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KSIM 2.0: A SIMULATION OF KIDNEY ALLOCATION USING OPTN RECORDS

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ABSTRACT

The Organ Procurement and Transplantation Network (OPTN) in the US allocates kidneys for transplantation, but nearly one fifth of kidneys from deceased donors are not utilized due to the avoidance of transplantation for kidneys that have been removed from a donor for too long. To be able to provide clinically relevant recommendations to the OPTN contractor, we updated the KSIM discrete event simulation of kidney allocation in the academic literature using actual OPTN individual-level records for patients and donors. As a case study, we simulated offering kidneys at high risk of discard to the first accepting transplant center after 10 hours of accumulated cold time and found increased utilization. The updated model allows for greater clinical fidelity and can be embedded in medical decision support systems.

1 INTRODUCTION

The Organ Procurement and Transplantation Network (OPTN) is a complex partnership of member organizations responsible for allocating life-saving kidneys for transplantation in the United States. Nearly one fifth of kidneys obtained from deceased donors are not utilized (Barah et al. 2022). One notable factor that contributes to this phenomenon is the avoidance of transplantation for kidneys that have accumulated a significant amount of time since their removal from a donor (ibid.). Known as cold ischemia time, an increased duration between procurement of the organ and transplantation yields inferior outcomes for some patients and discourages transplant centers from accepting them (ibid).

Modifications to existing allocation policies may allow transplant centers to accept kidneys at risk of non-utilization for patients who could benefit from them after a set amount of cold time. Experimenting with allocation policies is prohibitive and poses undue safety risks for patients; therefore, we updated and scaled a discrete event simulation of kidney allocation to provide recommendations to the OPTN contractor.

Simulation is a well-established methodology for policy development in solid-organ transplantation. Pritsker et al. (1995) developed a discrete event simulation architecture for organ allocation that largely endures even today and was extended in different ways by contributors to the Winter Simulation Conference among others. Shoaib (2022) features a recent application and useful references.

2 KSIM 2.0 SIMULATION ARCHITECTURE

We updated the KSIM model developed in Davis et al. (2013) in Python 3.9 using an architecture similar to Kilambi (2018). Figure 1 depicts the architecture, whose novelty is that it employs actual OPTN individual-level records for patients and donors and allows for greater clinical fidelity. Computing one replication-year of kidney allocation requires 2.5 GB of input data, 18 CPU hours (with a clock speed of 4.0 GHz) over a single core. Input data may be historical or generated. New patient listings are generated each day by sampling from transplant centers' empirical distributions for arrival rates by blood type, day

of the week, and month of listing. Characteristics of new patients are assigned randomly from candidates with the same blood type listed at that transplant center historically. Changes to patient status were extracted from the corresponding original listing's recorded history with timestamps offset. For generated patients for whom the original waitlist history was censored by transplantation, histories were extended by cohort-matching on the original patient's gender, race, blood type, and health status. The number of new donors over a time interval were generated using a time-dependent Poisson process regression model with a cubic spline function estimating the mean arrival rate. Characteristics of new donors were sampled with replacement from donors with the same blood type and organ procurement organization historically. Allocation proceeds as described by OPTN policy. We use the model in Barah et al. (2022) to simulate transplant centers' acceptance of kidneys.

3 DEMONSTRATION

Figure 2 depicts simulation output (n=50 rep.): the distribution of the number of kidneys at risk of discard (i.e. donor risk index ≥ 1.75) that are accepted from 2018 to 2019 under current allocation policy (blue) and opening offer for all centers once the organ surpasses 10 hours of cold time (orange). Opening offer results in a significant increase in utilization of these kidneys. A total of 2,058 more offers were accepted across all centers. The simulation may be embedded in future decision support systems for accepting kidneys.

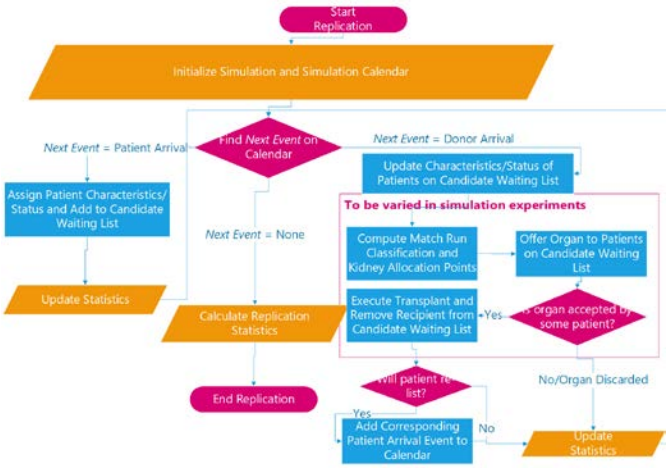

Figure 1: KSIM 2.0 architecture.

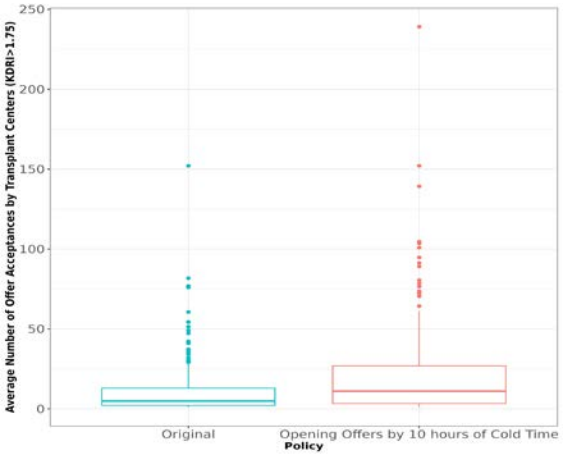

Figure 2: KSIM 2.0 acceptance of kidneys by policy.

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