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An Epidemiological Mixed-Integer Nonlinear Programming Framework for Vaccine Modeling and Patient Allocation During Pandemics

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Abstract

Pandemics strain healthcare systems worldwide, creating urgent challenges in allocating limited resources like hospital beds while controlling disease spread. Effective patient allocation during such crises is critical to minimizing unmet healthcare demand and ensuring equitable healthcare access across regions. This study addresses these issues by developing a mixed-integer nonlinear mathematical model that integrates Susceptible-Infected-Recovered-Vaccinated (SIRV) epidemic dynamics with patient transfer and allocation to improve patient distribution during outbreaks. Our approach also factors additional disease transmissions caused by the assignment of patients to different regions. Our model minimizes unmet demand per county for hospital beds and incorporates real-world data in the model parameters. We observe that in large metropolitan areas, where access to healthcare is critical, the vaccinated scenario exhibits significantly lower unmet hospital demand compared to the unvaccinated scenario, an outcome directly tied to the vaccines' success in lowering peak infection rates as demonstrated by the SIRV dynamics. The reduction in infection surges not only alleviates hospital capacity strain but also leads to fewer total patient transfers, underscoring the effectiveness of vaccination during pandemics. This research demonstrates the potential to enhance pandemic response strategies. The model provides policymakers and healthcare administrators with a robust, data-driven tool to make informed decisions, reducing strain on overburdened facilities and improving patient outcomes during pandemic scenarios.

Keywords
COVID-19, Patient Allocation, Data-Driven Optimization, Healthcare Systems, Epidemic Modeling

Biographies

Alexander DeLise is an undergraduate student at Florida State University pursuing a B.S. in Applied and Computational Mathematics and B.S. in Computational Science. His research interests include Operations Research, Industrial Engineering, Optimization, and Big Data.

Seyedreza Abazari is a Ph.D. candidate in the Department of Industrial and Manufacturing Engineering at the FAMU- FSU College of Engineering. His research interests include Data Science, Operations Research, and

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Dr. Arda Vanli is a Professor in the Industrial and Manufacturing Engineering (IME) Department at Florida A&M University and Florida State University, College of Engineering. Dr. Vanli's research interests lie in the general area of applied industrial statistics and data analytics with applications in quality and reliability improvement in modernmanufacturing processes, risk and vulnerability analysis for natural disasters and infectious disease data analysis. His research is published in journals including, Quality Engineering, Quality and Reliability Engineering International, Technometrics, IIE Transactions, IEEE Transactions on Semiconductor Manufacturing and Mechanical Systems and Signal Processing. He completed his Ph.D. in Industrial Engineering and Operations Research at the Pennsylvania State University, University Park, in August 2007. He received his M.S. degree in Mechanical Engineering from the Pennsylvania State University, University Park, PA in 2000 and his B.S. degree in Mechanical Engineering from the Middle East Technical University, Ankara, Turkey in 1998.