論文 / 著書情報
Article / Book Information

題目(和文)	メタポピュレーションモデルを用いた交通政策介入によるパンデミック管理対策
Title(English)	Pandemic Control Measures Considering Transportation Interventions in Metapopulation Structure
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

The COVID-19 pandemic has profoundly affected global systems, revealing critical vulnerabilities in both public health and economic resilience, especially in sectors reliant on transportation and mobility. In response, this study aims to create a robust, data-driven model for optimizing pandemic control measures, emphasizing transportation and vaccination strategies. By integrating epidemiological dynamics within a metapopulation structure, this research seeks to balance public health priorities with economic needs, offering a framework for policymakers to make more informed decisions during future pandemics. This work also explores how international cooperation through vaccine sharing can improve outcomes globally, thereby accelerating recovery and minimizing the socioeconomic impacts of health crises.

The study is structured into three main components, each designed to address different facets of pandemic control. First, it introduces a travel bubble transportation framework, a novel mathematical approach to managing long-distance travel while mitigating the risks of disease transmission within the bubble system. This framework is particularly relevant for countries that aim to restore economic activities, such as tourism and trade, without risking widespread outbreaks. By establishing controlled intra-bubble travel transportation policies, the model enables participating countries to resume domestic and international travels. The metapopulation epidemic model, combined with a cost-benefit analysis, forms the core of this framework, allowing policymakers to evaluate the economic and public health implications of reopening borders. A case study involving Australia, New Zealand, and Japan serves as a practical application of the travel bubble concept. Findings indicate that controlled travel bubbles can bring substantial economic benefits during the border reopening phase, supporting economic recovery while maintaining control over public health risks. This section demonstrates that with sufficient coordination, countries can safely manage domestic and international long-distance transportation, underscoring the potential of travel bubbles as a viable pandemic control strategy.

The second component of the study focuses on developing an optimal control framework that balances vaccine distribution and transportation restrictions within a spatially heterogeneous mobility network. This model is rooted in the need to account for the uneven distribution of resources and varying mobility patterns across regions, which can impact the spread and control of infectious diseases. The optimal control framework aims to minimize the total costs associated with both pandemic control measures and the health impacts on affected populations. This is achieved by adjusting vaccination rates across different regions and an overall domestic mobility control level. The findings highlight the effectiveness of transportation control and vaccine distribution in reducing both total costs and infection rates. Notably, the efficacy of these control measures exhibits regional variations, and the simultaneous implementation of both measures emerges as the most effective and economically viable strategy. The synergy effect between vaccine distribution and transportation restrictions is also a key observation in the simulations, showcasing their complementary roles in

pandemic control. By considering the spatial nuances of mobility networks and infection vulnerability, this framework provides a flexible and region-specific strategy to optimize the allocation of resources for domestic pandemic control, ultimately striking a balance between efficacy and economic feasibility.

In the final component, the study expands these control strategies to a global scale, presenting an integrated model for managing international and domestic transportation alongside vaccine distribution. The optimization framework seeks to minimize total costs associated with transportation restrictions, vaccination efforts, and infection spread for each country. This approach tackles the challenge of balancing infection control with economic activity and introduces a vaccine-sharing mechanism to enhance resource allocation among nations, fostering global response coordination. A case study with 16 countries tests the model's feasibility and effectiveness, analyzing how transportation and vaccination controls impact infection and benefit countries within a global mobility network. Findings indicate that the vaccine-sharing mechanism significantly lowers infection rates, speeds up transportation recovery, and reduces overall costs for all countries. The case study's three scenarios reveal the model's effectiveness compared to real-world outcomes, with considerable cost reductions across all scenarios. The results also indicate that countries experience different outcomes depending on factors such as population size, transportation connectivity, and vaccine availability. This research emphasizes the critical role of international cooperation in pandemic management and provides valuable insights for policymakers.

Overall, this thesis presents a comprehensive framework for optimizing pandemic control measures through a combination of transportation and vaccination strategies, addressing both national and global scales. By incorporating spatial heterogeneities and accounting for the unique conditions in each region, the research provides policymakers with flexible, data-driven solutions to balance public health with economic recovery. The findings underscore the importance of international cooperation, particularly in international transportation recovery and vaccine-sharing initiatives. This study contributes to the knowledge in pandemic management by providing a structured, multi-layered approach that aligns with both public health objectives and transportation activities. By demonstrating the transportation-focused interventions and vaccination strategies, this research offers actionable insights for managing pandemics in a globally connected world, and inspiring data-driven policies that foster both national resilience and international solidarity.