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A SIMULATION-OPTIMIZATION FRAMEWORK TO IMPROVE THE ORGAN TRANSPLANTATION OFFERING SYSTEM

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ABSTRACT

We propose a simulation-optimization-based methodology to improve the way that organ transplant offers are made to potential recipients. Our policy can be applied to all types of organs, is implemented starting at the local level, is flexible with respect to simultaneous offers of an organ to multiple patients, and takes into account the quality of the organs under consideration. We describe in detail our simulation-optimization procedure and how it uses data from the Organ Procurement and Transplantation Network and the Scientific Registry of Transplant Recipients to inform the decision-making process. In particular, the optimal batch size of offers is determined as a function of location and certain organ attributes. We present results using our liver and kidney models, where we show that, under our policy recommendations, more organs are utilized and the required times to allocate the organs are reduced over the one-at-a-time offer policy currently in place.

EXTENDED ABSTRACT

Organ transplants have allowed many potential transplant patients to extend and improve the quality of their lives by giving them the chance of receiving a functional organ. In 1984, the Organ Procurement and Transplantation Network (OPTN) was created with the goal of overseeing the transplantation system in the United States. As of March 2022, there were more than 105,000 candidates on the national waiting list, and every ten minutes a new candidate is added to the list (OPTN 2020). Even though the numbers of donors and transplants have increased steadily over the years, there is still a significant shortage of organs; about 20 people die each day while waiting for an organ (HRSA 2020). The United States had 36.88 deceased organ donors per million population (PMP) (the second-highest rate in the world) and 22.99 living donors PMP (7th) in 2019 (IRODaT 2019). Unfortunately, a significant percentage of organs received by the OPTN for transplant are discarded, contributing to the demand-supply gap. For example, 19% of kidneys are discarded, while 9% of livers are discarded (SRTR/OPTN 2019).

We propose a simulation-optimization-based methodology to improve the way that organ transplant offers are made to potential recipients. Our contributions are three-fold:

1. We provide a simple, flexible, yet accurate simulation model that works for organs of all types (e.g., liver, kidney) and that starts at the local level—unlike previous work, which assesses the system at the national level.
2. We consider batch-offering policies in which the batch sizes are not fixed in advance; and our policies also incorporate organ characteristics and the location of the organs into the decision-making process.

3. We compare the quality of organs donated under our new policy to the overall quality of organs donated in the United States, which helps to ease concerns with respect to the use of organs that are otherwise lost.

Our main article is organized as follows. We begin with a detailed model overview, including data considerations (nature and preparation of data). This study used data from the Scientific Registry of Transplant Recipients (SRTR). The SRTR data system includes data on all donor, wait-listed candidates, and transplant recipients in the US, submitted by the members of the Organ Procurement and Transplantation Network (OPTN). The Health Resources and Services Administration (HRSA), U.S. Department of Health and Human Services provides oversight to the activities of the OPTN and SRTR contractors.

We then describe in detail our simulation-optimization procedure and how it uses data from the OPTN and SRTR to inform the decision-making process. Afterwards, we discuss model validation (i.e., our simulation results compared to the SRTR and OPTN data), and show that our simulation adequately mimics real-world data. We then describe how our experimentation is carried out, including characterization of performance metrics for our proposed policy. The optimal batch size of offers is determined as a function of location and certain organ attributes. We present results using our liver and kidney models, where we show that, under our policy recommendations, more organs are utilized and the required times to allocate the organs are reduced over the one-at-a-time offer policy currently in place.

For instance, for our kidney allocation model, we performed our simulation-optimization procedure with the goal of obtaining a policy maximizing the "gain" of the transplantation systems, where "gain" is a measure of the benefits of providing organs minus physician time expenditure costs and disappointment costs for patients asking for, but not receiving, a particular organ.

Our proposed policy outperforms the current policy (one-offer-at-a-time) with respect to the average number of allocated kidneys by about 650 additional organs per year, and also reduces by 37.2% the time needed to allocate the organs. The proposed strategy also outperforms the policies with up to five simultaneous offers with respect to allocated organs and revenues, while making fewer overall offers. Compared to the proposed policy, the policy of 6-at-a-time offers is the first yielding more allocated organs (2 per year), with the bonus of reducing the time to allocate by 57% (versus the one-offer-at-a-time policy); however, those advantages come at the cost of increasing the total number of offers by 18,000 and the number of disappointed offers (where a patient accepted the offer but the transplant was not assigned to that patient) by 415 which is approximately four times the amount of disappointed offers of our policy; resulting in an overall lower "gain" for the transplantation system. In any case, our results suggest that by increasing the number of simultaneous offers (up to our optimal value), more transplants would take place, and thus more lives could be saved.

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