Improved Liver Allocation using Optimized Neighborhoods

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Sanjay Mehrotra, PhD

Professor, Industrial Engineering and Management Science
McCormick School of Engineering
Feinberg School of Medicine (by courtesy)

Director,
Center for Engineering and Health, Institute for Public Health and Medicine,
Northwestern University
Experience

• PhD, Operations Research, Columbia University (1986)

• Chair, Optimization Society, Institute for Operations Research and Management Science (2013-2014)

• Board of Directors, Institute for Operations Research and Management Science (2006-2007)

• Methodological interests in mathematical optimization, health systems engineering, and decision analysis

• Teach graduate and undergraduate courses in healthcare systems engineering, healthcare analytics, and healthcare management science, optimization, and data driven decision making.

• Past methodological research supported by National Science Foundation, Office of Naval Research, Department of Energy, and National Institutes of Health

Relevant Publications


• The Author's Reply. (2015) Transplantation, editorial, 10.1097/TP.0000000000000833

• Modeling the Allocation System: Principles for Robust Design before Restructuring, Transplantation, (2015), editorial, 10.1097/TP.0000000000000656. PMID:25651120


• Changes in Geographic Disparity in Kidney Transplantation since the Final Rule, Transplantation, 2014, 98(9), 931-936. doi: 10.1097/TP.0000000000000446 PMID: 25286057.

• The Extent and Predictors of Geographic Disparity in Kidney Transplantation in the United States, Transplantation, 2013, PMID 24374790

Disclosures

• I am neither affiliated with nor involved with any efforts regarding SRTR, UNOS, any transplant lobby, or patient support group. I do not receive any financial compensation from Northwestern Medicine’s Comprehensive Transplant Center.

• My work in organ allocation is funded by a grant, titled *Addressing Geographical Disparities in Transplant Organ Accessibility Across United States*, from the National Science Foundation (2011-2016). The research results on Kidney Allocation were featured by the National Science Foundation in its *Science, Engineering and Education Innovation* highlights in 2015.

• NIDDK has recently funded one of my research projects. This project is not on liver allocation.

• I was invited to write an editorial (and subsequent reply) on principles of robust system design and its application to organ allocation based on my past work. References in this work were made regarding the methodology used in the current redistricting proposal. I received no financial compensation or any other special consideration for this.

  *The Author’s Reply*, (2016). Transplantation, , editorial, 10.1097/TP.0000000000000833


• Collaborators in transplantation research:
  • *Northwestern University*: M. Abecassis, J. Friedewald, D. Ladner, A. Skaro
  • *Others*: R. Gilroy, B. Kaplan, G. Klintmalm, Illinois Gift of Hope OPO
In June 2015, the UNOS Liver and Intestinal Committee granted me the opportunity to publicly comment on an 8-district redistricting proposal of the OPTN. My assessment was that the proposal required further independent testing and examining of plausible alternatives.

In good faith, my research team spent the past year replicating previous efforts and designing alternative structures for the OPTN to better address the weaknesses in redistricting. We all endeavor to find a design for the OPTN that satisfies the United States Department of Health and Human Service’s Final Rule: “Organs and tissues ought to be distributed on the basis of objective priority criteria and not on the basis of accidents of geography.”

In short, our principal finding is the following:

- Redistricting is preferable to doing nothing with respect to reducing annual mortalities and geographic disparities in access to liver transplantation; however,
- Better solutions that improve further upon the redistricting proposal are possible. The key is to form DSA-neighborhoods.

This presentation highlights some of the key findings that my research team plans to disseminate.
Redistricting limits local connectivity among DSAs

Should promote inter-connectivity among DSAs using neighborhoods

Western TN shares with AR and MO during regional allocation but not with Eastern TN in 8-district redistricting [1].

But Eastern TN shares with IL, IN, KY, OH, and WI during regional allocation.

Example DSA-neighborhood for Western TN:

During regional allocation, Western TN shares with Eastern TN and the above DSAs including its geographically immediate neighbors.
Key Elements of the Neighborhood Approach

- **Maintains current Local-Regional-National structure**
  - Regions are now defined by a specified set of neighbors for each DSA, instead of DSAs in a fixed district. A DSA’s set of neighbors is called that DSA’s *neighborhood*.
  - Liver allocation proceeds as before, except that during regional allocation, organs are shared with the procuring DSA’s set of neighbors.

- **Builds upon the concept of concentric circles**
  - Concentric Circles is a special case of the modeling framework.

- **Builds upon the concept of districting**
  - Districting is a special case of the modeling framework.

- **Applies principles from the theory of the design of manufacturing systems that are resilient to supply and demand uncertainty** [2-5]. This literature makes the following suggestions:
  - Increasing a DSA’s connectivity and creating overlapping neighborhoods promote resilience in responding to demand and supply uncertainty.
  - Balancing supply and demand across neighborhoods ensures greater equity.
Properties Ensured in Neighborhood Solutions

- We will discuss results using a specific neighborhood solution with the following properties:
  - **Immediate Neighbors**: DSAs have their geographically immediate neighbors in their neighborhood
  - **Population**: Each DSA’s neighborhood has a minimum population (25 million in the current model)
  - **Symmetry in DSA Relationships**: DSA A has DSA B in its neighborhood if and only if DSA B has DSA A in its neighborhood
  - **Contiguity**: Each DSA’s neighborhood is geographically contiguous
  - **Compactness**: The average transport distance/time for a DSA’s neighborhood is bounded (400 miles/4 hours in the current model)
  - **Transplant Centers**: Each DSA’s neighborhood has a minimum number of transplant centers (9 transplant centers in the current model)
  - **Formed using 10-year historical data**: The DSA-neighborhoods are formed using a 10-year period (2005-2014) and hence incorporate uncertainty in organ availability and needs
  - **Possibility to generate a spectrum of solutions, instead of one**: By parameter specifications, it is possible to generate many alternative solutions with different properties (e.g. average distance, mortality, disparity, etc.) to facilitate decision making.

¹Property also possessed by redistricting [1]
Simulating Neighborhood Solutions: LivSim

- **Needed to overcome LSAM[v.Aug.2014] limitations**
  - Unfortunately, to the best of our knowledge, LSAM’s current architecture cannot accommodate DSA-neighborhoods.
  - This LSAM limitation was overcome by implementing our own discrete-event liver allocation simulator in Python 3, hereafter referred to as LivSim. LSAM features are approximated to the best of our ability from information available in publically released sources.
  - We will make LivSim open-source and publically available for external examination.

- **LivSim incorporates**
  - Status 1A, Status 1B, HCC exceptions, Share 15, and Share 35 policies
  - MELD and MELD-Na scoring
  - Input files generated by LSAM for waitlist, patient listing, and patient status updates

- **Calibrated LivSim against LSAM**
  - Compare LivSim and LSAM results on the same input data for current allocation.
  - 5-year input data (2010-2014) for calibration generated by LSAM Candidate and Donor generators.
1) LivSim estimates are within 10% relative error of LSAM (except mean travel distance)
   - Methodology for distance calculations overestimates the distances and travel times as compared to LSAM and [6]. Consequently, actual average distance are less than the reported distances.
   - Smaller mortality estimates due to omission of re-transplants/re-lists and use of less patient and donor characteristics

2) Limitations of LivSim results:
   - Uses fewer patient and donor characteristics than LSAM
   - Uses a subset of variables from LSAM’s acceptance model
   - Re-transplants/Re-lists are ignored
   - Inactive/other waitlist statuses ignored
Study period and population:

- Simulation Setup:
  - Run-length: 5 years, January 2010 – December 2014
  - Five replications per year; i.e. 25 replication years
  - Used the same input data that was used for calibration
  - Patient listing and MELD progression generated by LSAM Candidate Generator
  - Organ donor data generated by LSAM Donor Generator

- Modeled with and without MELD-Na:
  - MELD Case:
    - Population with MELD exception points is included
    - HCC exceptions included (recent cap and delay policy not incorporated)
  - MELD-Na Case:
    - Assumed no exception points for non-HCC candidates
    - HCC exceptions included (recent cap and delay policy not incorporated)
# 5-Year Comparative Performance

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>Redistricting¹</th>
<th>Neighborhoods¹</th>
<th>National¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annualized Waitlist and Post Transplant Deaths</td>
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<td>-23.1</td>
<td>-48.2</td>
<td>-237.6</td>
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<td>Annualized Waitlist Deaths</td>
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<td>-155.3</td>
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<td>-46.7</td>
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<tr>
<td>DSA Mean Transplant MELD</td>
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<td>+0.6</td>
<td>+0.8</td>
<td>+1.6</td>
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<tr>
<td>DSA Mean Transplant MELD Standard Deviation</td>
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<td>-0.48</td>
<td>-0.50</td>
<td>-0.8</td>
</tr>
<tr>
<td>Average Organ Transport Distance (miles)</td>
<td>--</td>
<td>+35.5</td>
<td>+24.3</td>
<td>&gt; +300</td>
</tr>
</tbody>
</table>

¹All results obtained from LivSim for 2010-2014. Input data generated by LSAM Candidate and Donor generators.
### 5-Year Comparative Performance using MELD-Na

<table>
<thead>
<tr>
<th>Current</th>
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<th>Neighborhoods¹</th>
<th>National¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annualized Waitlist and Post Transplant Deaths</td>
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<td>-45.8</td>
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<tr>
<td>Annualized Waitlist Deaths</td>
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<tr>
<td>Annualized Post Transplant Deaths</td>
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<td>-8.1</td>
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<tr>
<td>Annualized Waitlist Removals</td>
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<td>-41.3</td>
<td>-46.8</td>
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<tr>
<td>DSA Mean Transplant MELD</td>
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<td>+0.6</td>
<td>+0.9</td>
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<tr>
<td>DSA Mean Transplant MELD Standard Deviation</td>
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<td>-0.59</td>
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<tr>
<td>Average Organ Transport Distance (miles)</td>
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<td>+43.4</td>
<td>+36.1</td>
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</tbody>
</table>

¹All results obtained from LivSim for 2010-2014. Input data generated by LSAM Candidate and Donor generators.
Summary

• The Optimized Neighborhoods solution compared to redistricting shows
  ✓ Greater Reduction in Disparity
  ✓ Greater Reduction in Total Mortalities Each Year
  ✓ Fewer Waitlist Deaths Each Year
  ✓ Smaller increase in average travel distance per transplanted organ

• The Optimized Neighborhoods framework is general
  o It brings science behind the design of concentric circles; and has
districting as a special case.
  o It is possible to generate alternative Neighborhood solutions meeting
pre-specified requirements for disparity and mortality reductions or
organ travel distance/time (cost) increases.

• The Optimized Neighborhoods framework is locally adaptive
  o Once implemented is possible to adjust a DSA’s neighborhood
(locally) to respond to policy and behavioral changes in the transplant
system, without causing a major disruption.
References


