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HUMAN BEHAVIORAL CHANGES AND ITS IMPACT IN DISEASE MODELING

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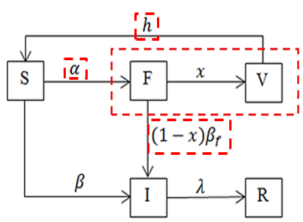
Graphical abstract



Abstract

One of the threats of the world health is the infectious diseases. This leads to the raise of concern of the policymakers and disease researchers. Vaccination program is one of the methods to prevent the vaccine-preventable diseases and hence help to eradicate the diseases. The impact of the preventive actions is related to the human behavioral changes. Fear of the diseases will increase one's incentive in taking the preventive actions to avoid the diseases. As human behavioral changes affecting the impact of the preventive actions, the individual-based model is constructed to incorporate the behavioral changes in disease modeling. The agents in the individual-based model are allowed to move randomly and interact with each other in the environment. The interactions will cause the disease viruses as well as the fearfulness to be spread in the population. In addition, the individual-based model can have different environment setups to distinguish the urban and rural areas. The results shown in this paper are divided into two subsections, which are the justification of using uniform distribution as random number generator, and the variation of disease spread dynamics in urban and rural areas. Based on the results, the uniform distribution is found to be sufficient in generating the random numbers in this model as there is no extreme outlier reported in the experiment. We have hypothesized the individuals in urban area to have higher level of fearfulness compared to those in rural area. However, the preliminary results of the survey conducted show a disagreement with the hypothesis. Nevertheless, the data collected still show two distinct classes of behavior. Thus, the distinction does not fall into the samples taken from rural or urban areas but perhaps more on the demographic factors. Therefore, the survey has to be study again and demographic factors have to be included in the survey as we could not distinguish the level of fearfulness by areas.

Keywords: Infectious diseases; individual-based model; human behavioral changes; vaccination decision; level of fearfulness

Abstrak

Salah satu ancaman kesihatan dunia adalah penyakit jangkitan. Ini menyebabkan kesedaran dari pihak berkuasa dan penyelidik penyakit telah ditinggikan. Program vaksinasi adalah salah satu kaedah untuk mencegah penyakit-penyakit jangkitan yang dapat dicegah melalui vaksin dan dengan itu membantu untuk membasmi penyakit. Kesan tindakan pencegahan penyakit adalah berkaitan dengan perubahan tingkah laku manusia. Ketakutan terhadap penyakit akan meningkatkan insentif seseorang untuk mengambil langkah-langkah pencegahan untuk mengelakkan penyakit. Disebabkan perubahan tingkah laku manusia akan menjejaskan kesan tindakan pencegahan, individual-based model dibina untuk menerapkan perubahan tingkah laku dalam pemodelan penyakit. Ejen-ejen dalam individual-based model dibenarkan untuk bergerak secara rambang dan berinteraksi antara satu sama lain dalam alam sekitar model. Interaksi akan menyebabkan virus penyakit serta ketakutan individu disebarkan di kalangan penduduk. Di samping itu, individual-based model mempunyai setup persekitaran yang berbeza untuk membezakan kawasan bandar dan luar bandar. Keputusan yang dibentangkan dalam kertas kerja ini dibahagikan kepada dua random, dan perubahan dinamik penyebaran penyakit di kawasan bandar dan luar bandar. Berdasarkan keputusan, taburan seragam didapati telah memenuhi tujuan penjanaan nombor random dalam model. Ini disebabkan tidak ada extreme outlier dilaporkan dalam eksperimen. Kami mengeluarkan satu hipotesis iaitu individu dalam kawasan bandar mempunyai tahap ketakutan terhadap penyakit yang lebih tinggi berbanding dengan mereka di luar bandar. Keputusan awal kajian yang dijalankan tidak bersetuju dengan hipotesis. Namun, data yang dikumpul masih menunjukkan dua kelas yang berbeza daripada tingkah laku. Oleh itu, perbezaan itu tidak jatuh ke dalam sampel yang diambil dari kawasan luar bandar atau bandar tetapi mungkin lebih kepada faktor-faktor demografi. Oleh itu, soal selidik ini akan dikaji lagi dan faktor-faktor demografi perlu dimasukkan dalam kajian ini kerana kami tidak dapat membezakan tahap ketakutan mengikut kawasan.

Kata Kunci: Penyakit jangkitan; individual-based model; perubahan tingkah laku manusia; keputusan mengambil vaksin; tahap ketakutan

1.0 INTRODUCTION

One of the main disease types that threaten the world health is infectious diseases. Some of the infectious diseases can be spread quite fast in a population. For example, Ebola has been spread widely and quickly in Africa. As of July, 2015, the total deaths caused by Ebola virus is 11268 [1]. The spread of the infectious diseases has drawn the attention from the public and it urges the public health organization to propose the effective ways of prevention. Some of the preventive actions are vaccination program, intensified hygienic care and self-isolation. The impact of these proposed preventive actions are depending on the human behavior. If the individuals have incentive to take the preventive action, the disease will then be controlled in the population.

The human behavioral changes are influenced by several factors such as education background, environmental knowledge or demographic [2]. Since the human behavior is affecting by different factors, the individuals are behaving differently during a disease outbreak. Besides, the human behavior will be modified according to the situation. For instance, the tourists who travel to Hong Kong and Singapore are reduced during the outbreak of Severe Acute Respiratory Syndrome (SARS) in 2003 [3]. This situation shows the individuals are modifying their behavior to prevent the disease infection.

Models have been constructed to study the spread of the infectious diseases. The conventional Susceptible-Infected-Recovered (SIR) model has been developed back in 1927 to model the disease dynamics [4]. SIR model is often been modified to consider different characteristics such as the latent period of the disease and the spatial factors affecting the disease dynamics. However, the conventional model does not consider the human behavior which is important in controlling the disease to be spread.

In these recent years, human behavioral changes have been considered in disease modeling [5]. Mathematical models have been used in the study of the human behavioral changes in disease modeling [6]. These models have considered the vaccination behaviors and fearfulness of the individuals separately. In fact, the fearfulness of the individuals will affect their incentives to make vaccination decision. This is due to the "fundamental" objective of human behavior where human are tend to protect themselves and avoid the disease infection during the disease outbreak when they are aware of the health threat [7]. As the fearfulness of the individuals affecting the vaccination decision, it hence brings impact to the vaccine coverage in the population and the efforts of eradicating the diseases will be affected as well [8].

Figure 1 shows the illustration of the transmission of fearfulness in the population. Due to the interaction of the individuals in the population, the fearfulness is considered as a social anxiety contagious process. The family, friends, neighbors or anyone who are surrounding the feared individual will be influenced and the fearfulness will be spread to them. The fearfulness will then be spread to the others. This explains the spread of fearfulness in the population. The fearfulness discussed in this paper referred to the fear of infectious diseases. Due to the advanced technology nowadays, the transmission of the fearfulness is not limited through face-to-face interaction, it can be spread through social networks, for instance, Twitter. Research shows that Twitter can be used as a digital surveillance of the fearfulness transmission [9]. As mentioned before, the fearfulness will influence the incentives of the individuals to take the preventive actions, thus, it will be taken into account in our study.

In our previous study, the significance of the incorporation of fearfulness in disease modeling and its response on the vaccination has been addressed [10].

The study is extended from the conventional SIR model by introducing the new compartments, namely "Feared" and "Vaccinated". This model is known as disease-behavior model. It is modeled as a mathematical model which is governed by ordinary differential equations. The preliminary result shows the disease outbreak is postponed when human behavioral changes are taken into account in disease modeling. As mathematical modeling assumes the population to be homogenous, we proposed another solution which is using individual-based modeling. This is due to the fact that population is not well-mixed in the actual scenario. Therefore, in order to address the heterogeneity of the population and the interactions between individuals, individual-based modeling has emerged in the researches recently [11]. The detailed comparison of both mathematical modeling and individual-based modeling will be discussed in the following section.

The next section presents the review on the modeling of diseases incorporates of human behavior. In Section 3, the formulation of the model is discussed. It is followed by the analysis of the results in Section 4. The last section will be discussed on the findings and conclusion.

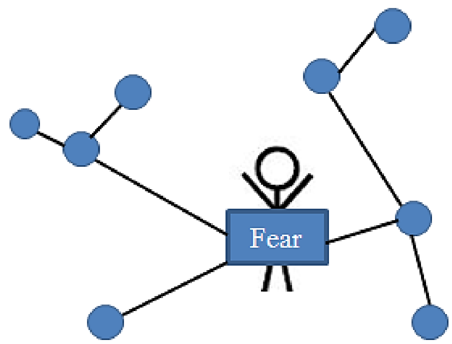


Figure 1 A simple illustration of the transmission of fearfulness in population. The circles indicate the neighbor of the individual. The individual will transmit the fearfulness to their neighbors.

2.0 LITERATURE REVIEW

As mentioned in the previous section, individual-based modeling has emerged in the researches to overcome the limitation of mathematical modeling. Mathematical modeling is a well-known approach in disease modeling. The work of Kermack-McKendrick marked the beginning of using mathematical modeling in the study of disease modeling [12]. The mathematical models are governed by a few equations. For instance, the conventional SIR model is governed by three ordinary differential equations. These models have a common assumption where the population is assumed to be homogenous.

However, in real world, the population has the characteristic of heterogeneity. The individuals will behave differently from one another. To capture the heterogeneity of a population in a model, thus overcoming the limitation of the mathematical model, cellular automata (CA)-based modeling and individual-based modeling (IBM) have been suggested. In CA-based modeling approach, the environment is characterized by discrete time step and space [13]. Thus, the non-homogenous and spatial factors in the problem can be captured by this approach. Although CA-based modeling approach can capture the heterogeneity of a population, however, it does not take into account of social behavior and interaction dynamics of the individuals [11]. Due to the concern of the attributes of social behavior and individuals' interaction dynamics, IBM has been widely used to describe the problems involving individuals' interactions.

There is a common characteristic shared by both mathematical modeling and IBM approaches, which is on expressing a relationship between two entities (or compartments) [14]. The difference between these two approaches is the way of expressing the relationship. In mathematical modeling approach, the relationship between the entities is expressed through mathematical equations. These equations do not present the relationship of the individuals explicitly [14]. In other words, the equations are representing the whole entity instead of individuals. On the other hand, IBM does not start the expression of the relationship with equations. Instead, the description of the individuals' behavior in the modeling environment is based on the rules assigned by the modelers [15]. Through these rules, the individuals are allowed to interact with each other in the environment to form the relationship. This is the way of expressing the relationship of the individuals in IBM approach.

In IBM, the agents are often used to represent the individuals in the real world population. Each of the agents is having two characteristics namely state and function. As mentioned previously, there are rules assigned to the agents allowing them to behave in the environment. Not only allowing the interaction and behaving in the environment, the rules are assisting the agents in making decision as well [16]. The rules are serving as the function for the agents. The function that allows the agents to behave and make decision will cause the agents' state to be varied at the next time step. IBM has been widely applied in several fields, such as economic [17; 18], disease modeling [19; 20], and social science [21; 22].

In this paper, the focus of the application of IBM will be on infectious disease modeling.

3.0 MODEL FORMULATION

At the beginning of the study of the integration of fearfulness and vaccination behavior in disease modeling, the problem is mathematically modeled. As the mathematical model assumes the population as homogenous, IBM emerged in this study to capture the heterogeneity of the population in real world. Before the problem is modeled, some assumptions have been made:

- The interaction of the individuals is not restricted, which means they are allowed to interact with each other randomly.
- The population is constant, which means the growth rate is omitted.
- There is an immunity for those patients who recovered.
- There is information about the disease spreading throughout the population via media mass and neighbors.
- The individuals in the Fear compartment have to make their vaccination decision, whether or not to vaccinate. If they could not make decision at this time step, it is to be assumed that they have selected not to vaccinate.
- Once the feared individuals decide to vaccinate, they are not allowed to reverse their vaccination decision. On the other hand, those feared individuals who do not want to be vaccinated at this time step are allowed to make another vaccination decision at the next time step.

Based on these assumptions, a compartmental model has been constructed. As mentioned earlier, the conventional SIR model (Figure 2) is extended to incorporate fearfulness and vaccination behavior of the individuals. To illustrate the compartmental model, a schematic diagram is drawn (Figure 3).

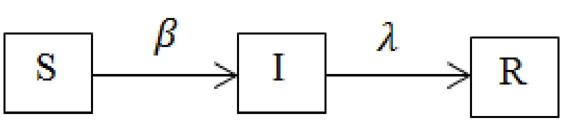


Figure 2 The conventional SIR model. β indicates the rate of disease transmission and λ indicates the recovery rate of the patients.

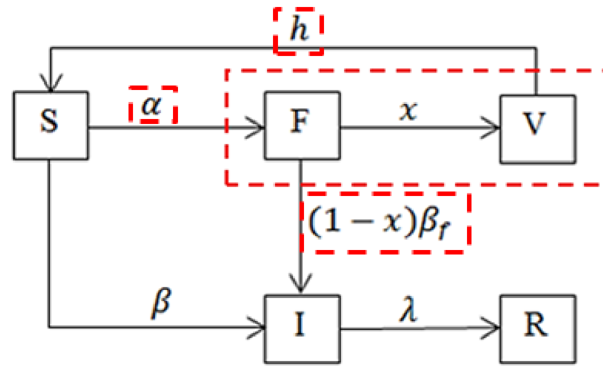


Figure 3 The schematic diagram of disease-behavior model. It illustrates the processes from each compartment to another compartment. The red dashed squares highlight the newly introduced compartments and parameters.

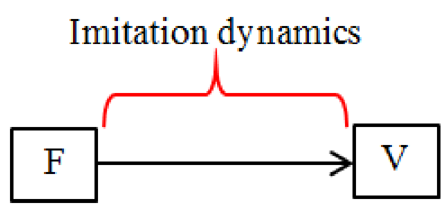


Figure 4 The process of feared individuals making vaccination decision is modeled by imitation dynamics.

There are five compartments in the disease-behavior model, namely Susceptible (S), Infected (I), Feared (F), Vaccinated (V), and Recovered (R). The infectious diseases studied in our research can be transmitted through the direct contact of the individuals. During the disease outbreak, the population is assumed to be in susceptible stage, except some random selected infected individuals, feared individuals, and vaccinated individuals. There is no recovered patient at the beginning of the disease outbreak. As β is indicating the disease transmission rate, the susceptible individuals may be infected by the disease viruses at this rate. Meanwhile, the information will be spread in the population. The individuals will acquire fearfulness when they receive the information. The rate of the fear transmission is denoted as α. The fearfulness of the individuals is believed to increase their incentives to take the preventive actions. Therefore, they have a lower chance to get infected by the viruses. This reduced disease transmission rate is denoted as β_f. The feared individuals are given opportunities to make their vaccination decision. It is assumed that there is an existing vaccine for that disease during the outbreak. However, there is a duration for the vaccine's effectiveness, $1/h$. After this duration, the vaccinated individuals will be returned to the susceptible stage. On the other hand, the infected individuals will be recovered after the sickness duration, $1/\lambda$.

The significant process in this disease-behavior model is the imitation dynamics process which determines the feared individuals to make their vaccination decision (Figure 4). Imitation dynamics is a kind of game theory. Game theory is a tool to state the individuals' decisions where the decision made is not only based on how the individuals opt for the strategies but also involve the interaction among the individual in the population and the strategies of their neighbors. In the process of making decision, the individuals are learning from their neighbors as well. This is where the imitation process takes place. There are many real world examples to be modeled by game theory. For instance, how to bid an auction can be modeled by game theory as the decision outcome of each individual in the auction is affecting the bid placed [23]. There are three categories of game theory, namely social dilemma, cooperative, and anti-coordination [24]. Social dilemma is a game that relates to the social behavioral changes. Cooperative game requires the individuals to cooperate to achieve the optimum output and anti-coordination game is contradicted with cooperative game where the individuals will only gain the optimum payoff by choosing different strategy from the opponents. No matter which category of the game, the basic concept of game theory is to optimize the individuals' payoffs. Vaccination is considered as a social dilemma game as it is related to the behavioral changes of the individuals [25]. When the risk of the infection is lower than the risk of the vaccination, the individuals tend to select the strategy of not to-vaccinate and vice versa. Therefore, the incentive of engaging in the vaccination program is important and fearfulness is the key to increase the incentive of the individuals.

Through the information gathered by the individuals, they will learn about the diseases and these pieces of information will be reflected as the payoffs for both of the strategies of to-vaccinate and not to-vaccinate. The payoffs for the strategies of to-vaccinate and not to-vaccinate are based on the risk of infection and the risk of vaccination respectively. If there is a high risk of getting infection in the population, the individuals will tend to take the vaccine. Otherwise, they will take other precautions as the risk of taking vaccine is higher than the risk of infection. In this disease-behavior model, both of the risks of infection and vaccination will be taken into account in the process of vaccination decision making. The risks of infection and vaccination are written as r_I and r_V respectively. The objective of the feared individuals in making the vaccination decision is to optimize their payoffs. The payoff of the strategy to-vaccinate is denoted as P_V while the payoff of the strategy not to-vaccinate is denoted as P_I. Apart from considering the risks, the feared individuals will imitate their neighbors in making vaccination decision. This imitation ability is based on the mindset of the individuals. By considering these components in making vaccination decision, the payoffs for both strategies are as follows:

$$P_V = -r_V \tag{1}$$

$$P_I = -r_I m I(t) \tag{2}$$

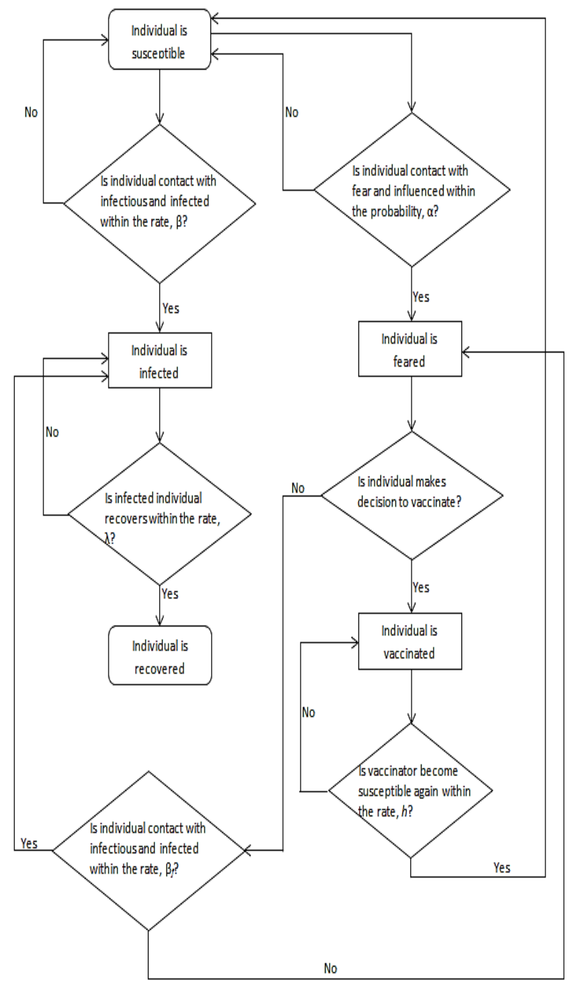


Figure 5 Flow diagram that assisted in characterizing the agents according to the compartment.

The equations above are adopted from [26] to calculate the payoffs for both strategies. In Eq. (2), m represents the imitation ability of the individuals and $I(t)$ represents the current number of infected individuals. If $P_V > P_I$, the feared individuals will tend to make their decision to vaccinate and they are not allowed to reverse their decision. On the other hand, the feared individuals do not want to take the vaccine will take the other preventive ways such as self-isolation. In this disease-behavior model, the fearfulness of the individuals will not fade out until the end of the outbreak period. Hence, the feared individuals who do not want to vaccinate at this time step are given opportunities to make another decision at the following time step as long as they stay in the compartment of Feared.

In the previous study, we proposed a mathematical model [10]. However, since the vaccination decision making process of the feared individuals requires the interactions among the neighborhood, thus we formulated and implemented the individual-based model. In the individual-based model, we created a set of agents categorized accordingly as in Figure 3. The agents hold their own status and they are allowed to behave based on the rules assigned to each compartment. The rules are described in a flow diagram to characterize the agents in the model (Figure 5).

Each agent has their own health state and mindset. Each of them is assigned with two random numbers to represent the health state and mindset respectively. The values of the health state assisted us to model the interaction and transmission of the disease. On the other hand, the values of mindset helped us to model the spread of the fearfulness through individuals' interaction. If the susceptible individual is interacting with a patient and his health state is lower than β, he will be infected by the viruses. On the other hand, if he is interacting with a feared individual and his mindset is lower than α, he will be feared of the disease as well. In other words, due to the unique health state and mindset of each individual, they have different chances to be infected by the viruses or influenced by the feared individuals. The individuals are allowed to move randomly in the model environment while interacting with one another. The interaction will then cause the viruses and the fearfulness to be spread in the population. At each time step, the health state, mindset and the belonging compartment of each individual will be updated.

We distinguished the individuals in the urban and the rural areas by adjusting the level of the health state and mindset. Due to the different culture, environment and belief system between these two areas, we hypothesized a higher value of health state and mindset for those in urban area. We believed that different level of health state and mindset will influence the dynamics of the disease transmission and fear spread. The difference in the fear contagion will affect the vaccination decision of the individuals and thus will bring impact to the vaccine coverage in the population.

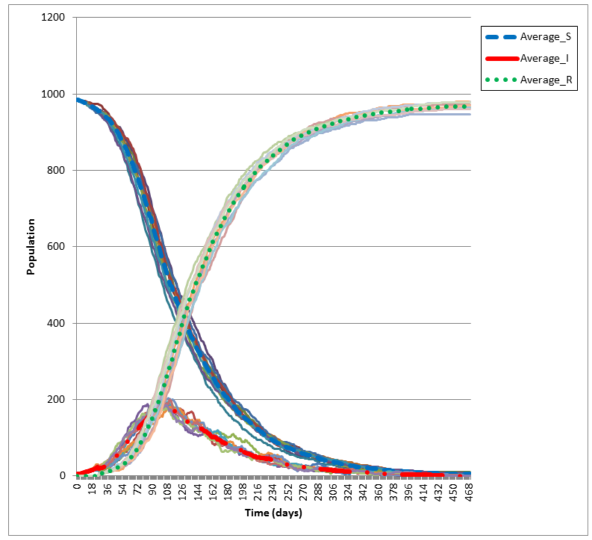


Figure 6 Average of 10 simulations to examine the suitability of uniform distribution as random number generator.

4.0 RESULTS AND ANALYSIS

We divided the analysis of the results into two subsections: First, we justify the use of uniform distribution to generate the random numbers for each individual's health state and mindset; Next, we show the results on the dynamics of the disease spread based on our hypothesis of different level of fearfulness in urban and rural areas. There are several platforms to implement the individual-based model, for instance, NetLogo [27], GAMA [28], and Repast [29]. The concept of implementing individual-based model in these platforms is similar. Due to the ease-of-use, we have chosen NetLogo as the platform to implement our disease-behavior model. NetLogo is a modeling platform to provide the simulation of natural and social phenomena. It is an open source platform that provide user-friendly environment to the modelers and users [30]. In the process of implementing the individual-based model, the flow diagram shown in Figure 5 is transformed into programming language in NetLogo environment. The parameters used in this model are rescaled from the previous study in mathematical model [30]: initial-susceptible= 985; initial-infectious= 5; initial-fear= 5; initial-vaccinator= 5; β= 0.014; α= 0.01; β_f= 0.0098; λ= 0.04; h= 0.0020.

4.1 Justification Of Using Uniform Distribution As Random Number Generator

As described in previous section in this paper, the individuals in our disease-behavior model will be assigned by two random numbers to represent their health state and mindset respectively during the disease outbreak. The numbers are generated randomly based on uniform distribution. In fact, there are several types of distributions to generate random numbers, for example, Poisson distribution, exponential distribution and uniform distribution are out of those common types of distributions. We have tested on both Poisson and exponential distributions in our disease-behavior model. However, we could not obtain the expected results which are similar to the results in our mathematical model. This is due to both Poisson and exponential distributions generate the random number based on the number of occurrences in a given period of time [31]. Our model does not control the number of occurrences of individuals to change their health state and mindset in a time interval. Instead, the health state and mindset have to be updated at every time step until the disease outbreak is over. Therefore, we carried out a series of simulations to examine the suitability of uniform distribution as the random number generator. We found that there is no extreme outlier throughout the series of simulation (Figure 6). We obtained the similar patterns for the simulations. Thus, the uniform distribution can be used as random number generator in the model in order to generate the health state and mindset to be assigned to the individuals.

4.2 Different Level Of Fearfulness In Urban And Rural Areas

The second part of this section is to present the results based on the hypothesis of the different level of fearfulness in both urban and rural areas. This hypothesis is made due to the more and complete information received by the individuals in urban areas through the advanced telecommunications. In our individual-based model, there are two environment setups, one for urban and another one for rural. Based on the hypothesis we have made, it is believed that the dynamics of the disease spread will be different in urban and rural areas. Therefore, we constructed an experiment on different environment setups in the individual-based model.

In this experiment, we have set a higher health state and mindset for the individuals in urban areas compared to those in rural areas as those in urban areas received more information due to the advance of telecommunication in urban areas. Our purpose of this experiment is to observe the difference of the dynamics of disease spread.

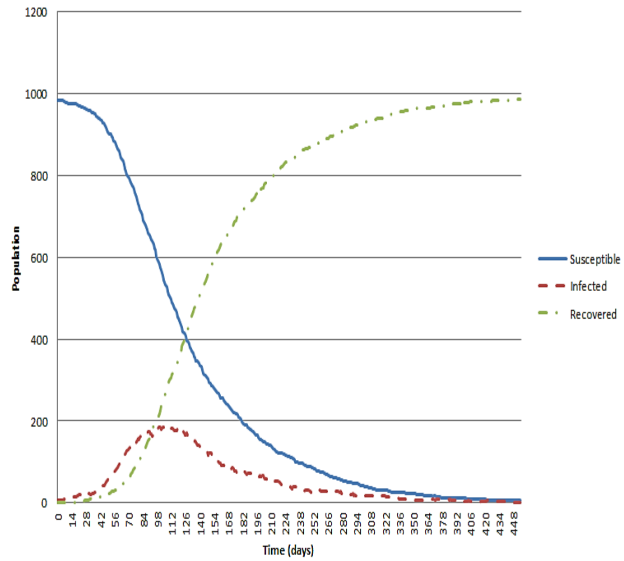


Figure 7 Susceptible, Infected, and Recovered curves in urban area.

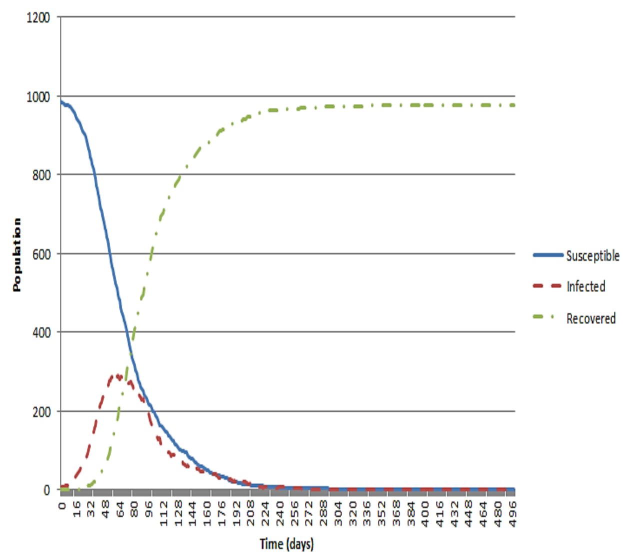


Figure 8 Susceptible, Infected, and Recovered curves in rural area.

Figure 7 and Figure 8 show the population count in the urban and rural areas respectively. From the curves, we observed that there are lesser individuals get infected by the viruses in urban area. The time taken for the disease to be spread in urban area is also longer compared to that in rural area. As we set a higher level of health state and mindset for the individuals in urban area, they have higher awareness and fearfulness to the diseases. This motivated them to take more preventive actions to avoid the infection. This will then cause the disease to be spread in slower mode. On the other hand, the individuals in rural area are hypothesized to have lower health state and mindset as they have been influenced by different belief system and environmental factors. This caused them to have less awareness and fearfulness to the diseases and hence take less preventive actions. This explains the disease is spread in a shorter time in rural area.

However, the hypothesis has to be justified as the level of fearfulness affects the dynamics of the spread of disease. The level of the fearfulness affects the vaccination decision as well and thus will bring impact to the immunization in the population. Therefore, the level of fearfulness in rural and urban has to be quantified. A survey is conducted in both of these areas. This survey is conducted through distributing the questionnaires adopted from Fear Survey Schedule II (FSS-II) [32; 33]. The questionnaire consists of 25 items which related to deaths and diseases. The respondents are sampled randomly among the residents in both urban and rural areas aged from 15 to 60 years old. The questionnaires are sent out to the respondents in urban areas via internet where 149 respondents were collected. The same method is not applicable in the rural area. Instead of sending out the questionnaires via internet, structured interview based on the FSS-II, is carried out in the rural area. The interview was conducted in a remote site, that is, Long Lamai in Sarawak, Malaysia. There were 86 respondents collected in this site.

The preliminary analysis of the survey shows a disagreement with the hypothesis that we have made. From the analysis of the survey, the individuals in the rural area have a higher level of fearfulness compared to the individuals in the urban area. The phobic score obtained from the rural and urban areas are 0.88 and 0.31 respectively. Based on these values, we observed that the level of fearfulness may not be distinguished via areas. It may be affected through some demographic factors, such as age, education background, and belief system. Thus, the survey will be conducted again with the questionnaires consisting demographic factors.

5.0 DISCUSSION AND CONCLUSION

The infectious diseases are threatening the world's health. The fear of the diseases will increase the incentives of the individuals to take the preventive ways to avoid the infection. The vaccination program has been reported as an effective way to eradicate the infectious diseases [34]. However, the incentive of engaging in vaccination program is depending on the behavioral changes. In other words, the human behavioral changes play important roles in disease modeling.

The conventional mathematical modeling approach has a limitation of capturing heterogeneity of the population. As human behavioral changes are considered as components of heterogeneity in a population, an individual-based model is formulated to overcome the limitation of the mathematical model. The information spread during the disease outbreak will cause individuals to acquire fear of the disease. The fearfulness will then spread to the people in the neighborhood. When the level of fearfulness in a population increased, there are more individuals taking the preventive actions which include vaccination. In consequences of more vaccinators in the population, the disease will be eradicated as there is immunity in the population.

As discussed in previous section, each individual will be assigned by two random numbers to represent their health state and mindset. These random numbers are unique for each individual and they are generated by uniform distribution. These random numbers served as indicators for the individuals whether to be infected by viruses or influenced by fear. When the level of fearfulness in a population is higher, the mindset and the health state will be set as higher values as well. A hypothesis of the individuals in urban area will have higher level of fearfulness compared to those in rural area is made in this study. Based on this hypothesis, the experiment carried out shows the urban area with higher level of fearfulness has taken a longer time for the disease to be spread in the population. The total number of the infected individuals is lesser as well. On the other hand, the rural area with lower level of fearfulness has higher number of patients and the disease is spread faster in the population.

In order to quantify the level of fearfulness in both urban and rural area, survey is conducted by distributing questionnaires. The questionnaire is adopted from FSS-II and it consists of 25 items related to diseases and deaths. The finding from this survey shows disagreement with the hypothesis. However, there are two distinct classes of individuals in both areas, one has higher level of fearfulness compared to another one. These two classes of individuals in both areas show the level of fearfulness are not based on areas. It might induced by another factors such as belief system, education background, and demographic factors. To increase the level of fearfulness and awareness of diseases in the population, no matter in urban or rural areas, the policymakers may increase or enhance the campaign on the risk of disease and the advantages of taking vaccine.

To conclude, the individual-based model has the ability to capture the heterogeneity of the population and thus the interaction of the individuals can be included in the disease-behavior model as well. On the other hand, in order to know the factor affecting the level of fearfulness, the survey needs to be conducted again with extra demographic questions.

Acknowledgement

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