Public health emergencies, such as pandemics, pose complex challenges that require rapid, data-driven, and risk-aware decision-making to manage patients and allocate scarce medical resources efficiently. The scale, uncertainty, and inter-regional dependencies associated with infectious disease outbreaks demand integrative approaches that combine epidemiological forecasting with optimization-based decision-making. This dissertation develops a data-driven optimization framework for patient and resource allocation integrating epidemiological modeling, time-series analysis and under uncertainty quantification, to enhance healthcare system resilience and reduce unmet medical demand during public health crises.

The dissertation consists of three interconnected tasks. The first task focuses on patient allocation across regional healthcare networks. A compartmental Susceptible-Infected-Removed (SIR) epidemiological model is integrated into an optimization framework to simulate the temporal and spatial progression of an infectious disease. The model aims to allocate patients among neighboring regions while minimizing the total unmet demand for hospital beds and preventing the overloading of specific facilities. By explicitly capturing the interaction between infection dynamics and hospital capacity constraints, this task provides a more realistic and adaptive approach to patient transfer and admission management. Results demonstrate that interregional cooperation and optimized patient redistribution can significantly reduce local capacity shortages and balance the overall healthcare burden across the system.

The second task extends the patient allocation framework into a stochastic resource allocation model that addresses uncertainty in epidemic evolution and demand surges. Using a scenario-based optimization approach combined with the Conditional Value-at-Risk (CVaR) metric, the model minimizes both the expected and extreme levels of unmet demand across multiple stochastic realizations of the epidemic. The framework dynamically allocates limited medical resources, such as hospital beds, by considering how resource distribution influences infection trajectories through the SIR model. Comparative analyses between baseline deterministic and CVaR-based stochastic models reveal that the risk-averse approach reduces worst-case outcomes by prioritizing high-risk regions while maintaining acceptable overall performance. This integration of probabilistic disease modeling with risk-sensitive optimization offers a systematic and transparent mechanism for supporting policy decisions under uncertainty.

The third task develops a deterministic Susceptible-Vaccinated-Infected-Hospitalized-Recovered (SVIHR) modeling framework that integrates vaccination dynamics with hospital

capacity constraints and interregional hospital bed transfers. The model explicitly represents hospital congestion, patient waiting, and unmet demand within a spatially distributed healthcare system. It is used to examine the effects of alternative vaccination strategies, including uniform and targeted policies, under capacity-limited conditions. In addition, the framework incorporates interregional bed-sharing mechanisms to capture spatial dependencies and coordination across regions, providing a comprehensive setting for evaluating vaccination and resource allocation policies during epidemic scenarios.

Collectively, the methodologies developed from the three research tasks form a comprehensive decision-support system that integrates epidemiological modeling, stochastic optimization, and policy-oriented evaluation. The models are demonstrated using realistic epidemic data and parameter settings derived from regional healthcare networks in Florida. The findings emphasize the importance of accounting for disease transmission dynamics, interregional dependencies, and uncertainty in epidemic decision-making. By combining data-driven modeling with optimization under uncertainty, this dissertation contributes to both the methodological and practical understanding of how to design resilient, adaptive, and risk-aware healthcare allocation systems. The proposed frameworks can support policymakers, emergency planners, and hospital administrators in making timely and effective decisions to mitigate the impact of future public health emergencies.