When Epidemics Meet: Understanding Spatiotemporal Interactions of Two Pathogens on Metapopulation Networks via Reaction-Diffusion Dynamics

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Understanding interactions between the spread of multiple pathogens during an epidemic is crucial to assessing the severity of infections in living communities. I created two novel Multiplex Bi-Virus Reaction-Diffusion (MBRD) models for multiplex metapopulation networks, consisting of the super-infection (MBRD-SI) and co-infection (MBRD-CI) models. These deterministic models capture the dynamics of two pathogens with spatial diffusion and cross-diffusion instead of traditional stochastic processes, allowing the prediction of infection clustering and large-scale spatial distributions. Specifically, by accounting for diffusion, this new MBRD class of models is well-suited for predicting epidemic "waves" and large-scale pattern formation, while offering computational simplicity. I found that two-pathogen spread can give rise to stationary infection hotspots through mechanisms known as Turing and wave instabilities, and I derived mathematical conditions for both phenomena. To investigate the spatio-temporal evolution of two-pathogen epidemics, I studied the effects of diffusion and cross-diffusion rates, bi-virus parameters, and population migration levels on epidemic hotspot formation and pattern robustness. I also derived conditions for pattern formation involving three or four infection states, which had not previously been analyzed in a network setting. My results highlight the role of human behavior and mechanisms of viral transmission in amplifying or suppressing co-circulating infections and provide quantitative insight into conditions that drive persistent epidemic patterns, including public health policy. Beyond epidemiology, these findings have broader implications for multiplex contagion processes such as information diffusion and malware propagation.

Awards Won:
American Mathematical Society: Honorable Mention and One-Year Membership to AMS (for 5 projects with up to 3 team members per project)