A Simulation-Optimization Framework To Improve The Organ Transplantation Offering System

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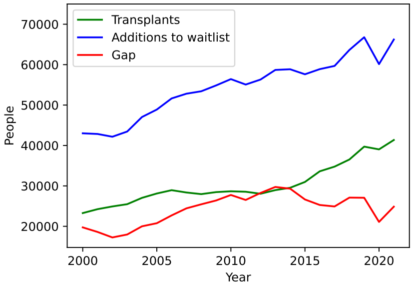
Winter Simulation Conference 2022

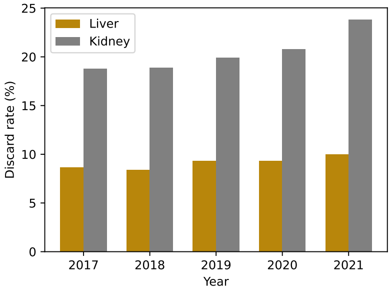
December 11, 2022

Motivation

1. +105,000 patients in waiting list.
2. A new candidate ∼ every 10 minutes.
3. ∼ 17 people die each day waiting for an organ.
4. Large gap between organ supply and demand.
5. High discard rate on some organs.

Can we reduce the supply-demand gap by reducing the discard rate?





Current System and Goal

Current System

Organ is procured → Quality check → Offered sequentially to patients on top of priority list → Organ accepted or offered until it is not viable anymore [Mankowski et al., 2019].

Current Literature

Prioritization and matching rules are complex and have been heavily studied [Zenios et al., 2000][Bertsimas et al., 2013].
Multiple-offer strategies have been studied, but only at a very high level [Mankowski et al., 2019].

Goal

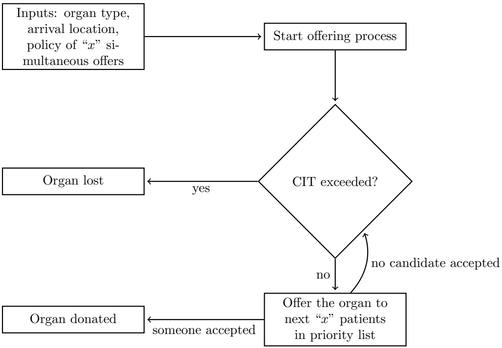
Propose a framework that improves the organ transplantation offering system by evaluating policies with multiple simultaneous offers, with a data-driven approach and at a granular level.

Methodology — Simulation

Data considered:

1. Donor and wait-listed candidates (2018-2019).
2. Organs' arrival process, historical distribution and centers' behavior.
3. Organ attributes.
4. Quality of organs (private data).

Simulation model for 1 year of the transplantation system and for any policy of x simultaneous offers.



Methodology — Optimization

"Gain" and "cost" approach:

- Donating an organ returns a "gain".
- Giving offers, centers performing organ evaluations/assessments and disappointed patients return a "cost".

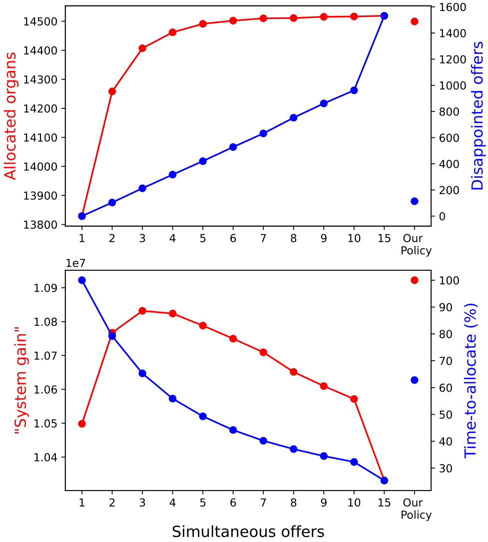
We seek to maximize the "net gain" = "gain" - "costs", and at a large glance our procedure works as follows:

1. Simulate many one-year period (replications) using different policies of x simultaneous offers.
2. For all replications record the "net gain" obtained for each organ (one sample in our training set).
3. Use the training set data to compute the expected value of a policy for a particular (organ attribute, location) pair.
4. Return the policy with the highest expected "net gain" for all (organ attribute, location) pairs.

Experimental Results — Kidney Model

Our policy

1. Clearly maximizes the “net gain” of the transplantation system.
2. Outperforms the benchmark (current) policy by around 650 donated kidneys per year.
3. Reduces time needed to allocate the organs by 37.2%
4. Produces less disappointed offers than most of the other policies.



Conclusions

We developed a model that:

- Allows us to obtain a policy that maximizes the “net gain” of the transplantation system for any set of parameters.
- Provides policy recommendations depending on the attributes of the organ and its arrival location.
- Yields better organ utilization than the current system while also reducing the time-to-allocation of donated organs.

Impact of the new organs donated:

We expect more lives would be saved because of the ability to transplant more organs of good enough quality. Further benefits could be expected as a lower time-to-allocation induces better patient outcomes [Cabello et al., 2011][Stahl et al., 2008].

References I

Bertsimas, D., Farias, V. F., and Trichakis, N. (2013).
Fairness, efficiency, and flexibility in organ allocation for kidney transplantation.
Operations Research, 61(1):73–87.

Cabello, M., Rodriguez-Benot, A., Mazuecos, A., Osuna, A., and Alonso, M. (2011).
Impact of cold ischemia time on initial graft function and survival rates in renal transplants from deceased donors performed in andalusia.
Transplantation Proceedings, 43(6):2174–2176.

Mankowski, M. A., Kosztowski, M., Raghavan, S., Garonzik-Wang, J. M., Axelrod, D., Segev, D. L., and Gentry, S. E. (2019).
Accelerating kidney allocation: Simultaneously expiring offers.
American Journal of Transplantation, 19(11):3071–3078.

Stahl, J. E., Kreke, J. E., Malek, F. A., Schaefer, A. J., and Vacanti, J. (2008).
Consequences of cold-ischemia time on primary nonfunction and patient and graft survival in liver transplantation: a meta-analysis.
PLoS One, 3(6):e2468.

Zenios, S. A., Chertow, G. M., and Wein, L. M. (2000).
Dynamic allocation of kidneys to candidates on the transplant waiting list.
Operations Research, 48(4):549–569.