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学 位 論 文 題 目	Epidemic dynamics of a vector-borne disease on a villages-and-city star network with commuters
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(別紙様式 2)
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論文内容の要旨

Summary of thesis contents

Background

The ambitious program to eradicate malaria in the 1950s-the Global Malaria Eradication Program-failed in most parts of the world. There were several reasons responsible for it's failure. One of the reasons was that the role of human mobility in the epidemic dynamics of malaria was not incorporated in the control activities. This reason forms the first motivation of this research.

Cities are centers of economic and social activities. People living in peri-urban or villages surrounding cities usually commute on a daily basis between their homes and the city. The commute pattern is therefore predictable. For example, a star shape in which the central part is the city and the surrounding areas are the villages can closely approximate this mobility or commute pattern. This system forms a meta-population – a system of interconnected populations with semi-independent local dynamics. This structural assumption is the second motivation of this research.

Purposes

The general purpose of this research was to investigate the behavior of the malaria outbreak (or epidemic) in a star network made up of a central city and surrounding villages. Specific purposes were as follows:

1. To derive the basic reproductive number of the star network; the basic reproduction number is defined as the average number of secondary infectious hosts resulting from a typical infectious host following its introduction into a totally susceptible population.
2. To use this unique formula for the basic reproductive number to ask and answer several questions of practical importance in the control of malaria, specifically;
    a. To investigate how mobility and the sizes of mosquito populations in the city and villages affect the focus of the control decision, and
    b. To investigate how mobility and the behavior of village mosquitoes and human densities affect the characteristics of the disease outbreak.

Methodology

After construction of the star network as described above I made several assumptions to simplify the mathematical presentation of the malaria outbreak. I used well-established malaria transmission mathematical models to formulate the infection process in each village and the city. For example I assumed that human beings would catch malaria and then recover and catch it again, while mosquitoes would catch it once and die. Then I allowed humans to move between villages and the city and mathematically analyzed the results of each purpose.

Findings

My findings are captured in the following four highlights:

1. The basic reproductive number for the epidemic in a star network was explicitly derived.
2. Malaria control decisions are sensitive to relative vector densities between the central city and surrounding villages as well as to the number of commuters; and favor focus in villages with increasing commuters.
3. With more vectors in the city commuting can paradoxically reduce the basic reproductive number.
4. Heterogeneous populations of vectors and humans in villages raise the basic reproductive number.

Discussion

I describe the highlights above in some detail:

1. As far as I am concerned, at the time of execution of this research, nobody had reported an explicit formula for the basic reproductive number in a well-defined contact structure like a star network. My research defined this important quantity.
2. With the formula for basic reproductive number in hand I performed what is called sensitivity analysis of this quantity to changes in the proportion of commuting humans

and to changes in mosquito densities between the city and villages. This enabled me to obtain a key result summarized by highlight number 2 above, that malaria control decisions are sensitive to relative vector densities between the city and villages as well as to the number of commuters but favor focus in villages as commuters increase.

3. Investigation of the changes in the network structure (with respect to population sizes) together with commuting produced highlights 3 and 4. For highlight 3 I found a paradoxical case in which when there are more vectors in the city, commuting reduces the basic reproductive number, contrary to a general intuition in networks, in which more connectivity is supposed to increase the basic reproductive number. When I introduced heterogeneity by varying the possibilities of mosquito and human densities in the villages I obtained that epicenters of intense infections in the villages can lead to a high disease burden in the entire meta-population system.

Conclusion

My research produced novel information that calls for more focus on the commute patterns as well as commuters themselves and their villages for effective control of vector-borne infections.

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博士論文の審査結果の要旨

Summary of the results of the doctoral thesis screening

The ambitious program to eradiate malaria in the 1950s (the Global Malaria Eradication Program) failed in most part of the world, and one of the reasons for the failure was that the role of human mobility in the epidemic dynamics of malaria was not incorporated in the control activities. Motivated with this, Emmanuel Mpolya focused in his doctoral thesis on the control of malaria on the basis of the epidemic dynamics with human movement on its regular commuting network structure. The system to be studied falls in the category of a meta-population epidemiological dynamics with commuting. He adopted a simple star network consisting of a central city and surrounding villages as the simplest but practically important structure. The purpose of the study was to investigate the behavior of malaria epidemic in a star network. Specific aim of the paper were as follows:

1) To derive an analytical expression for the basic reproductive ratio, which is defined as the mean number of secondary cases resulting from a single infectious host introduced in totally susceptible population, of a star network.
2) Using the analytical expression, to study practically important questions in the control of malaria, for example,
    a) To investigate hos mobility and the size of mosquito populations in the city and villages affect the focus of control decision
    b) To investigate how the degree of mobility between city and villages affect the characteristic of disease outbreak.

The major finding of the study can be summarized as follows.

1) The basic reproductive ratio for the epidemic in a star network was explicitly derived.
2) Malaria control decisions are sensitive to the vector density of the central city relative to that of surrounding villages. Increasing the fraction of commuters between city and villages, the more control should be focused in villages.
3) With more vectors in the city, a greater degree of commuting can paradoxically reduce the basic reproductive ratio.
4) Heterogeneous populations of vectors and humans in villages raise the basic reproductive ratio.

This study produced novel information that calls for more focus on the commute patterns. The clear practical message for better control strategy on the basis of analytical expressions make this study a substantial contribution to theoretical epidemiology.

(Separate Form 3)

An oral presentation of the thesis to open audience was held at the Hayama campus of Sokendai on February the 12th, 2014. Emmanuel gave a one-hour talk on his entire research with concise description on the background behind his work. The talk was in fluent English, and his message was quite clear. The following question-session was also in English. Emmanuel provided reasonable answers to all questions from the committee members and the audience, indicating that he has strong understanding of his research area. Emmanuel's presentation and the following answers to the questions demonstrated his depth of knowledge in theoretical epidemiology. After a short discussion, the committee made a unanimous decision that Emmanuel deserves a PhD.