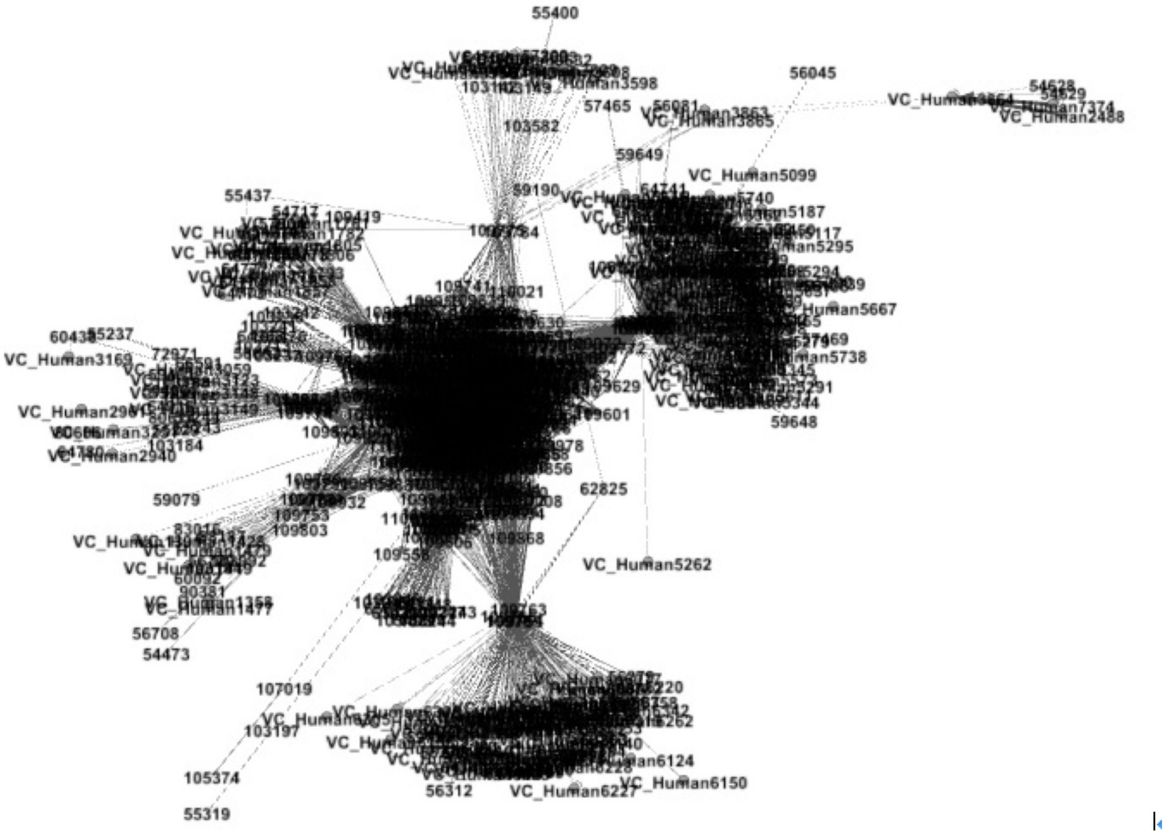


FIGURE 3.6: Visualization of social network in Oshima

the population-wide social network in the Oshima city. Besides, since there is no social network data about people younger than 20 years old in JGSS, intimacy degree of all agents under 20 years old is set as a random number from 1 to 3.

According to this process, we construct 7584 personal networks for the every human agent in the model. In the model, 7584 personal networks are embedded in a population-wide network structure of the Izu-oshima city. Figure 3.6 illustrates the visualization of the constructed social network. Each node in the graph represents one of the human agents, which we name them as ‘ VC_Human1 ’, ‘ VC_Human2 ’…‘ VC_Human7584 ’ in the model. The edges in the graph are double arrows, which illustrate personal contact of each agent in the social network model. We generate this social network figure with Yifan Hu multilevel layout algorithm **(Hu; Yifan; 2005)** by network graphs visualization software Gephi [2] **(Bastian; M.; Heymann; S.; Jacomy; M; 2009)** .

[2]Gephi can be download free from http://oss.infoscience.co.jp/gephi/gephi.org/

In the constructed population-wide social network. Each node represents an individual agent, Edges between them are the relationship within them. In the model there are 6 types of relationship among individual agents: parent - child relationship; couple relationship(husband-wife); family relationship(except couple relation and parent - child relation in family); officemate relationship; schoolmate relationship and friend relationship. Table. 3.4 gives a statistic of relationship types in the constructed Oshima social network. Since edges in the network hold double-direction, which means relationship between one pair of agents is relative, there are 155654 edges within the whole Oshima social network.

TABLE 3.4: Statistic of relationship types in the constructed network

relationship type	number
family relationship	953
parent - child relationship	2885
couple relationship	1887
schoolmate relationship	42645
officemate relationship	14466
friend relationship	14991
Total rnumber	77827

In addition, we will show an example about personal work, which is one part inside the whole social network as Figure 3.7. The figure is also made with Gephi. In Figure 3.7, ‘ VC_Human317 ’ and ‘ VC_Human7405 ’, ‘ VC_Human5786 ’, ‘ VC_Human418 ’, ‘ VC_Human6509 ’ and ‘‘ VC_Human5092 ’ work in a same office. We can find that relations between them are ‘ officemate ’. All personal networks of these 6 workers are shown in Fig.8. In addition, relationship between each pair of the human agents is recorded on the edges. For example: ‘ VC_Human316 ’ and ‘ VC_Human318 ’ are children of ‘ VC_Human317 ’ (In Figure 3.7, ‘ w ’=wife; ‘ h ’=husband; ‘ c ’= child; ‘ o ’= officemate; ‘ f ’= friend;). Besides, the numbers written on the edge represent the intimacy degree. Particularly, intimacy from A to B and intimacy from B to A can be different. For example, ‘ VC_Human418 ’ views his intimacy degree with his wife ‘ VC_Human419 ’ is only ‘ 1 ’. On the contrary, his wife ‘ VC_Human419 ’, who is a housewife and her personal network only includes friends and husband, views intimacy with her husband ‘ VC_Human418 ’ as ‘ 3 ’.

All personal networks similar to Fig.8 compose of the whole social network. In the personal network of each agent, we record the name of human agent, relationship type and intimacy degree with acquaintances, who appear in his network. Personal information of these acquaintances, such as sex, age, job, school, current location etc. is also recorded in the computer model.

FIGURE 3.7: Visualization of personal network

As an application of the model, we will apply the model to a pandemic immunization simulation. The details about the application will be introduced in next section. Except the pandemic immunization simulation, we can also apply the model to another research field by adding parameters and another modules. Moreover, we can also us the same social network generation method to construct social networks for another specific cities by changing the GIS and census data in the model.

This chapter introduced an approach to generate a social network model with agent-based simulation method. To begin with, considering Japanese General Social Survey provided us with the basis of reality about existing personal networks, this paper analyzed the general characteristics about personal networks from the survey data and introduced a way to apply the results into a geography-based virtual city model. Moreover, by specifying the personal information (age, sex, job, etc.), geographic location, social interaction, and a series of entity rules of behaviors for each human agent, this paper generated a realistic model of virtual Oshima city using computer simulation. Finally, this paper applied the data analysis result into the virtual city model for the purpose of estimating the degree of intimacy in relationships between all agents in the model. Agents living in the virtual city and the relationships between them constituted the entire social network model.

This research applied the data analysis result about personal networks on a geography-based virtual city model for generating a social network. Since this social network generation approach used the statistical data, the results about the city structure, population location and intimacy between human agents could certainly match statistics in reality on macro-level. On micro-level, it is very difficult to compare the results with real data, because it is almost impossible to know all activities between acquaintances, which is one of the limitations of this approach. In the paper, we used the approach to generate a social network for a specific city Oshima. Since the number of agents and their home location and social institution in the model were fixed as the real Oshima city, the city population density and relation between agents approximated reality.

We analyzed social network from a country level, but we could not generate the whole social network of Japan in this research. Because (1) there are some technical limitations (such as storage capacity and computing power, etc.); (2) geography based census and city survey are not complete for all cities in Japan; (3) the whole network and social structure in Japan are quite complicated. Therefore, we considered using a representative example to explain our approach. The example we generated was Oshima. We chose this city because our research group had a long project with Oshima so that we could get details of the city survey, which made the virtual Oshima model convincible. Except Oshima, through the same approach, we can also get another social network models for another city.

In the next chapter, the constructed social network model will be applied in a pandemic immunization simulation and revival of the vaccination diffusion phenomenon in the social network system.

Chapter 4

Pandemic Immunization Model

In chapter 3, we conducted an agent-based simulation to generate a realistic spatial social network based on a virtual city model by obtaining real geographic information of a specific city area and considering geographical proximity as a contribution to intimacy between humans. In this work, all human agents compose a whole pandemic immunization community. Each individuals living in the community can use vaccination behavior modification mechanism to improve pandemic immunization decision-making performance, so that the influence of immunization decision-making process in self-awareness and attitudes toward vaccination during social interaction will be simulated in the whole model.

In this chapter, the paradigm of vaccination behavior modification will be proposed in order to determine the relative prognostic importance of the various factors predisposing to immunization of individuals. Besides, the vaccination leading in the immunization system in this research is designated as seasonal influenza vaccination. Moreover, inoculation module, which include vaccination behaviors of all individuals in the constructed social network, will be introduced in the final section.

It is notable that we do not consider side effect of vaccine in this model. There is no doubt that side effect is a noticeable issue in real pandemic immunization system. However, considering we only consider seasonal influenza vaccination in the immunization system in this research and the side effect rate is very small (according to "Side effect report about influenza vaccination in 2013 season", side effect incidence rate is 0.0005% [1]), side effect is a negligible amount in the community of Oshima, where population is less than ten thousand.

4.1 Vaccination Behavior Modification

As the paper has mentioned in the introduction chapter, voluntary shots and usually paid as an out-of-pocket expense, so that low voluntary vaccination coverage rates and high target disease incidence are assumed to be a consequence of voluntary vaccination. Therefore, this work focuses on voluntary vaccination decision-making behavior and characterize the effect of personal values, health beliefs, and influence from interpersonal relationships within population-wide social network during the process of immunization decision modification. Specifically, to figure out prospective factors in vaccination behavior modification and evaluate degree of the influence from the factors for each individual, we will apply the variables of Theory of Reasoned Action (TRA) to distinguish inoculation program participants from nonparticipants. In our model, risk and value cognition towards immunization and subjective norm are viewed as the main predictors of vaccination behavioral intentions. The details with be introduced as following section.

4.1.1 Theory of Reasoned Action in Social Psychology

As a kind of preventive health behavior, vaccination behavior is adapted to traditional behavior modification theories, such as Theory of Planned Behavior, Precaution Adoption Process Model, etc. However, most of traditional behavior modification theories focus on the individuals' psychological factors concerned with the purpose of preventing disease rather than social norms and community enforcement. Conversely Fishbein & Ajzen**(Fishbein**; **M.**; **Ajzen**; **I; 1975**; **1980)** provided a critical review of Behavior Modification investigations and proposed the Theory

[1] Side effect report about influenza vaccination in 2013 season
http://www1.mhlw.go.jp/kinkyu/iyaku_j/iyaku_j/anzenseijyouhou/318_3.pdf

of Reasoned Action(TRA). This research purposes to apply the variables of TRA to explain the mechanism of personal immunization decision-making and figure out prospective factors in voluntary vaccination behavior modification.

TRA was formulated in 1967. As one of a classic persuasion model of psychology, TRA serves to understand an individual's voluntary behavior **(Doswell**; **Willa M.**; **et al.; 2011)** . Since voluntary vaccination behavior is a kind of voluntary behavior obviously, we can claim TRA is a effective way to give a spiritual insight into personal vaccination behavior and immunization related problems. Specifically, TRA focuses on theoretical constructs concerned with individual motivational factors as determinants of the likelihood of performing specific behaviors **(Montano**; **Daniel E.**; **et al.2008)** .

According to the original component of TRA, An actual behavior is determined by behavior intention, which states that an individual 's motivation to engage in a behavior is defined by the attitudes that influence the behavior. TRA is subsequently give an overall assessment via determining the quantity of behavioral intention, which is supposed to be a subjective probability to the assessment, evaluation and alteration of behavior concentrating on the development of adaptive, prosocial behavior and reduction of maladaptive behavior in everyday life. The behavioral intention consists of 2 parts: [attitude toward behavior] and [subjective norms]. Original schematic of TRA is shown as Fig. 4.1

TRA has explained a large proportion of the variance in intention and health behavior related behavior, including human papillomavirus (HPV) vaccine immunization **(Roberto**; **Anthony J.**; **et al.; 2011)** , HIV prevention **(Fishbein**; **Martin; 2000)** , mammography participation prediction**(Montano**; **Daniel E. et al. 1991)** , etc. Though numerous of prior researches successfully explained the individual health behavior or vaccination behavior, seldom researches elucidated the influence of personal vaccination behavior on the whole immunization community from a social system point of view. Therefore, the work will explain personal vaccination behavior in terms of a specific voluntary vaccine by applying the variables of TRA to distinguish

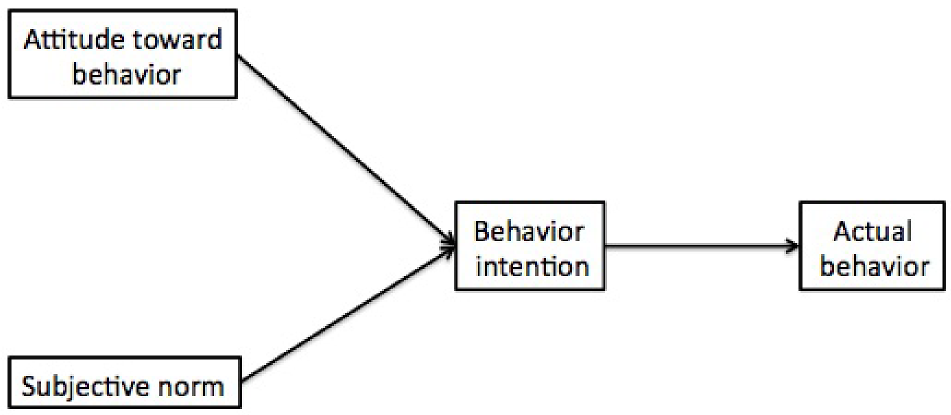


FIGURE 4.1: Schematic of TRA
(adopted from Fishbein, M., Ajzen, I; 1975)

inoculation program participants from nonparticipants, and simulate the whole immunization system as well.

4.1.2 Vaccination Behavior Modification Mechanisms

Since the behavior intention is determined by [attitude toward behavior] and [subjective norms], this work will embed the fundamental dimensions into the vaccination behavior. [attitude toward behavior], which is explained as human personal beliefs that immunization behaviors lead to certain outcomes and the his evaluation of these outcomes according to the decrease of rick after immunization, stands for risk and value cognition towards immunization. Conversely [subjective norms] represents normative beliefs and motivation to copy or comply with referents. It can be viewed as the human personal beliefs that specific individuals or groups think he should perform the behavior and his motivation comply with the specific referents. The schematic of Vaccination Behavior Mechanism based on TRA is shown as Fig. 4.2.

In Fig. 4.2, on the one hand, the first element [attitude toward behavior] of vaccination behavior intention is determined by risk and value cognition towards vaccination. Since this part belongs to subjective self-reference research field, the relevant

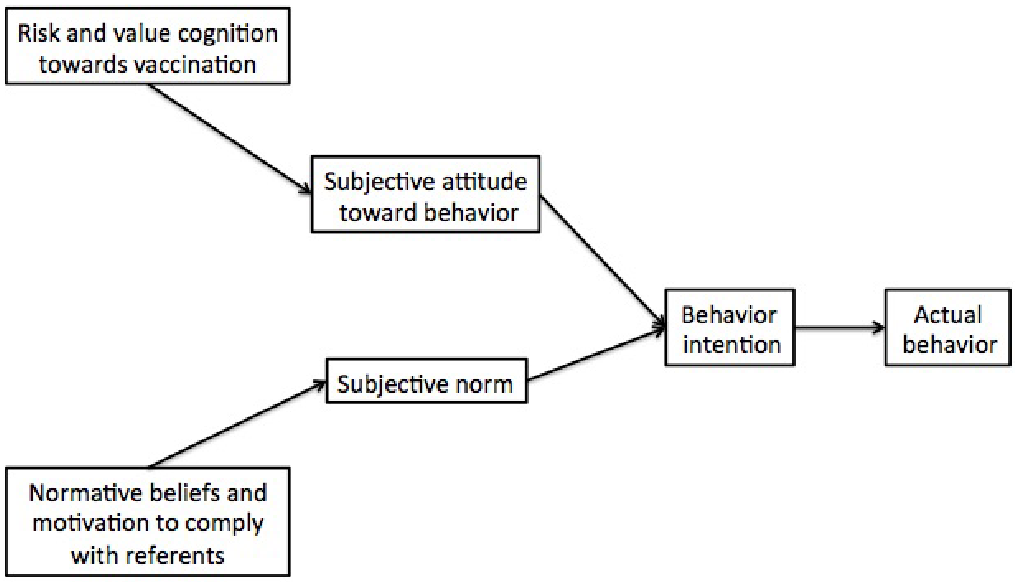


FIGURE 4.2: The Schematic of Vaccination Behavior Mechanism

parameters are all from the original properties of each individual agent in the community. For the purpose of making a connection between individual properties and subjective risk and value cognition, we apply Health Belief Model (HBM) to evaluate the personal cognition towards vaccination. It is notable that though we have discussed that HBM is not sufficient to explain the actual vaccination behavior at the first chapter, we have to admit HBM is favorable tool to explain the self-reference related factor in personal behavior. Dimensions of perceived susceptibility and perceived severity are directly derived from the properties individual agent. After synthetic evaluating perceived susceptibility and perceived severity, individuals will calculate the value of vaccination behavior in advance. If accept vaccination will bring positive benefits to the individual, individual himself will have a high probability to modify vaccination behavior. Whereas if perceived barriers are likely to be higher than benefits, the individual will refuse vaccination behavior. Besides, subsidy from the outside is able to adjust human vaccination behavior by affect the cost and break down the balance between benefits and barriers. The details of subjective attitude towards vaccination will be illustrated in Section 4.1.3.

On the other hand, the second element [subjective norm] of vaccination behavior intention is determined by normative beliefs and personal motivation to comply with his or her referents. Considering subjective norm stand for a social component, in which individual agent will subjective choose to engage or not to engage in a health behavior in terms of the social pressure, social network plays a very important role in forming of the subjective norm. Since all individuals agents in the community constitute the population-wide social network, all personal relationship networks in the community, social interactions between individual agents and personal influence over society will decide individual's normative belief, which is often then multiplied by motivation to comply with another individuals in the personal network of the specific individual. Clearly defined or formulated subjective norm will be introduced in Section 4.1.4.

Owing to these reasons, Fig. 4.3 expresses the whole organization of vaccination intention.

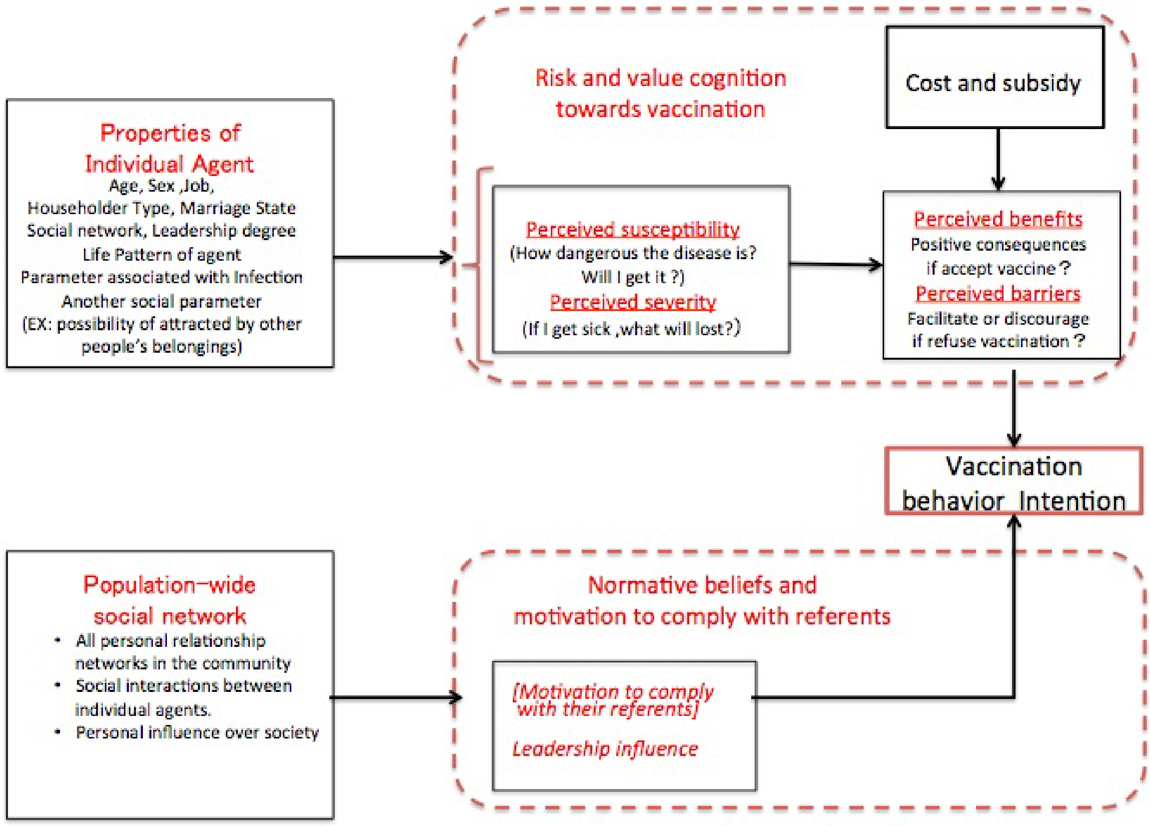


FIGURE 4.3: Organization of vaccination intention

4.1.3 Subjective Attitude towards Vaccination

"Subjective" represents the personal thinking of a individual. [Attitude towards vaccination] determined the behavior intention. Although there is no doubt that personal attitude is a subjective value original, the conditions which decide the attitude can be classified as subjective conscious and objective experience. For example, the infectious risk affect personal attitude towards vaccination, but real value of infectious risk always be expanded or contracted by individual agents because of the gap between their subjective conscious and objective experience. In other words, people cannot realize the sense of impending crisis in subjective level so that they make decision depending on subjective conscious instead of objective experience in infection season. Therefore, we emphasize "subjective" for the purpose of stressing the distinct between subjective conscious and objective experience.

In this section, this work refer to HBM, which is a socio-psychologic theory of decision-making for individual health-related behaviors, to construct a fundamental structure to reflect the self-reference in immunization process. Although HBM is a good conceptual tool as a socio-psychological model to explain personal behavior to participate in immunization programs to prevent or to detect disease, it cannot elucidate the connection of each factor in concrete terms. To conquer such weakness, we improve this model by building up a mathematic description to deal with the connection of each vaccination awareness factor in concrete terms depending on decision-tree analysis, which is used to risk assessment. Moreover, considering the decision-making process involves personal characters in reality in use of decision-making tree, and there is a gap between subjective conscious and objective experience, we use amendatory values in aspiration level with subjective performance. By simulating the immunization decision making process in a psychology level, we are able to predict the effect from vaccination subsidy in use of the pandemic immunization model.

As the brief introduction which has already be given in Chapter 1, HBM have invested relationships between financial cost and vaccination intentions. It is a psychological model used to reflect health behavior change for studying and promoting the uptake of health services. Since we would like to evaluate the psychological reason of vaccination action and immunization belongs to health service category, the arrangement of immunization awareness internal factor is available to refer to HBM. Depending on HBM, internal factors are divided into 4 parts: [Perceived Susceptibility] (an individual's assessment of their risk of getting a certain medical condition), [Perceived Severity] (an individual's assessment about how serious a condition and its consequences are), [Perceived Barriers] (an individual's assessment of the influences that psychological costs of the promoted behavior), and [Perceived Benefits] (an individual's belief in the efficacy of adopting the behavior to reduce risk or seriousness of impact).

Specifically, HBM provides a fundamental structure for evaluating the sense of impending crisis towards infection disease. That means perceived susceptibility and severity factors just relate to individual characteristics and affect the perceived likelihood of getting disease (Personal vulnerability/susceptibility). Therefore, each individual achieves motivation for vaccination by comparing the merit [Perceived Benefits] and demerit [Perceived Barriers]. The contribution of [Perceived Benefits] and [Perceived Barriers] can be gathered into a [Sense of Implementing Crisis]. The conceptual diagram is shown as Fig. 4.4.

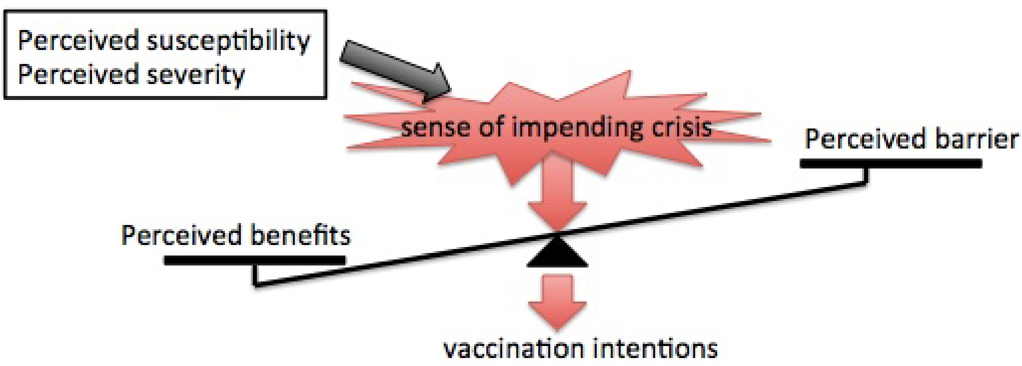


FIGURE 4.4: Conceptual diagram of HBM

Each part and its expression in pandemic immunization model is presented as following:

- [Perceived Susceptibility]

  It is not hard to image that child with a greater number of classmates who are infected has a high level of interest in receiving vaccine. The elderly who believes he is not at risk of virus is less likely to endorse vaccination or oppose to it. [Perceived susceptibility] are such parameters reflecting the risk of getting disease and can be achieved from the property of individual. The involved parameters are shown as Table. 4.1.

TABLE 4.1: Parameters related to「Perceived Susceptibility」

P_1	Infection rate without immunization
P_2	Serious ill rate with immunization
P_3	Death rate with immunization

The parameter P_1 stand for the risk of getting an infection, it is a probability according to the size of the space (spot) and also upon the number of people who are infected. If the size of the spot 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.

The parameter P_1 can be calculated from the previous agent-based epidemic model **(Ichikawa et al.; 2014)** and **(Kanatani et al.; 2014)** (Table. 4.2).

In this work:

$$P_1 = P_1[i](k, t) \tag{4.1}$$

$P_1[i](k, t)$ stand for a infection risk of individual agent$[i]$ at spot $[k]$ at time $[t]$.

Value of serious ill rate P_2, death rate P_3 and some parameters in formulation of $P_1[i](k, t)$ depend on the infectious itself. According to **Deguchi et al. (2011)** who proposed a pathological transition module for categorizing infection levels into several states, and utilizing a model, which is defined by the number

TABLE 4.2: Formulation of $P_1[i](k,t)$

(adopted from Ichikawa M. et al. (2014)& Kanatani Y. et al.(2008)

Name	Value	Implication
ADS[i]		Agent Disease Stage
AES[i]		Agent Excretion Scale
AHL[i]	$AHL[i](t) = AES[i](t) * 1$	Agent Hazard Level
AHL[k]	$AHL[k]$= Σ $AHL[i]$ ∣ i ∈ $Spot[k]$	Agent Hazard Level on the Spot
EnSAF[k](t-1)	$0 - 1$	Spot Attenuation Filter by Environment
StSAF[k](t-1)	$0 - 1$	Spot Attenuation Filter by Sterilization
SpotAF[k]	$SpotAF[k] = EnSAF[k] * StSAF[k]$	Total Spot Attenuation Filter
SCL[k](t)	$SCL[k](t) = AHL(t)$ $+SCL[k](t-1) * SpotAF[k]$	Spot Contamination Level
VSS[k]		Virtual Space Size:
VD[k]	$VD[k] = 1/VSS[k]$	Virtual Density
DRSCL[k]	$DRSCL[k](t) = SCL[k](t) * VD[k]$	Density Risk by SCL
ACPF[i]	$0 - 1$	Agent Contamination Protection Filter
SHLAP[k,i]	$SHLAP[k,i] =$ $DRSCL[k](t) * ACPF[i]$	Spot Hazard Level After Protection
ACL[i](t)	$ACL[i](t) = SHLAP[k,i](t)$ $+ACL[i](t-1) * AgentAF[i](t-1)$	Agent Contamination Level
StAAF[i]		Sterilization Agent Attenuation Filter
EnAAF[i]		Environment Agent Attenuation Filter
AgentAF[i]	$AgentAF[i] = EnAAF[i] * StAAF[i]$	Total Agent Attenuation Filter
FP		Fitting Parameter
TP		Tick Parameter
$P_1[i](k,t)$	$P_1[i](k,t) =$ $1 - exp(-FP * TP * ACL[[i])$	Infection of Agent[i] per step

of days spent that each state endures and the probability of transition between states, smallpox and influenza have a different value of serious ill rate, death rate, etc. Therefore, we have to designate a specific epidemic disease. We will discuss it at Section 4.2.

- [Perceived Severity]

[Perceived Severity] evaluate the payment in each agent 's mind. Complementary variables of [Perceived Severity] are shown as Table. 4.3.

TABLE 4.3: Parameters related to「Perceived Severity」

C_{se}	The risk and economic loss of Seriously illness
C_{sl}	The risk and economic loss of Slight illness
C_{die}	The risk and economic loss of Death

Value of C_{se}, C_{sl} and C_{die} record the risk and economic loss of illness. As is known to all, getting sick is likely to bring us numbers of trouble beyond the medical fees, economic loss should include all the risk and loss, which patient may encounter, such as the absence of job because of sickness. Especially, since the elderly over 65 year-old have a high risk to get another sickness accompanied with influenza, the economic loss is considered to be the highest one. (depending on the literature from **Yasushi Ohkus (2005)** the value is 6 million for an elderly with an advanced disease). To reduce loss of potential, the vaccination subsidy for elderly plays an essential role as an immunization policy.

- [Perceived Benefits] and [Perceived Barriers]

  Since we get parameter of [Perceived Severity] and [Perceived Susceptibility] from the virtual city model. We should deal with the parameters to achieve [Sense of Impending Crisis] which represent the factors [Perceived Benefits] and [Perceived Barriers].

  To quantify the risk and value cognition of human beings, we define a parameter: [Willing to Pay]: $C(pay)$, which is used to evaluate the expected payment of each individual. $C(pay)$ is designed to be an index to reflect marginal utility of balance between merit and demerit for each individual. The value can be achieved from the parameters associated with [Perceived Susceptibility] and [Perceived Severity] and used to evaluate the expected payment in each individual agent 's mind.

  If the vaccination price $C(vac)$ is higher than $C(pay)$, Agent may care about the price obstacles in the way of adopting immunization and abandon to accept vaccine. In this case, price obstacles are the judgment of [Perceived Barriers]. On the contrary, if the price is lower than the potential economic loss, immunization is a brilliant chance to prevent the loss of the money absolutely, which is also the power of [Perceived Benefits].

Especially, vaccination subsidy controls the immunization awareness by adjusting the price of vaccine. To meet up with the efficiency of vaccination subsidy, policy should provide an effective amount of money to make the margin between $C(pay)$ and $C(vac)$ to a minimization extents.

Preventive vaccination requires that people anticipate a future health problem. Market of preventive vaccine therefore must ensure people awareness of the risks of infection disease and motivate them to take preventive action. Considering a successful preventive vaccination not only improve the health status of the vaccinated person but also deteriorate it due to adverse events sometimes, to perceive the [Sense of Impending Crisis], individuals must engage in counterfactual thinking.

In this work, $C(pay)$ is constructed according to decision-making tree method (Figure. 4.5), which considers parameters associating with previous pathology model **(Ichikawa et al.; 2014)** & **(Kanatani et al.; 2014)** and parameters about [Perceived Susceptibility] and [Perceived Severity].

Besides, in the decision tree measure, we try to seek the mathematic relationship of factors in HBM. However, P_1, P_2, P_3 are objective parameters which is the same for every individual agents, and can be achieved from the pathology model ot statistic data. In reality, everybody has chance to encounter lack of cognitive skill to some extent, so that we cannot make sure all people perceive the value of parameters. Therefore, we consider introducing a subjective probability in aspiration level to replace the objective parameters. People decide the subjective probability depending on objective parameters to a large extent.

Considering human has chance to encounter lack of cognitive skill in reality, we introduce a subjective equation $W(P)$ to reflect vaccination decision making in aspiration level with subjective performance. The [willing to pay] equation is shown as follows:

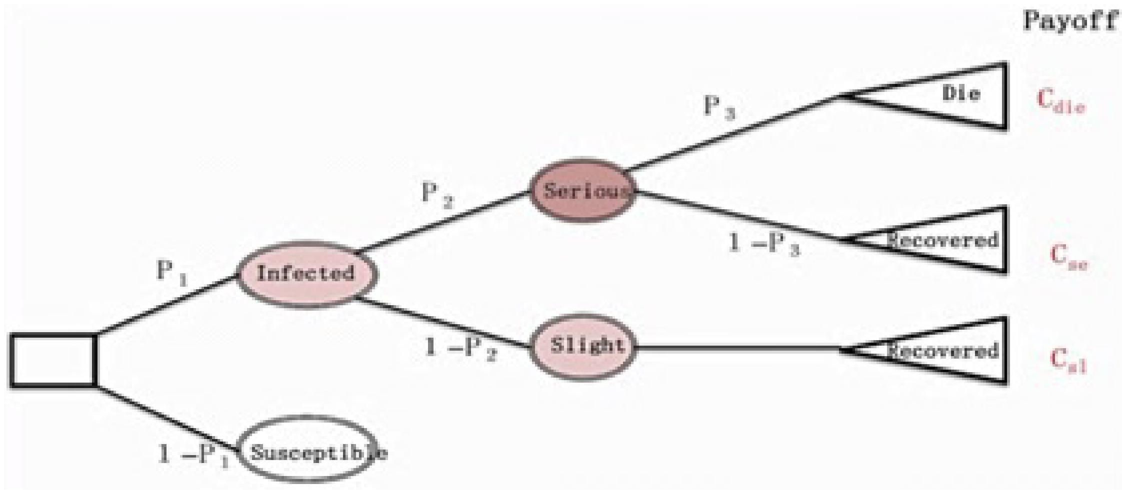


FIGURE 4.5: Decision-making tree

$$C(pay) = W(P_1) * P_2 * P_3 * C_{die} + W(P_1) * P_2 * (1 - P_3) * C_{se} + W(P_1) * (1 - P_2) * C_{sl} \quad (4.2)$$

if $r > a\%$, then $W2(P) < P$;

$$W(P) = W^{-} = exp(-(lnP)^{1/r}) \quad (4.3)$$

if $r < a\%$, then $W(P) > P$;

$$W(P) = W^{+} = exp(-(lnP)^{r}) \quad (4.4)$$

$$r = \frac{Number\ of\ [healthy\ people\ in\ personal\ relationship\ network]}{Number\ of\ [people\ in\ personal\ relationship\ network]}$$

In the equation, r is health rate of individual. $W(P_1)$ is designed to explain the cognitive psychology towards infectious risk of individual in aspiration level with subjective performance. Parameter a represents the bound of healthy confidence of individual agents towards themselves. More confident human think he would be, the lower value of a is. We design the value of a depending on the data analysis results from JGSS data. According to the statistic results (Figure. 4.6) about subjective perceived healthy condition of different age of people, we found that:

- Almost 50% people, whose age surrounding 20 to 30 years old, believe their healthy condition are very good, whereas almost 0% of them think their healthy condition are very poor.
- All elderly, whose age is beyond 70 years old, have less confidence toward their healthy condition comparing with another age of people. Especially, more than 8% of them think their healthy condition are very poor.
- People are like to loose confidence toward healthy condition accompanying with increasing of the age.

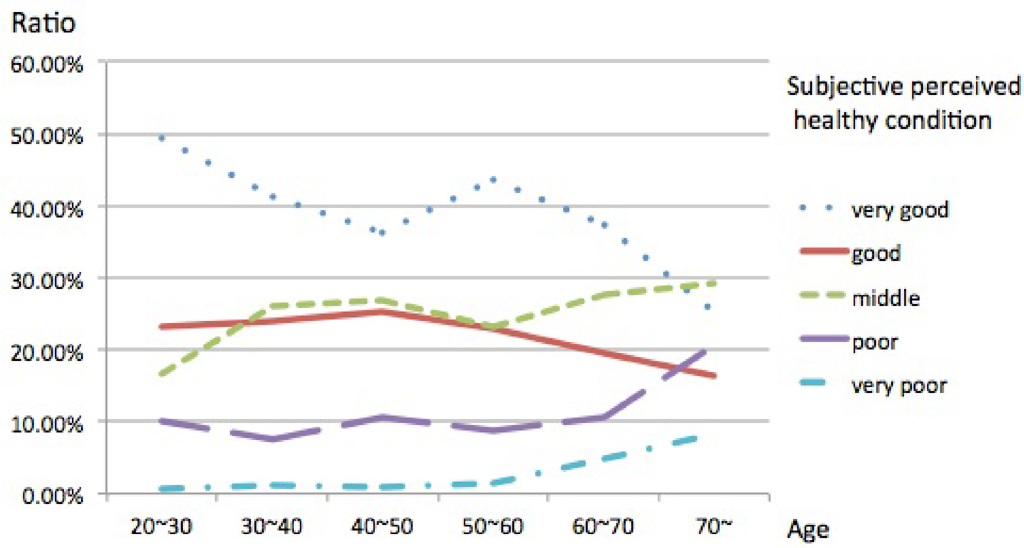


FIGURE 4.6: Subjective perceived healthy condition

Therefore, we define the parameter a depending on to the statistic results.

The value of a is shown as Table. 4.4. For example, if age of individual agent is surrounding 20 to 30 years old, then subjective perceived healthy condition of he or she has 49.40% to be 'very good'. subjective perceived healthy condition. In contrast, that individual agent has only 0.60% to believe his or her healthy condition is 'very poor'.

TABLE 4.4: Value of healthy confidence related parameter a

Probability \ a / Age	very good (a=0.95)	good (a=0.9)	middle (a=0.85)	poor (a=0.8)	very poor (a=0.75)
20∼30	49.40%	23.21%	16.67%	10.12%	0.60%
30∼40	41.29%	23.86%	26.14%	7.58%	1.14%
40∼50	36.33%	25.31%	26.94%	10.61%	0.82%
50∼60	43.67%	22.89%	23.19%	8.73%	1.51%
60∼70	37.31%	19.54%	27.66%	10.66%	4.82%
70∼	25.33%	16.33%	29.33%	20.67%	8.33%

Moreover, according to the definition of $W(P)$ in Equation 4.4, there are some properties about $W(P)$:

- As same as P_1,P_2 and P_3, $W(P)$ is a probability:

$$W : [0, 1] \rightarrow [0, 1]$$

- If $r > a\%$; accompanying with the increase of health rate surrounding the agent, the margin between subjective $W(P)$ and P will be expanded to W^-.

$$if\ r \rightarrow \infty, \quad then\ W(P) \rightarrow 0$$

$$r \propto 1/W;$$

  For example, if there is no threat of flu virus surrounding the agent, individual agent is likely to have no use to get flu shot.

- If $r < a\%$;. r is inversely proportional to $W(P)$. Especially, the increase of r results in the $W(P)$ appropriating to P, though $W(P)$ is still larger than P.

$$if\ r \rightarrow a\%, \quad then\ W \rightarrow P$$

$$r \propto 1/W(P);$$

After calculating [Willing to pay] $C(pay)$, If the price is lower than the price of vaccination, $C(pay) < C(vac)$. We assume that individual agent may care about the price obstacles in the way of adopting immunization and abandon to accept vaccine. In this case, price obstacles are the judgment of [Perceived Barriers]. On the contrary, if the price is lower than the potential economic loss, Immunization is absolutely a brilliant chance to prevent the loss of the money, when [Perceived Benefits] take a prior position to be taken into consideration. In particular, vaccination subsidy affects the immunization awareness by controlling the price of vaccination $C(vac)$.

4.1.4 Subjective Norms in Vaccination Awareness

This work attempts to simulate immunization awareness diffusion phenomena under the social network of the city and vaccination behaviors change interaction in the personal network of every individual agent. According to an investigation about the degree of recognition towards immunization, the recommendation from family or friends is one of the main reasons, which affect the immunization awareness of humans. Such phenomenon occurs because that social environment is potential influences on vaccine decision-making and vaccination behavior modification. The relevant social-environmental issues including perceived social norms and the persuasive influence of groups of people living in the same social network represent the subjective norms in this work. Subjective norms of individual addressed include peer health beliefs and attitudes related to vaccine preventable immunization from families, as well as another acquaintances. Therefore, to construct a pandemic immunization module on the city model, all personal relationship networks in the community, social interactions between individual agents and personal influence over society should be taken into consideration.

Subjective Norms reflect the influence of vaccination awareness from the social network individual lives in. Considering if intimate relevant people in the personal relationship network are vaccinated, the individual will develop tendency to inoculate, we quantitate the influence from Subjective Norms (ISN), which is viewed as a probability to decide whether human is affected or not, for human‘ i ’as following equation.

$$ISN(i) = \frac{\sum_j^{all\ vaccinated\ people\ in\ network\ of\ human\ i} w_{i,j} * L_j}{\sum_j^{all\ people\ in\ network\ of\ human\ i} w_{i,j} * L_j} \tag{4.5}$$

$$w_{i,j} = intimacy\ degree\ of\ i\ to\ j;$$

$$L_j = leadership\ degree\ of\ j$$

'j' is the human living in the personal network of 'i'. Leadership degree of all humans can be deduced from the information of social network according graph entropy method. Figure. 4.7 shows the correlates of subjective norms of individual among the intimacy-based social network and immunization system.

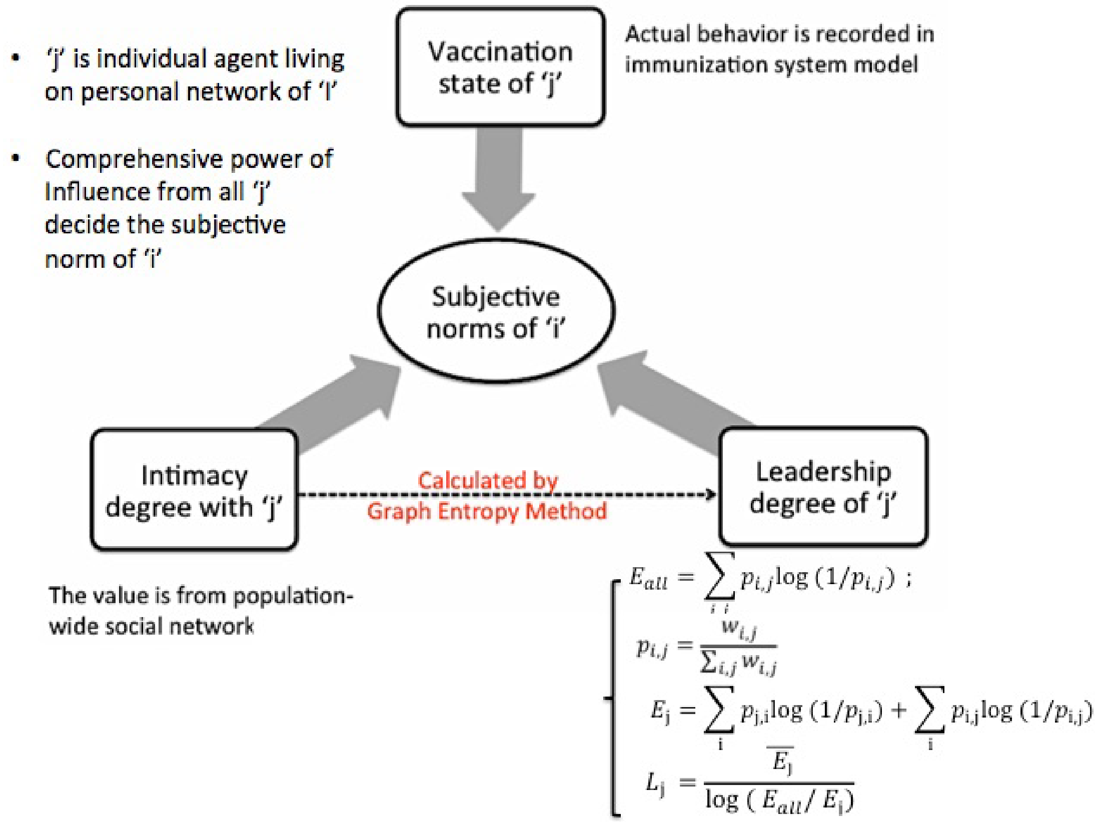


FIGURE 4.7: Correlates of subjective norms

According to the definition of personal subjective norms of each individual, there are several properties of the value of $ISN(i)$.

- $ISN(i)$ is a value with domain [0, 1]:

$$ISN(i) : [0, 1] \rightarrow [0, 1]$$

- If number of vaccination people increase, $ISN(i)$ will be increased:

  We assume the number of vaccinated people in the population-wide social network is a value 'm'.

$$if\ m \rightarrow \infty, \qquad then\ ISN(i) \rightarrow 1$$

$$m \propto ISN(i)$$

Specifically, if all people living in the social network are vaccinated, then $ISN(i)$ is a value tend to 1, which means the probability of vaccination behavior modification equals to 100%.

Conversely,

$$if\ m \rightarrow 0, \qquad then\ ISN(i) \rightarrow 0$$

That implies if no one take vaccination, then individual agent will almost have a 0% possibility to get vaccination.

4.2 The Study Object: Seasonal Influenza Vaccination

Considering infectious risk, kinds of vaccination, inoculation pattern vary in a big way for different pandemic, though the vaccination behavior modification mechanism is applicable for all voluntary vaccinations, this research focuses on a typical study object: seasonal influenza vaccination.

The parameters in Table. 4.2 can be derived from the seasonal influenza disease state transition model (Figure. 4.8).

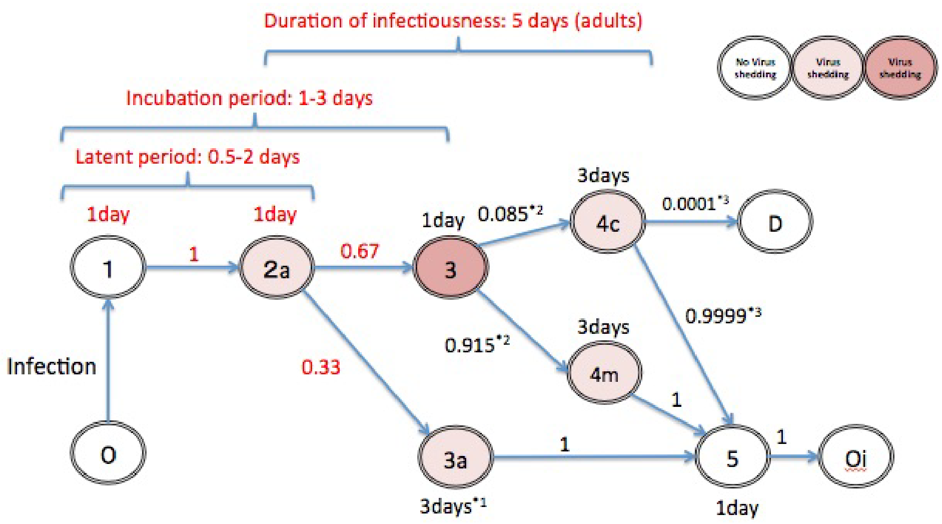


FIGURE 4.8: Pathological transition model for seasonal influenza (adopt from **Ichikawa M. et al. (2014)**)

Circled numbers denote pathology levels, which equal to parameters $ADS[i]$ in Table. 4.2. Similarly we can find another parameters in Table. 4.2 matching with the pathological transition model for seasonal influenza

Specifically, value of serious ill rate $P_2 = 0.085$ and death rate $P_3 = 0.0001$ according to Figure. 4.8.

Via implementing the pathological pandemic transmission algorithm in the virtual city model, **Ichikawa M. et al. (2014)** has already successfully simulate the spread if seasonal influenza in the geography based virtual city. This research will calculate the infectious rate according to Formulation of $P_1[i](k,t)$ in Table. 4.2 for each individual agent by the pathological pandemic transmission algorithm and attempt to simulate immunization awareness diffusion phenomena under the social network of the virtual city and vaccination behavior modification process in the personal network for every human agent belonging to the population-wide social network.

Besides, we assume seasonal influenza starts from Oshima high school and 5 high school students are infected at the initial step in this model.

4.3 Inoculation Module based on the Constructed Social Network

This research aims to figure out prospective factors in vaccination behavior modification and evaluate degree of the influence for every human agent from the pandemic immunization model. However, we found that according to the questionnaire about the degree of recognition towards immunization by Banyu Pharmaceutical co.ltd [2] . in April.2010, for the group of [immunization advocates] and [health advocates], their attitudes toward vaccination cannot be modified, which is the same as the group of people who lack conviction towards effectiveness of vaccination at all.

[2] Japanese Immunization Awareness Investigation by Banyu Pharmaceutical co.ltd (April. 2010). http://www.msd.co.jp/newsroom/banyu-archive/pdf/product/product_news_0520.pdf/

Therefore, all agents initial attitudes toward vaccine are divided in 3 kinds: [Positive], [Stubborn] and [Normal]. [Positive] agents choose immunization with no doubt. On the contrary, [Stubborn] agents reject immunization at all. Inoculation module is useful to judge vaccination behavior modification for all [Normal] agents, for whom the schematic of vaccination behavior mechanism is necessary to trigger the decision-making process. In the model, [positive] individual agents are vaccinated at the beginning of the epidemic season. Such initial immunization group lead the trend of immunization system and immunization awareness diffusion in the population-wide social network originated in such [immunization advocates] and [health advocates].

Since we cannot make insight of the factors and psychological immunization awareness of initial immunization group, we assume that numbers of initial immunization individual agents take a percentage of all individual agents in this work. In the following content of this paper, we always suppose (initial immunization group) take 5% of the entire population indiscriminately. The number is capable of change and the variable of the number result in influence on the whole immunization system, which we will certificate at Chapter 7.

The whole pandemic immunization model is the combination of the inoculation module, the influenza transmission module and the population-wide social network in virtual city (Fig. 4.9).

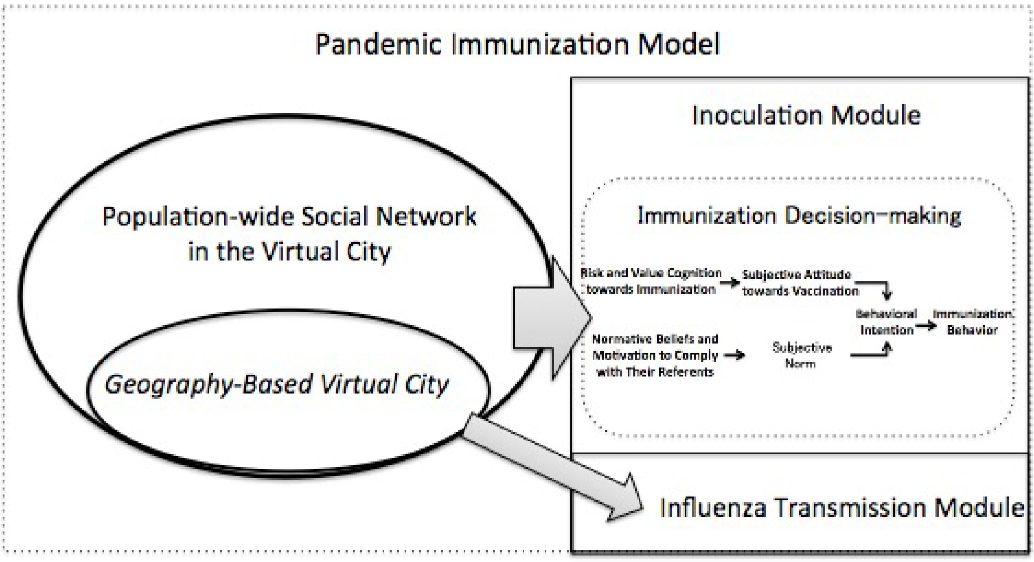


FIGURE 4.9: Schematic diagram of pandemic immunization model

Chapter 5

Simulation Result Analysis

The immunization simulation with agent-based approach links micro-level individual vaccination intention analysis to macro-level immunization phenomena by making an insight of the properties of individual agents. In this chapter, we are going to analyze the simulation results in a more comprehensive manner from both macro-level and micro-level perspectives. They will be represented separately in the following.

5.1 Macro-level Analysis and Implications

Macro-level characteristics of the immunization system in influenza season is analyzed from the viewpoints of immunization coverage.

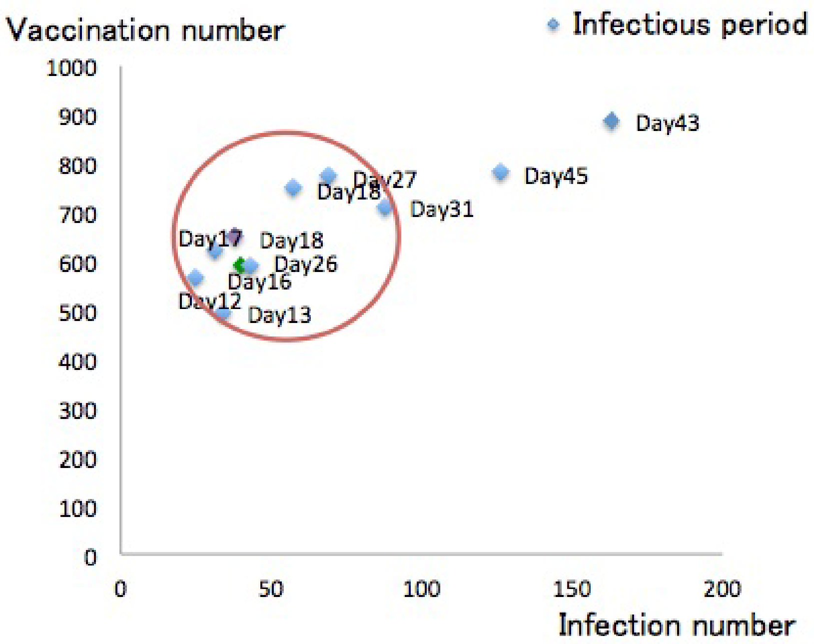
5.1.1 Epidemic Period, Infection Number and Immunization Coverage

As is known to all, immunization comes into being along with the emergence of infectious disease. Ordinarily individuals vaccination behavior purpose to protect themselves against influenza disease that can cause serious illness and disability or be fatal. Therefore, there must be some kinds of relationship between tendency of infectious disease and immunization coverage. Besides, immunization behavior should be executed before or during the epidemic season. considering it will take some time for building up antibodies to influenza after inoculation, prior vaccination is recommended by universal viewpoints. However, it is notable that vaccination is also available during the epidemic season and there are still a lot of people inoculating with the expansion of infection disease in reality. Therefore, the immunization system simulation in this work will discuss the relevant factors involving epidemic period, infection number and immunization coverage.

Figure. 5.1 shows the simulation results of epidemic period, infection number and immunization coverage after executing the model 10 times. Every dot in Figure. 5.1 records the value of total infection number in pandemic season at horizontal axis and corresponding vaccination number or immunization coverage at vertical axis, the number 'x-day' nearby the dot represents epidemic period complying with per simulation result.

Because of the uncertain factors inside the transition of infectious disease model (for example: the infection rate without immunization P_1 is a percentage record the probability to be infected, individual may or may not infected be infected in the model if $0 < P_1 < 1$), we cannot make sure the simulation results are unique values when we execute the model every time. In particular, in spite that simulation is a tool to reflect all possible phenomena in reality, phenomena themselves include numerous uncertain elements. For this reason, one simulation result reflect only one possible situation in the real world. Thus Figure. 5.1 represents ten possible situations of epidemic period and corresponding infection number and immunization coverage.

Though we cannot get an unique certain result from the simulation, it is useful to predict and evaluate what is potential to happen in reality. According to the simulation results in Figure. 5.1. Simulation results are converged in the red circle eight times, which means epidemic period, infection number and immunization coverage inside the circle are much more likely to match with the real situations. Moreover,



#Statistic of value converged in the circle

	Average	Standard deviation	Coefficient variation
Infection number	47	20.3	43.1%
Vaccination number	629	90.6	14.3%

FIGURE 5.1: Simulation results of epidemic period, infection number and immunization coverage

according to the statistic of value converged in the circle, coefficient variation of infection people is 43.1%, whereas coefficient variation of vaccination people is just 14.3%, which is much lower than total infection number. Such result implies that vaccination number is more stable than infection number. In other words, comparing with the prediction of transition of infectious disease, immunization coverage in the experimental results is more approximate well to reality.

Furthermore, there are still dots cannot converged in the circle, which means the probabilities of these possible epidemic period, infection number and immunization coverage inside the dots are very small. Please notice that small does not equal to an impossibility. It is meaningful to have a good knowledge of overall possible situations in reality. We will analyze these small probability situations in the next section.

5.1.2 Epidemic transmission Processes and Relative Immunization Coverage

In this section, we are going to separately pick up the simulation results generated in section 5.1.1 in details.

On the one hand, we suppose to pick up any two simulation results from the converged circle. The Epidemic transmission processes and the relative immunization coverage from these two results are shown in Figure. 5.2. One records the result of 'Day16' epidemic period, the other one shows the result of 'Day18' epidemic period,

According to the simulation results,

- Except the initial 5% vaccination advocators, there is a rapid increase in number of initial vaccinators at the beginning of the pandemic season 'Day0'. The reason of such phenomena owing to the interaction from subjective norms in vaccination awareness. Individual agents surrounding the vaccination advocators are likely to be influenced and inoculate.

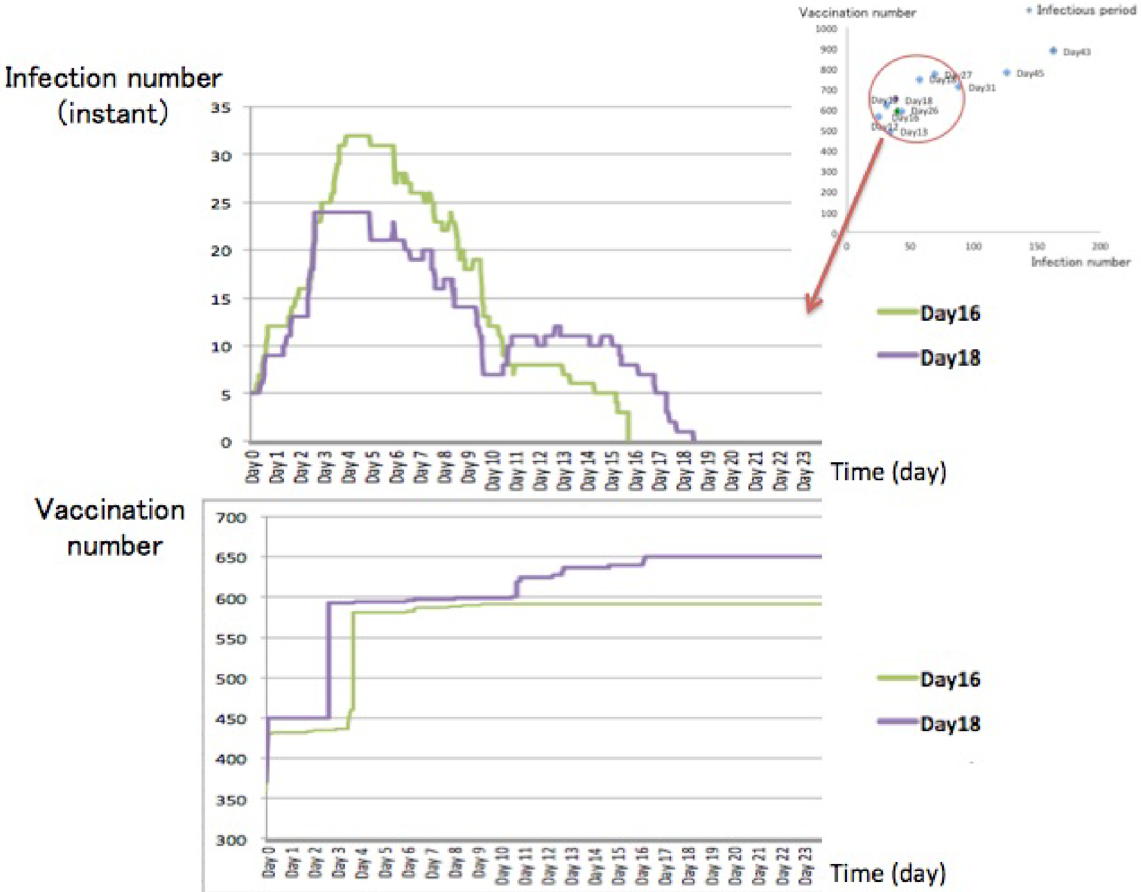


FIGURE 5.2: Epidemic transmission processes and the relative immunization coverage of converged results

- Vaccination number increases with a corresponding increase in infection number, whereas, vaccination number tends to be stable when corresponding infection number decreases.In other words, vaccination popularity always finishes much more early before disease being stable. Specifically, in the result of 'Day18' epidemic period, there is small amplitude of infection number from 'Day10' in the pandemic season. The small increases in infection number result in the growth in vaccination number. In contrast, the vaccination number back to a stable state after 'Day16' when the infection number begins to drop down.
- It is obvious that longer time the epidemic spreads, more substantial immunization coverage would likely to be.

On the other hand, the result of 'Day43' epidemic period is selected as a nonconvergence dot in the circle. The Epidemic transmission processes and the relative immunization coverage of it are shown in Figure. 5.2.

- Influenza outbreak in this city continue for almost 45 straight days with infection rate reaches crest value twice. Comparing with the results converged in the red circle, the result of 'Day43', there are two vaccination booms during the influenza season accompany with the spread of pandemic disease. That result certificates he conclusion " longer time the epidemic spreads, more substantial immunization coverage would likely to be" which is drawn before.
- Vaccination number increases rapidly in response to the second peak of infection number. Contrary to the amplitude of infection number in results of 'Day18', amount of increase of infection number in the second crest of 'Day43' result is larger and faster. That results in a larger amount of increase in vaccination number correspondingly.
- Since it is possible to form the second peak in real pandemic transition season, researches about such kinds of small probability simulation results separately will make sense to know the real work properly.

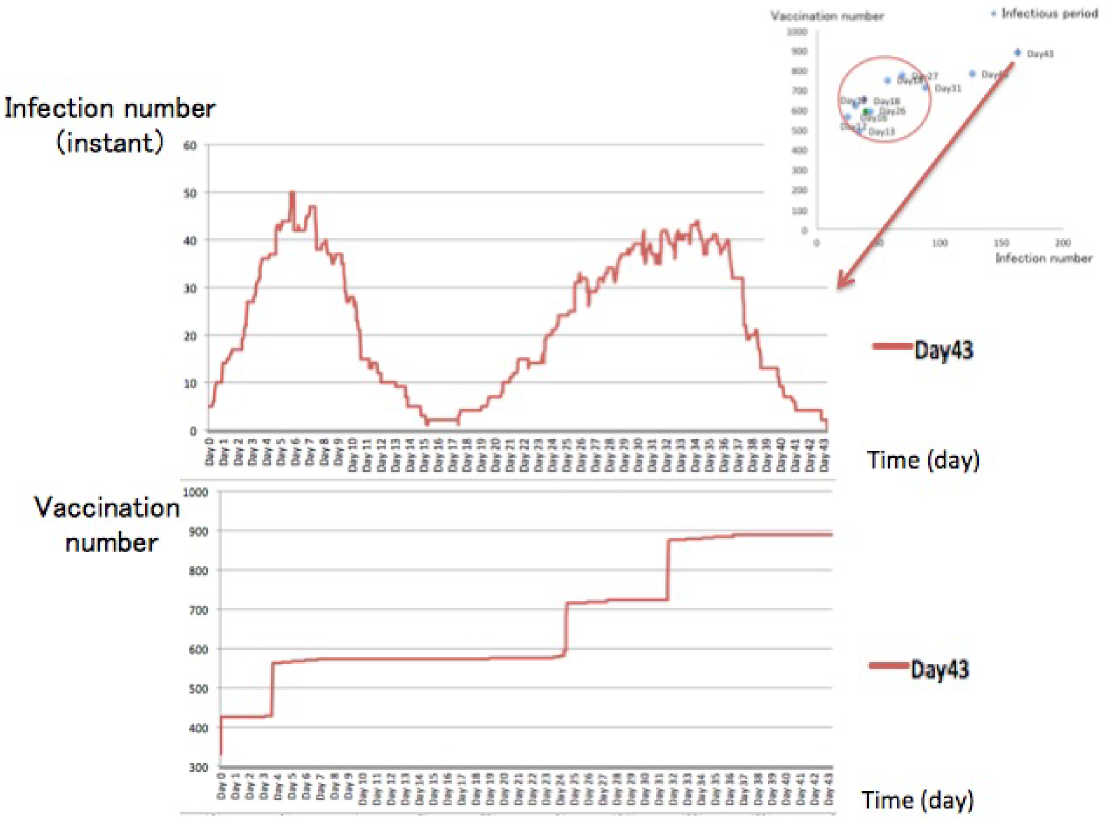


FIGURE 5.3: Epidemic transmission processes and the relative immunization coverage of a nonconvergence result

5.2 Micro-level Analysis and Implications

The macro-level results in immunization system are formed by micro-level agents' vaccination behaviors. Unlike macro-level analysis, micro-level simulation result analysis attempts to explain the internal decision-making and vaccination behavior modification process from the viewpoint of the factors related with every human agent.

In the social network model, all 7584 personal relationship networks of every agent and vaccination state of agents in the network are records per step (1step=15min). Personal networks and state change process per step is shown in Figure 5.4. The state change process are recorded until the end of pandemic season. Since the recorded data is very huge, we use Falconseed[1], which is a data analysis software to open it.

Table. 5.1 is one example to explain the format of the personal network at one step. In the result, human agent himself or herself is also included in his own personal network, but the intimacy degree with himself is 0.

TABLE 5.1: One example: format of the personal network at one step
agent_vc_type: relationship type, w=wife, h=husband, c=child, p=parent;
degree: intimacy degree;
vac: record the of vaccination status of relevant people;
agent: name of relevant people.

Name	Personal relationship network at 0/00:00
VC_Human3014	$[agent\_vc\_type = c, degree = 0.0, vac = no, agent = VC\_Human3014,$ $agent\_vc\_type = officemate, degree = 1.0, vac = no, agent = VC\_Human144,$ $agent\_vc\_type = officemate, degree = 2.0, vac = no, agent = VC\_Human3136,$ $agent\_vc\_type = c, degree = 1.0, vac = yes, agent = VC\_Human3015,$ $agent\_vc\_type = h, degree = 2.0, vac = no, agent = VC\_Human3012,$ $agent\_vc\_type = w, degree = 1.0, vac = no, agent = VC\_Human3013,$ $agent\_vc\_type = officemate, degree = 1.0, vac = no, agent = VC\_Human3018,$ $agent\_vc\_type = officemate, degree = 1.0, vac = no, agent = VC\_Human3832,,$ $agent\_vc\_type = c, degree = 1.0, vac = no, agent = VC\_Human3016,]$

Every agent, as a participant of immunization system, organizes his or her own behavior intention and affect the vaccination behavior of other agents directly or

[1] Falconseed download page http://www.soars.jp/falconseed3-0-0/

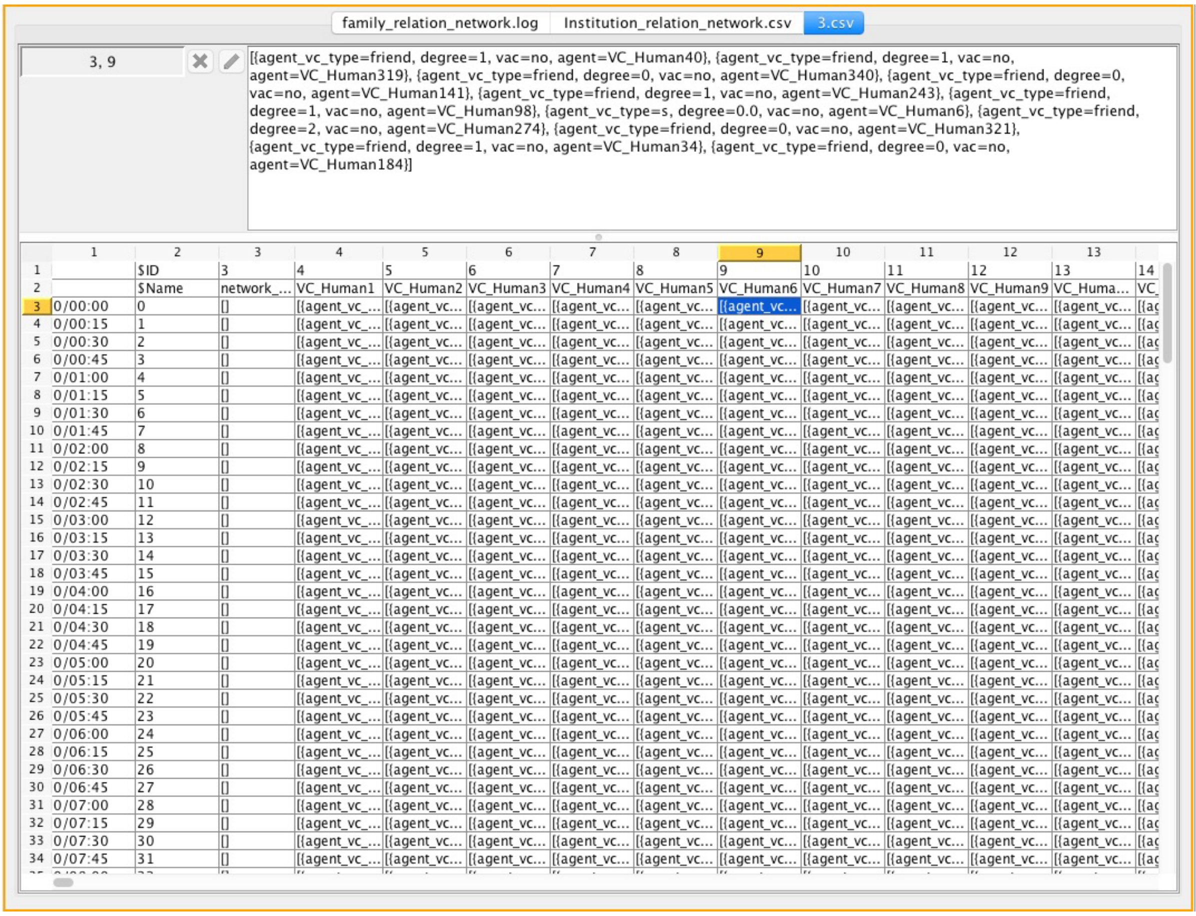


FIGURE 5.4: Personal networks and state change process per step

indirectly in the constructed social network. An individual-level vaccination behavior intention is generated by both subjective attitude towards vaccination and subjective norms in vaccination awareness of individual. Since this work focus on the social reference influence from population-wide social network, we will discuss immunization intention under social norms as following.

5.2.1 Immunization Intention under Social Norms

The social network model includes 7584 human agents and all personal relationship networks of them. We provide one example of the immunization awareness change process in the personal network of a specific human agent: ‘ Human418 ’, whose personal network has already been visualized in Figure 3.7.

In the social network model, ‘ Human418 ’ is a man, a worker, 50 years old, and lives with his wife. The vaccination information in his personal social network is updated at every iteration. The diffusion process of his immunization awareness accompanies the vaccination information change in his personal network at every iteration; we record these changes as states. The information in personal relationship network is update on time. Figure 5.5 illustrates its transformation. (State1⟶State2⟶State3⟶State4)

The simulation result certificates that recommendations from family or friends is one of the main influences which affect the immunization aware- ness of humans. Such a phenomenon occurs because people are likely to be influenced by suggestions from their acquaintances.

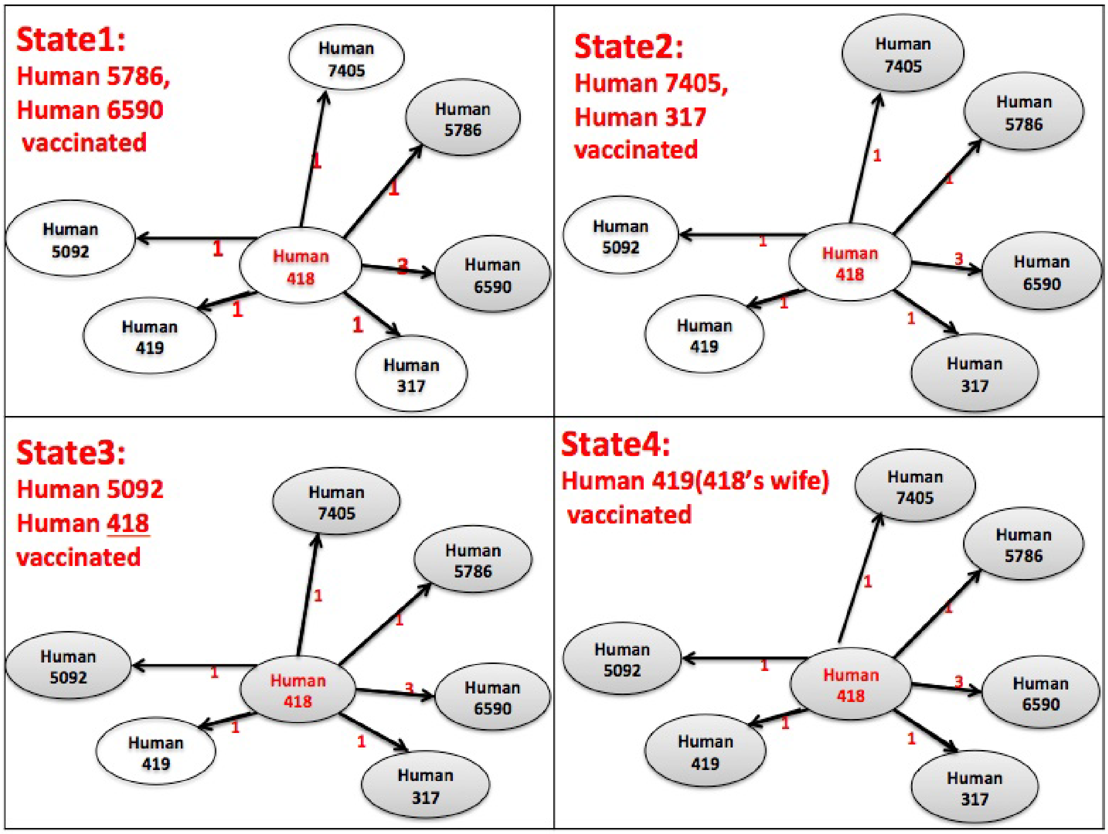


FIGURE 5.5: Immunization diffusion process in a personal network

Chapter 6

Effect Estimates of Vaccination Policies with Pandemic Immunization Simulation

Ordinarily, vaccination policies are carried out based on decision-making of individuals themselves rather than being mandatory. In healthcare field, subsidy policies are offered by the government side to promote vaccination coverage. Though vaccination subsidies has achieved distinct effects in reality, we have to admit that 1: not all subsidy policies are effective in controlling the transmission of infectious diseases; 2: different vaccination policies cause varying degrees of influence on immunization system; 3:the same subsidy may result in different benefits in different area because of the the regional bias or regional disparity of social network inside the community.

Considering these kinds of possible problems in vaccination policies establishment, simulation provides us a good tool to predict the effectiveness in pandemic immunization system. Therefore, for the purpose of certificating reasonable vaccination policies tend to promote healthcare behavior modification and giving decision support to assess the relative impact of public health services for pandemic control, this chapter will introduce scenarios about subsidy policies for improving healthcare service. Personal cognitive factors that tend to have an effect on the process of vaccination decision-making behavior via the immunization model will be estimated as well.

6.1 Growth of Immunization Coverage Before Epidemic Season

Figure. 6.1 shows the result that initial immunization group takes 5%, 7.5%, 10% of the entire population indiscriminately.

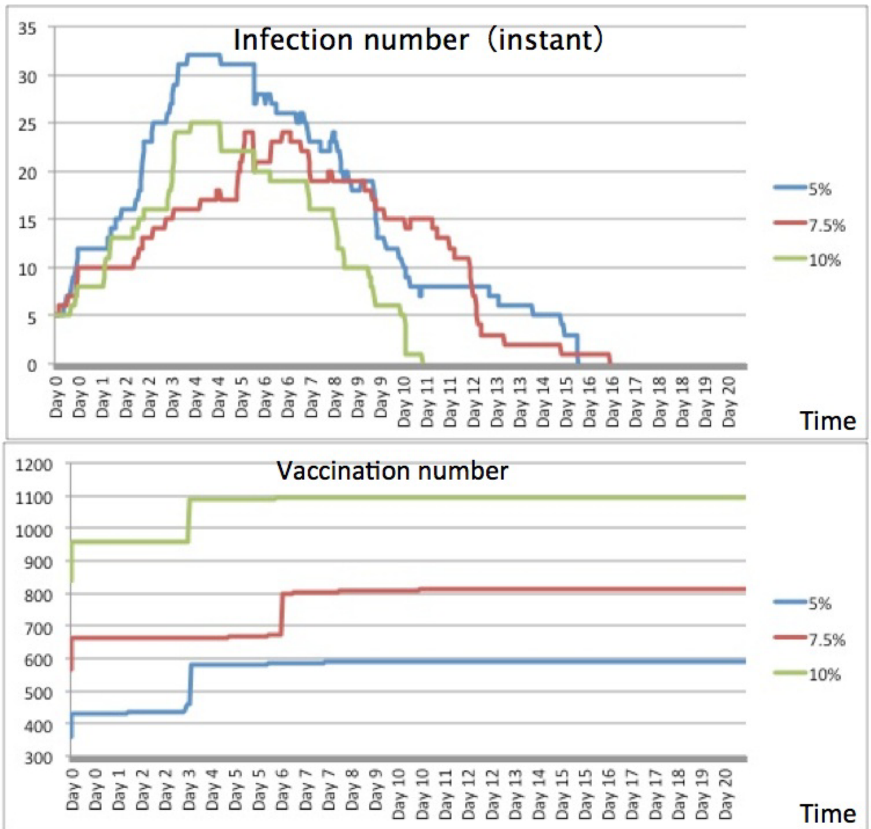


FIGURE 6.1: Epidemic transmission processes with different initial immunization coverage

Since expansion of infection is decided by the epidemic transmission root, it is hard to claim that small-scale transmission derives from high initial immunization coverage. However, different immunization coverage result in period delay in spread of epidemic disease on the social network obviously. According to the simulation result, the curve has a gentler slope from the beginning of infectious season to the first crest with the lager number of human agents in initial immunization group.

The main reason of the result is because conformity involves changing behavior of human agents in order to "fit in" or "go along" with the other agents around them. If a lot of agents take the same immunization behavior initially, social influence forces agents to act like the majority of inoculated agents.

6.2 Subsidy Amount, Epidemic Transmission Processes and Vaccination Coverage

Vaccination subsidy strives to provide financial support to a group of susceptible population and contributes to the improvement of vaccination coverage by enhancing immunization awareness for [Normal] agents. In this section, vaccination subsidy scenarios purpose to investigate the relationships between subsidy, vaccination intention and the corresponding behavior.

In the vaccination behavior modification mechanism, [Willing to Pay] is in charge of evaluating the expected payment for each individuals. Subsidy will release the economic burden from vaccination price so that promoting the motivation of inoculation.

In the subsidy amount scenarios, this research analyzes the efficacy of 4 types of subsidy amount, the new price of immunization is free, half price, regular price, and 1.5 times the regular price. The epidemic transmission processes and immunization coverage with different subsidy amount are shown as Figure. 6.2.

When the regular price goes down to half or free, immunization coverage at the beginning of the epidemic season increases. On account of high initial immunization rate, infectious disease doesn't spread and the period of epidemic season is

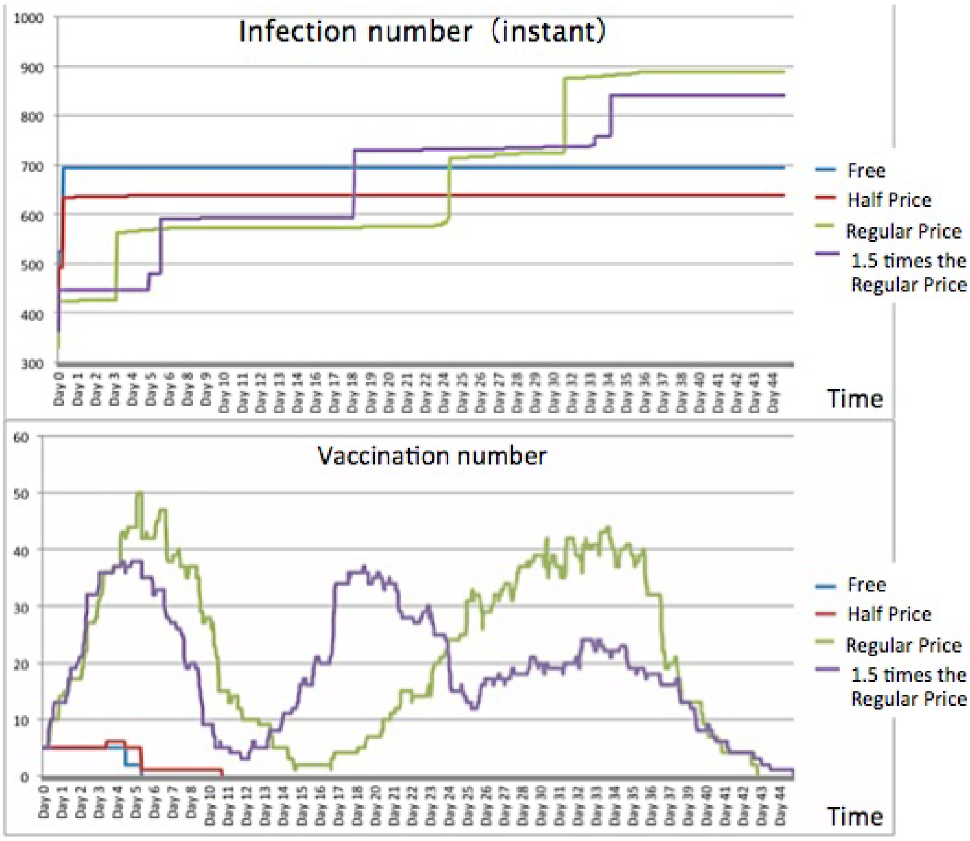


FIGURE 6.2: Epidemic transmission processes and immunization coverage with different subsidy amount

considerably reduced so that the number of immunization coverage tend to be stable, because there are no more need to get inoculation after the season finishes for agents.

Conversely if vaccination has risen in price, numbers of immunization population increases accompanying with the epidemic transmission processes. Specifically, the period of epidemic season of 1.5 times the regular vaccination price is longer than the regular one. However, the final immunization rate of 1.5 times the regular vaccination price is lower than regular one.

Besides, we found in Figure. 6.2 that, comparing with free vaccination, the simulation result about half price vaccination is considerable as well. From government point of view, they prefer for a way concerning with small investment that pays a big return. Therefore, we purpose to look for the tradeoff between regular price (3600yen) and half price (1800yen).

The vaccination prices from 50% one to regular one are classified as 60% price: 2160yen; 70% price: 2520yen; 80% price: 2880yen; 90% price: 3240yen. Figure. 6.3 , Figure. 6.5 , Figure. 6.7 and Figure. 6.9 represent ten possible situations of epidemic period and corresponding infection number and immunization coverage at each case of price. For each price scenario, epidemic transmission processes and immunization coverage of every result for the first 5 days are recorded in the following of the simulation result figures.

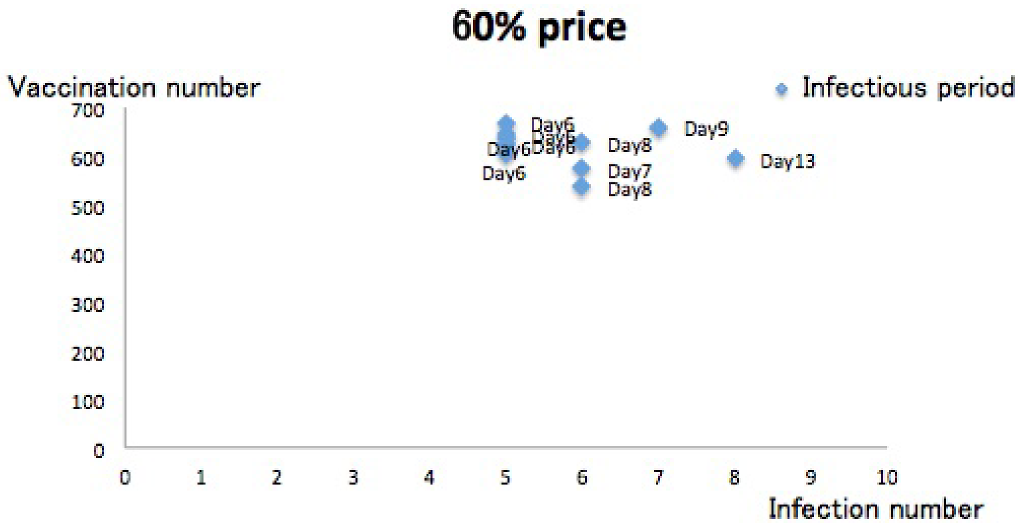


FIGURE 6.3: Simulation results of 60% price

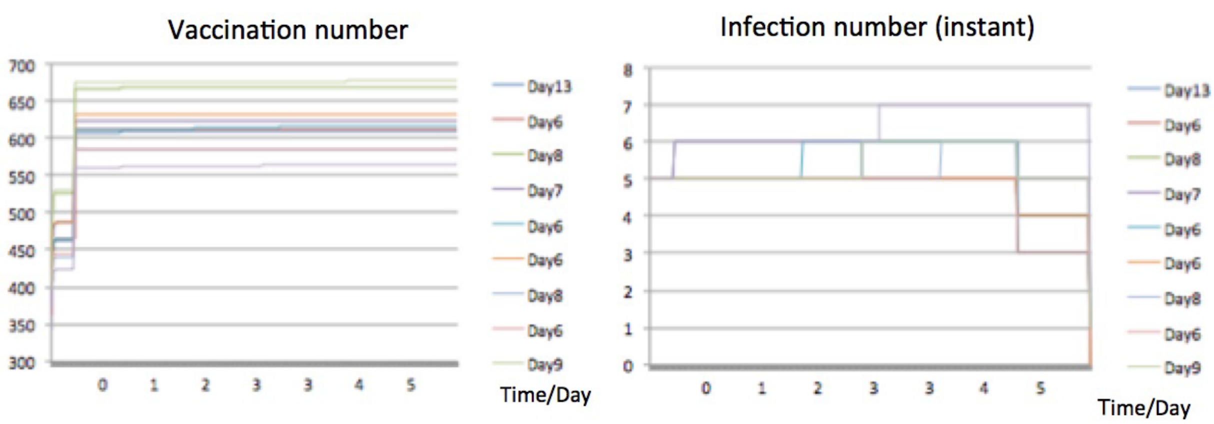


FIGURE 6.4: Epidemic transmission processes and immunization coverage of 60% price

- According to the simulation results, if there was no new infection number in the community, influenza would disappear after 6 days later, in other words, influenza should continue in the community at least 6 days.

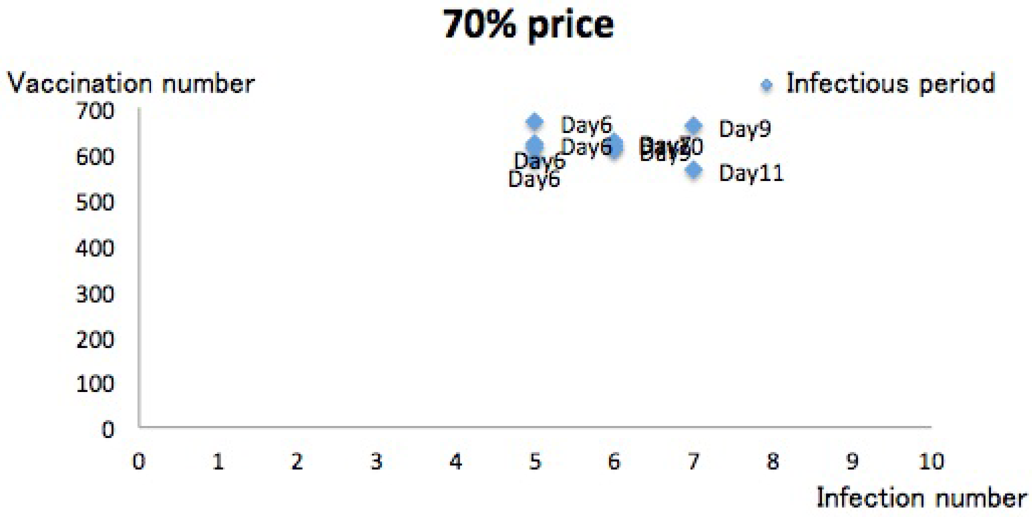


FIGURE 6.5: Simulation results of 70% price

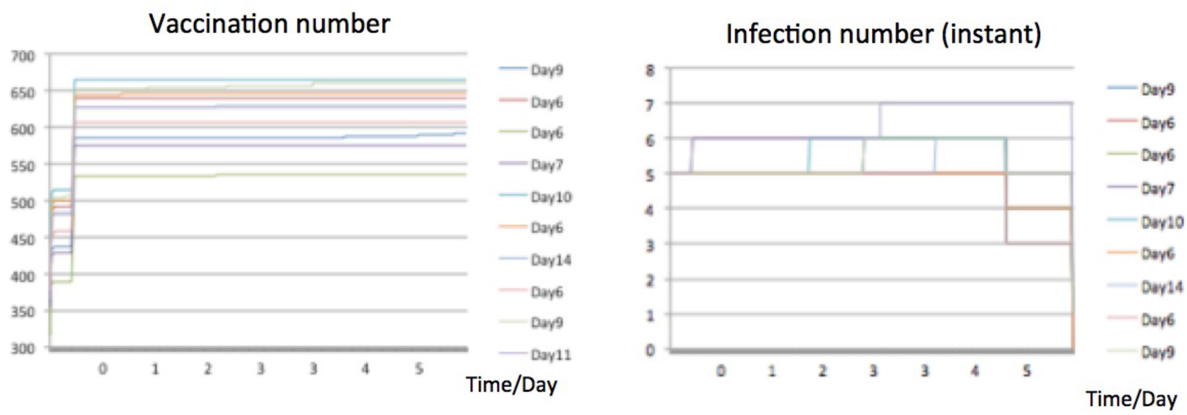


FIGURE 6.6: Epidemic transmission processes and immunization coverage of 70% price

- The average number of vaccinators of each scenario at the beginning of time 'Day0' is shown as follows.It is obvious that cheaper vaccine results in lager vaccinator number at the initial time from the result.

TABLE 6.1: Initial vaccinator number at 'Day0'

Scenario	60% price	70% price	80% price	90% price
Initial vaccinator number at 'Day0'	615.4	583.5	467.1	429.9

- In addition, when the price of vaccine went down until 60% and 70%, though five from ten times of results which influenza disappeared at 6 days in '60% case' while four from ten times of results which influenza disappeared at 6 days in '70% case', there was no apparent difference in both cases.

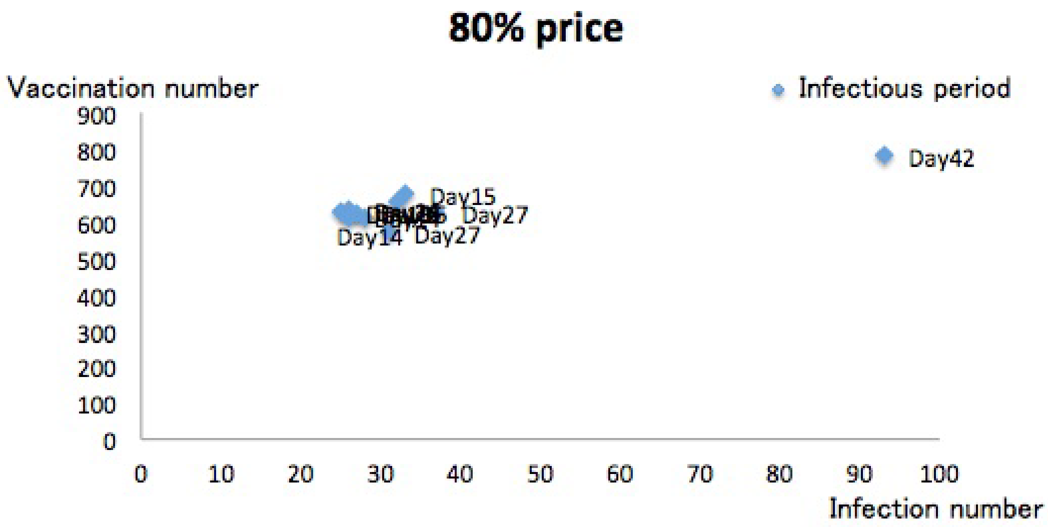


FIGURE 6.7: Simulation results of 80% price

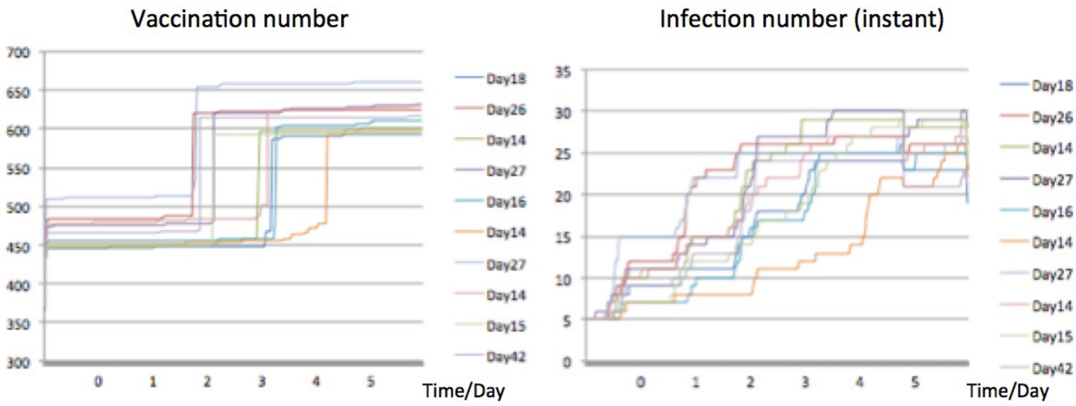


FIGURE 6.8: Epidemic transmission processes and immunization coverage of 80% price

However, average infectious period for result of 60% price is 7.5 days. Whereas average infectious period for result of 70% price is 8.4 days, which is relatively longer than cheaper price scenario.

- Comparing with '60% case' to '70% case', significant changes were seen in '80% case' and '90% case'. In particular, there was no 6 days infectious period when the reduction of vaccine price was over than 80% of regular price. Both infected agents number and infectious period were rapid increased comparing with '60% case' and '70% case'. The reason of such results concerns with the initial vaccinator number. More initial vaccinators can decrease the risk of diffusion of the disease, therefore, it is meaningful to get vaccination before

FIGURE 6.9: Simulation results of 90% price

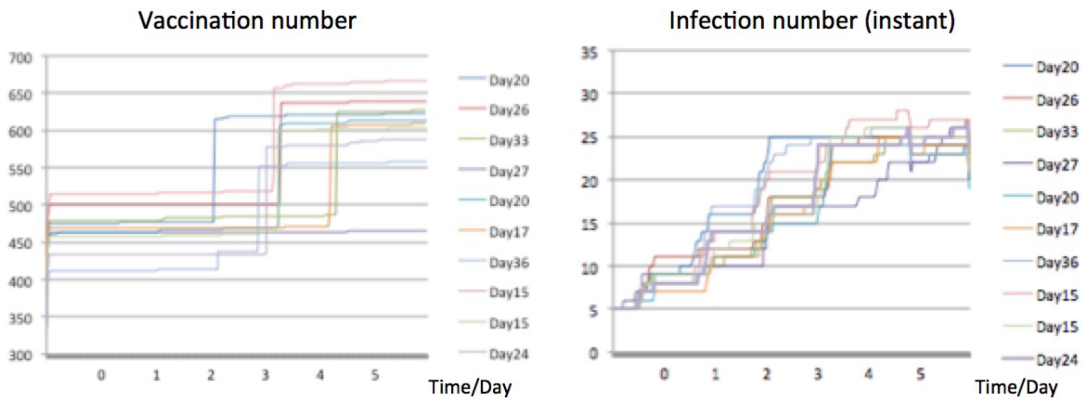


FIGURE 6.10: Epidemic transmission processes and immunization coverage of 90% price

infectious season.

Besides, it was notable that there was a special dot in Figure. 6.7. which meant that simulation result of "Day42" was also potential to happen in the reality even with the subsidy. Thus, we could draw conclusion that subsidy should be one of way to decrease the risk of disease transition as far as possible, but there must still be a lot of uncertain factor in infectious itself so that subsidy or another immunization policies could not be regarded as a panacea.

- Moreover, comparing with Figure. 5.1, which recorded the epidemic period, infection number and immunization coverage or regular one, discount in vaccine price could enlarge the immunization coverage and shorten epidemic period. Despite price of ’80% case’ and ’90% case’ didn’t earn results as good as price lower than 70%, effectiveness of immunization was much more stable than regular one. Therefore, the simulation results certificated that reduction of vaccine contributed to better management towards immunization system.

- In both ’70% case’ to ’80% case’, Results with infectious period ’Day14’ appeared several times. Though infectious period is the same for each result, total infection number and total vaccination number were different. Especially, in the result of ’70% case’, total infection number was less than all results in ’80% case’.

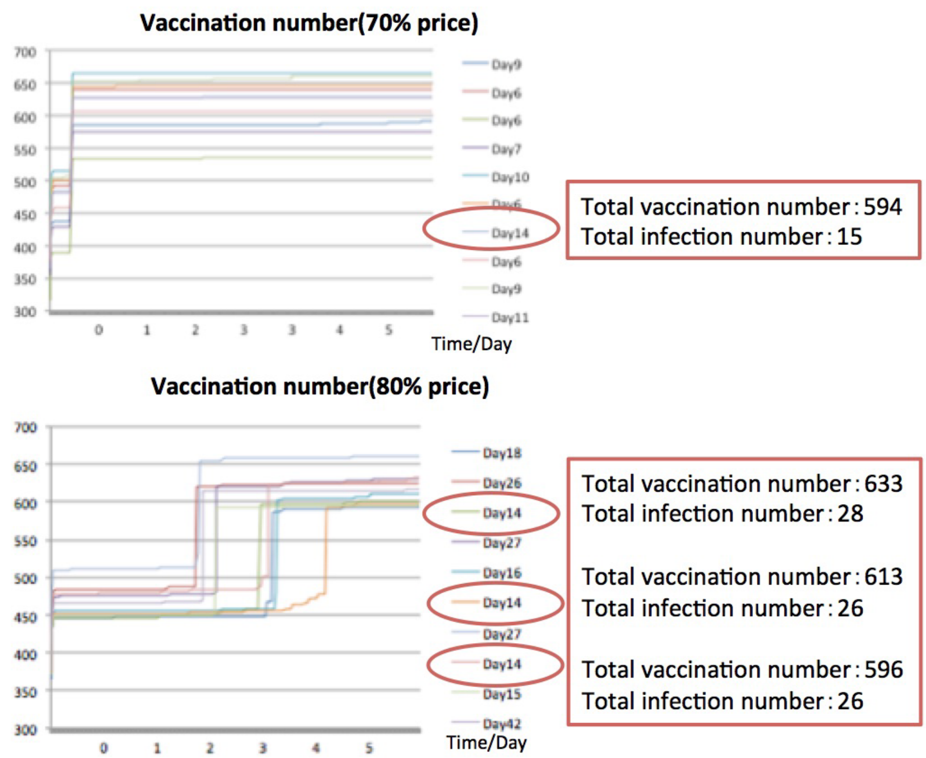


FIGURE 6.11: Results of infectious period ’Day14’

- At last, we took into consideration of immunization budget and infectious transition synthetically. Price between 70% and 80% was the best measure for immunization system with all due respect.

6.3 Subsidy for Different Group of People

In the previous section, we simulate the subsidy amount, in which the immunization price goes down to half. All agents in that scenario can enjoy half price indiscriminately. Unlike the previous setting, we specify these 5% people for several special groups: child (Primary school students and children in kindergarten), teenager (middle school students and high school students), elderly (people over 65 years old), and calculate the total immunization numbers for different age of agents. Number of immunization agents with half-price subsidy is shown as Figure. 6.12.

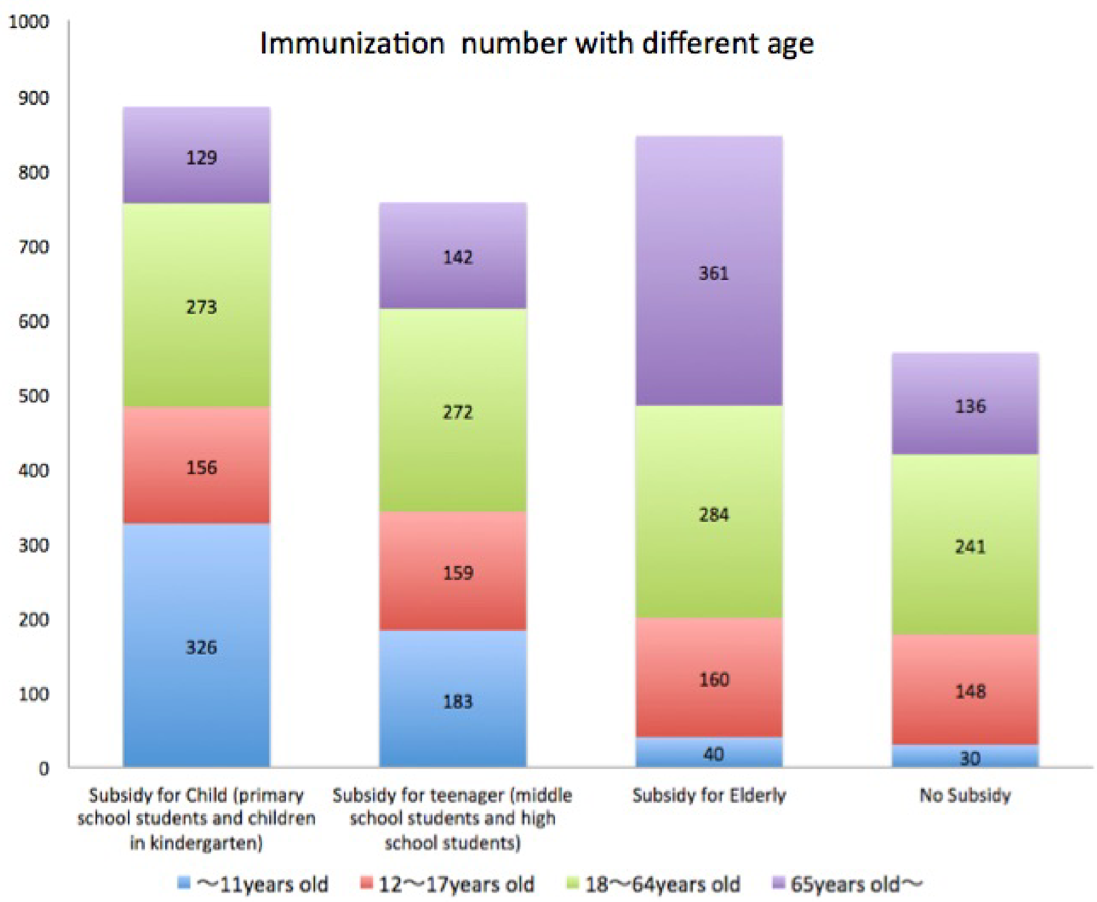


FIGURE 6.12: Immunization number with different age under half-price subsidy

Fig. 6.12 implies that subsidy can promote immunization awareness of for individuals, who are the target of the subsidy. Since different target groups lead to different immunization coverage, Selection of target group is a big mission for subsidy decision maker. In the simulation result. Immunization rate of teenagers doesn't present conspicuous difference even when teenagers are the target group of subsidy, which is because epidemic breakouts in high school, increasing students vaccinator will shorten epidemic period. Besides, comparing with indiscriminate result, pandemic immunization campaign or subsidy for a specific group of population would change the whole immunization coverage.

The simulation results about the pre-estimate of subsidies efficacy suggest that reasonable subsidy tend to promote vaccination behavior modification and gives decision support to assess the relative impact of public health services for pandemic control. Reasonable subsidy is available for increase in immunization rate as well as disease control.

6.4 Subsidy and Budget Proposals

Though subsidy policies are able to promote the vaccination coverage and effective in controlling the transmission of infectious diseases, budget proposals of healthcare project will reduce outlays for subsidies and administrative costs. Thus the goal of subsidy policies is to improve cost-effectiveness instead of enlarging the investment on subsidy even beyond the limited budget proposals.

In the specific area Oshima, which is our research subject, the budget proposals for healthcare programs is 1,720,000 yen in 2015 according to the draft budget of Oshima in 2015. We assume immunization project will take 1/3 part of draft budget in the whole healthcare budget proposals. Considering pandemic immunization campaign always prefers to provide vaccination to school students in real case, we also purpose to make use of the 1/3 budget to teenager vaccination subsidy policy in this work. As typical case studies, we estimate the immunization efficacy of forced vaccination and compare the result in middle school and high school(Figure 6.13).

In the model, there are 126 middle school students and 153 high school students in

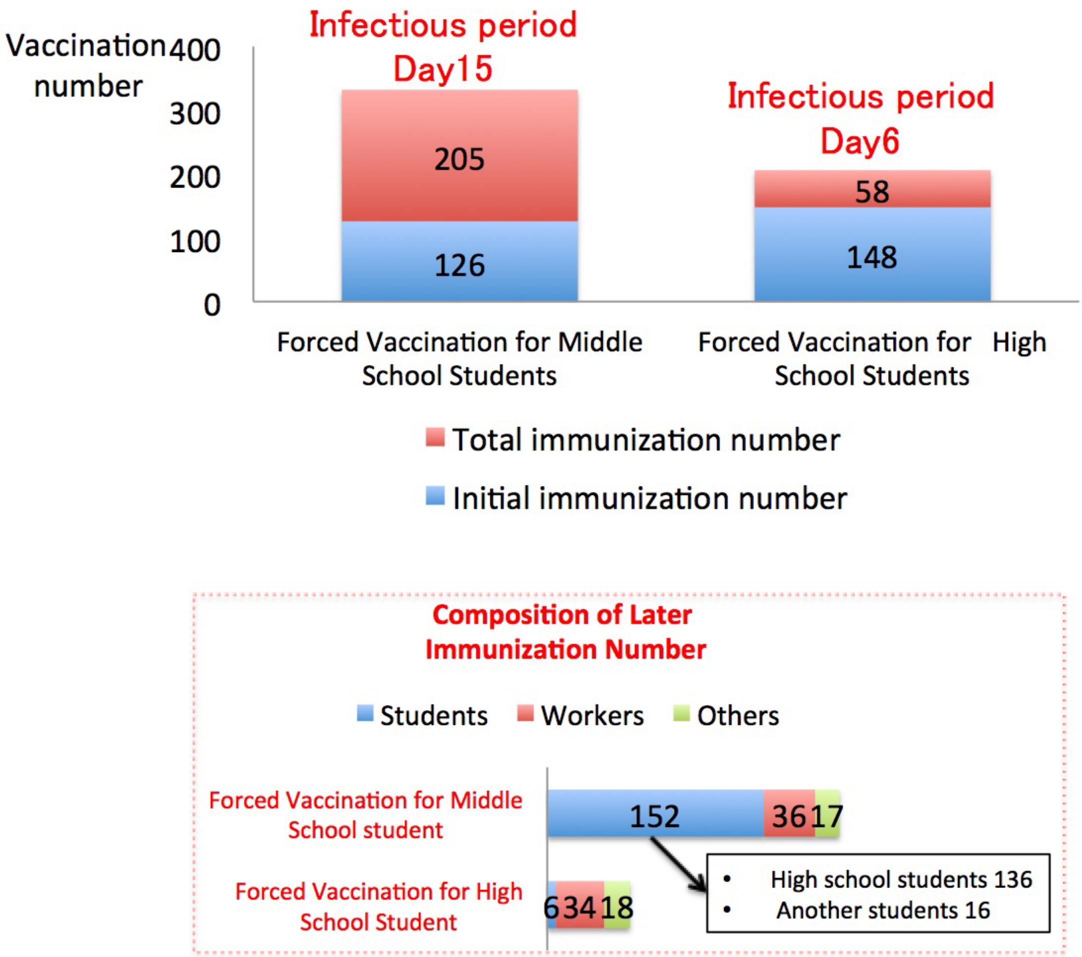


FIGURE 6.13: 2 typical cases: forced vaccination in middle school and high school

Oshima. Since pandemic start from the unique high school and 5 students are infected at the initial step, initial immunization number in high school is 148. Mandatory vaccination for high school students will cost 30.98% from the whole healthcare draft budget, while mandatory vaccination for middle school students is 26.37%. Since the upper limit of cost is 1/3, both of mandatory subsidy policies will fit the bill and nearby 1/3.

In both cases, pandemic doesn't spread in the whole city and disappear in a relatively short time. Since pandemic starts from the high school students, pandemic season could stop quickly when high school student get vaccination.

Moreover, the immunization actions of 126 middle school students affect 205 acquaintances to get the same immunization action as them. Especially 152 from 205 vaccinators are students. Whereas vaccination diffusion deriving from high school students is not influential as middle school students on account of short pandemic period and great risk cognitive on high school students in pandemic season.

Chapter 7

Conclusions and Implication

7.1 Concluding Remarks

This thesis generated a pandemic immunization model and analyzed the influence of immunization awareness diffusion on an overall social network architecture. We carried out an agent-based simulation approach to construct an intimacy-based social network model and introduce an pandemic immunization model to evaluate the vaccination awareness of individuals in the network by considering risk cognition, and subjective norms in a comprehensive manner. The simulation provided an effective strategy involving estimation and heuristics of healthcare behaviors. Moreover, by introducing scenarios about vaccination policies for improving healthcare service, the model suggested that reasonable subsidy tend to promote vaccination behavior modification and gives decision support to assess the relative impact of public health services for pandemic control. Specifically, immunization awareness diffusion and immunization decision-making process of each human in the constructed social network are shown in this paper. As a result, the model suggests that structure of social network is a great influence on pandemic immunization campaign.

The contributions of this thesis are listed as follows.

- This work introduced an approach to generate a social network model with agent-based simulation method. For one thing, this research applied the data analysis result about personal networks on a geography-based virtual city model for generating a social network. Since this social network generation approach used the statistical data, the results about the city structure, population location and intimacy between human agents could certainly match statistics in reality on macro-level. On micro-level, it is very difficult to compare the results with real data, because it is almost impossible to know all activities between acquaintances, which is one of the limitations of this approach. In the paper, we used the approach to generate a social network for a specific Oshima city. Since the number of agents and their home location and social institution in the model were fixed as the real oshima city, the city population density and relation between agents approximated reality.

- For another, as an application of the constructed social network model, this thesis carried out an agent-based simulation method to construct a pandemic immunization model and analyze the influence of immunization decision-making process in self-awareness and attitudes toward vaccination during social interaction. In the immunization decision-making part, this research inherited the paradigm of preventive behavior modification, and constructed the schematic of vaccination behavior mechanism. Then by applying the variables of the constructed mechanism in pandemic immunization model, we gave a micro insight for a personal relationship network and its status during pandemic season. As a result, we claimed structure of social network play an essential role in vaccination diffusion.

- Furthermore, comparing to the most literatures, this thesis focused on the subjective performance, and gave a micro insight for personal vaccination behavior from social psychological point of view. We interpret a subjective level as an outcome that takes a special position in the decision process. This work also presented necessary and sufficient conditions under which the overall probability of immunization is more important than the overall probability of unimmunization for individual. As a simulation result, we concluded that the sense of impending crisis towards pandemic transmission can enhance vaccine acceptance, which also contributes to immunization coverage.

- Finally, based on the acknowledgement about immunization psychology, we analyzed the relationship between human vaccination behavior modification and influence from tendency of infectious, vaccination subsidy and social norms. As a result,, we verify that influenza subsidy vaccination plays an important role in increase of immunization coverage. According to our model, the price of vaccine was of critical significance and operates the inoculation decision-making of people. The simulation results suggested that reasonable subsidy tend to promote vaccination behavior modification and gives decision support to assess the relative impact of public health services for pandemic control.

7.2 Future Research

There are still many potential future works left to be explored and carried out to advance our understanding of this field. In the following, some major ones are proposed. The future work of this research are listed in the following.

- Though we analyzed social network from a country level, we could not generate the whole social network of Japan in this research. Because (1) there are some technical limitations (such as storage capacity and computing power, etc.); (2) geography based census and city survey are not complete for all cities in Japan; (3) the whole network and social structure in Japan are quite complicated. Therefore, we considered using a representative example to explain our approach.

  The example we generated was Oshima. We chose this city because our research group had a long project with oshima so that we could get details of the city survey, which made the virtual Oshima model convincible. In the future, except Oshima, we can also achieve another social network models and immunization systems for another cities with the same approach we introduced in this thesis. Specifically, since General Social Survey is being implemented in more than 30 countries, it is possible to apply the research approach to another countries or cities beside Japan.

- In the current setting, for children under 18 years old, efficiency of social norms in immunization behavior modification process can only be effected by their families. There is no doubt influence from families is one of the major factor for behavior intention of children. However, education and social circumstance also should also be taken into account.

  Meanwhile, even for children under 18 years old, the influence from parents or families are relatively wrong. For example, primary students obey the command from families, whereas high school students are more likely to follow their own thinking instead of being subordinate to the outer circumstance. Therefore, children under 18 years old can be categorized more particularly.

- In the current immunization system model, all individual agents can accept vaccination if their behavior intention satisfy the condition to be inoculated. On account of the limitation in vaccination resource and financial stress, the conflict between immunization behavior and behavioral intention cannot be ignored in the future work.

- Besides, though we argued the correct recognition is important for immunization and government should enhance the correct understanding towards vaccination of residents by the enforcement of subsidy, we just focus on the contents of subsidy itself instead of the propaganda effect of subsidy. Similarly, propaganda effect from social media are also ignored in this thesis.

  To make up this deficiency, social media and government can be considered as elements in the whole social network. They connect with all individual agents on terms of intimacy and hold a great leadership in the immunization system. The promotion of immunization from them will lead to diffusion in the population-wide social network in the form of propaganda effect.

- In the future, we plan to estimate the economic impact of immunization subsidy. Vaccine is viewed as a special commodity, and government can manage the price and the total number of supply. Considering limited vaccination resource and economic burden, government may do not need to provide the free vaccine for all. But government can control the consumption by enforce the vaccination subsidy. Since setting the vaccination subsidy is a pattern of investment, there is a trade-off relationship between the investment and possible immunization coverage change. Such investment can fulfill the balance with vaccination rate.

- Finally, unlike the normal commodity, vaccine is special product not only in relationship with the awareness of purchasing, but also deeply associated with the protection motivation for health and dilemma with other susceptible individuals. For example, epidemiological studies of influenza indicate that elderly individuals, who face the highest mortality risk, are best protected by vaccination of young individuals, who contribute most to disease transmission. In forward planning, we will consider the effect of altruism behavior in decision-making process and how to promote altruistic behaviors by subsidy.

Appendix A

Statistic of human types in Oshima

- Sex:

  male=1; female: sexx=2;

- Age:

  twenties=2; thirties=3; forties=4; fifties=5; sixties=6; beyond seventies=7;

- Marital Status:

  married=1; unmarried=2;

- Job:

  worker=1; retired=2; student=3; house worker (housewife)=4; others: jobb=5;

- Household type

  one-person household=1; two-person household=2; three-person household=3; four-person household=4; five-person household=5;

  more than six-person household=6

TABLE A.1: Statistic of human types in Oshima

Sex	Age	Marital Status	job	Household type	Number of people
1	2	1	1	2	19
1	2	1	1	3	15
1	2	1	1	4	8

1	2	1	1	5	3
1	2	2	1	1	60
1	2	2	1	3	32
1	2	2	1	4	24
1	2	2	1	5	29
1	2	2	2	6	1
1	2	2	2	1	1
1	2	2	5	3	3
1	2	2	5	4	5
1	2	2	5	5	1
1	3	1	1	2	42
1	3	1	1	3	79
1	3	1	1	4	46
1	3	1	1	5	23
1	3	1	2	6	3
1	3	1	2	1	5
1	3	2	1	1	104
1	3	2	1	3	74
1	3	2	1	4	31
1	3	2	1	5	52
1	3	2	2	6	1
1	3	2	5	3	11
1	3	2	5	4	10
1	3	2	5	5	10
1	4	1	1	6	1
1	4	1	1	2	77
1	4	1	1	3	99
1	4	1	1	4	58

1	4	1	1	5	31
1	4	1	2	6	2
1	4	1	2	1	4
1	4	2	1	1	132
1	4	2	1	3	34
1	4	2	1	4	17
1	4	2	1	5	24
1	4	2	2	6	1
1	4	2	5	3	5
1	4	2	5	4	5
1	4	2	5	5	9
1	5	1	1	2	163
1	5	1	1	3	103
1	5	1	1	4	46
1	5	1	1	5	15
1	5	1	2	6	1
1	5	1	2	1	2
1	5	2	1	1	183
1	5	2	1	3	29
1	5	2	1	4	19
1	5	2	1	5	14
1	5	2	5	3	6
1	5	2	5	4	2
1	5	2	5	5	7
1	6	1	1	6	1
1	6	1	1	2	148
1	6	1	1	3	35
1	6	1	1	4	20

1	6	1	1	5	14
1	6	1	2	2	147
1	6	1	2	3	26
1	6	1	2	4	18
1	6	1	2	5	15
1	6	1	3	1	1
1	6	2	1	1	77
1	6	2	1	3	33
1	6	2	1	4	8
1	6	2	1	5	6
1	6	2	2	6	1
1	6	2	2	1	64
1	6	2	2	3	27
1	6	2	2	4	5
1	6	2	2	5	3
1	6	2	3	6	1
1	6	2	5	3	4
1	6	2	5	4	3
1	6	2	5	5	1
1	7	1	2	2	230
1	7	1	2	3	53
1	7	1	2	4	35
1	7	1	2	5	17
1	7	1	3	6	2
1	7	1	3	1	4
1	7	2	2	1	85
1	7	2	2	3	17
1	7	2	2	4	6

1	7	2	3	6	1
2	2	1	1	2	21
2	2	1	1	3	21
2	2	1	1	4	5
2	2	1	1	5	2
2	2	1	2	2	124
2	2	1	2	3	19
2	2	1	2	4	22
2	2	1	2	5	14
2	2	1	3	1	3
2	2	1	4	2	3
2	2	1	4	3	1
2	2	1	4	4	2
2	2	1	5	1	1
2	2	2	1	1	44
2	2	2	1	3	26
2	2	2	1	4	14
2	2	2	1	5	20
2	2	2	2	1	39
2	2	2	2	3	10
2	2	2	2	4	3
2	2	2	5	3	2
2	2	2	5	4	5
2	2	2	5	5	2
2	3	1	1	2	53
2	3	1	1	3	79
2	3	1	1	4	50
2	3	1	1	5	21

2	3	1	2	6	2
2	3	1	2	1	3
2	3	1	2	2	75
2	3	1	2	3	17
2	3	1	2	4	8
2	3	1	2	5	19
2	3	1	3	1	1
2	3	1	4	2	10
2	3	1	4	3	11
2	3	1	4	4	9
2	3	1	4	5	4
2	3	1	5	1	1
2	3	2	1	1	48
2	3	2	1	3	44
2	3	2	1	4	25
2	3	2	1	5	44
2	3	2	2	1	24
2	3	2	2	3	12
2	3	2	2	4	5
2	3	2	3	6	1
2	3	2	5	3	10
2	3	2	5	4	4
2	3	2	5	5	6
2	4	1	1	6	1
2	4	1	1	2	82
2	4	1	1	3	81
2	4	1	1	4	39
2	4	1	1	5	33

2	4	1	2	6	3
2	4	1	2	1	4
2	4	1	4	2	16
2	4	1	4	3	10
2	4	1	4	4	11
2	4	1	4	5	1
2	4	2	1	1	43
2	4	2	1	3	39
2	4	2	1	4	15
2	4	2	1	5	18
2	4	2	2	6	1
2	4	2	5	3	9
2	4	2	5	4	2
2	4	2	5	5	2
2	5	1	1	2	184
2	5	1	1	3	78
2	5	1	1	4	36
2	5	1	1	5	14
2	5	1	2	6	1
2	5	1	2	1	2
2	5	1	4	2	24
2	5	1	4	3	9
2	5	1	4	4	5
2	5	1	4	5	1
2	5	2	1	1	91
2	5	2	1	3	31
2	5	2	1	4	10
2	5	2	1	5	14

2	5	2	5	3	4
2	5	2	5	4	1
2	5	2	5	5	1
2	6	1	1	2	128
2	6	1	1	3	30
2	6	1	1	4	20
2	6	1	1	5	18
2	6	1	2	1	1
2	6	1	2	2	148
2	6	1	2	3	29
2	6	1	2	4	21
2	6	1	2	5	17
2	6	1	3	6	1
2	6	1	3	1	1
2	6	1	4	2	20
2	6	1	4	3	2
2	6	1	4	4	2
2	6	1	4	5	2
2	6	1	5	4	1
2	6	2	1	1	71
2	6	2	1	3	39
2	6	2	1	4	3
2	6	2	1	5	8
2	6	2	2	1	83
2	6	2	2	3	32
2	6	2	2	4	5
2	6	2	2	5	4
2	6	2	3	6	1

2	6	2	5	3	10
2	6	2	5	5	1
2	7	1	2	2	191
2	7	1	2	3	49
2	7	1	2	4	33
2	7	1	2	5	22
2	7	1	3	1	5
2	7	2	2	1	190
2	7	2	2	3	54
2	7	2	2	4	10
2	7	2	2	5	7
2	7	2	3	6	2

Bibliography

[1] Nakayama, Tetsuo. "Vaccine chronicle in Japan." Journal of Infection and Chemotherapy 19.5 (2013) p:787-798.

[2] Hiroaki Nobuhara, Yumi Watanabe, Yoshihiko Miura. "Estimated influenza vaccination rates in Japan." Japanese Journal of Public Health Vol. 61 No.7 (2014) p:354-359.

[3] Makoto Ono and Kei Numazaki. "Guardian attitude survey on voluntary pediatric vaccines. " Japanese Journal of Chemotherapy. 58 (5) (2010) p:555-559.

[4] Haverkate, M., et al. "Mandatory and recommended vaccination in the EU, Iceland and Norway: results of the VENICE 2010 survey on the ways of implementing national vaccination programmes." Robert Koch-Institut, Infektionsepidemiologie (2012).

[5] Yasushi Ohkusa, et al. "Varricela vaccination policy subsidy evaluation." The Journal of the Japanese Association for Infectious Diseases 84.2 (2010) p:159-164.

[6] Shono, Aiko, and Masahide Kondo. "Factors that affect voluntary vaccination of children in Japan." Vaccine 33.11 (2015) p:1406-1411.

[7] Kelly, Robert B., Stephen J. Zyzanski, and Sonia A. Alemagno. "Prediction of motivation and behavior change following health promotion: Role of health beliefs, social support, and self-efficacy." Social science & medicine 32.3 (1991) p: 311-320.

[8] Janz, Nancy K, and Marshall H. Becker "The health belief model: A decade later." Health Education & Behavior 11.1, (1984) pp.1-47.

[9] Yoko Kobayashi "Factors influencing female high-school students' intention to receive the human papilloma virus vaccine : An investigation using the health belief model (Japanese)." Journal of Educational Research No.31, (2015) p:13-26.

[10] Aho WR. "Participation of senior citizens in the Swine Flu inoculation program: An analysis of health belief model variables in preventive health behavior." Journal of Gerontology 34.2, (1979) p:201-208.

[11] Cummings KM, Jette AM, Brock BM, et al. "Psychosocial determinants of immunization behavior in a Swine Influenza campaign." Medical Care 17.6, (1979) p:639-649.

[12] Rundall TG, Wheeler JRC. "Factors associated with utilization of the Swine Flu vaccination program among senior citizens." Medical Care 17.1, (1979) p:191-200.

[13] Larson EB, Olsen E. Cole W, et al. "The relationship of health beliefs and a postcard reminder to influenza vaccination." The Journal of family practice 8.6, (1979) p:1207-1211.

[14] Yasushi Ohkusa. "An analysis of the demand for influenza vaccination among the elderly in Japan (Japanese)", Japanese Journal of Public Health Vol. 50, No. 1, (2003) p:27-38.

[15] Fishbein, M., Ajzen, I. "Belief, Attitude, Intention, and Behavior: An Introduction to Theory and Research." MA: Addison-Wesley. (1975).

[16] Ajzen, I., Fishbein, M. "Understanding attitudes and predicting social behavior. Englewood Cliffs", NJ: Prentice-Hall, (1980).

[17] Moreno, Jacob L., and Helen H. Jennings. "Statistics of social configurations."Sociometry (1938) p:342-374.

[18] Barnes, John A. "Graph theory and social networks: A technical comment on connectedness and connectivity." Sociology 3.2, (1969) p:215-232.

[19] Hamill, Lynne, and Nigel Gilbert. "Simulating large social networks in agent-based models: A social circle model." Emergence: Complexity and Organization 12.4, (2010) p:78-94.

[20] Fowler, James H., and Nicholas A. Christakis. "Cooperative behavior cascades in human social networks." Proceedings of the National Academy of Sciences 107.12 (2010) p:5334-5338. .

[21] Holyoak, Keith J., and Peter C. Gordon. "Social reference points." Journal of Personality and Social Psychology 44.5 (1983) p:881.

[22] Sox, Harold C., and Michael C. Higgins. "Medical decision making." ACP Press, (1988).

[23] Podgorelec, Vili, et al. "Decision trees: an overview and their use in medicine." Journal of medical systems 26.5 (2002) p:445-463.

[24] Champion, Victoria L., and Celette Sugg Skinner. "The health belief model." Health behaviour and health education; theory, research, and practice (2008) p:45-65.

[25] Nexoe, Jorgen, Jakob Kragstrup, and Jes Sogaard. "Decision on influenza vaccination among the elderly: A questionnaire study based on the Health Belief Model and the Multidimensional Locus of Control Theory." Scandinavian journal of primary health care 17.2 (1999) p:105-110.

[26] Artemis D. Avgerou, Yannis C. Stamatiou, "Privacy Awareness Diffusion in Social Networks", IEEE Security & Privacy, vol.13, no. 6, (2015) p:44-50.

[27] Doner, Lynne. Marketing public health: Strategies to promote social change. Jones & Bartlett Learning, (1998).

[28] Valente, Thomas W. Thomas W. Network models of the diffusion of innovations. No. 303.484 V3. (1995).

[29] Cain, Mary, and Robert Mittman. Diffusion of innovation in health care. Oakland CA: California Healthcare Foundation, (2002).

[30] Gaba, David M. "The future vision of simulation in health care." Quality and safety in Health care 13.suppl 1 (2004) p:i2-i10.

[31] Rwashana, AGNES SEMWANGA, and Ddembe Wileese Williams. "Modeling the dynamics of immunization healthcare systems-the Ugandan case study." The 26th International Conference of the System Dynamics Society; July 20-July. Vol. 24. (2008).

[32] Arman Kussainov."Use of system dynamics and simulation in modeling and analysis of vaccine supply chain management", Information technology, management and society 8(1) (2015) p:32-37.

[33] Koelling, Patrick, and Michael J. Schwandt. "Health systems: A dynamic system-benefits from system dynamics." Simulation Conference, 2005 Proceedings of the Winter. IEEE, (2005).

[34] Liu, Fengchen, et al. "The role of vaccination coverage, individual behaviors, and the public health response in the control of measles epidemics: an agent-based simulation for California." BMC public health 15.1 (2015).

[35] Deguchi. "Agent Based Approach for Social Complex Systems - Management of Constructed Social World." In Toru Ishida Ed., Community Computing and Support Systems LNCS 1519, Springer, (1998) p:62-77.

[36] Strand, Espen, Geir Huse, and Jarl Giske. "Artificial evolution of life history and behavior." The American Naturalist 159.6 (2002) p:624-644.

[37] Grimm, Volker, et al. "A standard protocol for describing individual-based and agent-based models." Ecological modelling 198.1 (2006) p:115-126.

[38] Ichikawa, Manabu, Yuhsuke Koyama, and Hiroshi Deguchi. "Virtual city model for simulating social phenomena." Simulating Interacting Agents and Social Phenomena, Springer Japan (2010) p:253-264.

[39] Deguchi, H., Kanatani, Y., Kaneda, T., Koyama, Y., Ichikawa, M., Saito, T.,

Tanuma, H. "Agent Based Epidemiological Simulation for Pandemic Protection of Emerging and Re-emerging Infectious Diseases". In Proceedings of the 51st Annual Meeting of the ISSS-2007, Vol. 51, No. 2 Tokyo, Japan (2007).

[40] Ichikawa, Manabu, Hideki Tanuma, and Hiroshi Deguchi. "Infectious Disease Simulation Model for Estimation of Spreading." Development in Business Simulation and Experimental Learning 38 (2011) p:358-366.

[41] Ichikawa, M., Hiroshi Deguchi, H. "System of Virtual City Constructing Environment for Social Simulation. "(in Japanese) Proceedings of The Sociey of Instrument and Control Engineers, 7th Symposium of Technical Committee on Social Systems, (2014) p:91-94.

[42] Inamasu, T., Sudo, K., Kato, S., Deguchi, H., Ichikawa, M., Shimizu, T., Saito, T. "Pandemic Influenza Virus Surveillance, Izu-Oshima Island, Japan." Emerg Infect Dis 18 (2012) p:1882-1885.

[43] Hiroshi Deguchi, Tomoya Saito, Manabu Ichikawa, Hideki Tanuma. "Simulation Tabletop Exercise for Risk Management Anti Bio-terorism Multi Scenario Simulated Tabletip Exercise." Annual Conference for the Association for Business Simulation and Experiential Learning, Published in the Developments in Business Simulation and Experiential Learning, Volume 38 (2011).

[44] Wasserman, Stanley, and Garry Robins. "An introduction to random graphs, dependence graphs, and p." Models and methods in social network analysis 27 (2005) p:148-161.

[45] Airoldi, Edoardo M., and Kathleen M. Carley. "Sampling algorithms for pure network topologies: a study on the stability and the separability of metric embeddings." ACM SIGKDD Explorations Newsletter 7.2 (2005) p:13-22.

[46] Lusher, Dean, Johan Koskinen, and Garry Robins, eds. Exponential random graph models for social networks: Theory, methods, and applications. Cambridge University Press, (2012).

[47] Molina, Jose Luis, Carlos Lozares, and Miranda J. Lubbers. "The Geographical Distribution of the Personal Networks of People Living in Catalonia: a dual society." GRAFO working papers 1 (2012) p:1-19.

[48] Axhausen, Kay W. "Social networks, mobility biographies, and travel: survey challenges." Environment and planning. B, Planning & design 35.6 (2008) p:981-996.

[49] Van den Berg, Pauline, Theo A. Arentze, and Harry JP Timmermans. "Size and composition of ego-centered social networks and their effect on geographic distance and contact frequency." Transportation Research Record: Journal of the Transportation Research Board 2135.1 (2009) p:1-9.

[50] Battiston, B., Walter, F.E., Schweitzer, F. "Impact of Trust on the Performance of a Recommendation System in a Social Network." In: W Proceedings of the Fifth International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS ’06). Hakodate, Japan, (2006).

[51] Yang, H.-L., Yang, H.-F. "Recommender agent based on social network." In: Okuno, H.G., Ali, M. (eds.) IEA/AIE 2007. LNCS (LNAI), vol. 4570, Springer, Heidelberg, (2007) p:943-952.

[52] Arentze, Theo, and Harry Timmermans. "Social networks, social interactions, and activity-travel behavior: a framework for microsimulation." Environment and Planning B: Planning and Design 35.6 (2008) p:1012-1027.

[53] Eubank, Stephen, Kumar, V. S., Marathe, M. V., Srinivasan, A., Wang, N.l. "Structural and algorithmic aspects of massive social networks." Proceedings of the fifteenth annual ACM-SIAM symposium on Discrete algorithms. Society for Industrial and Applied Mathematics, (2004) p:718-727.

[54] Eubank, Stephen, Guclu, H., Kumar, V. A., Marathe, M. V., Srinivasan, A., Toroczkai, Z., Wang, N. "Modelling disease outbreaks in realistic urban social networks." Nature 429.6988 (2004) p:180-184.

[55] Arentze T A, van den Berg P, Timmermans H J P, " Modeling social networks in geographic space: approach and empirical application " Environment and Planning A 44 (2012) p:1101-1120.

[56] Burt, Ronald S. "Network items and the general social survey." Social networks6.4 (1984) p:293-339.

[57] Lin, Nan, and Mary Dumin. "Access to occupations through social ties." Social networks 8.4, (1986) p:365-385.

[58] J.Shettyand J,Adibi, "Important Nodes Through Graph Entropy the case of Enron Email Database." in Proceedings of the 3rd International Workshop on Link Discovery,(2005) p:74-81.

[59] Ichikawa, Manabu, et al. "SOARS: introduction as a social microscope for simulations of social interactions and gaming." Organizing and Learning through Gaming and Simulation Proceedings of ISAGA 2007 (2007) p:149-158.

[60] Tanuma, H., Deguchi, H., Shimizu, T, "SOARS: Spot Oriented Agent Role Simulator - Design and Implementation," Agent-Based Simulation: From Modeling Methodologies to Real-World Applications, (2005) p:1-15.

[61] Hu, Yifan. "Efficient, high-quality force-directed graph drawing." Mathematica Journal 10.1 (2005) p:37-71.

[62] Bastian, M., Heymann, S., Jacomy, M, " Gephi: an open source software for exploring and manipulating networks. " ICWSM, (2009) p:361- 362.

[63] Doswell, Willa M., et al. "Testing the theory of reasoned action in explaining sexual behavior among African American young teen girls." Journal of pediatric nursing 26.6 (2011) p:e45-e54.

[64] Montano, Daniel E., et al. "Theory of reasoned action, theory of planned behavior, and the integrated behavioral model." Health behavior: Theory, research and practice (2008).

[65] Roberto, Anthony J., et al. "Predicting pediatricians' communication with parents about the human papillomavirus (HPV) vaccine: an application of the theory of reasoned action." Health communication 26.4 (2011) p:303-312.

[66] Fishbein, Martin. "The role of theory in HIV prevention." AIDS care 12.3 (2000) p:273-278.

[67] Montano, Daniel E., and Stephen H. Taplin. "A test of an expanded theory of reasoned action to predict mammography participation." Social science & medicine 32.6 (1991) p:733-741.

[68] Kanatani Y, Deguchi H, Saito T. "The Project Analysis and Pandemic Preparedness Program against New Type Influenza."(Japanese) The Operation Research Society of Japan 53(12) (2008) p:667-671.

[69] Yasushi Ohkusa. "Policy evaluation for the subsidy for influenza vaccination in elderly." Vaccine; 23(17-18):22 (2005) p:56-60.