**MODELING THE SPREAD OF INFECTIOUS DISEASES
IN URBAN TRANSPORTATION SYSTEM**

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Abstract

This dissertation focuses on developing a series of mathematical models to understand the role of urban transportation systems in the spreading process of infectious diseases within metropolitan areas. The disease contagion is a function of exposure duration and distances of healthy people to infected population, and urban transportation system serves as the catalyst of disease spreading from two aspects: it not only provides the mobility for bringing people to participate intensive urban activities, but the system also possesses high passenger density and long commuting time, which are necessities for the spread of contagious diseases. As the spread of infectious diseases becomes a major threat for urban population, it is necessary to investigate how existing urban transportation systems may contribute to more severe disease outbreaks and understand potential control and design measures to improve the resilience of the our transportation system. In light of various modeling needs to understand the problem at various levels, both macroscopic and microscopic mathematical models are developed and the dissertation consists of three main parts.

The first part of the dissertation aims to model the macroscopic level of disease spreading within urban transportation system based on disease compartment models. The tasks include modeling the disease spreading over the metropolitan areas with various travel modes, comparing models with and without modeling travel contagion, understanding how urban transportation system may facilitate or impede the invasion of diseases, and devising control strategies to mitigate epidemic at the network level. The dissertation starts with the dynamic system which captures stable movement of urban population, and then builds the non-linear system of ordinary differential equations to jointly characterize the dynamics of infectious diseases within transportation system and when individuals arrive at their destinations. The hybrid modeling approach and reachability analysis method are introduced to account for the needs of different levels of control methods and uncertainties of initial epidemic size, which projects the guaranteed over-approximation of the actual disease trajectories. The data from 2003 Beijing SARS are used to validate the effectiveness of our modeling approach. Comprehensive numerical experiments are conducted to understand the importance of modeling travel contagion for modeling disease spreading in urban areas and devise possible control measures to regulate the entry of urban transportation system and reduce the size of disease outbreaks.

The second part of the dissertation develops a data-driven framework to investigate the disease spreading dynamics at individual level. The primary interest of the individual model is to understand how individual contact pattern within the transportation system is related to the dynamics of infectious diseases. In particular, I develop the contact network generation algorithm to reproduce individuals' contact pattern based on smart card transaction data of metro systems from three major cities in China. The disease dynamics are coupled with the contact network based on individual based mean field approach and origin-destination pair based mean field approach. I identify that the vulnerability of the contact network solely depends on the risk exposure of the most dangerous individual in that network, however, the overall degree distribution of the contact network determines the difficulties in controlling the disease from spreading. To improve our understanding on individual contact pattern within transportation system, I further derive the generation mechanism that describes how individuals get into

contact and how long will two people get exposed to each other, based on their travel characteristics. The metro data are used to validate the correctness of the generation model, provide insights into monitoring the risk level of transportation systems, and evaluate possible control strategies to mitigate the impacts from infectious diseases.

Finally, the third part of the dissertation focuses on the role played by information in urban travel, and develops a multiplex network based approach to investigate the co-evolution of disease dynamics and information dissemination. I consider that individual behavior will change with their improved knowledge of the disease state, and individuals can obtain such information by observing the disease symptoms from the people they met during travel as well as from centralized information sources such as news agencies and social medias. As a consequence, the multiplex network is constructed with one layer capturing information percolation and the other layer modeling the disease dynamics, and the dynamics on both layers are mutually affected. Based on the multiplex network model, I identify three possible stable states of the system and their corresponding threshold values, and investigate the effectiveness of local and global information in reducing the size of disease outbreaks or even contributing to the eradication of the disease.