

Gerrymandering for justice: Redistricting U.S. liver allocation

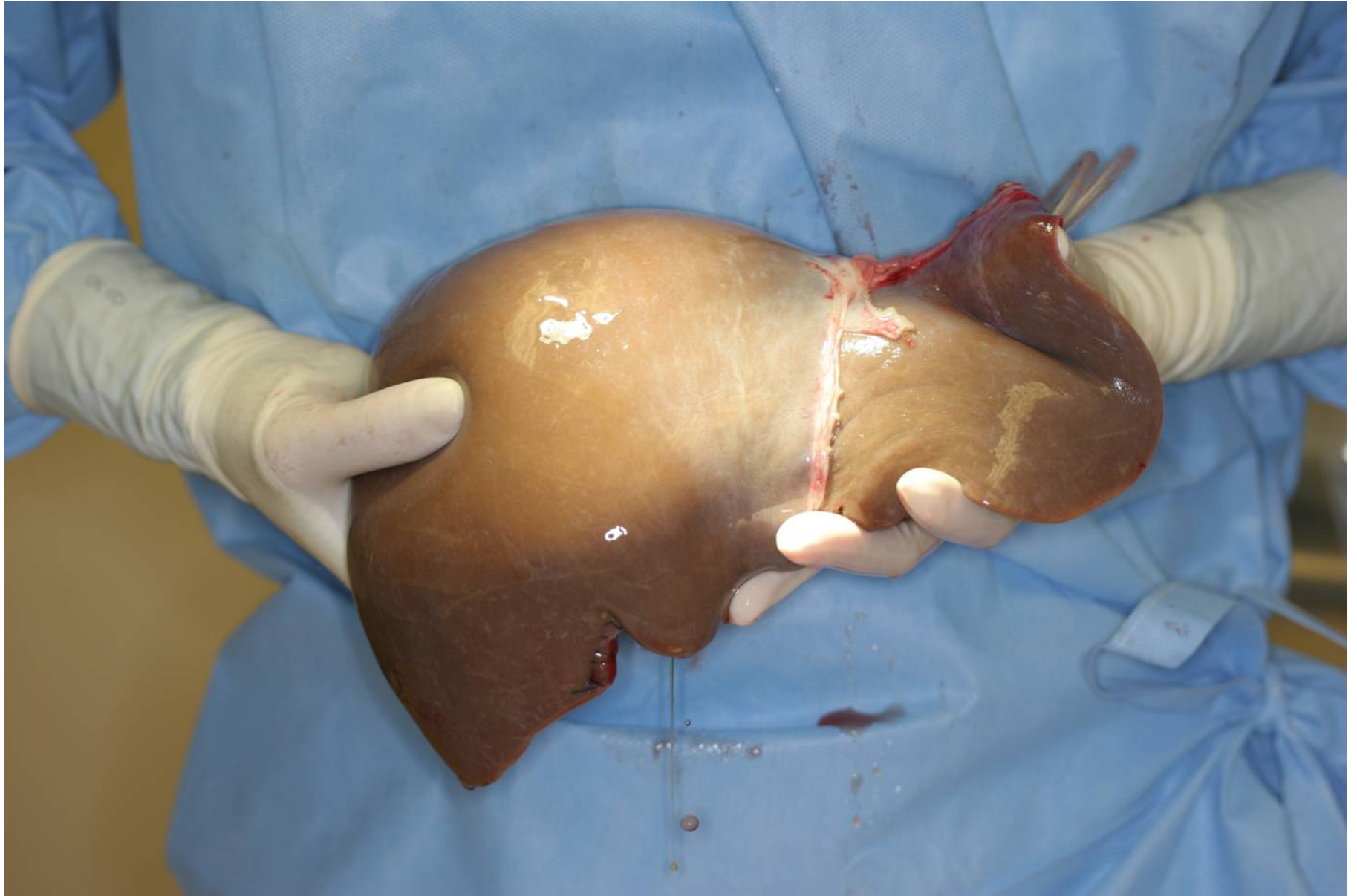
Daniel H. Wagner Prize Competition

Sommer Gentry

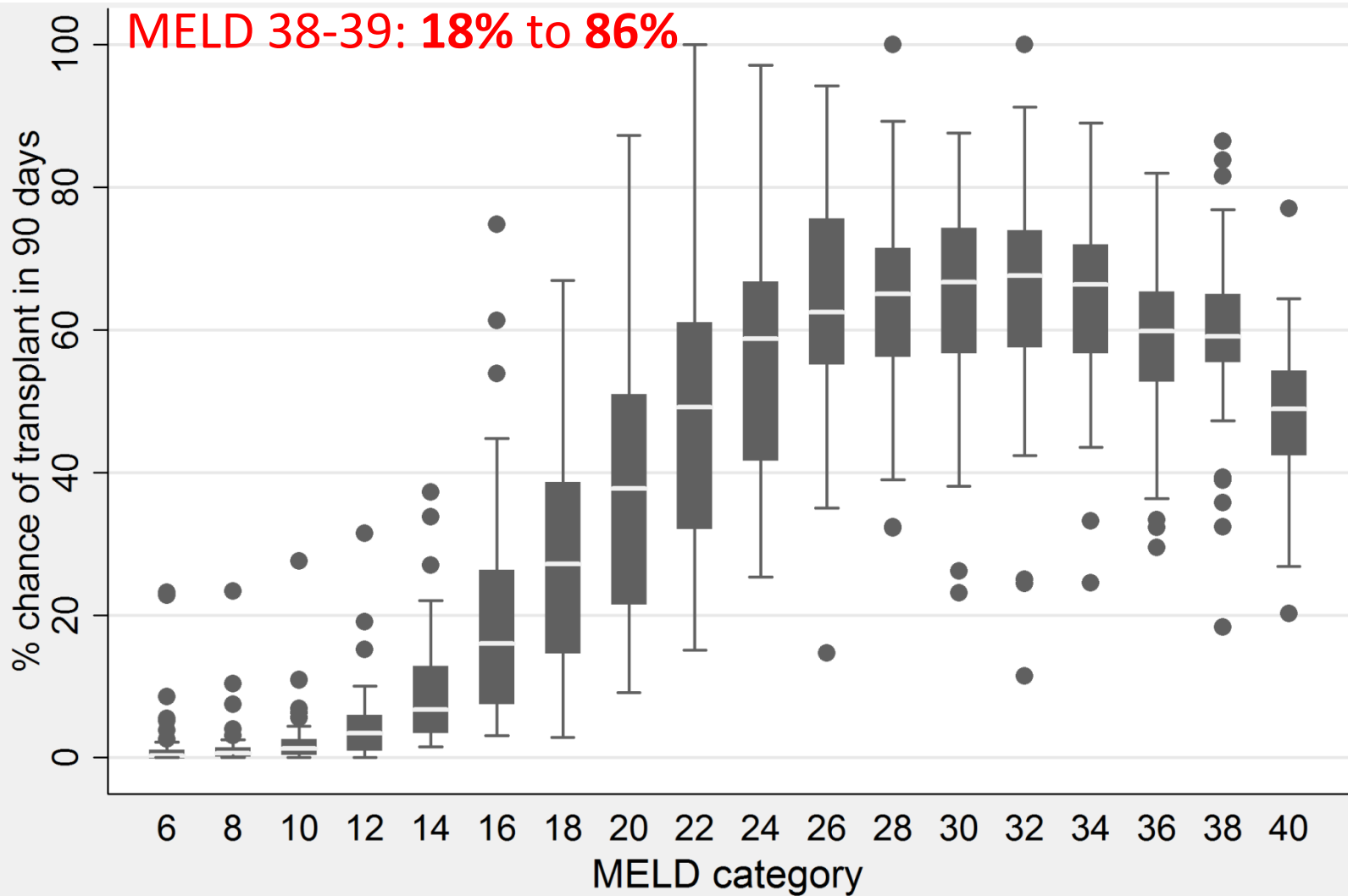
Department of Mathematics
United States Naval Academy

Dorry Segev

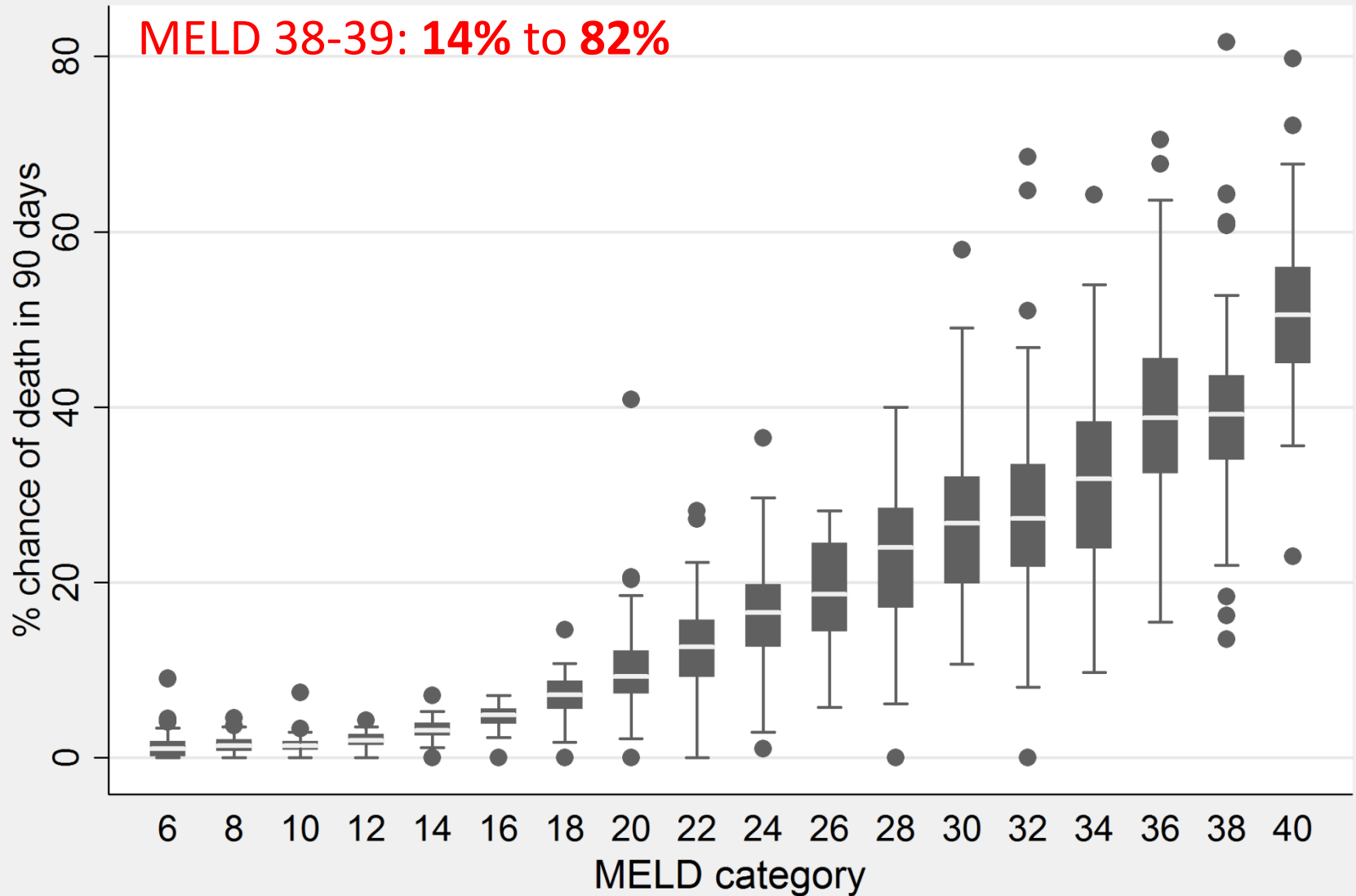
Department of Surgery
Johns Hopkins University



Range of transplant rates, by DSA



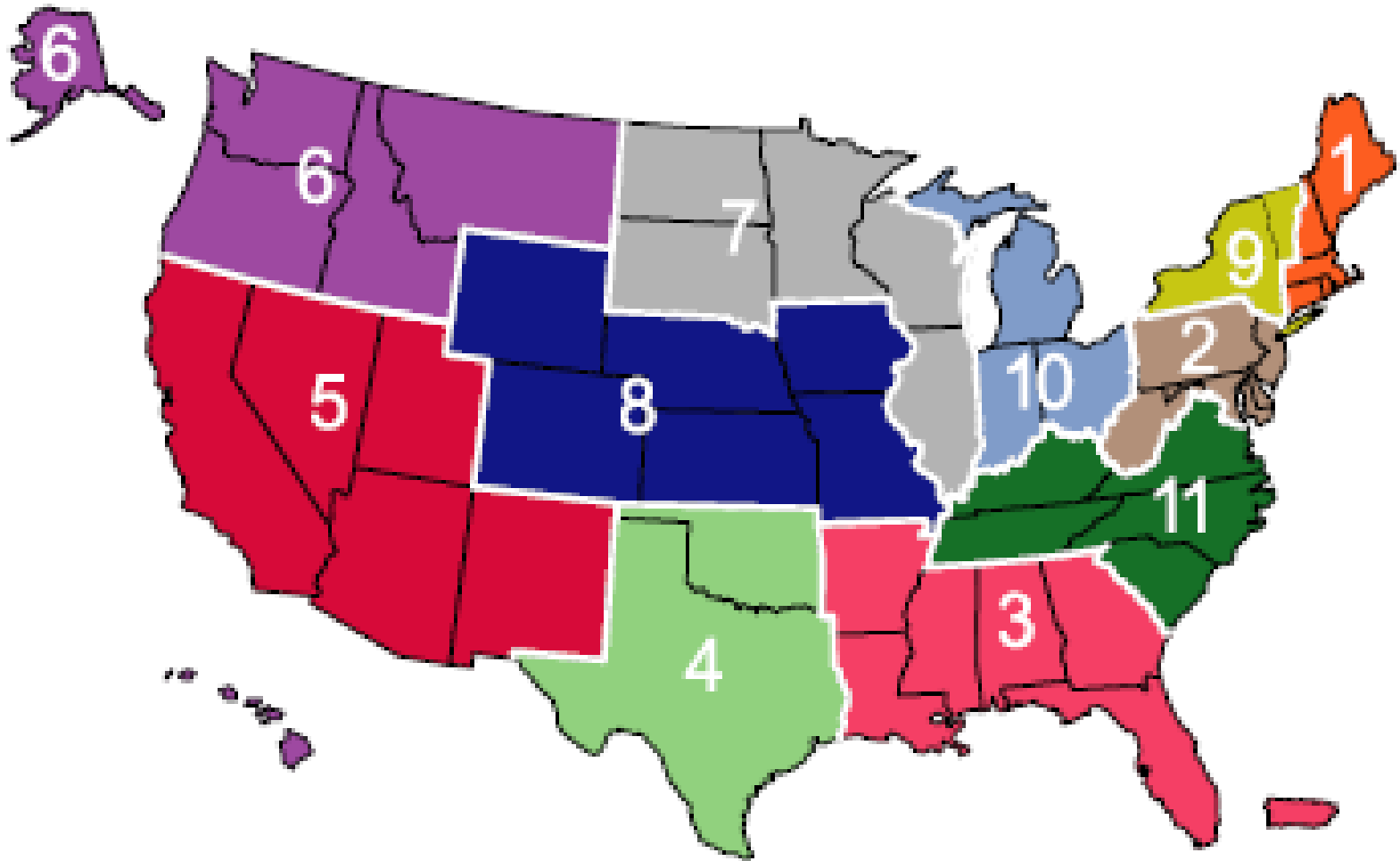
Range of waiting list death rate, by DSA

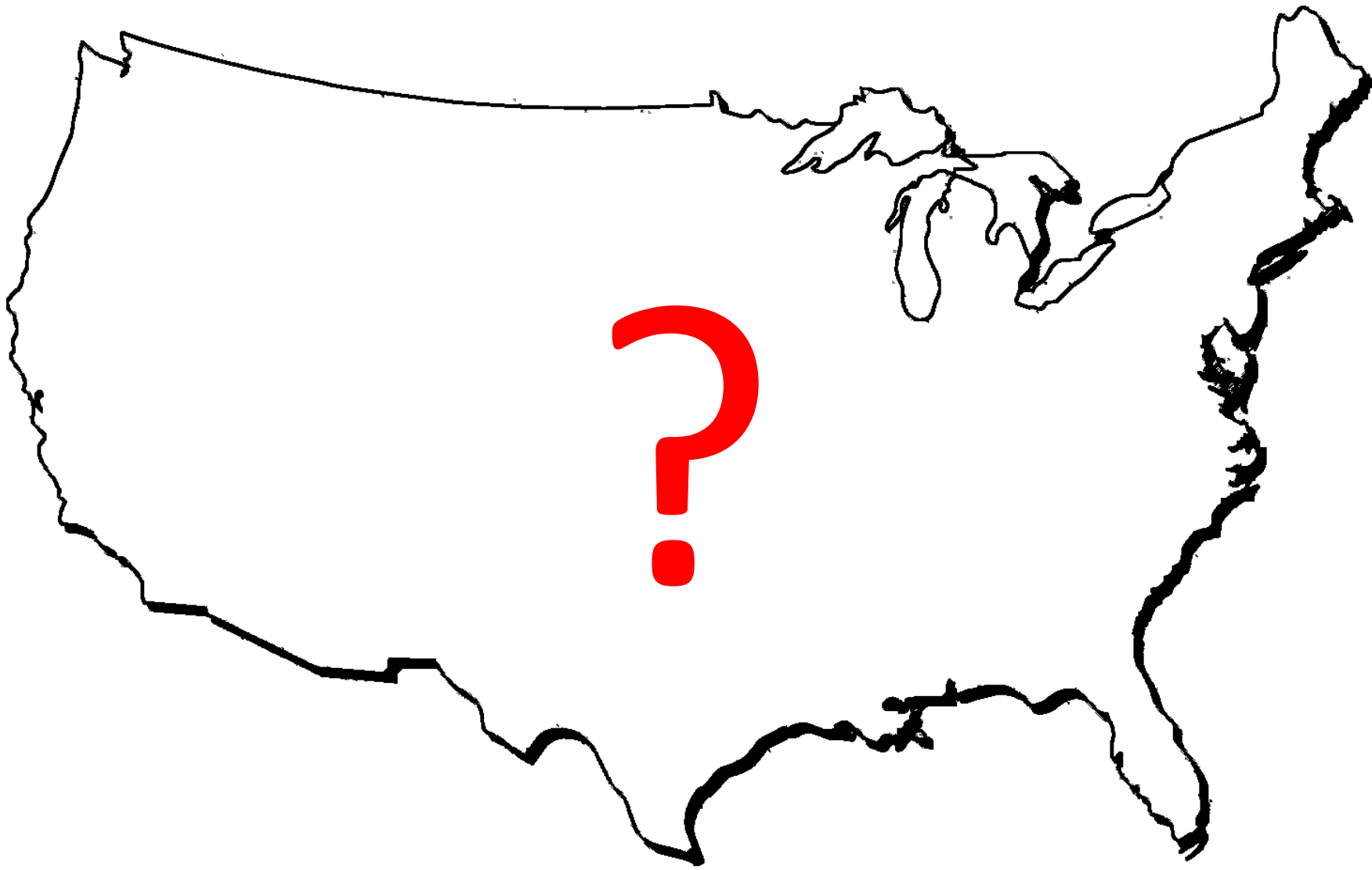


Department of Health and Human
Services Final Rule (1998)
42 CFR Part 121.8(b)

“Neither place of residence nor
place of listing shall be a major
determinant of access to a
transplant.”

DSAs are partitioned into regions





The New York Times

December 29, 1999

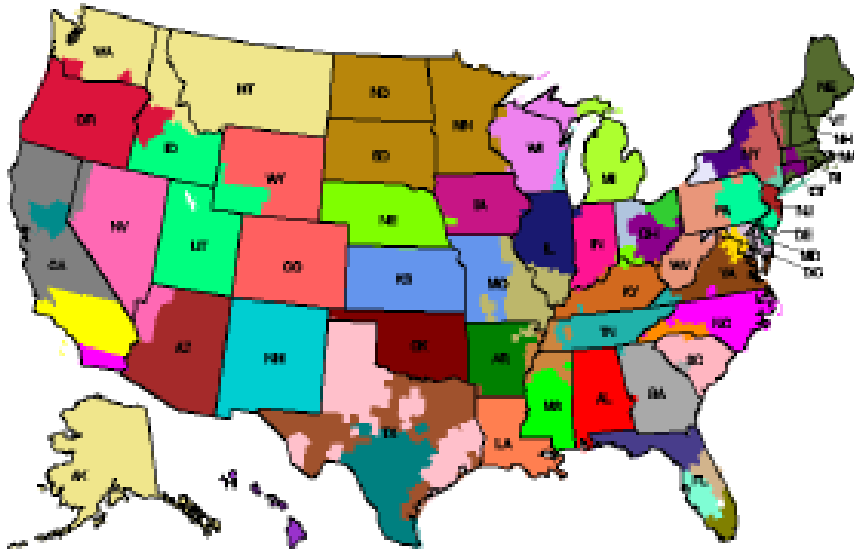
Iowa Turf War Over Transplants Mirrors Feuds Across the Nation

*“But the debate is not just about saving lives... the fight, they say, is about **which transplant centers -- not which patients -- will get the scarce organs, and the profits and prestige that go with them.**”*

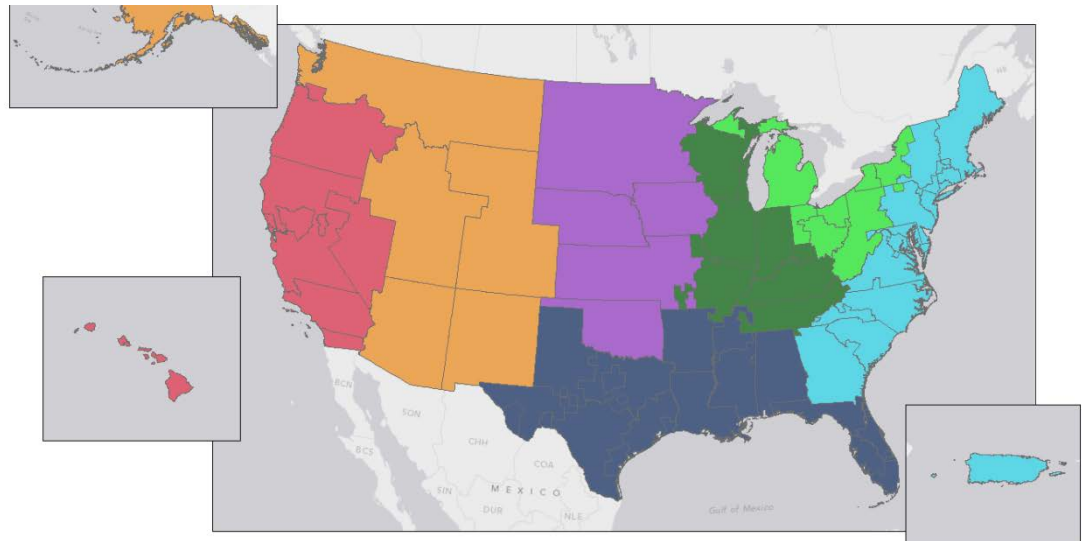
Optimal Redistricting

- Redistricting uses integer programming to design geographic boundaries between units
 - There is a substantial body of OR literature on redistricting for voting districts and school districts, dating from 1950s to the present
- Our contribution is in formulating a transparent, transplant-relevant model
- We partition the DSAs into new districts
 - design first (OPL/CPLEX), then analyze (LSAM)

Partition DSAs into districts



Under redistricting, livers would be allocated to the sickest candidate anywhere in the district



Prior work: redistricting liver allocation

- Institute of Medicine (1999)
- Maximize a pure efficiency metric (Kong et. al 2010)
- Maximize a combined efficiency / equity metric (Stahl et. al 2005, Demirci et. al 2012)
- Redistricts using branch and price approaches, plus decomposition using geographic covers
- Neglects MELD prioritization of candidates in the definition of equity, overweights the impact of transport distance on transplant success rate, and depends on an inaccurate notion of liver compatibility matching

Redistricting Objective

- Minimize *number of misdirected organs*
 - Misdirected organs = difference between number of donors a district *should* have (if organs went to highest MELD patient anywhere in the country) and number of donors in a proposed district
 - Minimize sum of these disparities over all districts
- Pure equity objective
 - MELD predicts waiting list death
 - Getting each liver to the sickest candidate should also be efficient, reducing waiting list deaths

Liver Committee's design constraints

- Districts should be contiguous.*
- The number of districts should be at least 4 and no more than 8.
- The maximum median transplant-volume-weighted transport time between DSAs is 3 hours.
- Minimum number of transplant centers per district is 6.

$\mathcal{I} = \mathcal{K} = \{1, 2, 3, \dots, 57\}$ DSAs

$w_{ik} = 1$ if DSA i is in the district with center at DSA k , and 0 if not

$Y_k = 1$ if DSA k is selected as the center of a district, and 0 if not

c_k = active liver transplant centers in DSA k

d_k = donors available in DSA k

p_k = number of donors that should go to DSA k with national-level allocation

δ_{ij} = volume-weighted distance from DSA i to j

τ_{ij} = volume-weighted transport time between DSAs i and j

Minimize:
$$\sum_{k \in \mathcal{K}} \left| \sum_{i \in \mathcal{I}} p_i W_{ik} - \sum_{i \in \mathcal{I}} d_i W_{ik} \right|$$

Objective: minimize geographic disparity in liver availability by minimizing the sum of misdirected livers

subject to: $\sum_{k \in \mathcal{K}} W_{ik} = 1$ for all $i \in \mathcal{I}$

$W_{ik} - Y_k \leq 0$ for all $i \in \mathcal{I}$ and $k \in \mathcal{K}$

Each DSA is assigned to one district

If a DSA k is assigned as the center of the district containing DSA i ,

Y_k should be 1

$$\sum_{k \in \mathcal{K}} Y_k = N$$

$$\sum_{i \in \mathcal{I}} h_i W_{ik} \geq \bar{h} Y_k \quad \text{for all } k \in \mathcal{K}$$

Number of districts is N

Require at least \bar{h}
transplant centers in each district

$$W_{ik} \tau_{ik} \leq \bar{\tau} \quad \text{for all } i \in \mathcal{I} \text{ and } k \in \mathcal{K}$$

Maximum transport time from each district to its district center is $\bar{\tau}$

$$\sum_{k \in \mathcal{K}} \alpha_{ijk} W_{ik} \leq 1 - Y_j \quad \text{for all } i \in \mathcal{I} \text{ and } j \in \mathcal{K}$$

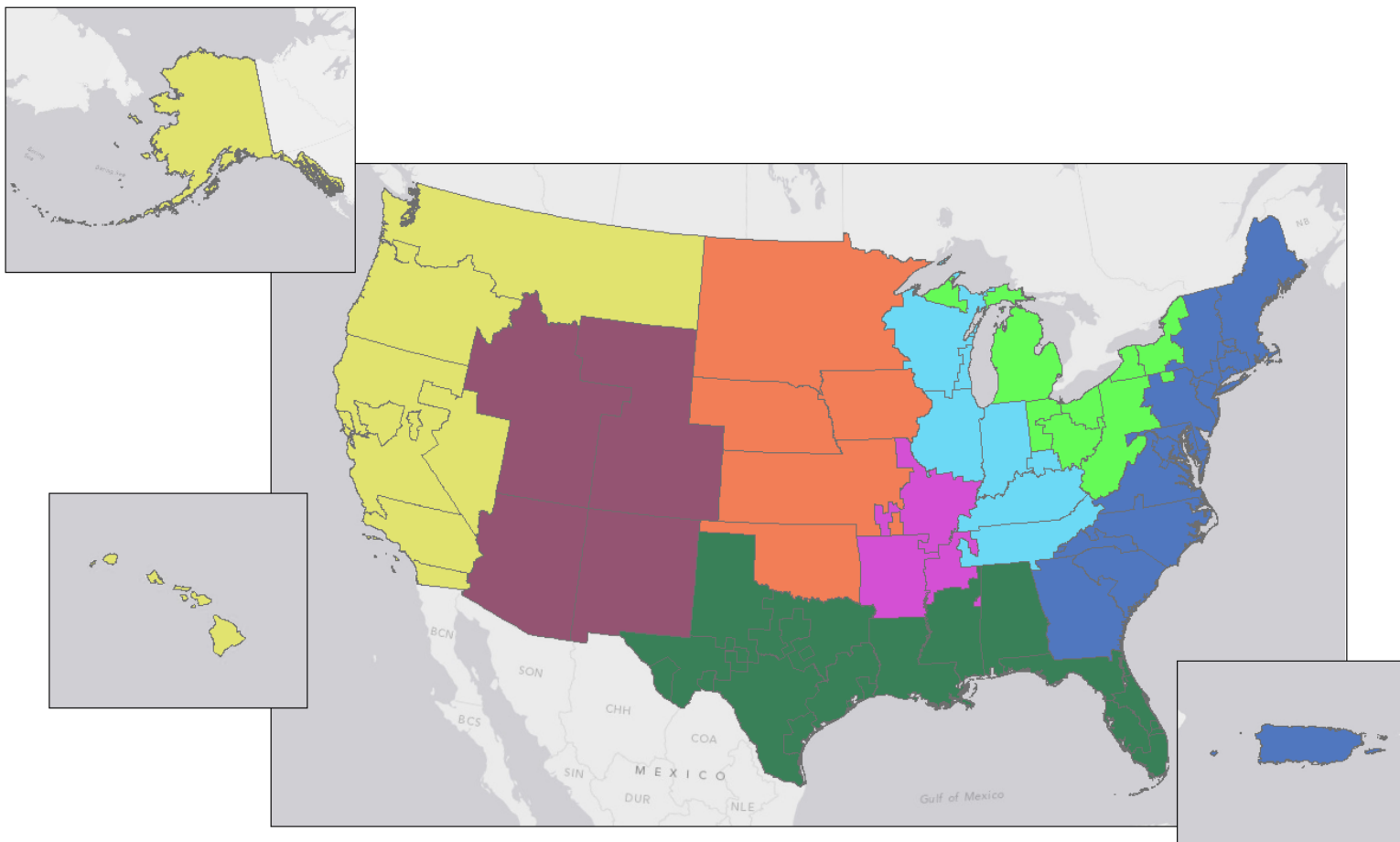
δ_{ij} = volume-weighted distance from DSA i to j

$$\alpha_{ijk} = \{1 \text{ if } \delta_{ik} > \delta_{ij}, 0 \text{ if not}\}$$

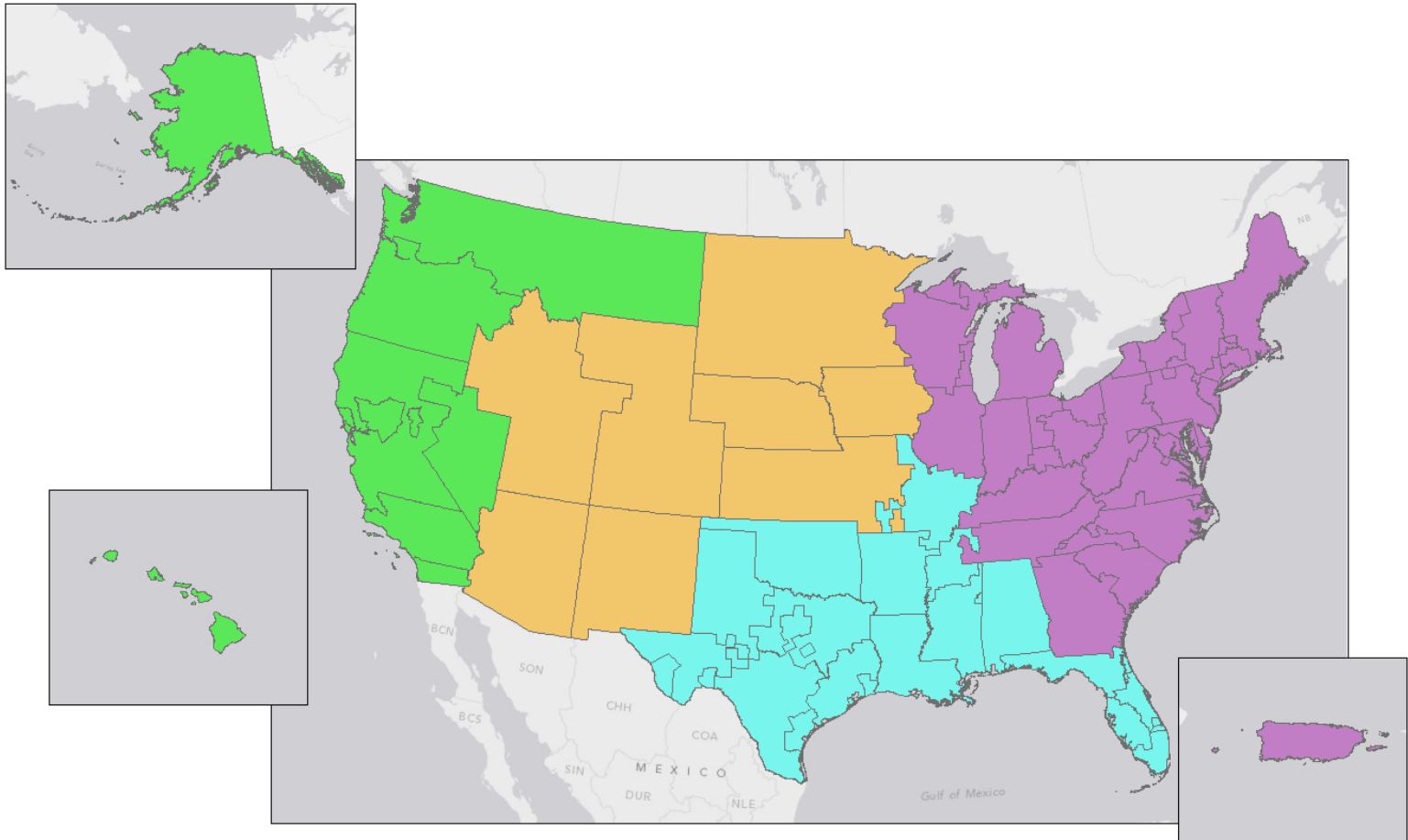
Every DSA is assigned to its nearest
district center

(Daskin, Service Science, 2010)

8 districts



4 districts

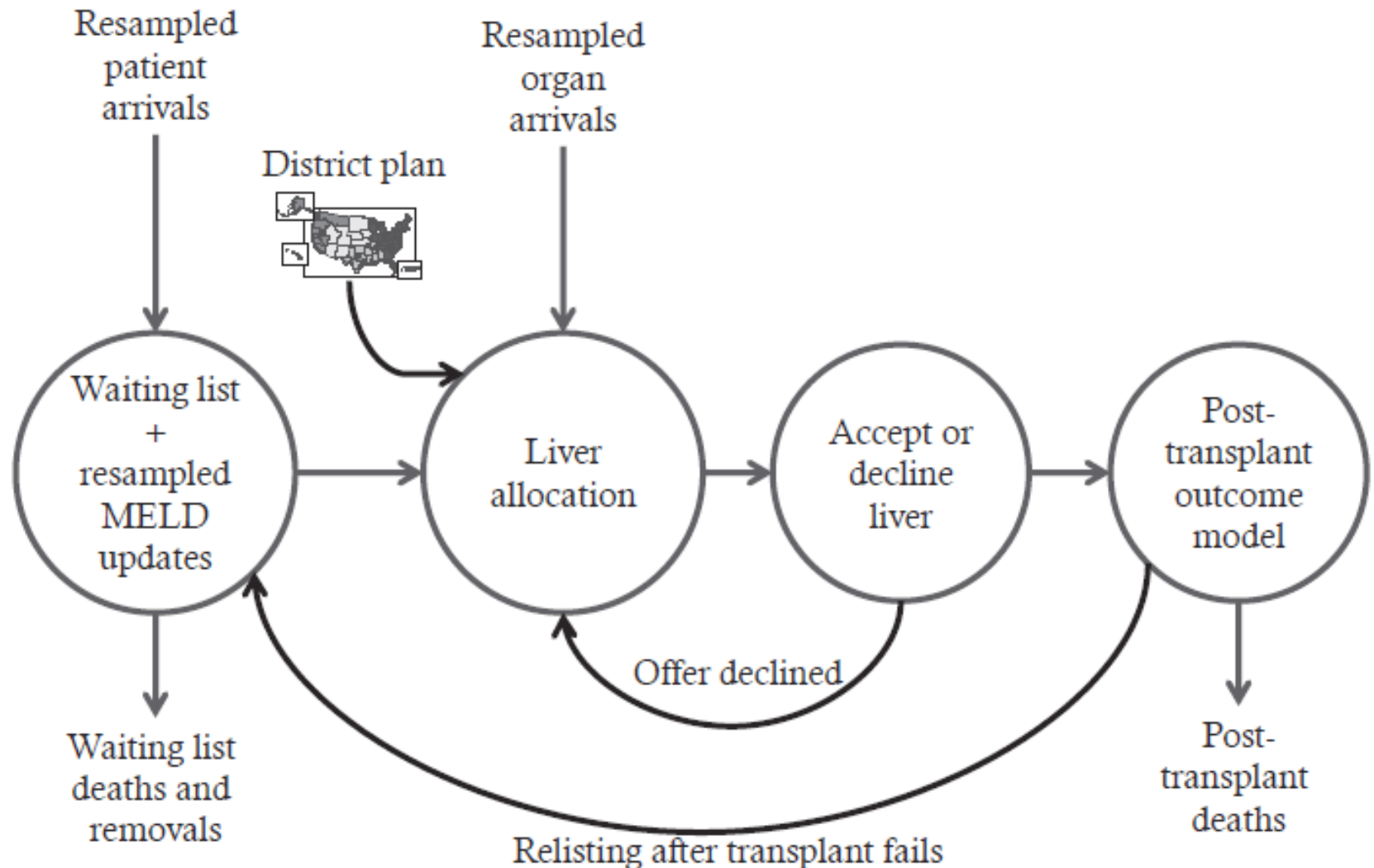


Liver Simulated Allocation Model

- The redistricting integer program is greatly simplified
 - Assume MELDs are fixed, does not model deaths
 - Assumes all offers are accepted
 - Assumes all livers are identical
- Liver Simulated Allocation Model reintroduces realistic clinical detail
 - Standard deviation of median MELD at transplant among DSAs is a dynamic geographic equity metric

Liver Simulated Allocation Model

Thompson and Waisanen, 2004



Organ Transport Time Model

- Distance is very weakly correlated with cold ischemia time
- Delay attributable to allocation is the transport time from donor hospital to transplant center
- Detailed transport model uses:
 - Locate all donor/transplant centers and airports
 - Google API for driving times
 - Flight times plus drive times to airport locations
 - Decision: drive if drive time < 2 hours, or if drive time $<$ flying time

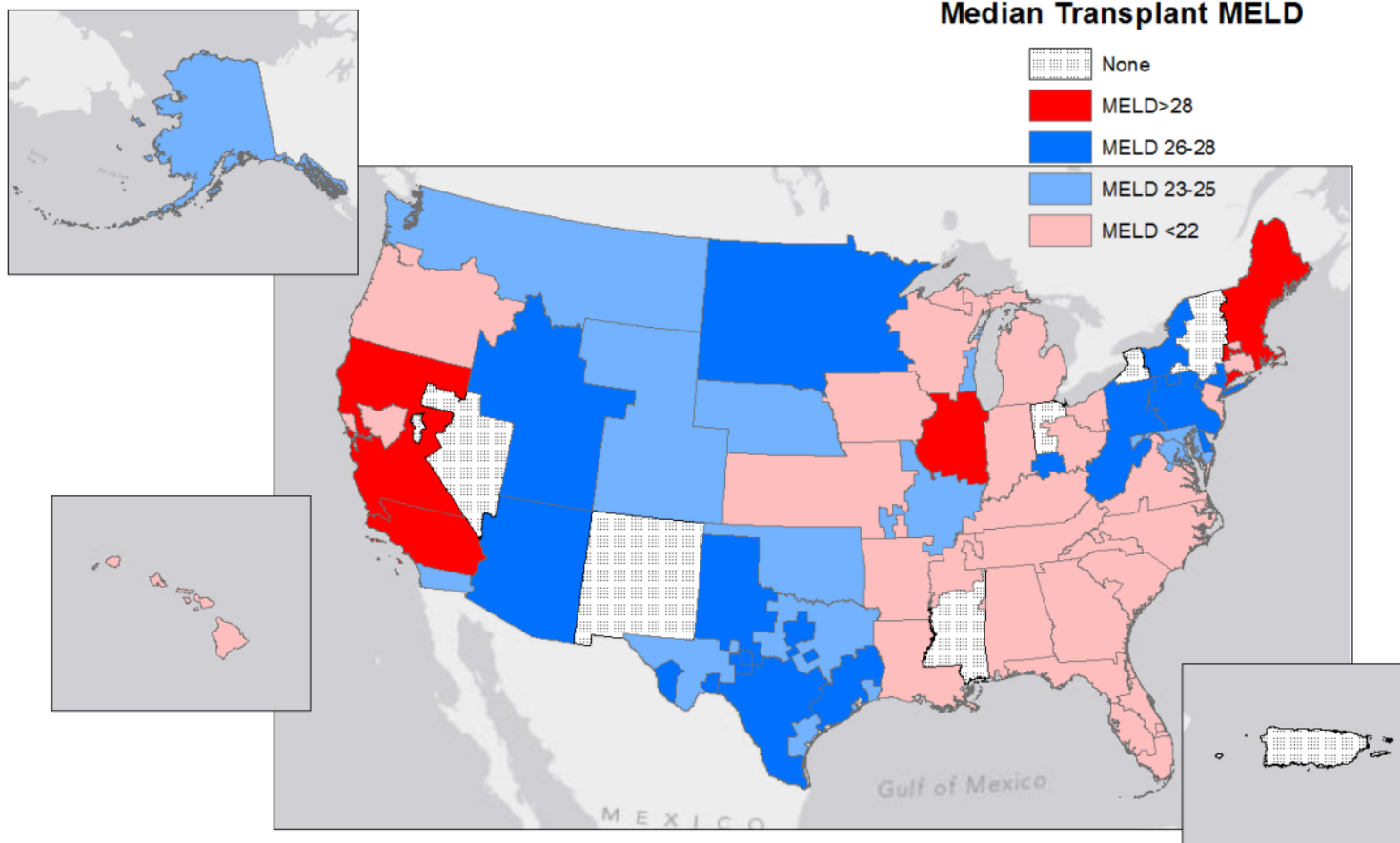
Transport and transplant costs

- Transport cost
 - by car (Lynch RJ et al. 2009): \$1108
 - by helicopter: \$4742
 - by charter aircraft: according to linear regression fit from flight distance and cost records
- Pre-transplant, transplant, and post-transplant costs for all candidates
 - Adjusts for MELD, age, comorbidities, etc.

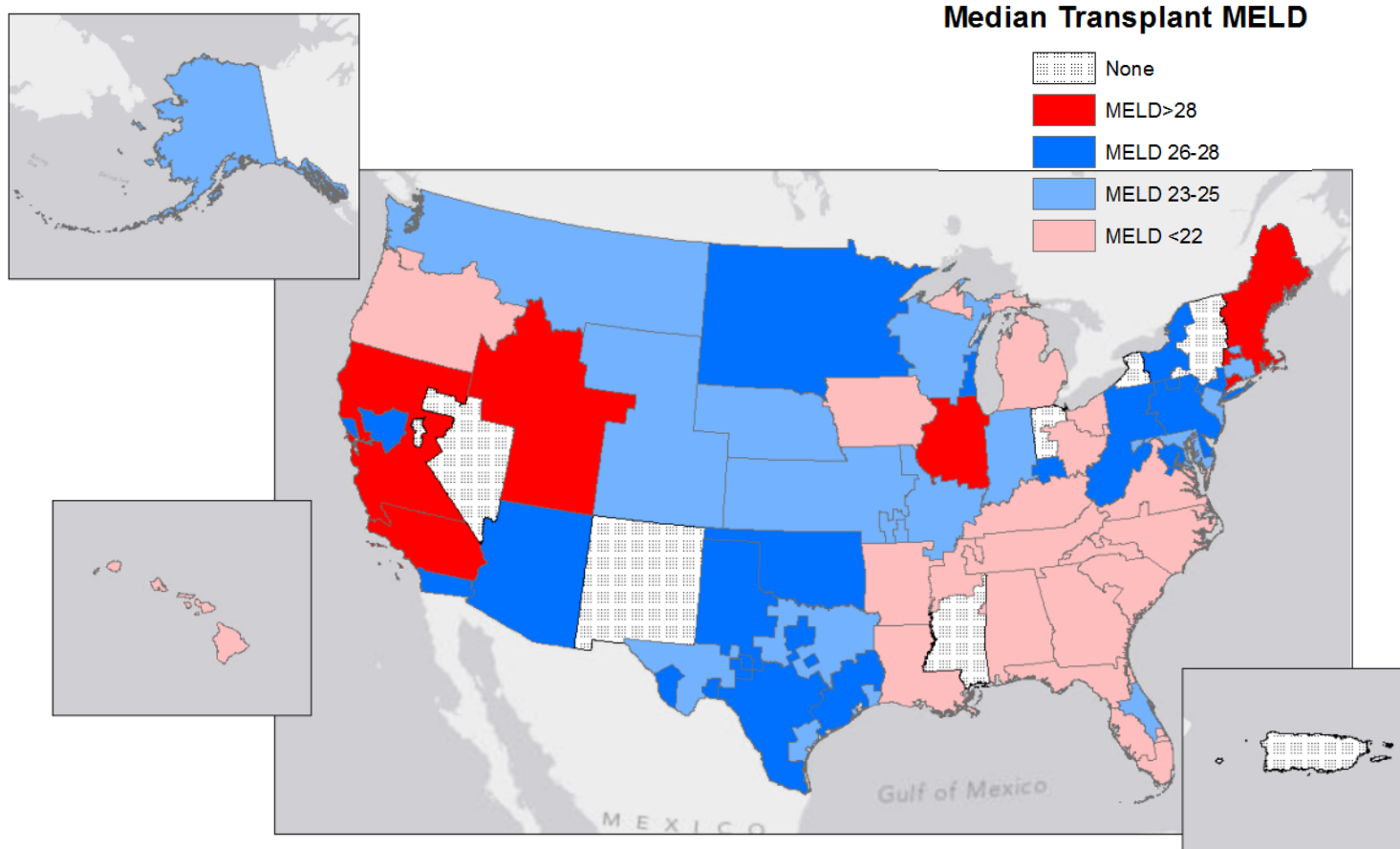
Simulated redistricting impacts over 5 years

Allocation	Misdirected Livers	Std Dev MELD	Net Waitlist Deaths
Local	2363	3.01	0
Regional	1317	3.26	-165
National	0	1.66	-344
4 Districts	128	1.87	-554
8 Districts	156	2.08	-332

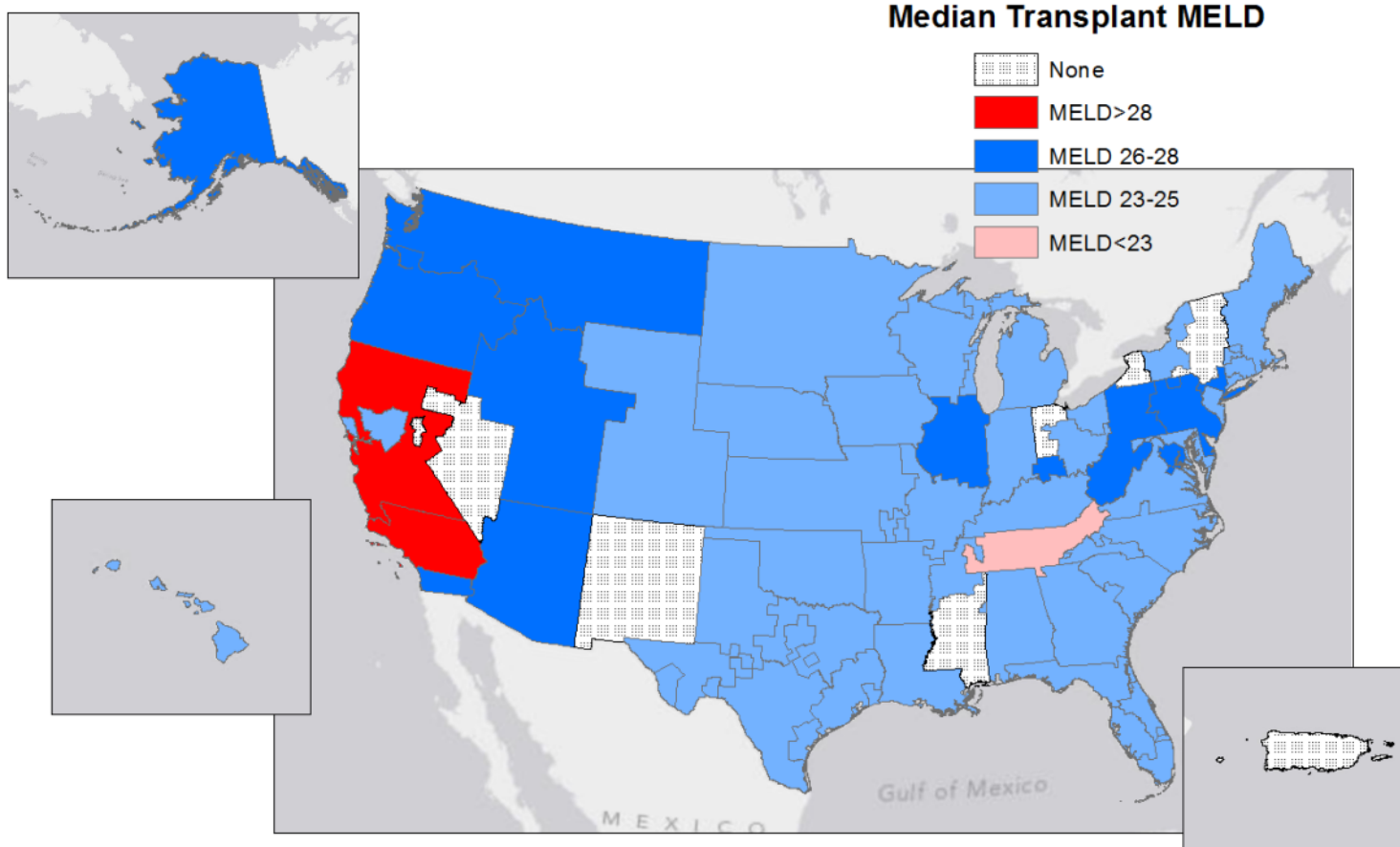
Disparity in transplant MELD, local



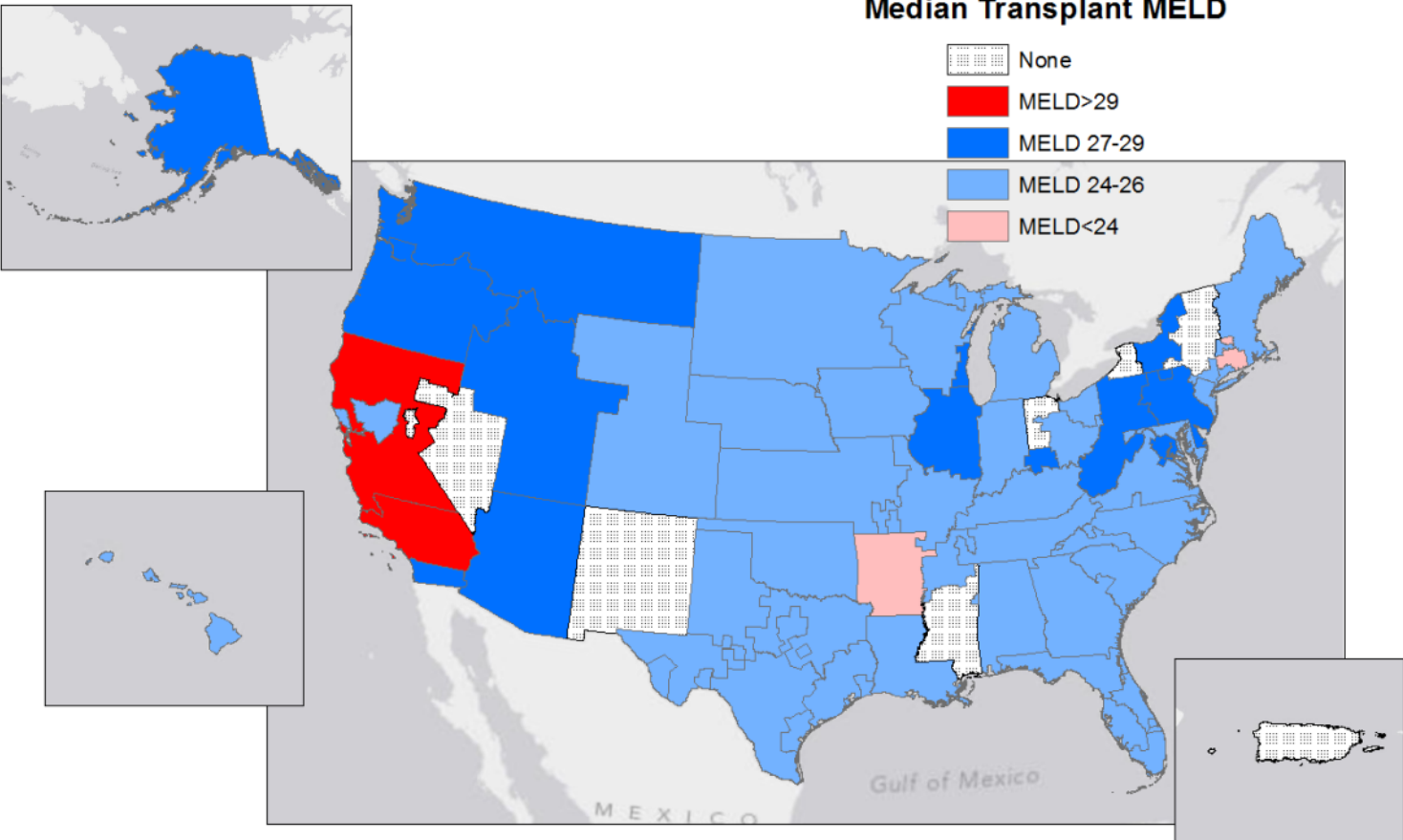
Disparity in transplant MELD, regional



Disparity in transplant MELD, 8 districts



Disparity in transplant MELD, 4 districts



Redistricting and organ transport

Allocation	Median Time	Median Distance	% Flying
Local	1.5 hours	68 miles	44%
Regional	1.7 hours	137 miles	61%
4 Districts	2.1 hours	340 miles	74%
8 Districts	1.8 hours	178 miles	64%

Redistricting is cost-saving

Allocation	Transport Cost	Pre-transplant Cost	Transplant Cost	Total Cost
Local	\$125 mil	\$1629 mil	\$3576 mil	\$5330 mil
Regional	\$165 mil	\$1487 mil	\$3468 mil	\$5120 mil
4 Districts	\$191 mil	\$1358 mil	\$3453 mil	\$5002 mil
8 Districts	\$176 mil	\$1387 mil	\$3462 mil	\$5025 mil

ATC Today

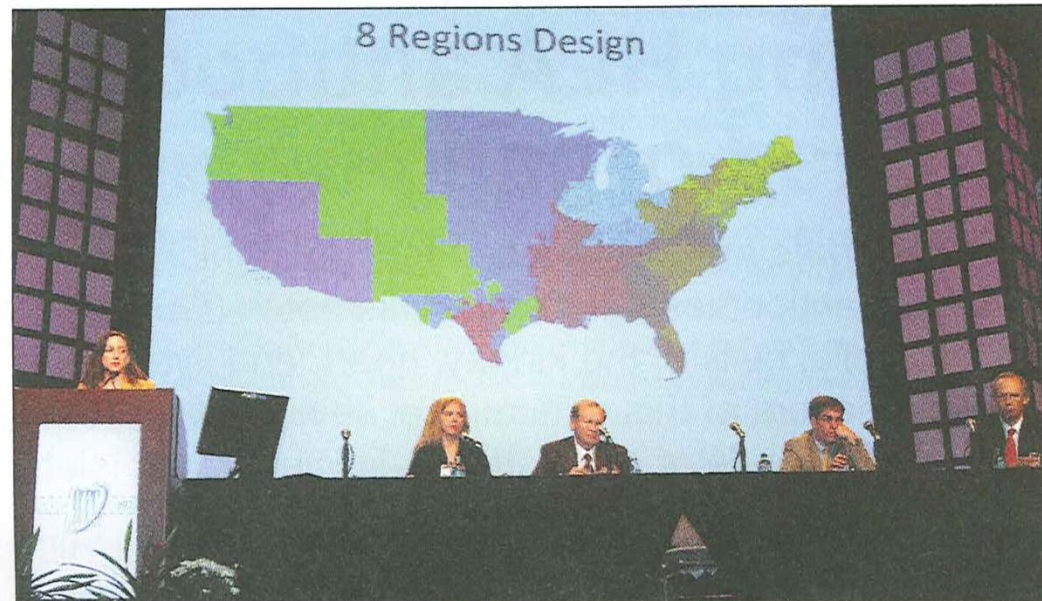
Monday, May 2, 2011



Change Needed in Deceased-Donor Liver Allocation

Receiving a life-saving liver transplant from a deceased donor seems to hinge on what part of the country the hopeful recipient of an organ resides, with odds weighing more heavily in favor of patients in less densely populated parts of the country. Organ transplantation policy researchers addressed this disparity from various perspectives during Sunday's Controversies in Transplantation.

"The consensus among major organ policy experts is favoring small, incremental steps to broaden distribution with the goal to minimize waitlist deaths and limit the distance the organ needs to travel," said James F. Markmann, MD, PhD, Chief, Division of Transplant Surgery, Massachusetts General Hospital, Boston. "Elimination of geographic disparities may not only



Listening to Sommer Gentry, PhD, make her presentation Sunday during Controversies in Transplantation are (L-R) Chairs Krista Lentine, MD, and Goran Klintmalm, MD, PhD, and panelists David Axelrod, MD, MBA, and James F. Markmann, MD, PhD.

OPTN Board Resolution, Nov 2012

The existing geographic disparity in allocation of organs for transplant is **unacceptably high**.

The Board directs organ-specific committees to define the metric of fairness and any constraints for each organ system by June 30, 2013...

The Board requests that **optimized systems** utilizing overlapping versus non-overlapping geographic boundaries be compared, including using or disregarding current DSA and region boundaries in allocation.

OPTN/UNOS Liver and Intestinal Organ Transplantation Committee

all

August 21, 2013 3pm EDT

1. Committee Priorities, 2013-2014. The Committee leadership met via conference call to prioritize the long list of approved projects for the 2013-2014 year. The top three priorities for the year are as follows:
 - Liver Distribution Redesign Modeling
 - Develop materials to educate RRB members / promote consistent review of exceptions / Ongoing review of MELD/PELD Exceptions
 - Changes to Policy for Hepatocellular Carcinoma (HCC) Exceptions

“In short, the unanimous vote taken on April 1st that sent two optimized redistricting plans forward for public comment was ***unprecedented***. I could not have imagined that every single member of the Liver Committee, including members representing transplant centers that are expected to do fewer liver transplants as a result of redistricting, would vote in favor.”

- Dr. David Mulligan, Chair, OPTN Liver and Intestinal Transplantation Committee

September 2014 public forum



The long policy road

- First, the OPTN Liver Committee must issue a formal proposal incorporating input from the public forum
- A required public comment period begins no earlier than March 2015
- The policy could be implemented in November 2015 with the approval of the OPTN Board of Directors

Lessons for implementing OR solutions in healthcare

- Build transparent optimization models
- Enable decision-makers to focus on principles and objectives, not on constructing or critiquing ad hoc policies
- Make things as simple as they must be, but then use simulation to make them detailed enough to be plausible to clinicians

Lessons for implementing OR solutions in healthcare

- Develop credibility through years of engagement with particular communities of healthcare practice
 - Optimizing kidney exchange (Segev et al. 2005, Gentry et al. 2005, plus)
 - An act of Congress (Charlie W. Norwood Act, 2007)
 - Advised OPTN on creating its national kidney exchange registry, donated our software
- Engagement with OPTN Liver Committee
 - We thank these physicians and other representatives for their contributions

Thank you to our
colleagues at the
**Scientific
Registry for
Transplant
Recipients**

John Lake, MD

David Zaun, PhD

Ajay Israni, MD

Jon Snyder, PhD

Josh Pyke, PhD

Eugene Shteyn, MS

Bert Kasiske, MD PhD

Epidemiology Research Group in Organ Transplantation

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Core Research Group

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Computational Science

Sommer Gentry, PhD
Computer Science

Eric Chow, MHS
Decision Process Models

Corey Wickliffe
Geographic Information Systems

Epidemiology

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Epidemiology

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