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A Revealed Preference Analysis to Develop a Composite Score That Approximates Liver Allocation Policy

Final Results Memo

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Executive Summary

As of July 2022, more than 11,000 people were waiting for a liver transplant (Organ Procurement and Transplantation Network [OPTN], 2022). Because there are more patients on the waiting list than available livers, choices must be made to allocate donor livers to patients in a way that balances concerns for both equity and medical utility. These liver allocation decisions are made according to policies developed by the OPTN, which is operated by the United Network for Organ Sharing (UNOS). Specifically, when a donor liver becomes available, these policies determine how potential recipients are ranked according to objective characteristics (e.g., medical urgency/benefit, blood type, proximity to donor hospital). This ranking process is carried out by a computerized algorithm, known as the match system. Each time a donor liver becomes available and potential recipients are ranked, it is known as a "match run."

Although the current classification-based system has helped thousands in need, it still faces some limitations. In particular, a candidate in a lower classification—even one who is highly medically urgent—may not be prioritized ahead of candidates in a higher classification (Stewart et al., 2021). To address this limitation in liver allocation policy, UNOS is working to migrate to a points-based, continuous distribution system.

One way to facilitate a transition to a points-based system would be to determine if current liver allocation policies could be captured, at least approximately, by such a points-based framework. Our analysis seeks to accomplish that goal in two steps.

First, we use conventional discrete choice modeling techniques to estimate four statistical models based on all non-import match runs from 2021—one for donors in each of the following categories:

1. donors who are younger than 11 years of age and who are not donating upon circulatory death (also known as donation after circulatory death [DCD] donation),

2. non-DCD deceased donors between 11 and 18 years of age,
3. non-DCD deceased donors between 18 and 70 years of age, and
4. DCD deceased donors and/or non-DCD deceased donors who are 70 years of age and older.

These statistical models estimate scores that quantify how important the following candidate attributes are in the liver allocation rank ordering: 1) medical priority, 2) candidate age, 3) proximity to the donor hospital, 4) blood type compatibility, and 5) how much time the candidate has been at their current urgency status. We found that medical priority is the most important attribute for determining a candidate's ranking in all four models.

Second, to confirm that the estimated scores adequately capture current liver allocation policy, they were used to predict what the candidate rankings would be in 2021 and 2022, if these scores had been used instead of the current system. The closer the predicted rankings are to the actual rankings, the more confidence we have that the scores approximate current allocation policies.

Overall, we found that the predicted rankings reasonably match the original rankings produced by the matching algorithm. Specifically, we found that the median Kendall's Tau rank correlation coefficient between the original ranks produced by the matching algorithm and the ranks produced by our models in 2021 and 2022 was at least 0.60 for all four donor categories. This suggests a moderate-to-strong correlation between the original rankings and our predicted rankings.

ES.1 DATA AND METHODS

Similar to the analysis of lung allocation policy in Stewart et al. (2021), we use rank-ordered logistic regression (logit) models to estimate statistical models that capture current liver allocation policies across categories. Specifically, we estimate separate rank-ordered logit model for each of the four donor categories listed above. All four models assume that a candidate's rank in a given match run is determined by the following candidate attributes:

- **Medical priority**: Defined using either the candidate's Model for End-Stage Liver Disease (MELD)/Pediatric End-Stage Liver Disease (PELD) score or whether they are Status 1A/1B. Note that combining MELD and PELD scores into a single variable create issues as MELD scores range from 6 to 40 and PELD scores range from −99 to 99. To avoid problems created by overlapping scales, we recode all PELD scores below 6 to 6.
- **Proximity:** Defined as nautical miles from transplant hospital to donor hospital.
- **Blood type compatibility:** Defined as whether blood type of candidate and donor are identical or not.
- **Candidate age:** Defined as whether the patient is younger than 18 years of age or not.
- **Waiting time:** Defined as the amount of time that the candidate has been at their current medical urgency status measured in days.

To estimate these models, we obtained de-identified data for all liver match runs from 2021 (January to December 2021) and all available liver match runs from 2022 (January to May 2022). Specifically, we obtained the following match run data for donors in the following four categories:

- **Non-DCD Deceased Donors Younger Than 11 Years of Age:** We obtained rankings produced by 462 match runs for pediatric donors younger than 11 years of age. An average of 1,201.44 candidates were ranked in each match run. As a result, we have data for 555,066 ranked candidates, with some candidates appearing on multiple match runs.
- **Non-DCD Deceased Donors 11 to 17 Years of Age:** We obtained rankings produced from 514 match runs for pediatric donors between 11 and 17 years of age. An average of 5,052.61 candidates were ranked in each match run. As a result, we have 2,597,043 observations for estimating the adolescent donor liver allocation model.
- **Non-DCD Deceased Donors 18 to 69 Years of Age:** We obtained rankings produced from 12,171 match runs

for adult donors 18 to 69 years of age. An average of 4,550.96 candidates were ranked in each match run. As a result, we have 55,389,712 observations for estimating the adult donor liver allocation model.

- **Donors Who Are at Least 70 Years of Age and/or DCD Donors:** We obtained rankings produced from 7,846 match runs for adult donors 70 years of age and older. An average of 2,760.04 candidates were ranked in each match run. As a result, we have 21,655,290 observations for estimating the adult donor liver allocation model.

ES.2 RESULTS

Table ES-1 contains the coefficients from the rank-ordered logit models estimated using data from all 2021 match runs by donor category.

Table ES-1. Rank-Ordered Logit Estimates Based on 2021 Match Runs

	Non-DCD Deceased Donors Younger Than 11 Years of Age	Non-DCD Deceased Donors 11 to 17 Years of Age	Non-DCD Deceased Donors 18 to 69 Years of Age	Donors Who Are at Least 70 Years of Age and/or DCD Donors
	Mean Coefficient (Standard Error)			
Medical Priority				
MELD/PELD score	0.0549*** (0.0002)	0.0583*** (0.0001)	0.0776*** (< 0.0001)	0.0745*** (< 0.0001)
Status 1A or Status 1B	3. 4654*** (0.0252)	4.2547*** (0.0232)	3.1727*** (0.0073)	3.0062*** (0.0151)
Proximity				
Distance (nautical miles)	−0.0005*** (< 0.0001)	−0.0004*** (< 0.0001)	−0.0001*** (< 0.0001)	−0.0002*** (< 0.0001)
Candidate Blood Type Relative to Donor Blood Type				
Identical vs. Nonidentical	1.8021*** (0.0043)	1.7897*** (0.0019)	1.7161*** (0.0004)	1.5124*** (0.0007)
Pediatric Priority				
Pediatric candidate vs. adult candidate	1.5636*** (0.0107)	1.3296** (0.0072)	0.2122*** (0.0025)	0.0613*** (0.0077)
Waiting Time				
Days the candidate has been at this status	0.0001*** (< 0.001)	0.0001*** (< 0.001)	0.0001*** (< 0.001)	0.0001*** (< 0.001)

Notes: (1) Status 1A or Status 1B, blood type, and pediatric priority are dummy coded, MELD/PELD, distance, and waiting time are coded as continuous variables. (2) *** denotes p < .01, **p < .05, *p < .10.

These coefficients can be used to make three different inferences about how candidate attributes influence donor liver allocation.

- **Direction of influence of individual attributes on candidate's allocation priority.** This can be done by evaluating the direction of the coefficients in Table ES-1. Based on these coefficients, we can see that attributes influence candidate rankings as one would expect. Specifically, we see that candidates across all four donor categories are given better priority if they: 1) have more urgent medical priority, 2) are located closer to the donor hospital, 3) are younger than 18 years of age, 4) have an identical blood type to the donor, and 5) have a longer waiting time.
- **Rank candidate attributes in terms of their relative importance to the liver allocation decision.** This can be done by taking the difference between the score for the most preferred level of an attribute and the score for the least preferred level of the same attribute. For example, as previously noted, the combined MELD/PELD score can range from 6 to 99. For non-DCD donors between 18 and 69 years of age, this implies that the maximum difference in MELD/PELD score is 7.22 (7.22=(0.0776*(99-6)). By making this calculation for each attribute, we can rank candidate attributes in order of importance, where larger maximum differences imply higher ranks. The results of these calculations are presented for all four donor models in Table ES-2. We can see that attributes related to medical priority (i.e., MELD/PELD and Status 1A/Status 1B) are clearly the most important attributes in liver allocation for all four donor categories.

Table ES-2. Rank of Candidate Attributes by Importance in Liver Allocation

Candidate Attribute	Most Preferred Value	Least Preferred Value	Score for Most Preferred Value	Score for Least Preferred Value	Maximum Difference in Score	Rank
Non-DCD Deceased Donors Younger Than 11 Years of Age						
MELD/PELD	99	6	5.44	0.33	5.11	1
Status 1A or 1B	1	0	3.47	0.00	3.47	2
Proximity (NM)	0	4,304.16	0.00	−2.15	2.15	3
Blood Type	1	0	1.80	0.00	1.80	4
Pediatric Priority	1	0	1.56	0.00	1.56	5
Waiting Time (days)	6,194	0	0.62	0.00	0.62	6
Non-DCD Deceased Donors 11 to 17 Years of Age						
MELD/PELD	99	6	5.77	0.35	5.42	1
Status 1A or 1B	1	0	4.25	0.00	4.25	2
Proximity (NM)	0	4,380.32	0.00	−1.75	1.75	4
Blood Type	1	0	1.79	0.00	1.79	3
Pediatric Priority	1	0	1.33	0.00	1.33	5
Waiting Time (days)	6,191	0	0.62	0.00	0.62	6
Non-DCD Deceased Donors 18 to 69 Years of Age						
MELD/PELD	99	6	7.68	0.47	7.22	1
Status 1A or 1B	1	0	3.17	0.00	3.17	2
Proximity (NM)	0	4,380.32	0.00	−0.44	0.44	5
Blood Type	1	0	1.72	0.00	1.72	3
Pediatric Priority	1	0	0.21	0.00	0.21	6
Waiting Time (days)	6,198	0	0.62	0.00	0.62	4
Donors Who Are at Least 70 Years of Age and/or DCD Donors						
MELD/PELD	99	6	7.38	0.45	6.93	1
Status 1A or 1B	1	0	3.01	0.00	3.01	2
Proximity (NM)	0	4,380.32	0.00	−0.88	0.88	4
Blood Type	1	0	1.51	0.00	1.51	3
Pediatric Priority	1	0	0.06	0.00	0.06	6
Waiting Time (days)	6,198	0	0.62	0.00	0.62	5

Note: Calculations performed using coefficients reported in Table ES-1, which were rounded to the fourth decimal place. NM = nautical mile.

- **Quantify the relative importance of candidate attributes (i.e., "exchange rates").** This can be done by expressing changes in one attribute in terms of another. For example, for non-DCD donors between 18 and 69 years of age, we can see from Table ES-1 that increasing a candidate's distance from the donor hospital by 1,000 nautical miles lowers their composite allocation score by 0.10 point (−0.10 = −0.0001 * 1,000). On its own, this calculation may not be very informative, because the units used to measure the proximity score are arbitrary. However, one way to add more context to this change is to express a change in one attribute in terms of a change in another attribute. For example, based on the same coefficients in Table ES-1, increasing a candidate's distance from the donor hospital by 1,000 nautical miles is equivalent to reducing a candidate's MELD/PELD score by 1.29 points. This is because reducing the candidate's MELD/PELD score by 1.29 points reduces their composite score by 0.10 point (−0.10 = 0.0776 *−1.29). In Table ES-3, we compare changes in each attribute in terms of changes in a candidate's MELD/PELD score.

Table ES-3. Converting Changes in Each Attribute into Changes in MELD/PELD Score

Change in Attribute	Change in Composite Allocation Score	Equivalent Change in MELD/PELD Score
Non-DCD Deceased Donors Younger Than 11 Years of Age		
Status: remove candidate priority status (i.e., Status 1A or 1A)	−3.47	−63.12
Proximity: increase candidate distance by 1,000 NM	−0.50	−9.11
Candidate Blood Type: change candidate blood type from identical to donor to compatible with donor	−1.80	−32.83
Pediatric Priority: change candidate from pediatric patient to adult patient	−1.56	−28.48
Waiting Time: reduce wait time by 100 days	−0.01	−0.18
Non-DCD Deceased Donors 11 to 17 Years of Age		
Medical Priority: remove candidate priority status (i.e., Status 1A or 1B)	−4.25	−72.98
Proximity: increase candidate distance by 1,000 NM	−0.40	−6.86
Candidate Blood Type: change candidate blood type from identical to donor to compatible with donor	−1.79	−30.70
Pediatric Priority: change candidate from pediatric patient to adult patient	−1.33	−22.81
Waiting Time: reduce wait time by 100 days	−0.01	−0.17
Non-DCD Deceased Donors 18 to 69 Years of Age		
Medical Priority: remove candidate priority status (i.e., Status 1A or 1B)	−3.17	−40.89
Proximity: increase candidate distance by 1,000 NM	−0.10	−1.29
Candidate Blood Type: change candidate blood type from identical to donor to compatible with donor	−1.72	−22.11
Pediatric Priority: change candidate from pediatric patient to adult patient	−0.21	−2.73
Waiting Time: reduce wait time by 100 days	−0.01	−0.13
Donors Who Are at Least 70 Years of Age and/or DCD Donors		
Medical Priority: remove candidate priority status (i.e., Status 1a or 1b)	−3.01	−40.35
Proximity: increase candidate distance by 1,000 NM	−0.20	−2.68
Candidate Blood Type: change candidate blood type from identical to donor to compatible with donor	−1.51	−20.30
Pediatric Priority: change candidate from pediatric patient to adult patient	−0.06	−0.82
Waiting Time: reduce wait time by 100 days	−0.01	−0.13

Note: Calculations performed using coefficients reported in Table ES-1. NM = nautical mile.

In addition to providing information on the relative importance of individual attributes, the coefficients reported in Table ES-1 can also be used to calculate composite allocation scores for each candidate.

However, this raises the question of exactly how similar this rank order is compared to current policy. To determine how closely the score-based approximation reflects candidate rank ordering under the current policy, we used the coefficients in Table ES-1 to calculate new rankings for all match runs in our dataset that included at least 10 candidates.

Specifically, we evaluate model performance in two ways. First, we use the parameters we estimated using 2021 data to predict the rank that each of the candidates would have received in each match run in 2021, if a points-based system had been used. We use Spearman's rank correlation coefficient and Kendall's Tau to compare how close the predicted rankings are to the actual 2021 rankings. We refer to this as our in-sample model evaluation. Second, we use the parameters we estimated using 2021 data to predict the rank that each of the candidates would have received in each match run in 2022, if a points-based system had been used. Again, we use Spearman's rank correlation coefficient and Kendall's Tau to compare how close the predicted rankings are to the actual 2022 rankings. We refer to this as our out-of-sample model evaluation.

Table ES-4 reports the results for the in-sample evaluation. As this table shows, the median Spearman correlation coefficient and Kendall's Tau are at least 0.62 for all four donor models. This suggests a moderate-to-strong correlation between our points-based rankings and actual rankings for a majority of 2021 match runs.

Table ES-4. In-Sample Predictive Performance Metrics

	Mean	SD	Minimum	25th Percentile	50th Percentile	75th Percentile	Maximum
Non-DCD Deceased Donors Younger Than 11 Years of Age							
Spearman correlation	0.74	0.14	0.28	0.65	0.79	0.85	0.92
Kendall’s Tau	0.59	0.12	0.23	0.50	0.62	0.69	0.78
Non-DCD Deceased Donors 11 to 17 Years of Age							
Spearman correlation	0.77	0.12	0.38	0.67	0.83	0.86	0.92
Kendall’s Tau	0.64	0.11	0.30	0.54	0.68	0.72	0.79
Non-DCD Deceased Donors 18 to 69 Years of Age							
Spearman correlation	0.82	0.10	0.44	0.78	0.86	0.88	0.95
Kendall’s Tau	0.70	0.10	0.35	0.63	0.74	0.77	0.85
Donors Who Are at Least 70 Years of Age and/or DCD Donors							
Spearman correlation	0.81	0.09	0.48	0.78	0.84	0.87	0.92
Kendall’s Tau	0.69	0.09	0.38	0.63	0.72	0.77	0.83

Table ES-5 reports the results for the out-of-sample evaluation. As this table shows, the median Spearman correlation coefficient and Kendall’s Tau are at least 0.63 for all four donor models. This indicates a moderate-to-strong correlation between our points-based rankings and actual rankings for a majority of 2022 match runs. This result is encouraging because it also suggests that the model estimated using 2021 data captures liver allocation policy in other time periods equally well.

Table ES-5. Out-of-Sample Predictive Performance Metrics

	Mean	SD	Minimum	25th Percentile	50th Percentile	75th Percentile	Maximum
Non-DCD Deceased Donors Younger Than 11 Years of Age							
Spearman correlation	0.74	0.12	0.45	0.66	0.79	0.83	0.91
Kendall's Tau	0.60	0.10	0.35	0.52	0.63	0.67	0.79
Non-DCD Deceased Donors 11 to 17 Years of Age							
Spearman correlation	0.77	0.12	0.38	0.67	0.83	0.85	0.91
Kendall's Tau	0.63	0.11	0.30	0.55	0.68	0.71	0.78
Non-DCD Deceased Donors 18 to 69 Years of Age							
Spearman correlation	0.82	0.10	0.44	0.77	0.86	0.88	0.99
Kendall's Tau	0.70	0.10	0.35	0.63	0.74	0.77	0.93
Donors Who Are at Least 70 Years of Age and/or DCD Donors							
Spearman correlation	0.80	0.10	0.47	0.74	0.82	0.88	0.95
Kendall's Tau	0.68	0.10	0.36	0.61	0.70	0.76	0.83

1. Introduction

As of July 2022, more than 11,000 people were waiting for a liver transplant (Organ Procurement and Transplantation Network [OPTN], 2022). Because there are more patients on the waiting list than available livers, choices must be made to allocate donor livers to patients in a way that balances concerns for both equity and medical utility. These liver allocation decisions are made according to policies developed by the OPTN, which is operated by the United Network for Organ Sharing (UNOS). Specifically, when a donor liver becomes available, these policies determine how potential recipients are ranked according to objective characteristics (e.g., blood type, proximity to donor hospital). This ranking process is carried out by a computerized algorithm, known as the match system. Each time a donor liver becomes available and potential recipients are ranked, it is known as a "match run."

Although the current classification-based system has helped thousands of liver transplant candidates in need, it still faces some limitations. In particular, a candidate in a lower classification—even one who is highly medically urgent—may not be prioritized ahead of candidates in a higher classification (Stewart et al., 2021). To address this limitation for liver allocation policy, UNOS is working to migrate to a points-based, continuous distribution system.

A points-based allocation framework has at least two major benefits. First, it is more transparent than the current computerized match system because it quantifies how important each candidate attribute is in organ allocation, given that it assigns this attribute a numerical score. Second, a points-based allocation framework would allow for the combined influence of many candidate attributes to be considered simultaneously, as opposed to allowing any single attribute to trump combinations of other attributes.

An initial step in determining the feasibility of points-based alternatives would be to determine if current liver allocation policies could be captured, at least approximately, by a points-based framework. Feasibility could be determined by using data from recent match runs to estimate statistical models that capture the thrust of current allocation policies. These models could be estimated using discrete choice modeling techniques. Discrete choice models are used extensively in health economics to statistically relate the choices between alternatives made by individuals to the attributes of the alternatives themselves. These models are typically estimated using data collected in experimental settings (Bridges et al., 2011; de Bekker-Grob et al., 2012; Soekhai et al., 2019). However, these models can also be estimated using data collected from actual choices (Mark & Swait, 2004).

UNOS contracted with RTI International to help take this initial step. In this report, we summarize the major results of this project. The remainder of the report is organized as follows. Section 2 provides details on the liver allocation policies that are currently used in the United States that our statistical models hope to capture. Section 3 describes the methods that will be used to estimate these statistical models. Section 4 presents our results. Section 5 concludes with a discussion of our results and their limitations.

2. Background of U.S. Liver Allocation Policy

The OPTN was established in 1984 by the National Organ Transplant Act to maintain a national registry for organ matching (Moore & Weimer, 2021). This act also called for the network to be operated by a private nonprofit organization under federal contract. Since the initial network contract was finalized in 1986, UNOS has served as the OPTN under contract with the U.S. Department of Health and Human Services (HHS). In this section, we describe how organ allocation policy is created under this framework and provide a history of how livers were allocated to recipients in the past.

2.1 HOW ORGAN ALLOCATION POLICY IS CREATED

Through collaboration of relevant committees, the OPTN Board of Directors (BOD), and the general public, the OPTN is able to create an organ allocation policy that governs the operation of all member transplant hospitals, organ recruitment organizations, and histocompatibility labs in the United States (UNOS, 2019). The extensive policy procedure is governed by both federal rules and OPTN bylaws (OPTN, 2019).

The policy process starts with identifying a problem the transplant community is facing. OPTN encourages anyone in the transplant community to send ideas for proposed projects. All project forms and ideas are electronically documented by the UNOS Policy department. Ideas are regularly reviewed by staff and OPTN committee leadership for selection and further investigation. Once a problem is selected, it is analyzed using different tools to help define the scope of the project.

All committee projects must be reviewed and approved by the OPTN Policy Oversight Committee (POC) and Executive Committee (EC). If a project is approved, committees and UNOS staff develop and analyze potential solutions for the project. Often committees coordinate feedback from relevant stakeholders and committees to build a consensus on the issue and solution. For example, the Pediatrics Committee may give input on pediatric concerns and the Ethics Committee on ethical issues. A public comment proposal is then sent to the POC and EC for approval; however, this time the POC also reviews the proposal to determine whether sufficient stakeholder correspondence occurred during the previous process. If approved, the proposal goes on to public comment, which includes seeking input from relevant stakeholder organizations, other OPTN committees, online comments on the OPTN website, and in-person regional meetings. Staff then analyze and summarize public comment feedback. Once modifications are complete, committees vote to send the proposal to the OPTN BOD.

The BOD is the governing body that oversees and participates in developing policies that provide equitable organ allocation, ensure quality standards for membership, and establish data submission requirements (HHS, 1999). The board must have at least 34 directors but no more than 42, at least 50% must be transplant surgeons and physicians, at least 25% must be transplant community members (recipients, candidates, donors), one director must represent pediatric interests, and the board must contain representatives from organ procurement organizations at transplant hospitals. If the BOD approves the policy proposal, then the designated committee implements it. OPTN officials are notified and mobilized to educate the transplant community of the new policy. The policy is then regularly analyzed to ensure it meets the stated goals and does not cause unintended consequences. The effort to constantly improve organ policy has created a liver allocation system that is vastly different from its beginnings. This history is discussed in more detail in Section 2.2.

2.2 HISTORY OF U.S. LIVER ALLOCATION POLICY

Before 1998, a patient's priority for liver transplant was determined by two factors:

1. the amount of time they spent on the OPTN waiting list and
2. the patient's current hospitalization status. Patients who were considered critical (i.e., patients in the intensive care unit [ICU]) were given priority over non-ICU hospitalized patients followed by outpatients.

However, whether a patient is considered critical was more subjective prior to 1998. For example, patients could be admitted to the ICU who did not meet the criteria for advanced care (Polyak et al., 2021). This problem created the potential for misuse of the priority system.

In 1998, UNOS attempted to address this concern by adopting the Child-Turcotte-Pugh (CTP) scoring system. The CTP score had the advantage of being a more objective measure of medical urgency because it used five clinical and laboratory criteria to categorize patients: serum bilirubin, serum albumin, ascites, neurological disorder, and prothrombin time. However, the CTP score also suffered from several limitations. First, the CTP score still included elements that were subjectively measured like ascites and encephalopathy (Ruf et al., 2022). Second, only 10 different CTP scores were available. This limitation was particularly significant because patients could not be adequately differentiated based on the severity of the disease. As a result, waiting time had a considerable impact on candidate prioritization (Ruf et al., 2022).

In 2000, HHS issued the Final Rule, which mandated that organ allocation should be based on a medical urgency measure that is determined by objective and reproducible data and that the importance of time spent on the waiting list should be minimized (Moore & Weimer, 2021). This mandate for an objective measure of medical urgency that minimized the importance of waiting time led OPTN to adopt the Model for End-Stage Liver Disease (MELD) score for candidates who are at least 12 years of age. This score was found to be a reliable method for predicting 3-month mortality in patients with cirrhosis. In addition, candidates can be assigned to a continuum of MELD scores ranging from 6 (less ill) to 40 (very ill). Using MELD minimized the need for using waiting time when prioritizing transplant candidates. At the time this study was conducted, the MELD score was calculated[1] as follows:

$$\mathrm{MELD}_i = 0.957 * ln(serum\ creatinine) + 0.378 * \ln(bilirubin) + 1.120 * \ln(INR) + 0.643$$

where

- Serum creatinine (mg/dL; for patients who have had dialysis twice within the last week, or 24 hours of continuous venovenous hemodialysis, the creatinine value will be automatically set to 4 mg/dL)[2]
- Bilirubin (mg/dL)[3]
- International Normalized Ratio (INR)[4]
- Serum sodium (mEq/L)[5]

Note that if the value is less than 1 for any of the inputs above, then the value is rounded to 1. The MELD score is rounded to the 10th decimal place and then multiplied by 10.

For candidates with an initial MELD_i score greater than 11, the score is recalculated using the following formula:

$$\mathrm{MELD} = MELD_i + 1.32 * (137 - Na) - [0.033 * MELD_i * (137 - Na)]$$

[1] This report was completed prior to the PELD-Cr and MELD 3.0 implementation (Organ Procurement and Transplantation Network, n.d.).
[2] Measures kidney function, which is often associated with severe liver disease.
[3] Measures how effectively the liver excretes bile.
[4] Measures the liver’s ability to make blood clotting factors.
[5] Measures hyponatremia in the body.

where

- Na (mmol/L)[6]

Note that sodium values less than 125 mmol/L are set to 125, and values greater than 137 mmol/L are set to 137.

A different measure has been adopted for objectively assessing the medical priority of candidates younger than 12 years of age called the Pediatric End-Stage Liver Disease (PELD) score (Oregon Health & Science University, 2019). Candidates can be assigned PELD scores on a continuum ranging from −99 (less ill) to 99 (very ill). However, candidates generally have PELD scores between 6 and 40. The PELD score is calculated in a similar fashion as the MELD score, but the PELD score includes additional metrics for calculation to take into account the patient's growth and development needs. Specifically, the PELD score at the time of this study was calculated[7] as follows:

$$\begin{aligned}\mathrm{PELD} = 0.436 * \left(Age\ (< 1\ year)\right) - 0.687 * \ln(albumin) + 0.480 \\ * \ln(bilirubin) + 1.857 * \ln(INR) \\ + 0.667(growth\ failure)\end{aligned}$$

where

- Albumin (g/dL)[8]
- Bilirubin (mg/dL)
- INR
- Growth failure (based on gender, height, and weight)
- Age at listing

Like the MELD score, if the value is less than 1 for any of the inputs, then the value is rounded to 1. The PELD score is rounded to the 10th decimal place and then multiplied by 10. Candidates registered for a liver transplant prior to their first birthday continue to receive a value of 0.436 until the candidate becomes 2 years of age.

[6] Measures hyponatremia in the body.
[7] This report was completed prior to the PELD-Cr and MELD 3.0 implementation (Organ Procurement and Transplantation Network, n.d.).
[8] Protein made by a liver. Albumin levels can help determine if liver or kidney disease is present or if the body is not absorbing enough protein.

In addition to medical priority, it was determined that geographic proximity would be considered in prioritizing candidates. Distance from the donor to the transplant patient is important given the need for careful preservation of the organ and lack of ability to freeze livers (OPTN, 2022). A liver must be transplanted within several hours of extraction (Moore & Weimer, 2021) and even sooner if the donor is older.

After the Final Rule was released in 2000, the distribution of donor livers was prioritized first to patients within a local donation service area (DSA), then to patients within the OPTN region, and then finally to patients in the rest of the United States. However, differences in population size and demographics within DSAs and OPTN regions gradually led to significant geographic disparities in the MELD score at time of transplant. As a result, these differences also created geographic disparities in access to liver transplantation (Polyak et al., 2021). To address these disparities, OPTN adopted a series of changes to minimize the importance of geography in liver allocation:

- **2005:** Regional Share 15 was implemented, which called for livers to be offered to patients with a MELD score greater than 15 first regionally before it is offered to a local patient with a MELD score of less than 15 (Merion et al., 2005).
- **2013:** Regional Share 35/National Share 15 was implemented, which gave priority to patients with a MELD score of 35 or greater within a region over a local patient. If no patient in the region has a MELD score of 15 or greater, then the liver is offered nationally before it is offered locally (Moore & Weimer, 2021).

Despite the adoption of these policy changes, significant geographic disparities in access to liver transplantation still existed. To further address these disparities, OPTN eliminated the use of DSAs and OPTN regions in organ allocation. In their place, OPTN adopted a system of acuity circles based on concentric geographic circles around the donor hospital (i.e., within 150, 250, and 500 nautical miles [NM]), which replaced local and regional boundaries. These acuity circles were passed in 2018 and then implemented in 2020 and are still used for measuring geographic proximity today (Moore & Weimer, 2021). In Section 3, we provide additional details on how medical priority (MELD and PELD scores), geographical proximity, and other criteria are currently used to make liver allocation decisions.

2.3 U.S. LIVER ALLOCATION POLICY TODAY

Today, when a donor liver becomes available, a computerized algorithm (known as the match system) generates a list of potential recipients ranked according to objective criteria. Under current liver allocation policy, these objective criteria include the following:

- **Medical priority:** How medical priority is measured differs based on the age of the candidate.
  - Candidates 18 years of age or older can receive one of four medical priority assignments: 1) adult Status 1A (assigned to candidates with acute liver failure who are not likely to live more than 7 days without a transplant), 2) calculated MELD score (discussed above), 3) exception MELD score (score assignment when a candidate's transplant program believes the candidate's MELD score does not appropriately reflect the candidate's medical urgency), and 4) inactive status.
  - Candidates younger than 18 years of age can receive one of five medical priority assignments: 1) pediatric Status 1A (assigned to candidates with acute liver failure who are not likely to live more than 7 days without a transplant), 2) pediatric Status 1B (assigned to chronically ill patients), 3) calculated MELD or PELD score (discussed above), 4) exception MELD or PELD score (score assignment when a candidate's transplant program believes the candidate's MELD or PELD score does not appropriately reflect the candidate's medical urgency), and 5) inactive status.

  Appendix A provides additional details on how exceptions to MELD and PELD score are determined.
- **Proximity:** Proximity measures the distance between the donor hospital and transplant hospital using a categorical system. Distance from the donor is typically measured using acuity circles based on concentric geographic circles around the donor hospital (i.e., within 150 NM, 250 NM, and 500 NM).

  Liver allocation acuity circles are the same for the contiguous 48 states, but Hawaii and Puerto Rico have different geographical requirements as a result of their geographic isolation. The variance for Hawaii and Puerto Rico is 2,400 NM and 1,100 NM, respectively. These variances are only used for patients with high medical priority (MELD or PELD of 37 or greater) to ensure they have adequate access to donor organs. Of note, Alaska, which also has geographic isolation, has no transplant center, so Alaskan organs are treated as if they were recovered in Seattle, Washington.

- **Blood type compatibility:** Candidates can have blood types that are identical to those of the donor, compatible with the donor, and incompatible with the donor.
- **Candidate's age:** Age of the candidate at registration is a criterion. However, the current age of the candidate is used for deciding if a MELD or PELD score should be issued.
- **Waiting time:** Length of transplants' candidates wait at their current urgency status is used as a tiebreaker if every other criterion is the same for candidates.

The ranking of each candidate is intended to reflect how each factor above is prioritized according to OPTN policy. However, these prioritizations differ based on the age of the liver donor and their cause of death. In this section, we first describe how liver allocation decisions are made when the deceased donor candidate is younger than 70 years of age and is not donating upon circulatory death (also known as donation after circulatory death [DCD] donation). Next, we describe how liver allocation decisions are made when the liver donor is at least 70 years of age and/or DCD donor. Lastly, we describe how liver allocation decisions are made when the donor is younger than 18 years of age.

2.3.1 Path of Allocation for Livers from Adult, Non-DCD Donors Who Are Younger Than 70 Years of Age

The majority of deceased liver donors are adults who are younger than 70 years of age and who are not donating upon DCD. When a liver becomes available from one of these donors, wait list candidates are ranked to determine who will be offered the donor liver first. These rankings reflect prioritization based on each candidate's medical priority, proximity to the donor hospital, and blood type.

First, livers from these donors are offered to Status 1A and 1B candidates within a radius of 500 NM and any blood type. If no candidate accepts the organ, then Status 1A and 1B candidates will be considered if they are within 2,400 NM and registered in Hawaii or within 1,100 NM and registered in Puerto Rico. Candidates with Statuses 1A and 1B are ranked based on blood type compatibility: candidates with identical blood types come before candidates with compatible blood types, who come before candidates with incompatible blood types.

If no Status 1A or 1B candidate accepts the organ, candidates with lower medical priority will be considered. Specifically, candidates are prioritized based on medical priority so that candidates with a MELD or PELD score of 37 or higher will be considered first. Within this class of medical priority, candidates are further prioritized based on proximity to the donor hospital so that candidates with a radius of 150 NM of the donor hospital are considered first, then candidates within a radius of 250 NM, then candidates within a radius of 500 NM, then patients within 2,400 NM and registered in Hawaii or within 1,100 NM and registered in Puerto Rico. Within each proximity zone, patients are further prioritized based on blood type. If the donor’s blood type is O, candidates with type O or type B blood are prioritized over others. If the donor’s blood type is not O, then candidates will be ranked based on identical, compatible, and incompatible blood type, with patients with identical blood types receiving a liver before those with compatible blood types, and those with compatible blood types receiving a liver before those with incompatible blood types.

If no candidate with a MELD or PELD score of 37 accepts the organ, a similar process is repeated for candidates with lower medical priority. Specifically, the process will move to candidates with ranges of MELD or PELD scores from 33 to 36, then to candidates with scores ranging from 29 to 32, and then to candidates with scores ranging from 15 to 28.

Table B-1 in ***Appendix B*** provides the full path of liver donation for adult donors who are 18 to 70 years of age and non-DCD donors.

2.3.2 Path of Allocation for Livers from Adult Donors Who Are at Least 70 Years of Age and/or DCD Donors

When a liver becomes available from a deceased adult donor who is older than 70 years of age and/or who died as a result of DCD, the criteria for determining how the candidates are ranked are the same as in Section 3.1. Organs are first offered to Statuses 1A and 1B candidates within 500 NM with any blood type. In contrast to the allocation path described in the previous section, livers from this age group and/or DCD donors are not offered to candidates in Hawaii and Puerto Rico. Candidates are further ranked by blood type compatibility: identical blood types receive a liver before compatible blood types and compatible blood types receive a liver before incompatible blood types. If the organ is not accepted by patients with high medical urgency, it is then offered to compatible candidates with a MELD or PELD of 15 or higher within a radius of 150 NM of the donor hospital, followed by candidates within a radius of 250 NM, then candidates within a radius of 500 NM. If the organ is not accepted by a candidate with a MELD or PELD score of 15 or higher, a similar process continues for candidates with a lower MELD or PELD score. Most livers from these donors are accepted for local candidates because they are most viable when the preservation time between recovery and transplantation is brief.

With each proximity zone, blood type compatibility is also considered. Similar to before, if the donor’s blood type is O, candidates with type O or B blood are prioritized over others. If the donor’s blood type is not O, then candidates are ranked on identical, compatible, and incompatible blood types, and identical blood types receive a liver before compatible blood types and compatible blood types receive a liver before incompatible blood types.

Table B-2 in ***Appendix B*** provides the full path of liver donation for adult donors who are at least 70 years of age and/or DCD donors.

2.3.3 Path of Allocation for Livers from Non-DCD Pediatric Donors

There are two potential allocation paths for pediatric liver donors (younger than 18 years of age) depending on the donors’ age. However, in both allocation paths, there is a better priority for pediatric candidates before adult candidates at the same level of medical urgency.

For donors 11–17 years of age, livers are first offered to Status 1A or 1B candidates with any blood type within a radius of 500 NM of the donor hospital. Specifically, pediatric Status 1A candidates are given priority, followed by adult Status 1A candidates, then pediatric Status 1B candidates. Candidates are also ranked on blood type compatibility, as discussed in Sections 3.1 and 3.2. If no candidate accepts the organ, it is offered to Status 1A or 1B candidates within a radius of 2,400 NM and registered in Hawaii or within 1,100 NM and registered in Puerto Rico. Specifically, pediatric Status 1B candidates receive priority, followed by adult Status 1A candidates, then pediatric Status 1B candidates. This process is repeated for candidates with lower medical urgency. Within each class of medical priority, candidates within a 500 NM radius are prioritized over candidates within a radius of 2,400 NM and registered in Hawaii or within 1,100 NM and registered in Puerto Rico.

For donors younger than 11 years of age, livers are first offered to Status 1A or 1B candidates with any blood type. Candidates are also ranked based on blood type compatibility, as discussed in Sections 3.1 and 3.2. Pediatric Status 1A candidates who are within a radius of 500 NM receive best priority, followed by pediatric Status 1A candidates who are younger than 11 years of age and located anywhere in the United States. If a pediatric Status 1A candidate does not accept the donor organ, it is next offered to adult Status 1A candidates within a radius of 500 NM, followed by pediatric Status 1B candidates within a radius of 500 NM. These candidates are then followed by pediatric Status 1A candidates who are also younger than 12 years of age, then adult Status 1A candidates, then pediatric Status 1B candidates, all of whom must be within 2,400 NM and registered in Hawaii or within 1,100 NM and registered in Puerto Rico. As before, a similar process is repeated for candidates with less urgent medical priority for both potential pediatric allocation paths. However, the process does not use 150 or 250 NM as a criterion for ranking candidates.

Both pediatric liver allocation paths have a similar blood type requirement as that used for adults. If the donor’s blood type is O, candidates with type O or B blood are prioritized over others. If the donor’s blood type is not O, then candidates with identical, compatible, and incompatible blood type are considered in that order.

Tables B-3 and B-4 in ***Appendix B*** provide the full path of liver donation for pediatric donors.

3. Methods

The primary goal of this study is to determine whether a points-based framework can capture current liver allocation policies. We accomplish this goal by using data from all non-import match runs in 2021 to estimate discrete choice models that capture the essence of current policies by donor category.

Discrete choice techniques assume that when individuals choose between different options, they will select the one that yields the highest level of utility. This means that an individual can evaluate the attributes of an option, assign each option a utility score based on those attributes, rank options according to utility scores, and choose the option that has the highest score. The purpose of discrete choice models is to use data collected from choices made by individuals to estimate statistical models that capture these utility assessments.

We face a different challenge in this project from the one that is usually faced by discrete choice modelers. Instead of dealing with individuals who rank different options according to utility scores based on their subjective preferences, we are dealing with a matching algorithm that is ranking organ candidates, according to priorities established by liver allocation policy. Although the matching algorithm is different from a utility-maximizing individual, we believe they are analogous enough that their behavior can be modeled in a similar manner.

In this section, we describe the data and methods we will use to estimate and evaluate statistical models that capture current liver allocation policies.

3.1 DATA

As discussed in Section 2, when a donor liver becomes available, a computerized algorithm (known as the match system) generates a list of potential recipients ranked according to the objective criteria describe above. Each time a donor liver becomes available and potential recipients are ranked, it is known as a "match run." Each match run can involve ranking hundreds of candidates to determine who will be offered the donor liver first.

To estimate these models, we obtained de-identified data for all liver match runs from 2021 (January to December 2021) and all available liver match runs from 2022 (January to May 2022). Specifically, we have data for five major attributes that were used to rank these candidates in each match run: 1) medical priority, 2) proximity to the donor hospital, 3) blood type compatibility, 4) candidate age, and 5) wait time. In this section, we describe these data in more detail.

3.1.1 Match Run Data for Non-DCD Deceased Donors Younger Than 11 Years of Age

We obtained data produced by 462 match runs for 462 non-DCD deceased donors younger than 11 years of age. An average of 1,201.44 candidates were ranked in each match run. As a result, we have data for 555,066 ranked candidates, with some candidates appearing on multiple match runs.

3.1.2 Match Run Data for Non-DCD Deceased Donors 11 to 17 Years of Age

We obtained rankings produced from 514 match runs for 514 non-DCD deceased donors 11 to 17 years of age. An average of 5,052.61 candidates were ranked in each match run. As a result, we have data for 2,597,043 ranked candidates, with some candidates appearing on multiple match runs.

3.1.3 Match Run Data for Non-DCD Deceased Donors 18 to 69 Years of Age

We obtained rankings produced from 12,171 match runs for 12,171 non-DCD deceased donors 18 to 69 years of age. An average of 4,550.96 candidates were ranked in each match run. As a result, we have data for 55,389,712 ranked candidates, with some candidates appearing on multiple match runs.

3.1.4 Match Run Data for Adult Donors Who Are at Least 70 Years of Age and/or DCD Donors

We obtained rankings produced from 7,846 match runs for 7,846 donors are either non-DCD donors at least 70 years of age or DCD deceased donors. An average of 2,760.04 candidates were ranked in each match run. As a result, we have data for 21,655,290 ranked candidates, with some candidates appearing on multiple match runs.

3.2 MODEL SPECIFICATION

Analogous to how consumers derive utility from products based on their attributes, the matching algorithm could be imagined as assigning an unobserved priority score to each candidate during every match run, based on that candidate's characteristics. More formally, the priority score assigned to each candidate *j* can be represented by the following function:

$$u_j = v_j + \varepsilon_j,\ j = 1, \ldots, J, \qquad (3.1)$$

where v_j is the observable component of the function that depends on the attributes of the candidate (e.g., location, blood type). The term ε_j is a random error representing the component of priority assessment that is not captured by the observable component.

We specified the observable component of the priority function using the specification in Equation 3.2.

$$V = \beta_{STATUS} \times STATUS + \beta_{MELD\_PELD} \times MELD\_PELD + \beta_{DISTANCE} \times DISTANCE + \beta_{BLOODTYPE} \times BLOODTYPE + \beta_{PEDIATRIC\_PRIORITY} \times PEDIATRIC\_PRIORITY + \beta_{WAIT\_TIME} \times WAIT\_TIME \qquad (3.2)$$

where:

- **STATUS** is a dummy-coded variable that equals 1 for candidates assigned Status 1A or Status 1A and 0 for all other candidates,
- **MELD_PELD** is a continuous variable that captures the MELD score for candidates 12 years of age and older, the PELD score for candidates younger than 12 years of age. Candidates who were assigned Status 1A or Status 1B were coded 0,
- **DISTANCE** is a continuous variable that captures the distance from a candidate's transplant hospital to the donor hospital in nautical miles,
- **BLOODTYPE** is a dummy-coded variable that is equal to 1 if a candidate's blood type is "identical" to the donor's blood type and 0 otherwise,
- **PEDIATRIC_PRIORITY** is a dummy-coded variable that is equal to 1 for candidates younger than 18 years of age and 0 for candidates 18 years of age and older, and

- **WAIT_TIME** is a continuous variable that captures the length of time the candidate has been at their current medical priority status measured in days.

This model specification includes five of the candidate attributes (discussed in Section 2.3) that determine the allocation of donor livers: 1) medical priority (i.e., MELD score, PELD score, or priority status), 2) candidate proximity to donor hospital, 3) blood type, 4) candidate age (i.e., whether the patient is younger than 18 years of age or not), and 5) waiting time. We specified the variables associated with each of these attributes so that a score could be calculated for each attribute that captured its importance in the liver allocation decision. We discuss the variable specification decision for each attribute below.

First, specifying the variables associated with medical priority posed a particular challenge because how a candidate's medical priority enters the ranking differs based on the candidate's condition and age. As discussed in Section 2.3, adult and pediatric candidates who are not likely to live more than 7 days are assigned Status 1A. Pediatric candidates who are considered chronically ill are assigned Status 1B. If a candidate does not receive one of these priority status assignments and is 12 years of age and older, their medical priority is assessed using a MELD score. If a candidate does not receive one of these priority status assignments and is younger than 12 years of age, their medical priority is assessed using a PELD score.

For the purposes of this model, we simplify medical priority into only two variables—one that captures whether the candidate has received Status 1A or Status 1B and another that captures the MELD/PELD score for candidates who did not receive Status 1A or Status 1B. Specifically, the first variable (STATUS) is a dummy-coded variable that equals 1 for candidates assigned Status 1A or Status 1B and 0 for all other candidates.[9] Similarly, the second variable (MELD_PELD) is a continuous variable that equals the candidate's MELD score if they are 12 years of age and older and equals the candidate's PELD score if they are younger than 12 years of age. We assume that candidates who were assigned Status 1A or Status 1B have a

[9] We tested model specifications where we included Status 1A and Status 1B as separate variables. However, this created multicollinearity problems that prevented the model from being estimated.

MELD/PELD score of 0. This way, status and MELD_PELD are mutually exclusive measures of medical priority.

Combining MELD and PELD scores into a single variable in this way can create issues because MELD scores range from 6 to 40 and PELD scores range from −99 to 99. To avoid problems created by overlapping scales, we recode all PELD scores below 6 to 6.

Based on this model specification, the coefficients estimated for each of the two medical priority variables can be used to calculate a medical priority score for each candidate as follows. For candidates who received either Status 1A or Status 1B, their medical priority score would be equal to ($\beta_{STATUS} \times 1 + \beta_{MELD\_PELD} \times 0$), where β_{MELD_PELD} is an estimate of the marginal importance of a one-unit change in the candidate's MELD or PELD score. For candidates who did not receive either Status 1A or Status 1B, their medical priority score would be equal to ($\beta_{STATUS} \times 0 + \beta_{MELD\_PELD} \times \text{MELD\_PELD}$).

The second attribute included in our specification, proximity, is captured by a continuous variable that measures the distance from the donor hospital to each candidate in nautical miles. Under this approach, a candidate's proximity score would be equal to ($\beta_{DISTANCE} \times \text{DISTANCE}$), where $\beta_{DISTANCE}$ is an estimate of the marginal importance of a one-unit change in the candidate's proximity to the donor hospital.

The third attribute, blood type, is captured by whether the candidate has the same blood type as the donor. For the purposes of this model, we represent blood type using a dummy-coded variable, where the omitted category is "Compatible/Incompatible." Under this approach, a candidate's blood type score would be equal to ($\beta_{BLOODTYPE} \times 1$) if the candidate's blood type is identical to the donor's blood type and ($\beta_{BLOODTYPE} \times 0$) if it is not.

The fourth attribute, candidate age, is captured by whether the candidate is younger than 18 years of age or not at time of match (i.e., whether the candidate has pediatric priority or not). For the purposes of this model, we represent pediatric priority using a dummy-coded variable, where the omitted category is "18 years old or older." Under this approach, a candidate's pediatric priority score would be equal to

($\beta_{PEDIATRIC\_PRIORITY}$ × 1) if the candidate is younger than 18 years of age and ($\beta_{PEPIATRIC\_PRIORITY}$ × 0) if he or she is not.

The fifth attribute included in our specification, waiting time, is captured by a continuous variable that measures the length of time the candidate has been at this status. Under this approach, a candidate's waiting time score would be equal to (β_{WAIT_TIME} × WAIT_TIME), where β_{WT} is an estimate of the marginal importance of a one-unit change in the candidate's waiting time in days.

3.3 DETERMINING RELATIVE IMPORTANCE OF ATTRIBUTES

We quantified the relative importance of each attribute in the model described in Section 3.2 in two ways. First, for each of the four donor categories, we used the model coefficients to rank candidate attributes in terms of their relative importance to the ordering of candidates in liver allocation. This was done by taking the difference between the score for the most preferred value of an attribute and the score for the least preferred value of the same attribute.

Second, we quantified "exchange rates" to express the relative importance of each attribute in terms of changes in MELD/PELD score. These rates convey how much a patient's MELD/PELD score would have to increase to have the same effect on a candidate's total score as a change in proximity, blood type, pediatric priority, or waiting time.

3.4 EVALUATING MODEL PERFORMANCE

Once the donor models have been estimated, we can use the resulting parameters to calculate a points-based liver allocation score for each candidate. These scores can then be used to predict the rank that each of the candidates would have received, if the points-based system had been used. The closer these predicted rankings are to the actual rankings, the more we can say that the points-based scores capture current liver allocation policy. However, this raises the question of how to quantitatively measure the "closeness" or "similarity" of two rankings. In this study, we used two measures for comparing predicted and actual rankings:

- Spearman's rank correlation coefficient: The Spearman correlation coefficient is defined as the Pearson correlation coefficient between the rank variables. It ranges from –1 (perfectly dissimilar ranking) to 1 (perfectly similar ranking).
- Kendall's Tau: Like Spearman's rank correlation coefficient, Kendall's Tau also ranges from –1 to 1. However, Kendall's Tau is calculated by taking each pair of candidates for a given match and counting how many pairs are ordered in the same way. For example, consider the hypothetical match run in Table 3-1. There are two rankings of three candidates. Both rankings agree on the orderings of candidates 1–2 and 1–3, but not on 2–3, so they would have a Tau of 1/3 (i.e., (2–1)/3). If the rankings disagreed on all pairings, Tau would be –1 (i.e., (0–3)/3).

Table 3-1. Example Data for Calculating Kendall's Tau

Match ID	Candidate ID	Actual Rank	Predicted Rank
1	1	1	1
1	2	2	3
1	3	3	2

We use Spearman's rank correlation coefficient and Kendall's Tau to evaluate model performance in two ways. First, we use the parameters we estimated using 2021 data to predict the rank that each of the candidates would have received in each match run in 2021, if a points-based system had been used. We use Spearman's rank correlation coefficient and Kendall's Tau to compare how close the predicted rankings are to the actual 2021 rankings. We refer to this as our in-sample model evaluation. Second, we use the parameters we estimated using 2021 data to predict the rank that each of the candidates would have received in each match run in 2022, if a points-based system had been used. Again, we use Spearman's rank correlation coefficient and Kendall's Tau to compare how close the predicted rankings are to the actual 2022 rankings. We refer to this as our out-of-sample model evaluation.

4. Results

4.1 MODEL RESULTS

Table 4-1 contains the coefficients from the rank-ordered logit model estimated for all four donor categories described above. The direction of these coefficients tells us how changing one attribute would change a candidate's ranking in a given match run. Specifically, we see that candidates across all four donor categories receive better priority if they:

- have more urgent medical priority,
- live closer to the donor hospital,
- are younger than 18 years of age,
- have an identical blood type to the donor, or
- have a longer waiting time.

Table 4-1. Rank-Ordered Logit Estimates

	Non-DCD Deceased Donors Younger Than 11 Years of Age	**Non-DCD Deceased Donors 11 to 17 Years of Age**	**Non-DCD Deceased Donors 18 to 69 Years of Age**	**Donors Who Are at Least 70 Years of Age and/or DCD Donors**
	Mean Coefficient (Standard Error)			
Medical Priority				
MELD/PELD score	0.0549*** (0.0002)	0.0583*** (0.0001)	0.0776*** (< 0.0001)	0.0745*** (< 0.0001)
Status 1A or Status 1B	3. 4654*** (0.0252)	4.2547*** (0.0232)	3.1727*** (0.0073)	3.0062*** (0.0151)
Proximity				
Distance (nautical miles)	−0.0005*** (< 0.0001)	−0.0004*** (< 0.0001)	−0.0001*** (< 0.0001)	−0.0002*** (< 0.0001)
Candidate Blood Type Relative to Donor Blood Type				
Identical vs. Nonidentical	1.8021*** (0.0043)	1.7897*** (0.0019)	1.7161*** (0.0004)	1.5124*** (0.0007)
Pediatric Priority				
Pediatric candidate vs. adult candidate	1.5636*** (0.0107)	1.3296** (0.0072)	0.2122*** (0.0025)	0.0613*** (0.0077)
Waiting Time				
Days the candidate has been at this status	0.0001*** (< 0.001)	0.0001*** (< 0.001)	0.0001*** (< 0.001)	0.0001*** (< 0.001)

Notes: (1) Status 1A or Status 1B, blood type, and pediatric priority are dummy coded, MELD/PELD, distance, and wait time are coded as continuous variables. (2) *** denotes p < .01, **p < .05, *p < .10.

4.2 RELATIVE IMPORTANCE OF ATTRIBUTES

The coefficients in Table 4-1 can be used to quantify the relative importance of each attribute in two ways.

First, we used these coefficients to rank attributes in order of their importance to the liver allocation decision. This was done by taking the difference between the score for the most preferred level of an attribute and the score for the least preferred level of the same attribute. For example, the combined MELD/PELD score can range from 6 to 99. For non-DCD donors between 18 and 69 years of age, this implies that the maximum difference in MELD/PELD score is 7.22 (7.22 =(0.0776*(99-6)). By making this calculation for each attribute, we can rank candidate attributes in order of importance, where larger maximum differences imply greater importance. The results of these calculations are presented for all four donor models in **Table 4-2**. We can see that attributes related to medical priority (i.e., MELD/PELD and Status 1A/Status 1B) are clearly the most important attributes in liver allocation for all four donor categories.

Table 4-2. Rank of Candidate Attributes by Importance in Liver Allocation

Candidate Attribute	Most Preferred Value	Least Preferred Value	Score for Most Preferred Value	Score for Least Preferred Value	Maximum Difference in Score	Rank
Non-DCD Deceased Donors Younger Than 11 Years of Age						
MELD/PELD	99	6	5.44	0.33	5.11	1
Status 1A or 1B	1	0	3.47	0.00	3.47	2
Proximity (NM)	0	4,304.16	0.00	−2.15	2.15	3
Blood Type	1	0	1.80	0.00	1.80	4
Pediatric Priority	1	0	1.56	0.00	1.56	5
Wait Time (days)	6,194	0	0.62	0.00	0.62	6
Non-DCD Deceased Donors 11 to 17 Years of Age						
MELD/PELD	99	6	5.77	0.35	5.42	1
Status 1A or 1B	1	0	4.25	0.00	4.25	2
Proximity (NM)	0	4,380.32	0.00	−1.75	1.75	4
Blood Type	1	0	1.79	0.00	1.79	3
Pediatric Priority	1	0	1.33	0.00	1.33	5
Wait Time (days)	6,191	0	0.62	0.00	0.62	6

(continued)

Table 4-2. Rank of Candidate Attributes by Importance in Liver Allocation (continued)

Candidate Attribute	Most Preferred Value	Least Preferred Value	Score for Most Preferred Value	Score for Least Preferred Value	Maximum Difference in Score	Rank
Non-DCD Deceased Donors 18 to 69 Years of Age						
MELD/PELD	99	6	7.68	0.47	7.22	1
Status 1A or 1B	1	0	3.17	0.00	3.17	2
Proximity (NM)	0	4,380.32	0.00	−0.44	0.44	5
Blood Type	1	0	1.72	0.00	1.72	3
Pediatric Priority	1	0	0.21	0.00	0.21	6
Wait Time (days)	6,198	0	0.62	0.00	0.62	4
Donors Who Are at Least 70 Years of Age and/or DCD Donors						
MELD/PELD	99	6	7.38	0.45	6.93	1
Status 1A or 1B	1	0	3.01	0.00	3.01	2
Proximity (NM)	0	4,380.32	0.00	−0.88	0.88	4
Blood Type	1	0	1.51	0.00	1.51	3
Pediatric Priority	1	0	0.06	0.00	0.06	6
Wait Time (days)	6,198	0	0.62	0.00	0.62	5

Note: Calculations performed using coefficients reported in Table 4-1, which were rounded to fourth decimal place.
NM = nautical mile.

The second way to quantify the relative importance of each attribute is to use the coefficients in Table 4-1 to express changes in one attribute in terms of another. For example, for non-DCD donors between 18 and 69 years of age, we can see from Table 4-1 that increasing a candidate's distance from the donor hospital by 1,000 nautical miles lowers their composite allocation score by 0.10 point (−0.10 = −0.0001 * 1,000). On its own, this calculation may not be very informative, because the units used to measure the proximity score are arbitrary. However, one way to add more context to this change is to express a change in one attribute in terms of a change in another attribute. For example, based on the same coefficients in Table 4-1, increasing a candidate's distance from the donor hospital by 1,000 nautical miles is equivalent to reducing a candidate's MELD/PELD score by 1.29 points. This is because reducing the candidate's MELD/PELD score by 1.29 points reduces their composite score by 0.10 point (−0.10 = 0.0776 *−1.29). In **Table 4-3**, we compare changes in each attribute in terms of changes in a candidate's MELD/PELD score.

Table 4-3. Converting Changes in Each Attribute into Changes in MELD/PELD Score

Change in Attribute	Change in Composite Allocation Score	Equivalent Change in MELD/PELD Score
Non-DCD Deceased Donors Younger Than 11 Years of Age		
Status: remove candidate priority status (i.e., Status 1A or 1B)	−3.47	−63.12
Proximity: increase candidate distance by 1,000 NM	−0.50	−9.11
Candidate Blood Type: change candidate blood type from identical to donor to compatible with donor	−1.80	−32.83
Pediatric Priority: change candidate from pediatric patient to adult patient	−1.56	−28.48
Waiting Time: reduce wait time by 100 days	−0.01	−0.18
Non-DCD Deceased Donors 11 to 17 Years of Age		
Medical Priority: remove candidate priority status (i.e., Status 1A or 1B)	−4.25	−72.98
Proximity: increase candidate distance by 1,000 NM	−0.40	−6.86
Candidate Blood Type: change candidate blood type from identical to donor to compatible with donor	−1.79	−30.70
Pediatric Priority: change candidate from pediatric patient to adult patient	−1.33	−22.81
Waiting Time: reduce wait time by 100 days	−0.01	−0.17
Non-DCD Deceased Donors 18 to 69 Years of Age		
Medical Priority: remove candidate priority status (i.e., Status 1A or 1B)	−3.17	−40.89
Proximity: increase candidate distance by 1,000 NM	−0.10	−1.29
Candidate Blood Type: change candidate blood type from identical to donor to compatible with donor	−1.72	−22.11
Pediatric Priority: change candidate from pediatric patient to adult patient	−0.21	−2.73
Waiting Time: reduce wait time by 100 days	−0.01	−0.13
Donors Who Are at Least 70 Years of Age and/or DCD Donors		
Medical Priority: remove candidate priority status (i.e., Status 1A or 1B)	−3.01	−40.35
Proximity: increase candidate distance by 1,000 NM	−0.20	−2.68
Candidate Blood Type: change candidate blood type from identical to donor to compatible with donor	−1.51	−20.30
Pediatric Priority: change candidate from pediatric patient to adult patient	−0.06	−0.82
Waiting Time: reduce wait time by 100 days	−0.01	−0.13

Note: Calculations performed using coefficients reported in Table 4-1, which were rounded to third decimal place.
NM = nautical mile.

4.3 MODEL PERFORMANCE EVALUATION

Table 4-4 reports the results for the in-sample evaluation comparing the actual rankings produced by the matching algorithm in 2021 with points-based rankings calculated using our model results. As this table shows, the median Spearman correlation coefficients and Kendall's Tau are at least 0.62 for all four donor models. This suggests a moderate-to-strong correlation between our points-based rankings and actual rankings for a majority of 2021 match runs.

Table 4-4. In-Sample Predictive Performance Metrics

	Mean	SD	Minimum	25th Percentile	50th Percentile	75th Percentile	Maximum
Non-DCD Deceased Donors Younger Than 11 Years of Age							
Spearman correlation	0.74	0.14	0.28	0.65	0.79	0.85	0.92
Kendall's Tau	0.59	0.12	0.23	0.50	0.62	0.69	0.78
Non-DCD Deceased Donors 11 to 17 Years of Age							
Spearman correlation	0.77	0.12	0.38	0.67	0.83	0.86	0.92
Kendall's Tau	0.64	0.11	0.30	0.54	0.68	0.72	0.79
Non-DCD Deceased Donors 18 to 69 Years of Age							
Spearman correlation	0.82	0.10	0.44	0.78	0.86	0.88	0.95
Kendall's Tau	0.70	0.10	0.35	0.63	0.74	0.77	0.85
Donors Who Are at Least 70 Years of Age and/or DCD Donors							
Spearman correlation	0.81	0.09	0.48	0.78	0.84	0.87	0.92
Kendall's Tau	0.69	0.09	0.38	0.63	0.72	0.77	0.83

Table 4-5 reports the results for the out-of-sample evaluation comparing the actual rankings produced by the matching algorithm in 2022 with points-based rankings calculated using our model results. As this table shows, the median Spearman correlation coefficients and Kendall's Tau are at least 0.63 for all four donor models. This suggests a moderate-to-strong correlation between our points-based rankings and actual rankings for a majority of 2022 match runs.

Table 4-5. Out-of-Sample Predictive Performance Metrics

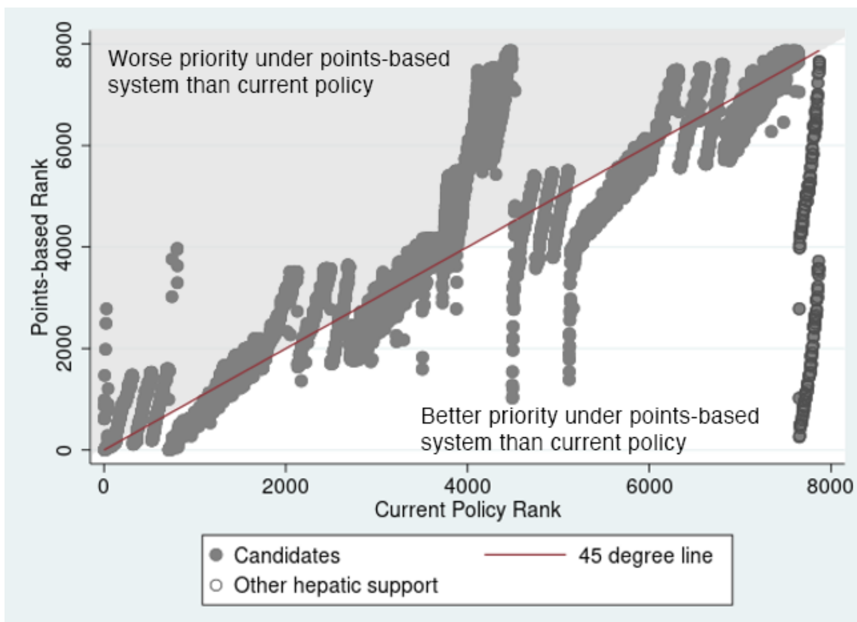
	Mean	SD	Minimum	25th Percentile	50th Percentile	75th Percentile	Maximum
Non-DCD Deceased Donors Younger Than 11 Years of Age							
Spearman correlation	0.74	0.12	0.45	0.66	0.79	0.83	0.91
Kendall's Tau	0.60	0.10	0.35	0.52	0.63	0.67	0.79
Non-DCD Deceased Donors 11 to 17 Years of Age							
Spearman correlation	0.77	0.12	0.38	0.67	0.83	0.85	0.91
Kendall's Tau	0.63	0.11	0.30	0.55	0.68	0.71	0.78
Non-DCD Deceased Donors 18 to 69 Years of Age							
Spearman correlation	0.82	0.10	0.44	0.77	0.86	0.88	0.99
Kendall's Tau	0.70	0.10	0.35	0.63	0.74	0.77	0.93
Donors Who Are at Least 70 Years of Age and/or DCD Donors							
Spearman correlation	0.80	0.10	0.47	0.74	0.82	0.88	0.95
Kendall's Tau	0.68	0.10	0.36	0.61	0.70	0.76	0.83

In addition to the correlation coefficients discussed above, we can visualize how closely the points-based rankings match the actual match run rankings. In Figure 4-1, we plot points-based policy rankings against current policy rankings for the median match run from the 18- to 69-year-old donor group for 2021 (i.e., the match run whose Kendall's Tau equals 0.74). This match run included 7,874 candidates.

If points-based rankings and current policy rankings were identical, we would expect the points on these scatter plots to fall along the 45-degree line extending from the origin. In actuality, we see deviations between the two sets of rankings. Specifically, candidates above the 45-degree line receive worse priority under the points-based rankings than they would under current policy. Similarly, candidates below the 45-degree line receive better priority under the points-based rankings than they would under current policy.

Figures like this can also be used to illustrate which factors are contributing to the differences between the actual rankings and the points-based rankings. For example, in **Figure 4-1**, we distinguish transplant candidates from other hepatic support candidates. As one can see, under current policy, hepatic support candidates always receive worse priority than transplant candidates. However, these candidates received better priority under a points-based ranking. This is due to the fact that the model does not distinguish between these two types of candidates. This limitation likely lowers the correlation between points-based rankings and current policy rankings.[10]

Figure 4-1. Comparison of Actual and Predicted Rankings for a Match Run with Median Kendall's Tau (*N* = 7,874 candidates)



To further explore which factors contribute to the differences between the points-based rankings and current policy rankings,

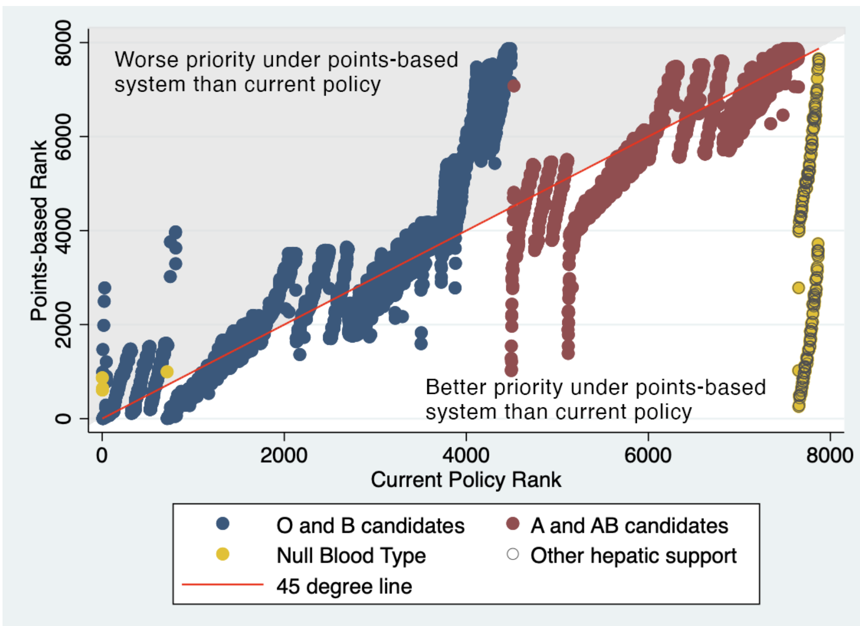
[10] We attempted to account for "other hepatic support" candidates by including a dummy variable for this attribute in the model specification, but this model specification was unable to converge for most donor categories. Similarly, we attempted to estimate models where "other hepatic support" candidates were excluded from the dataset. However, the coefficient estimates obtained for these models were counter intuitive.

we create three versions of Figure 4-1. Each version uses colors to distinguish different subgroups within the match run. Specifically, we investigate how points-based rankings and current policy rankings differ by:

- blood type,
- proximity, and
- medical priority.

Figure 4-2 breaks down the median match run by blood type. As one can see, under current policy, candidates with type O or type B blood received better priority in this match run than candidates with type A or type AB blood. Given that the blood type of the donor is O, a systematic preference for type A or type AB blood is consistent with our understanding of the allocation classifications discussed in Section 2.3. By contrast, it appears that a candidate's specific blood type is less important in determining priority under the points-based system. This is likely due to the fact that the points-based system does not explicitly take candidate blood type into account. Instead, the points-based system only considers whether candidates and donors have identical blood type or not.[11]

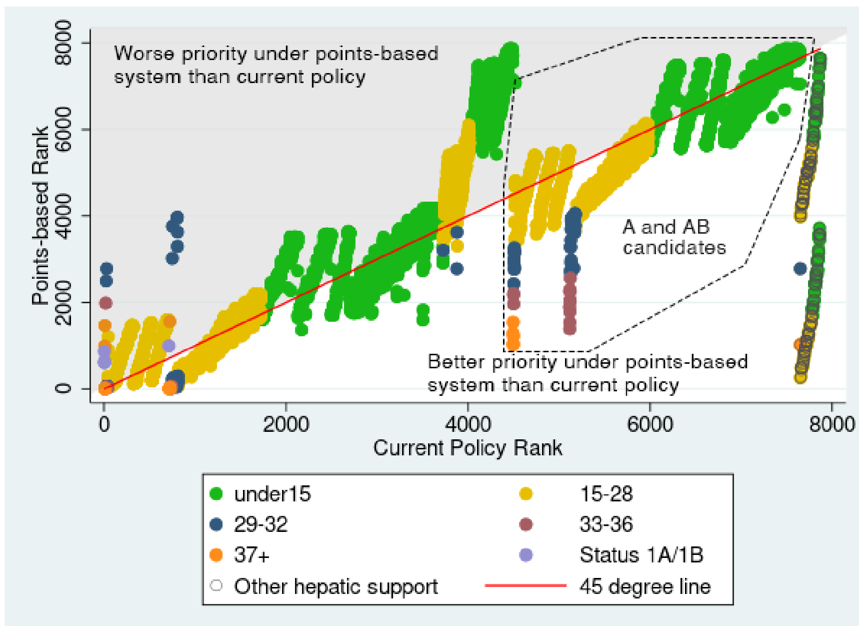
Figure 4-2. Comparison of Actual and Predicted Rankings for a Match Run with Median Kendall's Tau by Candidate Blood Type (*N* = 7,874 candidates)



[11] We considered model specifications that more explicitly account for donor blood type, but we found that these model specifications did not significantly improve our model's predictive performance.

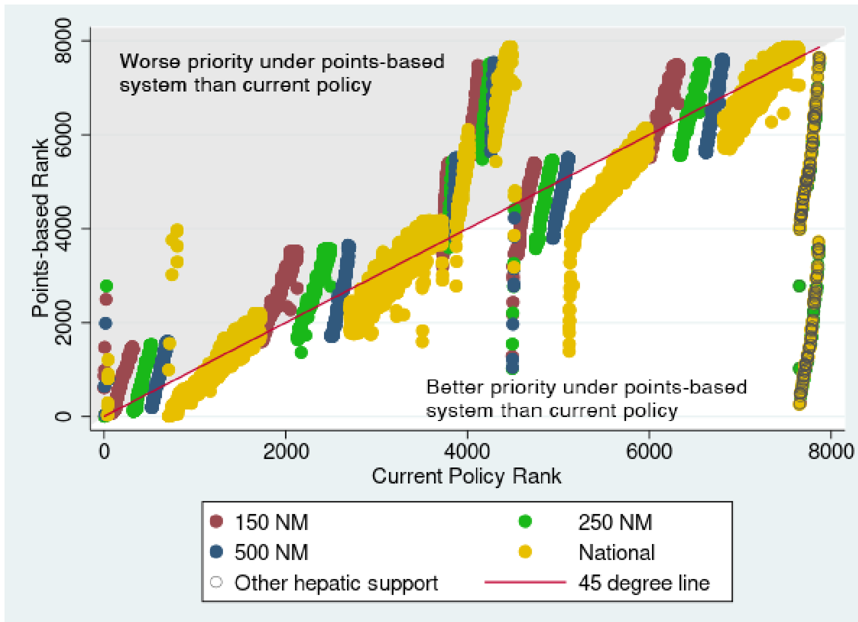
Figure 4-3 breaks down the median match run by medical priority. When compared with Figure 4-2, this figure further demonstrates that blood type was a driving difference between the points-based model and current policy for this particular match run. For example, under current policy, we see candidates with type A and type AB blood received worse priority than candidates with type O or type B blood even when they had higher MELD or PELD scores. This is illustrated by a cluster of candidates with type A or type AB blood that have MELD/PELD scores above 29 and appear below the 45-degree line (see points within the dashed-line bounding box). Many of these candidates would receive better priority under the points-based system compared to the current policy.

Figure 4-3. Comparison of Actual and Predicted Rankings for a Match Run with Median Kendall's Tau by Medical Priority and Blood Type (*N* = 7,874 candidates)



Lastly, **Figure 4-4** breaks down the median match run by proximity. Comparing Figures 4-3 and 4-4, it appears that candidates with approximately the same medical priority are ranked based on proximity under the current policy. This leads to a clear clustering of candidates by distance. By contrast, under a points-based policy, the importance of proximity is often overcome by other attributes, which leads to a more even distribution of distant candidates across the rankings.

Figure 4-4. Comparison of Actual and Predicted Rankings for a Match Run with Median Kendall's Tau by Proximity to the Transplant Hospital (*N* = 7,874 candidates)



5. Discussion and Conclusions

UNOS provides a vital link in the transplant process by matching donated organs with transplant candidates. When transplant hospitals register patients onto the waiting list, the patients are registered in a centralized, national computer network that links all donors and transplant candidates. For each donated liver that becomes available, a computerized algorithm (known as the match system) generates a list of potential recipients ranked according to objective criteria (e.g., blood type, medical priority, time on the waiting list, and distance between donor and recipient).

Although the computerized match system plays a critical role in linking donors and candidates, the value judgments inherent in the current classification-based system can be opaque. An alternative way to make organ allocation decisions would be to develop a points-based framework that captures the implicit priorities assigned to candidates on the match run today but in a simplified and more transparent form.

One way to establish the feasibility of points-based alternatives would be to determine if current liver allocation policies could be captured, at least approximately, by a points-based framework. Our analysis seeks to accomplish that goal in two steps. First, we use conventional discrete choice modeling techniques to estimate four statistical models based on all non-import match runs from 2021. These statistical models estimate scores that quantify how important the following candidate attributes are in liver allocation: 1) medical priority (i.e., MELD score, PELD score, or priority status), 2) candidate proximity to the donor hospital, 3) blood type, 4) candidate age, and 5) time on the waiting list.

Second, to confirm that the estimated scores adequately capture current liver allocation policy, we use them to predict what candidate rankings would be in sample (i.e., in 2021) and out of sample (i.e., in 2022) if these scores had been used instead of the current system. The closer the predicted rankings are to the actual rankings, the more confidence we have that the scores capture current allocation policies. Overall, we found a moderate-to-strong correlation between our predicted rankings and the original ranks produced by the matching algorithm.

Although the results we present are encouraging, it is important to note that they are subject to limitations. For example, the model specification we used for several key attributes oversimplified the role these attributes play in liver allocation. In addition, in our model specification, we do not differentiate between candidates with "Status 1A" from candidates with "Status 1B," which slightly reduces the accuracy of our model's predictions.

Similarly, we specify candidate proximity to the donor hospital as a linear, continuous variable. However, under current liver allocation policy, candidate proximity is actually measured using a system of concentric geographic circles around the donor hospital (i.e., within 150, 250, and 500 NM) as described in Section 2.2. Though specification of distance as a continuous, linear term instead of a zone-based categorical variable departs from the structure of current policy, this linear parameterization is more consistent with the spirit of composite-score based allocation (aka "continuous distribution").

In both cases, we chose specifications to obtain points-based models that could provide useful interpretations and overcome estimation challenges. However, there are trade-offs in every modeling decision. Specifically, in exchange for models that are transparent and parsimonious, we lose some ability to predict actual candidate rankings.

6. References

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Appendix A. Details on priority Patients and Exceptions to the MELD and PELD Scores

Although the MELD and PELD scores are used for most liver transplant candidates, there are other options for patients with medical conditions that these scores do not address well. If patients have a very urgent medical priority, they can be listed as Status 1A or 1B. Status 1A patients are not likely to live more than a few days due to sudden or severe onset acute liver failure. Status 1B patients are very sick, chronically ill patients younger than 18 years of age. Less than 1% (about 50 candidates) of all patients on the transplant list are listed as Status 1A or 1B at a given time. Within Statuses 1A and 1B, candidates are sorted by:

1. Total waiting time[12] and a blood type compatibility points system[13]
2. Total waiting time as Status 1A or 1B (OPTN, 2022)

If a candidate does not meet Status 1A or 1B requirements, the physician can submit a form for an exception Status 1A and 1B, which is reviewed by a committee. Once the form is submitted, the candidate is automatically listed as Status 1A or 1B. If the committee decides the candidate should not have the status, the hospital is flagged, which could affect liver donation for future candidates.

There are also exceptions to using the MELD and PELD score, such as when patients have conditions (e.g., liver cancer, hepatocellular carcinoma) where their scores are too low for their medical needs. In these cases, patients can get an exception score to be used in the match calculation in place of their MELD or PELD score.

[12] Candidates with the greatest total Status 1A or 1B waiting time receive 10 points. A fraction of 10 points is divided among the remaining candidates within each classification (Status 1A or 1B) based on candidates' waiting times.

[13] Candidates with the same blood type as the donor receive 10 points. Candidates with compatible blood types to the donor receive 5 points. Candidates with incompatible blood types with the donor receive 0 points.

A standard exception score can only be received if the patient meets the OPTN policy criteria, meaning the patient has one of the nine diagnoses[14] listed in the policy. Standard exception scores are compared with the median MELD at transplant (MMaT). The MMaT is the midpoint score based on the range of all recent transplants completed within 150 NM of the donor hospital.[15] This value differs for each donor hospital. In contrast, the standard exception for most PELD candidates is the national median PELD score because there are fewer pediatric transplants.

In addition to the standard exception score, specific patients might require a higher score because of unique medical needs. For these cases, the transplant team can ask the National Liver Review Board to review the patient and potentially grant a custom exception score. The board was implemented in 2019 and comprises physicians and surgeons around the country who decide if the patient's request is accepted or denied (UNOS, 2022). The request is anonymous and based only on medical information. If the patient is denied a custom exception score, the transplant team can file an appeal, which is returned to the original panel of reviewers.

[14] Cholangiocarcinoma, cystic fibrosis, familial amyloid polyneuropathy, hepatic artery thrombosis, hepatopulmonary syndrome, metabolic disease, portopulmonary hypertension, primary hyperoxaluria, and hepatocellular carcinoma.

[15] In this analysis, the median score represents the MMaT at the transplant hospital. As of June 28, 2022, the MMaT is based on the median score at the donor hospital.

Appendix B. Details on Liver Allocation Classification

Table B-1. Allocation of Livers from Non-DCD Deceased Donors at Least 18 Years of Age and Younger Than 70 Years of Age

Classification	At Least a MELD or PELD Score	Distance from Donor	Donor Blood Type	Candidate Blood Type
1	Status 1A	500 NM	Any	Any
2	Status 1B	500 NM	Any	Any
3	Status 1A	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Any	Any
4	Status 1B	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Any	Any
5	37	150 NM	O	O or B
6	37	150 NM	Non-O	Any
7	37	250 NM	O	O or B
8	37	250 NM	Non-O	Any
9	37	500 NM	O	O or B
10	37	500 NM	Non-O	Any
11	37	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	O	O or B
12	37	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Non-O	Any
13	33	150 NM	O	O or B
14	33	150 NM	Non-O	Any
15	33	250 NM	O	O or B
16	33	250 NM	Non-O	Any
17	33	500 NM	O	O or B
18	33	500 NM	Non-O	Any
19	30	150 NM	O	O or B
20	29	150 NM	O	O
21	29	150 NM	Non-O	Any
22	30	250 NM	O	O or B
23	29	250 NM	O	O
24	29	250 NM	Non-O	Any
25	30	500 NM	O	O or B

(continued)

Table B-1. Allocation of Livers from Non-DCD Deceased Donors at Least 18 Years of Age and Younger Than 70 Years of Age (continued)

Classification	At Least a MELD or PELD Score	Distance from Donor	Donor Blood Type	Candidate Blood Type
26	29	500 NM	O	O
27	29	500 NM	Non-O	Any
28	15	150 NM	O	O
29	15	150 NM	Non-O	Any
30	15	250 NM	O	O
31	15	250 NM	Non-O	Any
32	15	500 NM	O	O
33	15	500 NM	Non-O	Any
34	Status 1A	Nation	Any	Any
35	Status 1B	Nation	Any	Any
36	30	Nation	O	O or B
37	15	Nation	O	O
38	15	Nation	Non-O	Any
39	Any	150 NM	O	O
40	Any	150 NM	Non-O	Any
41	Any	250 NM	O	O
42	Any	250 NM	Non-O	Any
43	Any	500 NM	O	O
44	Any	500 NM	Non-O	Any
45	Any	Nation	O	O
46	Any	Nation	Non-O	Any
47	29	150 NM	O	B
48	29	250 NM	O	B
49	29	500 NM	O	B
50	15	150 NM	O	B
51	15	250 NM	O	B
52	15	500 NM	O	B
53	15	Nation	O	B
54	Any	150 NM	O	B
55	Any	250 NM	O	B
56	Any	500 NM	O	B
57	Any	Nation	O	B
58	37	150 NM	O	A or AB

(continued)

Table B-1. Allocation of Livers from Non-DCD Deceased Donors at Least 18 Years of Age and Younger Than 70 Years of Age (continued)

60	**37**	**500 NM**	**O**	**A or AB**
59	37	250 NM	O	A or AB
61	33	150 NM	O	A or AB
62	33	250 NM	O	A or AB
63	33	500 NM	O	A or AB
64	29	150 NM	O	A or AB
65	29	250 NM	O	A or AB
66	29	500 NM	O	A or AB
67	15	150 NM	O	A or AB
68	15	250 NM	O	A or AB
69	15	500 NM	O	A or AB
70	15	Nation	O	A or AB
71	Any	150 NM	O	A or AB
72	Any	250 NM	O	A or AB
73	Any	500 NM	O	A or AB
74	Any	Nation	O	A or AB
75	Status 1A for other method of hepatic support	Nation	Any	Any
76	Status 1B for other method of hepatic support	Nation	Any	Any
77	Any MELD or PELD for other method of hepatic support	Nation	Any	Any

Source: OPTN, 2022. NM = nautical mile.

Table B-2. Allocation of Livers from DCD Donors or Donors at Least 70 Years of Age

Classification	At Least a MELD or PELD Score	Distance from Donor	Donor Blood Type	Candidate Blood Type
1	Status 1A	500 NM	Any	Any
2	Status 1B	500 NM	Any	Any
3	30	150 NM	O	O or B
4	15	150 NM	O	O
5	15	150 NM	Non-O	Any
6	30	250 NM	O	O or B
7	15	250 NM	O	O
8	15	250 NM	Non-O	Any
9	30	500 NM	O	O or B
10	15	500 NM	O	O
11	15	500 NM	Non-O	Any
12	Status 1A	Nation	Any	Any
13	Status 1B	Nation	Any	Any
14	30	Nation	O	O or B
15	15	Nation	O	O
16	15	Nation	Non-O	Any
17	Any	150 NM	O	O
18	Any	150 NM	Non-O	Any
19	Any	250 NM	O	O
20	Any	250 NM	Non-O	Any
21	Any	500 NM	O	O
22	Any	500 NM	Non-O	Any
23	Any	Nation	O	O
24	Any	Nation	Non-O	Any
25	15	150 NM	O	B
26	15	250 NM	O	B
27	15	500 NM	O	B
28	15	Nation	O	B
29	Any	150 NM	O	B
30	Any	250 NM	O	B
31	Any	500 NM	O	B
32	Any	Nation	O	B
33	15	150 NM	O	B
34	15	250 NM	O	A or AB

(continued)

Table B-2. Allocation of Livers from DCD Donors or Donors at Least 70 Years of Age (continued)

Classification	At Least a MELD or PELD Score	Distance from Donor	Donor Blood Type	Candidate Blood Type
35	15	500 NM	O	A or AB
36	15	Nation	O	A or AB
37	Any	150 NM	O	A or AB
38	Any	250 NM	O	A or AB
39	Any	500 NM	O	A or AB
40	Any	Nation	O	A or AB
41	Status 1A for other method of hepatic support	Nation	Any	Any
42	Status 1B for other method of hepatic support	Nation	Any	Any
43	Any MELD or PELD for other method of hepatic support	Nation	Any	Any

Source: OPTN, 2022. NM = nautical mile.

Table B-3. Allocation of Livers from Non-DCD Deceased Donors 11 to 17 Years of Age

Classification	At Least a MELD or PELD Score	Distance from Donor	Donor Blood Type	Candidate Blood Type
1	Pediatric Status 1A	500 NM	Any	Any
2	Adult Status 1A	500 NM	Any	Any
3	Pediatric Status 1B	500 NM	Any	Any
4	Pediatric Status 1A	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Any	Any
5	Adult Status 1A	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Any	Any
6	Pediatric Status 1B	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Any	Any
7	PELD: 37	500 NM	O	O or B
8	PELD: 37	500 NM	Non-O	Any
9	PELD: 37	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	O	O or B
10	PELD: 37	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Non-O	Any
11	PELD: 30	500 NM	O	O or B
12	Any PELD	500 NM	O	O
13	Any PELD	500 NM	Non-O	Any
14	MELD of at least 37 and candidate < 18 years of age at registration	500 NM	O	O or B
15	MELD of at least 37 and candidate < 18 years of age at registration	500 NM	Non-O	Any
16	MELD of at least 37 and candidate < 18 years of age at registration	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	O	O or B
17	MELD of at least 37 and candidate < 18 years of age at registration	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Non-O	Any
18	MELD of at least 37 and candidate < 18 years of age at registration	500 NM	O	O or B
19	MELD of at least 37 and candidate < 18 years of age at registration	500 NM	O	O
20	MELD of at least 37 and candidate < 18 years of age at registration	500 NM	Non-O	Any
21	Pediatric Status 1A	Nation	Any	Any
22	Adult Status 1A	Nation	Any	Any

(continued)

Table B-3. Allocation of Livers from Non-DCD Deceased Donors 11 to 17 Years of Age (continued)

Classification	At Least a MELD or PELD Score	Distance from Donor	Donor Blood Type	Candidate Blood Type
23	Pediatric Status 1B	Nation	Any	Any
24	PELD: 30	Nation	O	O or B
25	Any PELD	Nation	O	O
26	Any PELD	Nation	Non-O	Any
27	MELD of at least 30 and candidate < 18 years of age at registration	Nation	O	O or B
28	Any MELD and candidate < 18 years of age at registration	Nation	O	O
29	Any MELD and candidate < 18 years of age at registration	Nation	Non-O	Any
30	MELD of at least 30 and candidate < 18 years of age at registration	500 NM	O	O or B
31	Any MELD and candidate < 18 years of age at registration	500 NM	O	O
32	Any MELD and candidate < 18 years of age at registration	500 NM	Non-O	Any
33	MELD of at least 30 and candidate < 18 years of age at registration	Nation	O	O or B
34	Any MELD and candidate < 18 years of age at registration	Nation	O	O
35	Any MELD and candidate < 18 years of age at registration	Nation	Non-O	Any
36	Any PELD	500 NM	O	B
37	Any MELD and candidate < 18 years of age at registration	500 NM	O	B
38	Any MELD	Nation	O	B
39	Any MELD and candidate < 18 years of age at registration	Nation	O	B

(continued)

Table B-3. Allocation of Livers from Non-DCD Deceased Donors 11 to 17 Years of Age (continued)

Classification	At Least a MELD or PELD Score	Distance from Donor	Donor Blood Type	Candidate Blood Type
40	Any MELD and candidate < 18 years of age at registration	500 NM	O	B
41	Any MELD and candidate < 18 years of age at registration	Nation	O	B
42	Any PELD	500 NM	O	A or AB
43	Any MELD and candidate < 18 years old at registration	500 NM	O	A or AB
44	Any PELD	Nation	O	A or AB
45	Any MELD and candidate < 18 years of age at registration	Nation	O	A or AB
46	Any MELD and candidate < 18 years of age at registration	500 NM	O	A or AB
47	Any MELD and candidate < 18 years of age at registration	Nation	O	A or AB
48	Adult or Pediatric Status 1A for other method of hepatic registration	Nation	Any	Any
49	Pediatric Status 1B for other method of hepatic support	Nation	Any	Any
50	Any MELD or PELD for other method of hepatic support	Nation	Any	Any

Source: OPTN, 2022. NM = nautical mile.

Table B-4. Allocation of Livers from Non-DCD Deceased Donors Younger Than 11 Years of Age

Classification	At Least a MELD or PELD Score	Distance from Donor	Donor Blood Type	Candidate Blood Type
1	Pediatric Status 1A	500 NM	Any	Any
2	Pediatric Status 1A and candidate < 12 years of age	Nation	Any	Any
3	Adult Status 1A	500 NM	Any	Any
4	Pediatric Status 1B	500 NM		
5	Pediatric Status 1A and candidate < 12 years of age	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Any	Any
6	Adult Status 1A	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Any	Any
7	Pediatric Status 1B	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Any	Any
8	PELD: 37	500 NM	O	O or B
9	PELD: 37	500 NM	Non-O	Any
10	PELD: 37	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	O	O or B
11	PELD: 37	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Non-O	Any
12	PELD: 30	500 NM	O	O or B
13	Any PELD	500 NM	O	O
14	Any PELD	500 NM	Non-O	Any
15	MELD of at least 37 and candidate < 18 years of age at registration	500 NM	O	O or B
16	MELD of at least 37 and candidate < 18 years of age at registration	500 NM	Non-O	Any
17	MELD of at least 37 and candidate < 18 years of age at registration	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	O	O or B
18	MELD of at least 30 and candidate < 18 years of age at registration	Hawaii: 2,400 NM; Puerto Rico: 1,100 NM	Non-O	Any
19	Any MELD and candidate < 18 years of age at registration	500 NM	O	O or B
20	Any MELD and candidate < 18 years of age at registration	500 NM	O	O

(continued)

Table B-4. Allocation of Livers from Non-DCD Deceased Donors Younger Than 11 Years of Age (continued)

Classification	At Least a MELD or PELD Score	Distance from Donor	Donor Blood Type	Candidate Blood Type
21	Any MELD and candidate < 18 years of age at registration	500 NM	Non-O	Any
22	Pediatric Status 1A and candidate is ≥ 12 years of age	Nation	Any	Any
23	Adult Status 1A	Nation	Any	Any
24	Pediatric Status 1B	Nation	Any	Any
25	PELD: 30	Nation	O	O or B
26	Any PELD	Nation	O	O
27	Any PELD	Nation	Non-O	Any
28	MELD of at least 30 and candidate < 18 years of age at registration	Nation	O	O or B
29	Any MELD and candidate < 18 years of age at registration	Nation	O	O
30	Any MELD and candidate < 18 years of age at registration	Nation	Non-O	Any
31	MELD of at least 30 and candidate < 18 years of age at registration	500 NM	O	O or B
32	Any MELD and candidate < 18 years of age at registration	500 NM	O	O
33	Any MELD and candidate < 18 years of age at registration	500 NM	Non-O	Any
34	MELD of at least 30 and candidate < 18 years of age at registration	Nation	O	O or B
35	Any MELD and candidate < 18 years of age at registration	Nation	O	O
36	Any MELD and candidate < 18 years of age at registration	Nation	Non-O	Any
37	Any PELD	500 NM	O	B
38	Any MELD and candidate < 18 years of age at registration	500 NM	O	B

(continued)

Table B-4. Allocation of Livers from Non-DCD Deceased Donors Younger Than 11 Years of Age (continued)

Classification	At Least a MELD or PELD Score	Distance from Donor	Donor Blood Type	Candidate Blood Type
39	Any PELD	Nation	O	B
40	Any MELD and candidate < 18 years of age at registration	Nation	O	B
41	Any MELD and candidate < 18 years of age at registration	500 NM	O	B
42	Any MELD and candidate < 18 years of age at registration	Nation	O	B
43	Any PELD	500 NM	O	A or AB
44	Any MELD and candidate < 18 years of age at registration	500 NM	O	A or AB
45	Any PELD	Nation	O	A or AB
46	Any MELD and candidate < 18 years of age at registration	Nation	O	A or AB
47	Any MELD and candidate < 18 years of age at registration	500 NM	O	A or AB
48	Any MELD and candidate < 18 years of age at registration	Nation	O	A or AB
49	Status 1A for other method of hepatic support	Nation	Any	Any
50	Status 1B for other method of hepatic support	Nation	Any	Any
51	Any MELD or PELD for other method of hepatic support	Nation	Any	Any

Source: OPTN, 2022. NM = nautical mile.