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Multi-Stage Disaster Response and Platelet Resource Allocation: A Stochastic Dual Dynamic Programming Approach

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In this paper, we study the stochastic casualty response planning problem and propose a multi-stage stochastic programming model, where initial decisions—such as the location of alternative care facilities (ACFs) and rescue vehicle assignments—are fixed, while patient assignments and allocations of apheresis machines (AM) for blood extraction are updated dynamically as uncertainty unfolds. In this framework, patient demands, blood donor availability, and hospital treatment capacities are treated as uncertain parameters. Our model focuses on deploying newly introduced portable AMs, like the Trima Accel 7, and incorporates both apheresis blood donation and whole blood collection methods, along with platelet transshipments among medical facilities to meet varying demands. This approach aims to improve patient outcomes by optimizing three key performance indicators: timely transport from disaster areas to medical facilities, timely surgeries, and compatible platelet transfusions. By matching platelet age and blood type to injury severity, we reduce the risks associated with mismatched transfusions. To address the scalability challenges in multistage stochastic optimization, we employ stochastic dual dynamic programming (SDDP) and benchmark it against nested Benders decomposition (NBD). To further enhance the efficiency of these algorithms, we develop a wide range of acceleration techniques, including strong cuts, multiple cuts, lower bounding functional valid inequalities (LBFVIs), and warm-up strategies. Effective scenario sampling is achieved through randomized quasi-Monte Carlo (RQMC), while K-means++ clustering is applied for scenario reduction, decreasing the number of scenarios by several orders of magnitude. We carry out extensive computational experiments demonstrating that these enhancements significantly boost the performance of the SDDP algorithm, resulting in a 6,078% reduction in the objective function across 2,500 out-of-sample scenarios and a 40% improvement in the value of the stochastic solution. Finally, a case study from the 2011 Van earthquake in Turkey demonstrates the practical applicability and efficiency of our optimized approach.

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