Appendix

A. Attributes

In order to create a reliable simulation model of the heart transplantation system and a flexible allocation policy module, several attributes and characteristics for patients and donated hearts were considered in this study. Tables A.1 and A.2 show these attributes for patients and hearts, respectively.

Table A.1. Patient Characteristics

Attribute	Groups
Age group(4)	[18-35]; [35-50]; [50-65]; [65+]
Gender(2)	[Female]; [Male]
Blood type(4)	[O]; [A]; [B]; [AB]
Region(11)	[Region 1]; …; [Region 11]
Ethnicity(7)	[White]; [African-American]; [Hispanic]; [Asian]; [American Indian/Alaska Native]; [Pacific Islander]; [Multiracial]
Disease(9)	[Dilated Myopathy (2 Groups)]; [Heart Re-transplant (Graft Failure)]; [Hypertrophic Cardiomyopathy]; [Restrictive Myopathy]; [Valvular Heart Disease]; [Congenital Heart Defect]; [Coronary Artery Disease]; [Other]
VAD status(2)	[1= If the patient has a VAD]; [0=Otherwise]
PTX status(2)	[1=If the patient has gone under transplantation before]; [0=Otherwise]
Health status(4)	[1A]; [1B] ; [2]; [Inactive (7)]
OPO(58)	[OPO 1]; …; [OPO 58]

Table A.2. Heart Characteristics

Attribute	Groups
Donor age group(4)	[18-35]; [35-50]; [50-65]; [65+]
Donor gender(2)	[Female]; [Male]
Donor blood type(4)	[O]; [A]; [B]; [AB]
Donor region(11)	[Region 1]; …; [Region 11]
Donor ethnicity(7)	[White]; [African-American]; [Hispanic]; [Asian]; [American Indian/Alaska Native]; [Pacific Islander]; [Multiracial]
Donor OPO(58)	[OPO 1]; …; [OPO 58]

A1. Disease Groups

UNOS considers more than 70 disease groups for patients with heart failure[1]. Table A.3 shows the number of patients in each disease group on the waiting list (Feb 2016). As can be seen from Table A.3, some disease groups have a few candidates, which make it impossible to create meaningful statistical distributions. In order to produce more accurate arrival distributions, we aggregated the UNOS heart disease categorization into 9 groups as listed in Table A.4. We used the UNOS categorization of reasons for heart transplantation in aggregating disease groups[1] (Table A.5).

Table A.3. Waiting List Disease Group Categorization in Feb 2016 (Adults)

Disease Group	Registrations
All Diagnosis	3,886
Dilated Myopathy: Post-Partum	61
Dilated Myopathy: Viral	54
Heart Re-Tx/Gf: Acute Rejection	2
Heart Re-Tx/Gf: Chronic Rejection	10
Heart Re-Tx/Gf: Coronary Artery Disease	75
Heart Re-Tx/Gf: Hyperacute Rejection	2

Heart Re-Tx/Gf: Non-Specific	4
Heart Re-Tx/Gf: Other Specify	4
Heart Re-Tx/Gf: Primary Failure	6
Heart Re-Tx/Gf: Restrictive/Constrictive	3
Hypertrophic Cardiomyopathy	95
Arrhythmogenic Right Ventricular Dysplasia/Cardio	9
Restrictive Myopathy: Amyloidosis	20
Restrictive Myopathy: Idiopathic	25
Restrictive Myopathy: Other Specify	7
Restrictive Myopathy: Sarcoidosis	21
Restrictive Myopathy: Sec To Radiat/Chem	7
Valvular Heart Disease	40
Other, Specify	88
Not Reported	200
Congenital Heart Defect -. Hypoplastic Left Heart	1
Congenital Heart Defect -. Prior Surgery Unknown	7
Congenital Heart Defect -. With Surgery	125
Congenital Heart Defect -. Without Surgery	14
Coronary Artery Disease	117
Dilated Myopathy: Adriamycin	56
Dilated Myopathy: Alcoholic	7
Dilated Myopathy: Familial	112
Dilated Myopathy: Idiopathic	1,307
Dilated Myopathy: Ischemic	1,111
Dilated Myopathy: Myocarditis	22
Dilated Myopathy: Other Specify	274

Table A.4. Disease Categorization in Model

Group	Diseases Included
Dilated Myopathy	1. Dilated Myopathy: Adriamycin
	2. Dilated Myopathy: Alcoholic
	3. Dilated Myopathy: Familial
	4. Dilated Myopathy: Idiopathic
	6. Dilated Myopathy: Myocarditis
	7. Dilated Myopathy: Other Specify
	8. Dilated Myopathy: Post-Partum
Dilated Myopathy : Viral	1. Dilated Myopathy : Viral
Restrictive Myopathy	1. Restrictive Myopathy: Amyloidosis
	2. Restrictive Myopathy: Idiopathic
	3. Restrictive Myopathy: Other Specify
	4. Restrictive Myopathy: Sarcoidosis
	5. Restrictive Myopathy: Sec To Radiat/Chem
Hypertrophic Cardiomiopathy	1. Hypertrophic Cardiomiopathy
Valvular Heart Disease	1. Valvular Heart Disease
Congenital Heart Defect	1. Congenital Heart Defect -. Hypoplastic Left Heart
	2. Congenital Heart Defect -. Prior Surgery Unknown
	3. Congenital Heart Defect -. With Surgery
	4. Congenital Heart Defect -. Without Surgery
Coronary Artery Disease	1. Coronary Artery Disease
	2. Dilated Myopathy: Ischemic
Heart Re-Tx/Gf	1. Heart Re-Tx/Gf: Acute Rejection
	2. Heart Re-Tx/Gf: Chronic Rejection
	3. Heart Re-Tx/Gf: Coronary Artery Disease
	4. Heart Re-Tx/Gf: Hyperacute Rejection

	5. Heart Re-Tx/Gf: Non-Specific
	6. Heart Re-Tx/Gf: Other Specify
	7. Heart Re-Tx/Gf: Primary Failure
	8. Heart Re-Tx/Gf: Restrictive/Constrictive
Other	1. Arrhythmogenic Right Ventricular Dysplasia/Cardio
	2. Not Reported
	3. Other/specify

Note: Re-Tx= re-transplantation, Gf= graft failure.

Table A.5. UNOS Table of Reasons for Heart Transplantation

Heart Diagnosis Categories	Heart Diagnoses
Cardiomyopathy	Dilated Myopathy: Idiopathic
	Dilated Myopathy: Myocarditis
	Dilated Myopathy: Other Specify
	Dilated Myopathy: Post-Partum
	Dilated Myopathy: Familial
	Dilated Myopathy: Adriamycin
	Dilated Myopathy: Viral
	Dilated Myopathy: Alcoholic
	Hypertrophic Cardiomyopathy
	Restrictive Myopathy: Idiopathic
	Restrictive Myopathy: Amyloidosis
	Restrictive Myopathy:Sarcoidosis
	Restrictive Myopathy: Endocardial Fibrosis
	Restrictive Myopathy: Other Specify
	Restrictive Myopathy: Sec To Radiat/Chem
Coronary Artery Disease	Coronary Artery Disease
	Dilated Myopathy: Ischemic
Congenital Heart Disease	Congenital Heart Disease
Valvular Heart Disease	Valvular Heart Disease
Retransplant/Graft Failure	Heart Re-Tx/GF: Coronary Artery Disease
	Heart Re-Tx/GF: Other Specify
	Heart Re-Tx/GF: Non-Specific
	Heart Re-Tx/GF: Acute Rejection
	Heart Re-Tx/GF: Hyperacute Rejection

	Heart Re-Tx/GF: Primary Failure
	Heart Re-Tx/GF: Chronic Rejection
	Heart Re-Tx/GF: Restrictive/Constrictive
Other	Cardiac Disease: Other Specify
	Heart: Other Specify
	Cancer

A2. Health Status Assignment

This section closely follows UNOS/OPTN policy reports. Each heart transplant candidate is assigned a health status that reflects the candidate's medical urgency for transplant. Heart candidates (18+) at the time of registration may be assigned any of the following health statuses[2].

- Adult status 1A
- Adult status 1B
- Adult status 2
- Inactive status

Adult Heart Status 1A Requirements

To assign a candidate adult status 1A, the candidate's transplant program must submit a Heart Status 1A Justification Form to the OPTN Contractor. A candidate is not assigned adult status 1A until this form is submitted. If the candidate is at least 18 years old at the time of registration, then the candidate's transplant program may assign the candidate adult status 1A if either of the following conditions is met:

1. The candidate is admitted to the transplant hospital that registered the candidate on the waiting list, or an affiliated Veteran's Administration (VA) hospital, and the candidate also meets at least one of the requirements in Table A.6.

Table A.6. Adult Status 1A Requirements for Candidates Currently Admitted to the Transplant Hospital

If the candidate meets this condition:	Then adult status 1A is valid for:
Has one of the following mechanical circulatory support devices in place: • Total artificial heart (TAH) • Intra-aortic balloon pump • Extracorporeal membrane oxygenation (ECMO)	14 days, and must be recertified by an attending physician every 14 days from the date of the candidate's initial registration as adult status 1A to extend the adult status 1A registration.
Requires continuous mechanical ventilation.	14 days, and must be recertified by an attending physician every 14 days from the date of the candidate's initial registration as adult status 1A to extend the Status 1A registration.
Requires continuous infusion of a single high-dose intravenous inotrope or multiple intravenous inotropes, and requires continuous hemodynamic monitoring of left ventricular filling pressures. The OPTN Contractor will maintain a list of the OPTN-approved qualifying inotropes and doses.	7 days, and may be renewed for additional 7 day periods for each occurrence of an adult status 1A listing under this criterion for this candidate.

2. A candidate who is at least 18 years old at the time of registration, and may or may not be currently admitted to the transplant hospital, may be assigned adult status 1A if the candidate meets at least one of the requirements in Table A.7.

Table A.7. Adult Status 1A Requirements for Candidates Current Hospitalization Not Required

If the candidate meets this condition:	Then adult status 1A is valid for:

Has one of the following mechanical circulatory support devices in place: • Left ventricular assist device (LVAD) • Right ventricular assist device (RVAD) • Left and right ventricular assist devices (BiVAD)	30 days, and the candidate may be registered as adult status 1A for 30 days at any point after being implanted once an attending physician determines the candidate is medically stable. The 30 days do not have to be consecutive. However, if the candidate undergoes a procedure to receive another device, then the candidate qualifies for a new term of 30 days. Any 30 days granted by the new device would substitute and not supplement any time remaining from the previous adult status 1A classification.
Candidate has mechanical circulatory support and there is medical evidence of significant device-related complications including, but not limited to, thromboembolism, device infection, mechanical failure, or life-threatening ventricular arrhythmias. A candidate's sensitization is not an acceptable device-related complication to qualify as adult status 1A. If a transplant program reports a complication that is not listed here, the registration will be retrospectively reviewed by the heart regional review board (RRB).	14 days, and must be recertified by an attending physician every 14 days from the date of the candidate's initial registration as adult status 1A to extend the adult status 1A registration.

If the attending physician does not update the qualifications for adult status 1A registration when required according to Tables A.6 and A.7, then the candidate's adult status 1A will expire and the candidate will be downgraded to adult status 1B.

Adult Heart Status 1B Requirements

To assign a candidate adult status 1B, the candidate's transplant program must submit a Heart Status 1B Justification Form to the OPTN Contractor. A candidate is not assigned adult status 1B until this form is submitted. The candidate's transplant program may assign the candidate as adult status 1B if the candidate is at least 18 years old at the time of registration and has at least one of the following devices or therapies in place:

1. Left ventricular assist device (LVAD)

2. Right ventricular assist device (RVAD)

3. Left and right ventricular assist devices (BiVAD)

4. Continuous infusion of intravenous inotropes

Candidates that continue to qualify for adult status 1B may retain this status for an unlimited period and this status does not require any recertification, unless the candidate's medical condition changes.

Adult Heart Status 2 Requirements

If the candidate is at least 18 years old at the time of registration and does not meet the criteria for adult status 1A or 1B but is suitable for transplant, then the candidate may be assigned adult status 2. The candidate may retain adult status 2 for an unlimited period and this status does not require recertification, unless the candidate's medical condition changes.

Status Updates

If a candidate's medical condition changes and the criteria used to justify that candidate's status is no longer accurate, then the candidate's transplant program must update the candidate's status and report the updated information to the OPTN Contractor within 24 hours of the change in medical condition. Hence, we decided to update the patients' health status daily in our simulation model.

A3. Region

For the administration of organ allocation and appropriate geographic representation within the OPTN policy structure, the membership is divided into 11 geographic regions[2]. Members belong to the Region in which they are located (Figure A.1). The Regions are as follows:

Region 1: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Eastern Vermont.

Region 2: Delaware, District of Columbia, Maryland, New Jersey, Pennsylvania, West Virginia, and the part of Northern Virginia in the Donation Service Area served by the Washington Regional Transplant Community (DCTC) OPO.

Region 3: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, and Puerto Rico.

Region 4: Oklahoma and Texas.

Region 5: Arizona, California, Nevada, New Mexico, and Utah.

Region 6: Alaska, Hawaii, Idaho, Montana, Oregon, and Washington.

Region 7: Illinois, Minnesota, North Dakota, South Dakota, and Wisconsin.

Region 8: Colorado, Iowa, Kansas, Missouri, Nebraska, and Wyoming.

Region 9: New York and Western Vermont.

Region 10: Indiana, Michigan, and Ohio.

Region 11: Kentucky, North Carolina, South Carolina, Tennessee, and Virginia.

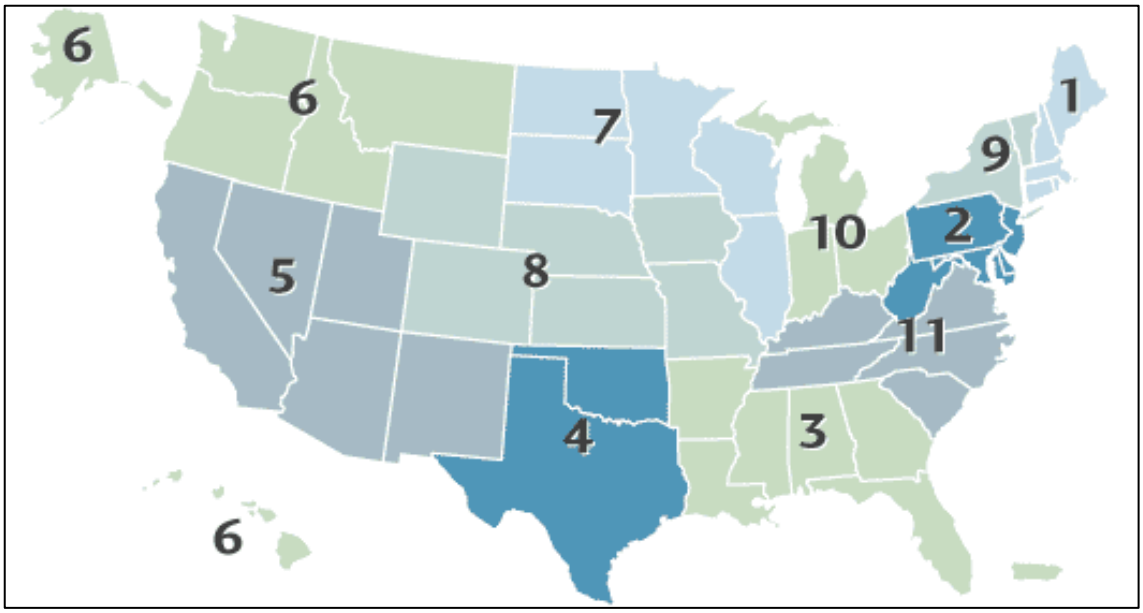

Figure A.1. Map of UNOS Regional Categorization

A4. Organ Procurement Organization (OPO)

OPO is an organization authorized by the Centers for Medicare and Medicaid Services, under Section 1138(b) of the Social Security Act, to procure organs for transplantation. Each region consists of several OPOs (Figure A.2). There are 58 OPO centers in the U.S.; each includes one or more transplant centers (hospitals). Table A.8 shows the number of OPOs and transplant centers in each region[1].

Figure A.2. Map of OPO Locations

Table A.8. Number of OPO and Transplant Centers in Each Region

Region	Number of OPO Centers	Number of Transplant Centers
1	2	14

2	5	35
3	10	30
4	4	30
5	8	33
6	3	9
7	4	22
8	5	19
9	4	14
10	6	20
11	7	24

Since the OPO-level arrival data were not available in UNOS datasets, in order to generate the OPO for an arrived patient/heart, we first generated her/its region, and then using Table A.8, randomly assigned one of the OPOs of the generated region as her/its OPO.

B. Patient Arrival Analysis

In order to generate the attributes of an arrived patient, we used statistical methods to create a series of conditional relationships. Figure A.3 demonstrates the three levels of these hierarchal relationships. We assessed the dependency of each of the attributes to time at the first level and to each other at the second and third levels in the patient arrival process. Since data for VAD were not available in UNOS datasets at the time of study, we assumed that it is dependent to time and included it in the first level of this hierarchy. We also excluded region and OPO from this statistical study, as yearly arrival rate generates the region arrival rates and region generates OPO. However, we reported the p-values of region dependency to time in the regression test for the first level. Another attribute that we did not consider in the first level of dependency was health status as

health status arrival rates is more dependent to disease and age. Other patient attributes were included in the statistical tests.

First, for each group of patient attributes, we used regression to test its dependency to time (calendar year). For example, for blood type, we tested 4 null hypotheses, i.e., the dependency of blood type "O," "A," "B," and "AB" to time. In particular, for blood type "O," the two variables included in the regression are A_O which stands for arrival of blood type "O" and T which shows time (in years). We tested whether the coefficient of time in equation $A_O = aT + b$ equals zero or not. In fact, the null hypothesis is defined as:

$$\begin{cases} H_0 : a = 0, \\ H_1 : a \neq 0. \end{cases}$$

By choosing a significance level α, a p-value less than α rejects the null hypothesis, and shows that the variable depends on time. Similar statistical tests were used to test the dependency of blood type groups "A," "B," and "AB" to time. By repeating the same procedure for the other patient attributes, we created Table A.9, which shows the p-values for each test. Then, for each attribute, we defined the degree of dependency to time, which is the percentage of groups of an attribute dependent on time. By comparing these degrees of dependency, we chose attributes gender, PTX status, and disease group to be dependent on time in our model. By doing so, we then created the first layer shown in Figure A.3. Note that we used programming language R to perform our statistical tests throughout this paper.

Table A.9. Regression p-values for Testing the Time Dependency of Attributes

Attribute	**Regression p-value**	**Dependency to time?**	**Degree of dependency**

Gender	Female:	0.0004452	Yes	2 out of 2
	Male:	0.0004450	Yes	(100%)
Ethnicity	White:	0.02793	Yes	4 out of 7
	African-American:	0.0001934	Yes	(57.14%)
	Hispanic:	0.0005916	Yes	
	Asian:	0.005559	Yes	
	American Indian/Alaska Native:	0.2516	No	
	Pacific Islander:	0.3977	No	
	Multiracial:	0.6751	No	
Blood type	O:	0.8458	No	1 out of 4
	A:	0.3584	No	(25%)
	B:	0.2806	No	
	AB:	0.07187	Yes	
Disease	Dilated Myopathy: Post-Partum	0.1939	No	13 out of 32 (40.62%)
	Dilated Myopathy: Viral	0.7376	No	
	Heart Re-Tx/Gf: Acute Rejection	0.1313	No	
	Heart Re-Tx/Gf: Chronic Rejection	0.1423	No	
	Heart Re-Tx/Gf: Coronary Artery Disease	0.1100	No	
	Heart Re-Tx/Gf: Hyperacute Rejection	0.1117	No	
	Heart Re-Tx/Gf: Non-Specific	0.3074	No	
	Heart Re-Tx/Gf: Other Specify	0.685	No	
	Heart Re-Tx/Gf: Primary Failure	0.8999	No	

Heart Re-Tx/Gf: Restrictive/Constrictive	0.08759	Yes
Hypertrophic Cardiomyopathy	0.0005736	Yes
Arrhythmogenic Right Ventricular Dysplasia/Cardio	0.2825	No
Restrictive Myopathy: Amyloidosis	0.9744	No
Restrictive Myopathy: Idiopathic	0.001643	Yes
Restrictive Myopathy: Other Specify	0.0001368	Yes
Restrictive Myopathy: Sarcoidosis	0.0001163	Yes
Restrictive Myopathy: Sec To Radiat/Chem	0.7919	No
Valvular Heart Disease	0.1260	No
Other, Specify	0.9980	No
Not Reported	0.9143	No
Congenital Heart Defect -. Hypoplastic Left Heart	0.0783	Yes
Congenital Heart Defect -. Prior Surgery Unknown	0.0446	Yes
Congenital Heart Defect -. With Surgery	0.1449	No
Congenital Heart Defect -. Without Surgery	0.01753	Yes
Coronary Artery Disease	0.2912	No
Dilated Myopathy: Adriamycin	0.6545	No
Dilated Myopathy: Alcoholic	0.01372	Yes
Dilated Myopathy: Familial	0.3949	No

	Dilated Myopathy: Idiopathic	0.000004267	Yes	
	Dilated Myopathy: Ischemic	0.08188	Yes	
	Dilated Myopathy: Myocarditis	0.000005622	Yes	
	Dilated Myopathy: Other Specify	0.00216	Yes	
Age group	[18-35]:	0.1635	No	1 out of 4
	[35-50]:	0.3096	No	(25%)
	[50-65]:	0.003668	Yes	
	[65+]:	0.1369	No	
PTX status	1:	0.001242	Yes	1 out of 2
	0:	0.1329	No	(50%)
Region	Region 1:	0.1275	No	3 out of 11
	Region 2:	0.1257	No	(27.27%)
	Region 3:	0.1599	No	
	Region 4:	0.01686	Yes	
	Region 5:	0.9526	No	
	Region 6:	0.1880	No	
	Region 7:	0.9564	No	
	Region 8:	0.2506	No	
	Region 9:	0.01458	Yes	
	Region 10:	0.0005045	Yes	
	Region 11:	0.2114	No	

We considered $\alpha = 0.1$ in this analysis.

After creating the first level, the Chi-squared independency test was used to test the dependency of each attribute in the first level to the remaining attributes. Results (p-values) of the Chi-squared independency test of attributes gender, PTX status, and disease group are reported in Tables A.10, A.11, and A.12, respectively. In the Chi-squared test the null hypothesis is to check the independency of the two tested variables. When the p-value reported by the test is smaller than a significance level, the null hypothesis is rejected and consequently the dependency of the variables is concluded.

Table A.10. P-values for Chi-squared Independency Test for Gender

Independency test of gender and:	**P-value**
Blood type	0.0008254
Age	$< 2.2\times10^{-16}$
Ethnicity	$< 2.2\times10^{-16}$

Table A.11. P-values for Chi-squared Independency Test for PTX Status

Independency Test of PTX Status and:	**P-value**
Blood type	$< 2.2\times10^{-16}$
Age	$< 2.2\times10^{-16}$
Ethnicity	$< 2.2\times10^{-16}$

Table A.12. P-values for Chi-squared Independency Test for Disease

Independency Test of Disease and:	P-value
Blood type	0.6651
Age	$< 2.2\times10^{-16}$
Ethnicity	0.4259

Based on reported p-values of the tests, we developed the hierarchy such that each attribute in level one had only one dependent variable in level two. Since most of the p-values were smaller than the usual significance levels, we chose the attribute with the smallest p-value as the dependent variable for each of the attributes in level one (Table A.13). Note that 2.2×10^{-6} is the smallest p-value that R programming language reports and this small number in fact shows a dependency between attributes.

Table A.13. Second Level Dependency of Patient Attributes

Attribute	Dependent Attributes
Gender	Age, ethnicity
PTX status	Blood type, age, ethnicity
Disease	Age

Age was the only dependent attribute to disease, and it was chosen as the second level variable depending on disease. The only remained choice for gender was ethnicity. For PTX status, though, we could choose blood type as its second level, we did not do so because blood type depends more on ethnicity than previous heart transplant (PTX status). The only remained variables are health

status, and blood type. So far, we created three conditional branches, that is, gender/ethnicity branch, disease/age branch, and PTX status branch. Among these branches we chose health status as the third level variable for disease/age branch, because the health status arrival depends more on disease/age than to gender/ethnicity or PTX status. Also, blood type group arrival rates depend more on gender/ethnicity. Creating the conditional relationships for patient attributes helps to estimate patient attribute arrival distributions more accurately.

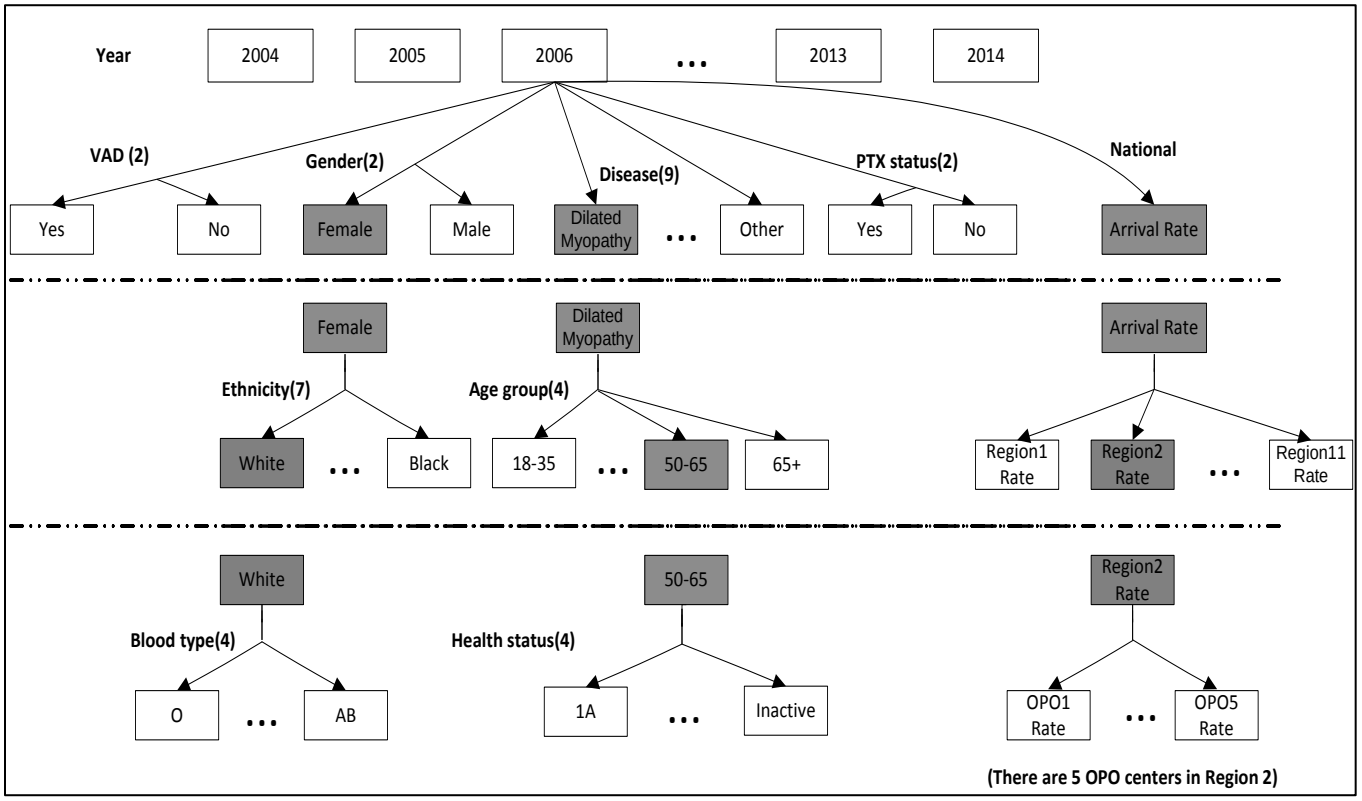

Figure A.3. Pattern of Dependency in Patient Arrival Data

C. Heart Arrival Analysis

When a heart is procured to the system, the model assigns its various attributes according to a series of conditional relationships. We used the same statistical methods described in Appendix B

for patient arrivals to test the dependency of heart attributes to each other, as well as time (calendar year). We included all the attributes of a heart considered by UNOS in our analysis. Table A.14 shows the p-values of time dependency test for each group of heart attributes, as well as their degree of dependency to time. Based on the results of Table A.14, we created the first level of hierarchy, which involves age group, blood type, and ethnicity because these attributes have a larger degree of dependency to time compared to the other attributes. Tables A.15, A.16, and A.17 show the p-values for Chi-squared independency test between each of the attributes in the first level with gender and region. However, since almost all the p-values were close to zero, we decided to consider the region to depend on blood type and gender to depend on age group in the second level. We generated the OPO of an arrived heart randomly based on its region. Figure A.4 shows these conditional relationships.

Table A.14. Regression p-values for Testing the Time Dependency of Attributes

Attribute		Regression p-value	Dependency on time?	Degree of dependency
Gender	Female:	0.1974	No	0 out of 2
	Male:	0.1974	No	(0%)
Ethnicity	White:	0.0006164	Yes	3 out of 7
	African-American:	0.005693	Yes	(42.85%)
	Hispanic:	0.5378	No	
	Asian:	0.000004241	Yes	
	American Indian/Alaska Native:	0.9271	No	
	Pacific Islander:	0.2107	No	
	Multiracial:	0.2567	No	
Blood type	O:	0.1157	No	2 out of 4

	A:	0.8177	No	(50%)
	B:	0.01799	Yes	
	AB:	0.003047	Yes	
Age group	[18-35]:	0.1635	No	1 out of 4
	[35-50]:	0.3096	No	(25%)
	[50-65]:	0.003668	Yes	
	[65+]:	0.1369	No	
	0:	0.1329	No	
Region	Region 1:	0.001061	Yes	3 out of 11
	Region 2:	0.5411	No	(27.27%)
	Region 3:	0.08117	Yes	
	Region 4:	0.3148	No	
	Region 5:	0.5095	No	
	Region 6:	0.7325	No	
	Region 7:	0.1348	No	
	Region 8:	0.1945	No	
	Region 9:	0.01194	Yes	
	Region 10:	0.6285	No	
	Region 11:	0.5649	No	

A significance level of $\alpha = 0.1$ is considered in this analysis.

Table A.15. P-values for Chi-squared Independency Test for Age Group

Independency Test of Age Group and:	**P-value**
Region	$< 2.2\times10^{-16}$
Gender	$< 2.2\times10^{-16}$

Table A.16. P-values for Chi-squared Independency Test for Blood Type

Independency Test of Blood Type and:	P-value
Region	$< 2.2\times10^{-16}$
Gender	6.7×10^{-8}

Table A.17. P-values for Chi-squared Independency Test for Ethnicity

Independency Test of Ethnicity and:	P-value
Region	$< 2.2\times10^{-16}$
Gender	$< 2.2\times10^{-16}$

Table A.18. Second Level Dependency of Heart Attributes

Attribute	Dependent Attributes
Age group	Gender, region
Blood type	Region
Ethnicity	Gender, region

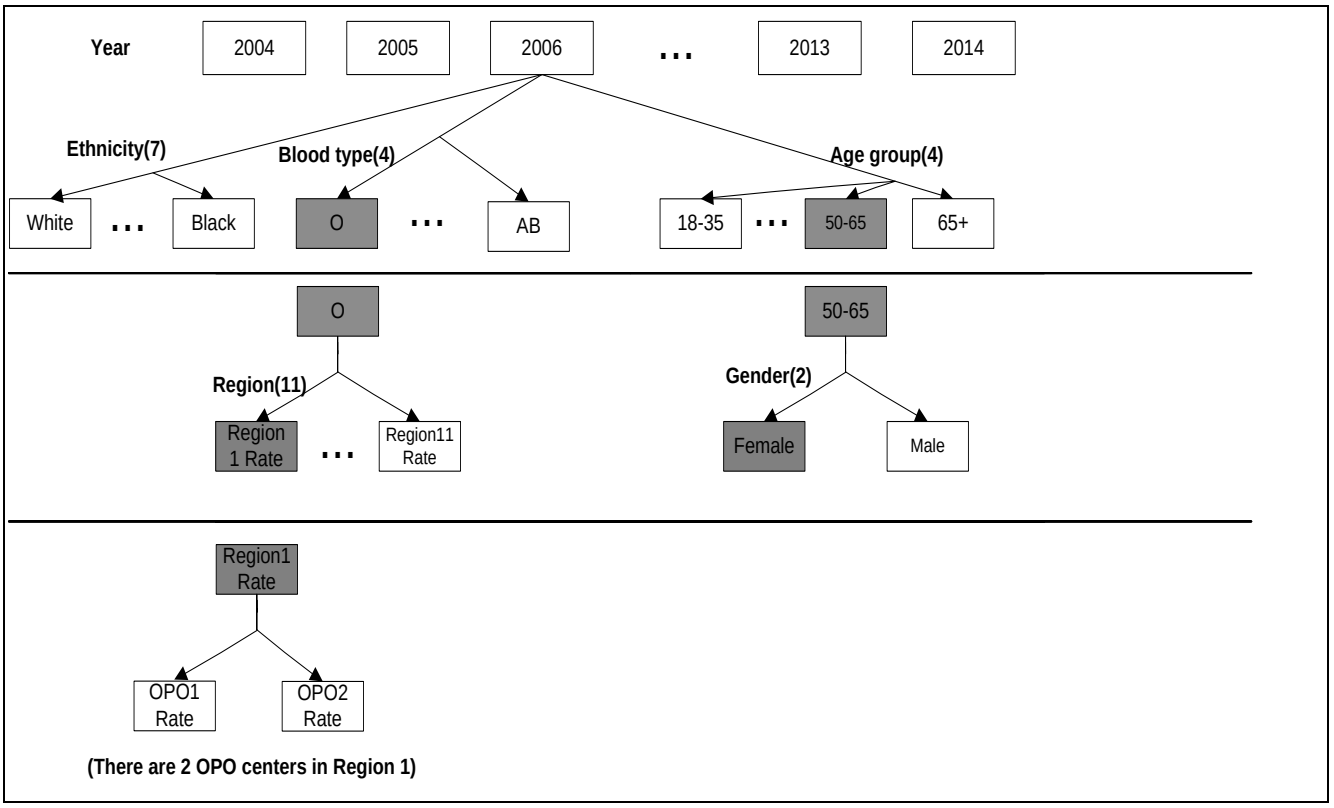

Figure A.4. Pattern of Dependency in Heart Arrival Data

D. Patient Health Status Change Module

We validated the health status change module by comparing the portion of patients in each health status produced by our simulation model with the historical data reported in UNOS datasets[1]. In particular, we used the Kolmogorov-Smirnov test to check whether the health status distributions produced by the model are statistically identical to the real health status distributions at the end of each calendar year during 2006-2014. P-values reported in Table A.19 indicate that the Markov chain developed to describe the health status change of patients on the waiting list, accurately estimates the proportion of patients in each health status over time. The transition probability matrix of the Markov chain is given by:

$$\begin{array}{c} \\ 1A \\ 1B \\ 2 \\ Inactive \end{array} \begin{array}{c} \begin{array}{cccc} 1A & 1B & 2 & Inactive \end{array} \\ \begin{pmatrix} 0.97919 & 0.01864 & 0.00103 & 0.00114 \\ 0.00447 & 0.99267 & 0.00052 & 0.00234 \\ 0.00012 & 0.00071 & 0.99668 & 0.00249 \\ 0.00021 & 0.00012 & 0.00031 & 0.99936 \end{pmatrix} \end{array}.$$

In order to estimate this matrix, we first estimated the monthly frequency of transition matrix using the SRTR annual data reports. Then, using Chapman-Kolmogorov equations, we estimated daily frequency of transition matrix by taking the 30-th root of the monthly one.

Table A.19. P-values for the Kolmogorov-Smirnov Test

Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
P-value	0.7714	0.2286	1	0.7718	0.7700	1	1	1	1

E. Delisting

In our simulation model, outflow of patients from waiting list occurs due to three reasons: transplant, death, and delisting. According to UNOS data, there are several reasons for delisting such as transplanted in another country, unable to contact candidate, medically unsuitable, refused transplant, transferred to another center, condition improved, too sick to transplant, transplanted at another Center, etc[1]. Using UNOS delisting data, we calculated the number of delisted patients during each year from 2006 to the end of 2014. Table A.20 shows the historical data for daily delisting rates (computed by dividing numbers delisted annually by 365) at each year. We model the delisting process as a nonstationary Poisson process. That is, at each day, using Table A.20, we generate a Poisson random number with the mean of the daily delisting rate. The generated number determines the number of patients to be delisted at that day. We then picked the patients

who are going to be delisted according to a distribution that depends on the health status. The rationale behind the choice of health status for the delisting process is that the delisting distribution significantly depends on health status, while weakly correlates with the other attributes according to the historical data reported by UNOS[1]. For example, the daily delisting rate for year 2014 is equal to 2.42. Suppose that the Poisson random number generated using a mean equal to 2.42 is equal to 3 in the simulation. Therefore, we delist 3 patients from the waiting list. The health status removal distribution of patients in 2014 is given by[1]:

- **Health status 1A:** 8.6 % of all delisted patients
- **Health status 1B:** 15 % of all delisted patients
- **Health status 2:** 14 % of all delisted patients
- **Health status 7 (Inactive):** 62.4 % of all delisted patients

We then remove 3 patients from the waiting list according to the above distribution.

Table A.20. Number of Yearly and Daily Delisting for UNOS Waiting List During 2006-2014

Year	2014	2013	2012	2011	2010	2009	2008	2007	2006
Transplanted in another country	1	0	0	0	0	0	0	0	0
Unable to contact candidate	14	13	6	19	17	3	68	5	13
Medically unsuitable	0	0	0	0	0	0	0	0	0
Refused transplant	24	13	22	17	13	24	22	26	17
Transferred to another center	76	42	62	60	70	32	34	37	45
Other	218	191	154	214	122	120	165	97	129
Condition improved	203	149	151	171	173	202	255	315	196
Too sick to transplant	317	274	219	234	196	177	134	111	108

Transplanted at another center	30	25	17	16	9	10	11	7	8
Total removal	883	707	631	731	600	568	689	598	516
Daily removal rate	2.42	1.94	1.73	2.00	1.64	1.56	1.89	1.64	1.41

F. Pre-transplant Death

Patients may die while waiting for a donor heart on the waiting list. We used the SRTR Cox proportional hazard model to generate the daily death probability for each patient on the waiting list[3]. Although this model estimates the patient survival based on patient data from 07/01/2012 to 06/30/2013, we used it to generate death probabilities for the other years.

The covariates for 1-year patient survival are reported in Table A.21[3]. Covariates for VAD status, Region, and OPO were not available in the proportional hazard model. Hence, we assigned 0 for those covariates.

Table A.21. Heart Waitlist Mortality Rates (07/01/2012-06/30/2013)

Characteristic	**Level**	**Estimate**	**Standard Error**	**P-value**
Age	17 and less	0.1383	0.2213	0.5321
	35-49	0.5141	0.1978	0.0093
	50-64	0.5834	0.1904	0.0022
	65+	0.7811	0.2059	0.0001
	18-34	0.0000	(Ref.)	(Ref.)
Blood Type	A	-0.0188	0.0984	0.8486
	AB	-0.0324	0.2755	0.9064
	B	0.0438	0.1355	0.7465
	O	0.0000	(Ref.)	(Ref.)
Diagnosis (Disease)	Cardiomyopathy	-0.1261	0.1091	0.2479
	Retransplant	0.7975	0.2066	0.0001
	Valvular Heart Disease	0.9104	0.2393	0.0001
	Congenital Heart Disease	0.6431	0.1977	0.0011
	Missing	0.0000	(Ref.)	(Ref.)
	Other	0.1390	0.3649	0.7032
Gender	Female	-0.1655	0.106	0.1185
	Male	0.0000	(Ref.)	(Ref.)

Race (Ethnicity)	African-American/Black	-0.0048	0.113	0.9663
	Hispanic/Latino	0.0168	0.1582	0.9152
	Asian	0.0610	0.2861	0.8313
	Other	-0.4669	0.5804	0.4212
	White	0.0000	(Ref.)	(Ref.)
Health Status	1A	1.1268	0.202	<0.0001
	1B	0.3857	0.2012	0.0552
	Inactive	2.3946	0.1754	<0.0001
Waiting Time	>Median	-0.9484	0.0933	<0.0001

The mechanism of our pre-transplant survival module is such that it assigns a probability of death for each patient at the start of each day, generates a random number between 0 and 1, and determines if the patient is going to die during that day, that is,

- Suppose that for a patient, the covariate coeficient associated with his attributes are equal to $\beta_1, \beta_2, \ldots, \beta_{11}$ (we read these numbers from the estimate column reported in Table A.20).
- Yearly probability of death (P_{yearly}) for the patient is equal to:

$$P_{yearly} = (\text{baseline hazard}) .\exp\left(\sum_{i=1}^{11} \beta_i\right)$$

- We convert it to a daily probability of death (P_{Daily}), by

$$P_{Daily} = 1 - \exp\left(-\frac{P_{yearly}}{365}\right)$$

- We generate a random number between 0 and 1 (R):
    - If $P_{Daily} \geq R$, the patient dies.
    - If $P_{Daily} < R$, the patient will remain on the waiting list,

where $\exp(x)$ is the exponential function and baseline hazard is a function that assigns a baseline probability of death for a patient according to the patient's age. We used the U.S. population life tables during 2013 reported in the CDC database to estimate this baseline hazard function[4] (Table A.22).

Table A.22. Abridged Life Table for the U.S. Total Population, 2013

Age (Years x to x+n)	Probability of Dying Between Ages x to x+n	Number Surviving to Age x	Number Dying Between Ages x to x+n	Person-Years Lived Between Ages x to x+n	Total Number of Person-Years Lived Above Age x	Life Expectancy at Age x
0-1	0.005958	100,000	596	99,475	7,882,785	78.8
1_5	0.001021	99,404	102	397,372	7,783,311	78.3
5_10	0.000590	99,303	59	496,355	7,385,939	74.4
10_15	0.000705	99,244	70	496,080	6,889,584	69.4
15-20	0.002227	99,174	221	495,400	6,393,505	64.5
20-25	0.004158	98,953	411	493,788	5,898,105	59.6
25-30	0.004869	98,542	480	491,535	5,404,318	54.8
30-35	0.005727	98,062	562	488,941	4,912,783	50.1
35-40	0.007072	97,500	690	485,855	4,423,842	45.4
40-45	0.009949	96,811	963	481,799	3,937,986	40.7
45-50	0.015604	95,848	1,496	475,781	3,456,188	36.1
50-55	0.024272	94,352	2,290	466,384	2,980,407	31.6
55-60	0.035563	92,062	3,274	452,547	2,514,024	27.3
60-65	0.050060	88,788	4,445	433,361	2,061,477	23.2
65-70	0.071576	84,343	6,037	407,404	1,628,116	19.3
70-75	0.109091	78,306	8,543	371,349	1,220,712	15.6
75-80	0.170567	69,764	11,899	320,641	849,363	12.2
80-85	0.271135	57,864	15,689	251,503	528,722	9.1
85-90	0.425836	42,175	17,960	166,078	277,219	6.6
90-95	0.614587	24,216	14,883	81,352	111,141	4.6
95-100	0.786379	9,333	7,339	25,247	29,789	3.2
100+	1.000000	1,994	1,994	4,541	4,541	2.3

G. Post-transplant Death

The mechanism of the post-transplant survival module is similar to the pre-transplant survival module. The only difference is that we used the post-transplant Cox proportional hazard model

reported in the SRTR[3] website to generate the daily probability of death for patients after transplantation (Table A.23). Some of the covariates presented in the Cox proportional hazard model were not available in our simulation and we did not consider them. However, some of these covariates such as bilirubin at transplant (mg/dL), dialysis at transplant, drug−treated HTN at listing, ischemic time (hrs), most recent CPRA/PRA, PA (Sys, mm Hg), and sudden death at listing have a possibility for missing data. Hence, we used the estimates for missing covariates in such attributes.

Table A.23. 1-Year Patient Post-Transplant Survival

Characteristic	Level	Estimate	Standard Error	P-value
Bilirubin at Transplant (mg/dL)	mg/dL	0.0872	0.014	<0.0001
	Missing	0.4301	0.5145	0.4032
Dialysis at Transplant	Yes	0.8372	0.2255	0.0002
	Unknown/Missing	−0.6518	0.6263	0.2981
	No	0.0000	(Ref.)	(Ref.)
Donor Age	0-34	−0.1602	0.1094	0.1429
	35+	0.0000	(Ref.)	(Ref.)
Donor Cause of Death	CVA/Stroke	0.1224	0.1288	0.3419
	Other	0.0000	(Ref.)	(Ref.)
Drug-Treated HTN at Listing	Missing	−0.2993	0.2348	0.2024
	Yes	0.2342	0.1117	0.0361
	No	0.0000	(Ref.)	(Ref.)
Ischemic Time (hrs)	In Hours (hrs)	0.1258	0.0477	0.0084
	Missing	0.5991	0.3244	0.0648
Medical Condition	In ICU	0.2127	0.1221	0.0815
	Hospitalized Not in ICU	0.1760	0.1459	0.2278
	Not Hospitalized	0.0000	(Ref.)	(Ref.)
Most Recent CPRA/PRA	Percent (%)	0.0010	0.0023	0.6553
	Missing	0.1588	0.2187	0.4679
PA (Sys, mm Hg)	Systolic (mm HG)	0.0028	0.0037	0.4528
	Missing	0.5562	0.2575	0.0308
Recipient Diagnosis	Cardiomyopathy	−0.0761	0.1087	0.4838
	Congenital Heart Disease	0.5220	0.2408	0.0302
	Other/Missing	−0.4738	0.369	0.1991

	Coronary Artery Disease	0.0000	(Ref.)	(Ref.)
Recipient Height (cm)	In Centimeters (cm)	−0.0124	0.0054	0.021
Recipient Race/Ethnicity	Black	0.0408	0.1287	0.7513
	Hispanic/Latino	0.1307	0.1893	0.4899
	Asian	−0.2627	0.2998	0.3808
	Multiracial/Other/Unknown/Missing	−0.2733	0.5826	0.639
	White	0	(Ref.)	(Ref.)
Recipient Serum Creatinine (mg/dL)	>1.6	0.635	0.1094	<0.0001
	1.6 or Less	0	(Ref.)	(Ref.)
Recipient on Life Support (ECMO)	Yes	0.8371	0.3776	0.0266
	No	0	(Ref.)	(Ref.)
Recipient on VAD	Yes	0.4382	0.1115	0.0001
	No	0	(Ref.)	(Ref.)
Recipient on Ventilator	Yes	0.4903	0.3452	0.1556
	No	0	(Ref.)	(Ref.)
Sudden Death at Listing	Yes	0.073	0.1437	0.6115
	Unknown/Missing	0.4062	0.1637	0.0131
	No	0	(Ref.)	(Ref.)

The other possibility that can occur for patients in the post-transplant is the graft (heart) failure. Since in the arrival of patients, we considered such patients (patients whose PTX status is equal to 1), to avoid double-counting them, we did not include the graft failure event in the post-transplant phase.

H. Allocation Policies

H1. Current UNOS Allocation Policy[2]

H1.1. Waiting Time Accumulation

Waiting time for heart candidates begins when the candidate is first registered as an active heart candidate on the waiting list, and is calculated within each heart status. As a result, waiting time

accrued at a higher status will be added to any time accumulated at a lower status, but waiting time accumulated at a lower status will not be added to any higher status. If a candidate's status is upgraded, waiting time accrued while registered at the lower status is not transferred to the higher status. Conversely, waiting time accrued while registered at a higher status is transferred to a lower status if the candidate is downgraded. Waiting time does not accrue while the candidate is inactive.

H1.2. Heart Allocation Classifications and Rankings

Allocation of Hearts by Blood Type

Within each heart status, hearts will be allocated to candidates according to the primary blood type matching requirements in Table A.24.

Table A.24. Primary Blood Type Matching Requirements

Hearts from donors with:	**Are allocated to the candidates with:**
Blood Type O	Blood type O or blood type B
Blood Type A	Blood type A or blood type AB
Blood Type B	Blood type B or blood type AB
Blood Type AB	Blood type AB

After hearts are allocated to primary blood type candidates, they are allocated to any secondary blood type compatible candidates, then to any eligible incompatible blood type candidates (Table A.25).

Table A.25. Secondary Blood Type Matching Requirements

Hearts from donors with:	Are allocated to the candidates with:
Blood Type O	Blood type A or blood type AB
Blood Type A	Not applicable
Blood Type B	Not applicable
Blood Type AB	Not applicable

Sorting Within Each Classification

Candidates are sorted within each classification by the total amount of waiting time that the candidate has accumulated at that status.

Allocation of Hearts from Donors at Least 18 years Old

Hearts from deceased donors at least 18 years old are allocated to candidates according to Table A.27. Table A.26 shows the zone definitions for the current UNOS policy.

Table A.26. Zone Definition for the UNOS Policy

Zone	Includes transplant hospitals :
A	Within 500 nautical miles from the donor hospital but outside of the donor's hospital DSA.
B	Within 1000 nautical miles from the donor hospital but outside of the zone A and donor's hospital DSA.
C	Within 1500 nautical miles from the donor hospital but outside of the zone B and donor's hospital DSA.
D	Within 2500 nautical miles from the donor hospital but outside of the zone C and donor's hospital DSA.

E	More than 2500 nautical miles from the donor hospital.

Table A.27. Allocation of Hearts from Deceased Donors At Least 18 Years Old in the UNOS Policy

Classification	Candidates that are within the:	And are:
1	OPO's DSA	Adult or pediatric status 1A and primary blood type match with the donor
2	OPO's DSA	Adult or pediatric status 1A and secondary blood type match with the donor
3	OPO's DSA	Adult or pediatric status 1B and primary blood type match with the donor
4	OPO's DSA	Adult or pediatric status 1B and secondary blood type match with the donor
5	Zone A	Adult or pediatric status 1A and primary blood type match with the donor
6	Zone A	Adult or pediatric status 1A and secondary blood type match with the donor
7	Zone A	Adult or pediatric status 1B and primary blood type match with the donor
8	Zone A	Adult or pediatric status 1B and secondary blood type match with the donor
9	OPO's DSA	Adult or pediatric status 2 and primary blood type match with the donor
10	OPO's DSA	Adult or pediatric status 2 and secondary blood type match with the donor
11	Zone B	Adult or pediatric status 1A and primary blood type match with the donor

12	Zone B	Adult or pediatric status 1A and secondary blood type match with the donor
13	Zone B	Adult or pediatric status 1B and primary blood type match with the donor
14	Zone B	Adult or pediatric status 1B and secondary blood type match with the donor
15	Zone A	Adult or pediatric status 2 and primary blood type match with the donor
16	Zone A	Adult or pediatric status 2 and secondary blood type match with the donor
17	Zone B	Adult or pediatric status 2 and primary blood type match with the donor
18	Zone B	Adult or pediatric status 2 and secondary blood type match with the donor
19	Zone C	Adult or pediatric status 1A and primary blood type match with the donor
20	Zone C	Adult or pediatric status 1A and secondary blood type match with the donor
21	Zone C	Adult or pediatric status 1B and primary blood type match with the donor
22	Zone C	Adult or pediatric status 1B and secondary blood type match with the donor
23	Zone C	Adult or pediatric status 2 and primary blood type match with the donor
24	Zone C	Adult or pediatric status 2 and secondary blood type match with the donor

25	Zone D	Adult or pediatric status 1A and primary blood type match with the donor
26	Zone D	Adult or pediatric status 1A and secondary blood type match with the donor
27	Zone D	Adult or pediatric status 1B and primary blood type match with the donor
28	Zone D	Adult or pediatric status 1B and secondary blood type match with the donor
29	Zone D	Adult or pediatric status 2 and primary blood type match with the donor
30	Zone D	Adult or pediatric status 2 and secondary blood type match with the donor
31	Zone E	Adult or pediatric status 1A and primary blood type match with the donor
32	Zone E	Adult or pediatric status 1A and secondary blood type match with the donor
33	Zone E	Adult or pediatric status 1B and primary blood type match with the donor
34	Zone E	Adult or pediatric status 1B and secondary blood type match with the donor
35	Zone E	Adult or pediatric status 2 and primary blood type match with the donor
36	Zone E	Adult or pediatric status 2 and secondary blood type match with the donor

In order to determine the set of OPOs in each zone and for each OPO center, by using Figure A.2, we calculated the distances between any pair of OPO centers (distances estimated by Google maps) and followed the definition of each zone[5].

H2. Policy I

This section explains how we proposed the three-tiered zone allocation system. If a donor heart is matched with no one in its Designated Service Area (DSA), it is offered to Zone 1 (union of Zones A, B, and C of UNOS allocation rule). Similarly, if it is not matched with a patient in Zone 1, it is offered in hierarchy to patients in Zone 2 (Zone D of UNOS allocation rule) and Zone 3 (Zone E of UNOS allocation rule). Table A.28 shows the zone definition for Policy I . Note that in each zone we considered the same health status, blood type match, and waiting time prioritization rules as UNOS. Table A.29 shows the allocation procedure for Policy I in the model.

Table A.28. Zone Definition for Policy I

Zone	Includes transplant hospitals :
1	Within 1500 nautical miles from the donor hospital but outside of the donor's hospital DSA.
2	Within 2500 nautical miles from the donor hospital but outside of the zone A and donor's hospital DSA.
3	More than 2500 nautical miles from the donor hospital.

Table A.29. Allocation of Hearts from Deceased Donors At Least 18 Years Old in Policy I

Classification	Candidates that are within the:	And are:
1	OPO's DSA and Zone 1	Adult or pediatric status 1A and primary blood type match with the donor

2	OPO's DSA and Zone 1	Adult or pediatric status 1A and secondary blood type match with the donor
3	OPO's DSA and Zone 1	Adult or pediatric status 1B and primary blood type match with the donor
4	OPO's DSA and Zone 1	Adult or pediatric status 1B and secondary blood type match with the donor
5	Zone 2	Adult or pediatric status 1A and primary blood type match with the donor
6	Zone 2	Adult or pediatric status 1A and secondary blood type match with the donor
7	Zone 2	Adult or pediatric status 1B and primary blood type match with the donor
8	Zone 2	Adult or pediatric status 1B and secondary blood type match with the donor
9	OPO's DSA and Zone 1	Adult or pediatric status 2 and primary blood type match with the donor
10	OPO's DSA and Zone 1	Adult or pediatric status 2 and secondary blood type match with the donor
11	Zone 3	Adult or pediatric status 1A and primary blood type match with the donor
12	Zone 3	Adult or pediatric status 1A and secondary blood type match with the donor
13	Zone 3	Adult or pediatric status 1B and primary blood type match with the donor
14	Zone 3	Adult or pediatric status 1B and secondary blood type match with the donor
15	Zone 2	Adult or pediatric status 2 and primary blood type match with the donor

16	Zone 2	Adult or pediatric status 2 and secondary blood type match with the donor
17	Zone 3	Adult or pediatric status 2 and primary blood type match with the donor
18	Zone 3	Adult or pediatric status 2 and secondary blood type match with the donor

H3. Policy *II*

To prioritize patients according to their health status, UNOS gives the first priority to health status 1A, the second priority to health status 1B, and finally the third priority to health status 2. The patients assigned with health status 7 (inactive) are not considered in the heart-patient matching algorithm. This allocation rule gives priority to patients with a higher medical urgency status. However, it has caused a significant imbalance in the distribution of donated hearts. In particular, more than 67% of all transplants correspond to status 1A while status 1A patients are only 10% of those on the waiting list. Moreover, less than 30% of all transplants correspond to health status 1B while these patients compromise 40% of the waiting list. This disparity has caused some patients in status 1B relocate together with their families to other regions with shorter waiting time[6]. Also, prioritizing the sickest patients may not be optimal as they may experience a shorter post-transplant survival compared to status 1B patients. Thus, in Policy *II* we followed the UNOS allocation system except that status 1B was prioritized over 1A in each classification. Table A.30 summarizes the allocation priority for this policy**.**

Table A.30. Allocation of Hearts from Deceased Donors At Least 18 Years Old in Policy *II*

Classification	Candidates that are within the:	And are:
1	OPO's DSA	Adult or pediatric status 1B and primary blood type match with the donor
2	OPO's DSA	Adult or pediatric status 1B and secondary blood type match with the donor
3	OPO's DSA	Adult or pediatric status 1A and primary blood type match with the donor
4	OPO's DSA	Adult or pediatric status 1A and secondary blood type match with the donor
5	Zone A	Adult or pediatric status 1B and primary blood type match with the donor
6	Zone A	Adult or pediatric status 1B and secondary blood type match with the donor
7	Zone A	Adult or pediatric status 1A and primary blood type match with the donor
8	Zone A	Adult or pediatric status 1A and secondary blood type match with the donor
9	OPO's DSA	Adult or pediatric status 2 and primary blood type match with the donor
10	OPO's DSA	Adult or pediatric status 2 and secondary blood type match with the donor
11	Zone B	Adult or pediatric status 1B and primary blood type match with the donor
12	Zone B	Adult or pediatric status 1B and secondary blood type match with the donor

13	Zone B	Adult or pediatric status 1A and primary blood type match with the donor
14	Zone B	Adult or pediatric status 1A and secondary blood type match with the donor
15	Zone A	Adult or pediatric status 2 and primary blood type match with the donor
16	Zone A	Adult or pediatric status 2 and secondary blood type match with the donor
17	Zone B	Adult or pediatric status 2 and primary blood type match with the donor
18	Zone B	Adult or pediatric status 2 and secondary blood type match with the donor
19	Zone C	Adult or pediatric status 1B and primary blood type match with the donor
20	Zone C	Adult or pediatric status 1B and secondary blood type match with the donor
21	Zone C	Adult or pediatric status 1A and primary blood type match with the donor
22	Zone C	Adult or pediatric status 1A and secondary blood type match with the donor
23	Zone C	Adult or pediatric status 2 and primary blood type match with the donor
24	Zone C	Adult or pediatric status 2 and secondary blood type match with the donor
25	Zone D	Adult or pediatric status 1B and primary blood type match with the donor
26	Zone D	Adult or pediatric status 1B and secondary blood type match with the donor

27	Zone D	Adult or pediatric status 1A and primary blood type match with the donor
28	Zone D	Adult or pediatric status 1A and secondary blood type match with the donor
29	Zone D	Adult or pediatric status 2 and primary blood type match with the donor
30	Zone D	Adult or pediatric status 2 and secondary blood type match with the donor
31	Zone E	Adult or pediatric status 1B and primary blood type match with the donor
32	Zone E	Adult or pediatric status 1B and secondary blood type match with the donor
33	Zone E	Adult or pediatric status 1A and primary blood type match with the donor
34	Zone E	Adult or pediatric status 1A and secondary blood type match with the donor
35	Zone E	Adult or pediatric status 2 and primary blood type match with the donor
36	Zone E	Adult or pediatric status 2 and secondary blood type match with the donor

H4. Policy ^{III}

Policy ^{III} considered the UNOS allocation rule except that in each zone waiting time is prioritized over health status, i.e., considering primary and secondary blood type match, patients are ranked

first by longer waiting time. Section H.1.1. explains how the waiting time in each health status is accumulated.

I. Sensitivity Analysis

I.1. Patient and heart arrival rates

In this section, we conducted sensitivity analysis on the arrival of patients and hearts to assess the impacts of change in the number of arrivals on the outcomes such as total death (pre- and post-transplant deaths). We let the arrival rates of patients and hearts to increase and decrease by a certain percentage (e.g., 10 percent) and compare the total patient death (including pre- and post-transplant deaths) for the following seven cases: (1) baseline scenario, (2) daily arrival rates of patients increased by 10 percent compared to the baseline rates, (3) daily arrival rates of hearts increased by 10 percent compared to the baseline rates, (4) daily arrival rates of patients and hearts both increased by 10 percent compared to the baseline rates, (5) daily arrival rates of patients decreased by 10 percent compared to the baseline rates, (6) daily arrival rates of hearts decreased by 10 percent compared to the baseline rates, (7) daily arrival rates of patients and hearts both decreased by 10 percent compared to the baseline rates. Figures A.5, A.6, and A.7 summarize the result of the sensitivity analysis for the aforementioned cases.

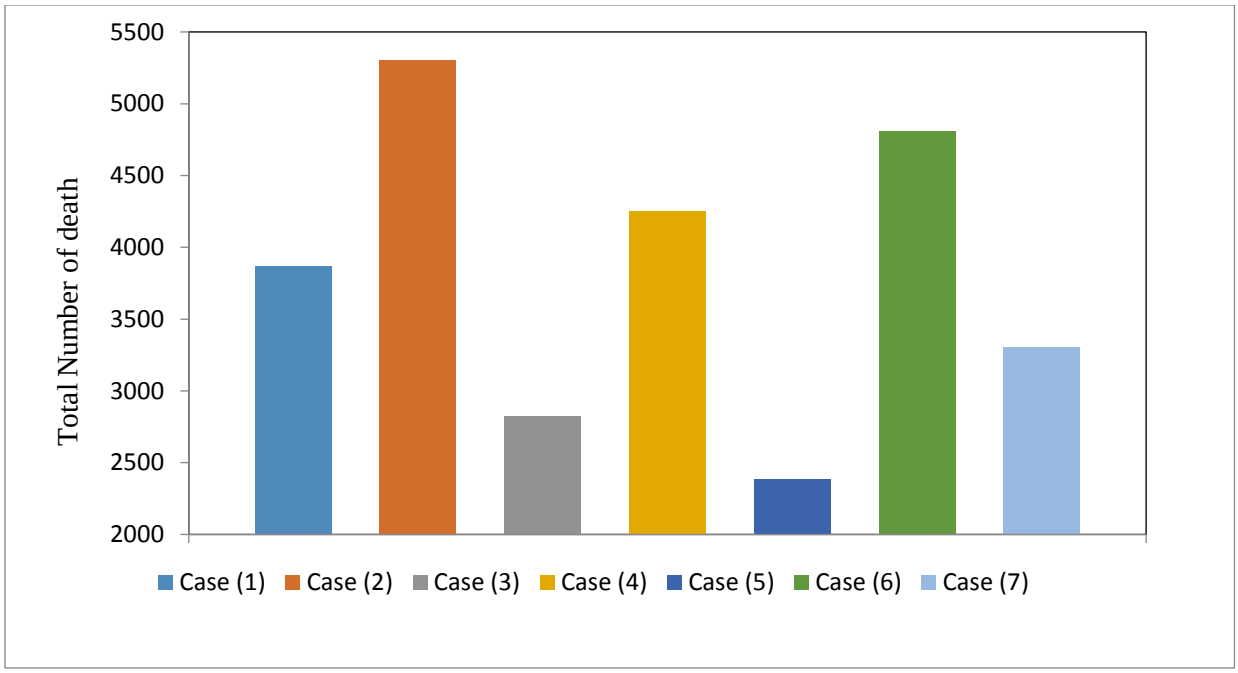

Figure A.5. Total Number of Deaths for Different Patient and Heart Arrival Rates

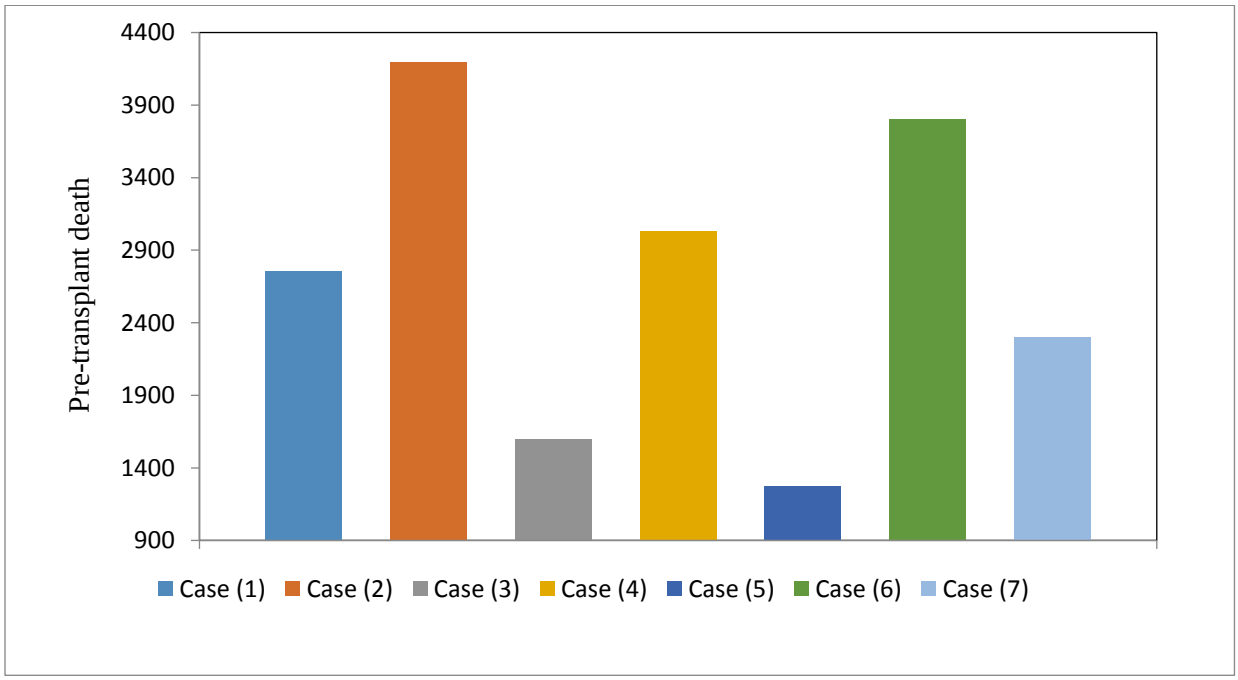

Figure A.6. Pre-Transplant Deaths for Different Patient and Heart Arrival Rates

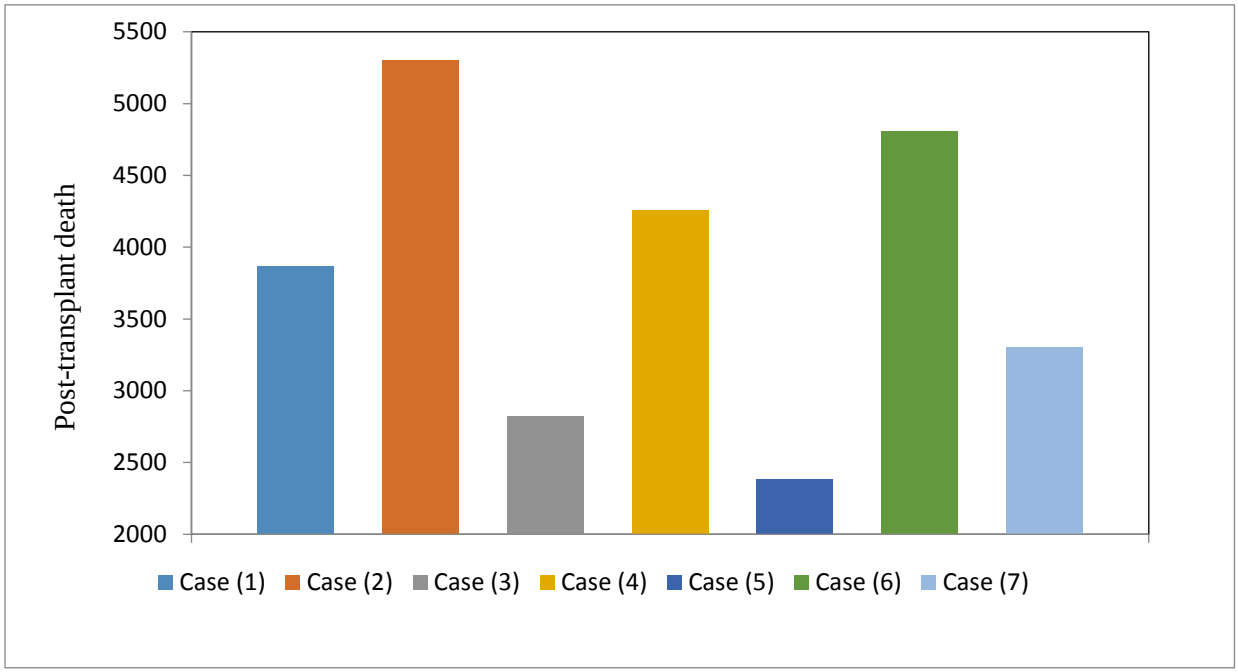

Figure A.7. Post-Transplant Deaths for Different Patient and Heart Arrival Rates

I.2. On allocation priority zones

As we have described in the paper, allocation priority zones are defined based on the proximity of patients' hospital to the donor's hospital. Current UNOS allocation policy, considers 5 allocation priority zones, i.e., Zone A, Zone B, Zone C, Zone D, and Zoned E, in addition to DSA. Our proposed Policy I in Section 2.2.1. of the paper aggregates Zones A, B, and C in the current UNOS policy into one single priority zone. We conducted sensitivity analysis on different combinations of priority zones. Specifically, we considered a policy that combines Zones A and B into single priority zone (Policy IV). Similar to the other policies, we calculated the total number of deaths (including pre- and post-transplant deaths) for this policy (Figures A.8, A.9, and A.10). We conducted fairness analysis on policy IV as well. We measured the proportional

fairness and max-min fairness for this policy using the same approach discussed in Section 2.4. of the paper (Figures A.11 and A.12).

These measures are reported for the following three policies:

(1) **Current UNOS allocation policy:** After offering an available heart in its DSA, it shares the organ to patients in Zone A (within 500 miles of the OPO of the available heart), Zone B (within 500-1000 miles of the OPO of the available heart), Zone C (within 1000-1500 miles of the OPO of the available heart), Zone D (within 1500-2500 miles of the OPO of the available heart), and Zone E (more than 2500 miles distance from the OPO of the available heart), respectively.

(2) **Policy I :** This policy combines Zones A, B, and C in the UNOS policy. After offering an available heart in its DSA, this policy shares it to patients in Zone 1 (within 1500 miles of the OPO of the available heart), Zone 2 (within 1500-2500 miles of the OPO of the available heart), and Zone 3 (more than 2500 miles distance from the OPO of the available heart), respectively.

(3) **Policy IV :** This policy combines Zones A and B in the current UNOS policy. After offering an available heart in its DSA, this policy shares it to patients in Zone 1 (within 1000 miles of the OPO of the available heart), Zone 2 (within 1000-1500 miles of the OPO of the available heart), Zone3 (within 1500-2500 miles of the OPO of the available heart), and Zone 4 (more than 2500 miles distance from the OPO of the available heart), respectively.

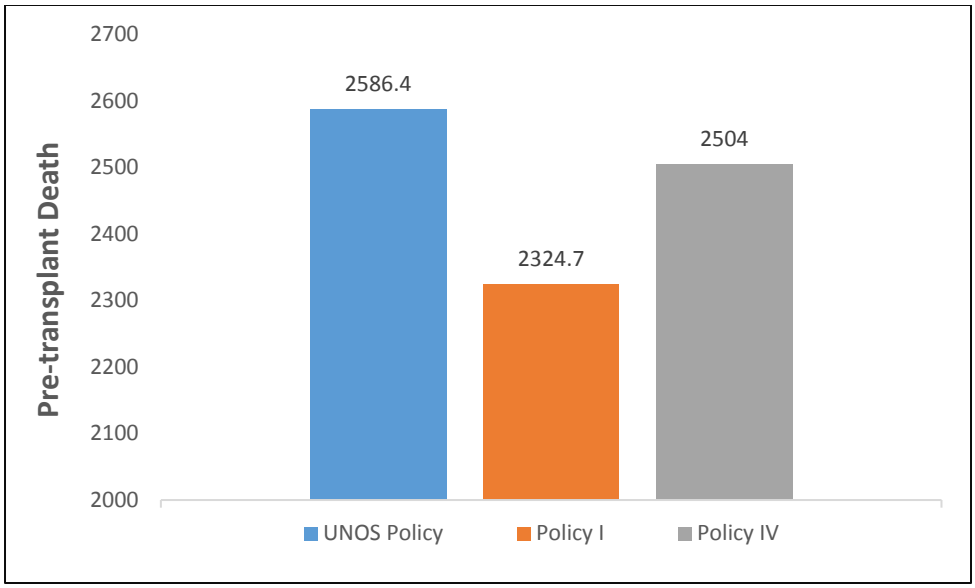

Figure A.8. Pre-Transplant Deaths

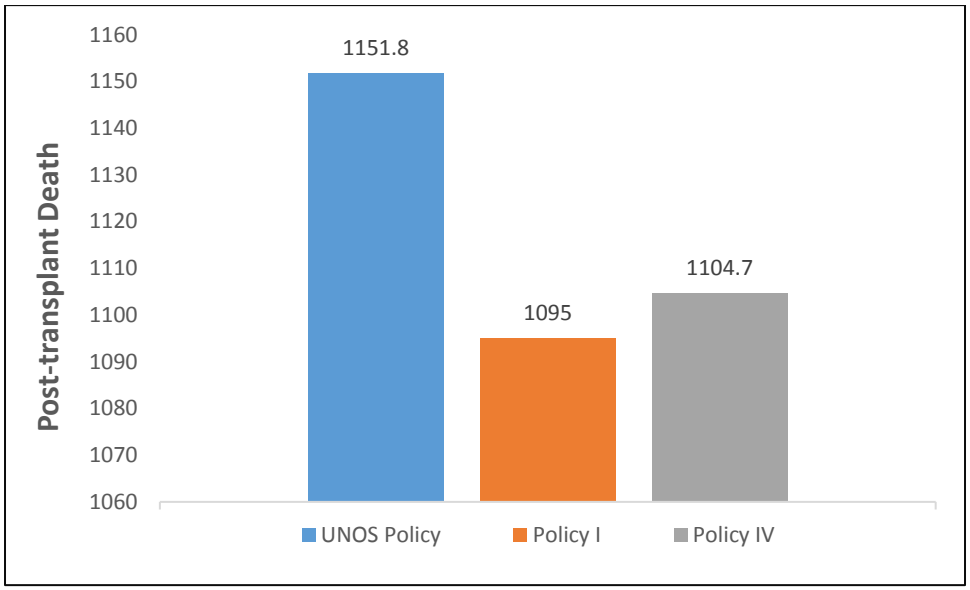

Figure A.9. Post-Transplant Deaths

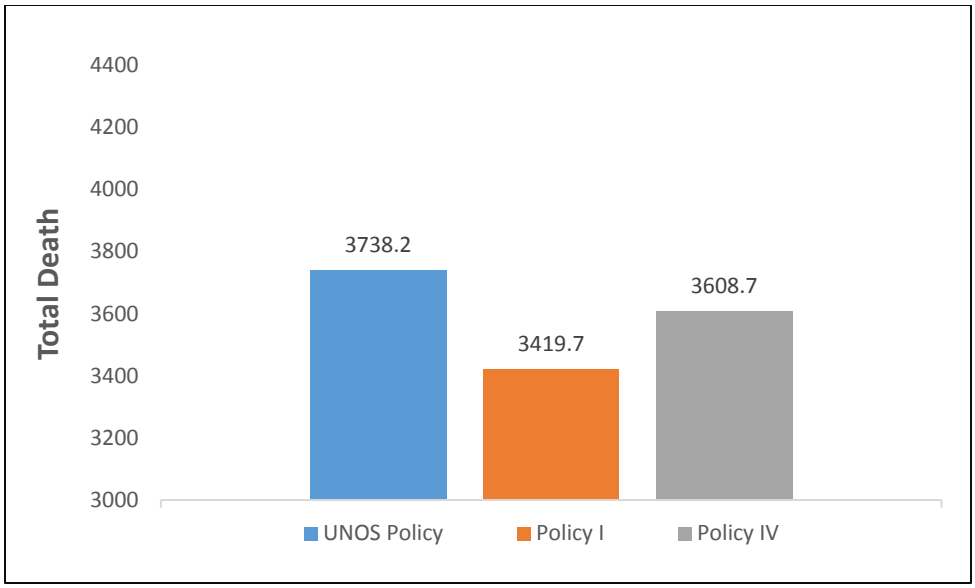

Figure A.10. Total Deaths

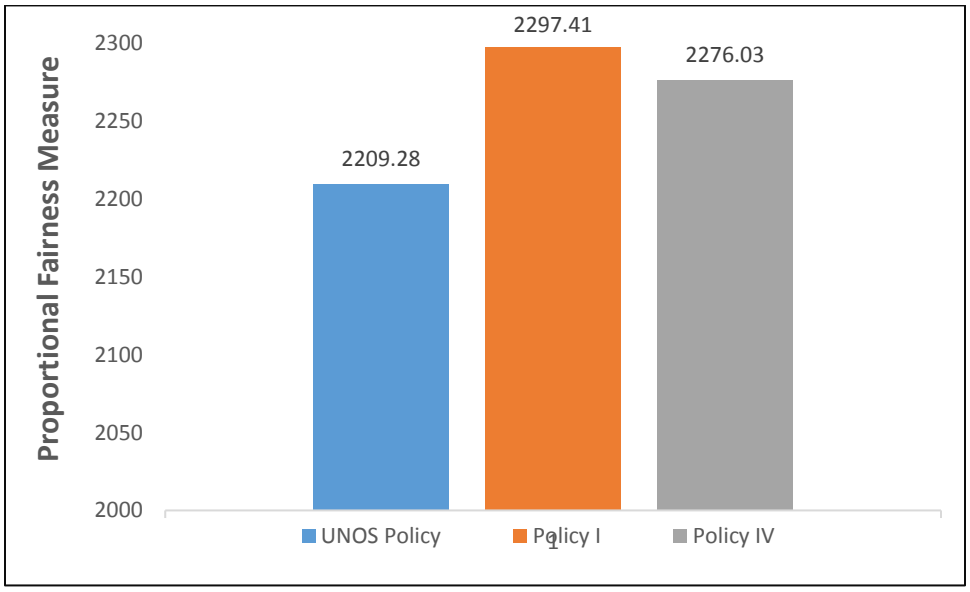

Figure A.11. Proportional Fairness Measure

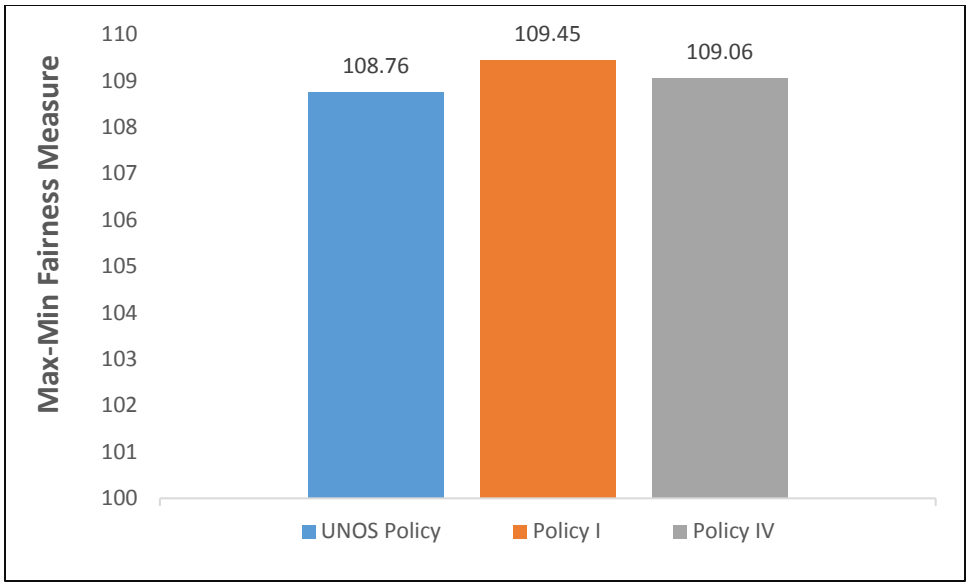

Figure A.12. Max-Min Fairness Measure

Furthermore, we conducted a sensitivity analysis on the arrival rate of patients to check its effect on the ordering of the policies in terms of efficiency (number of total deaths). As can be seen from Figure A.13, the order of policies remain unchanged as we increase the patient arrival rates. We increased arrival rates of patients by 10 percent in our planning horizon, and compared the total number of deaths for UNOS policy, three considered policies in main manuscript (Policies I, II, and III), and Policy IV. Our results show that ranking among policies does not change by changing the input parameters in the described range.

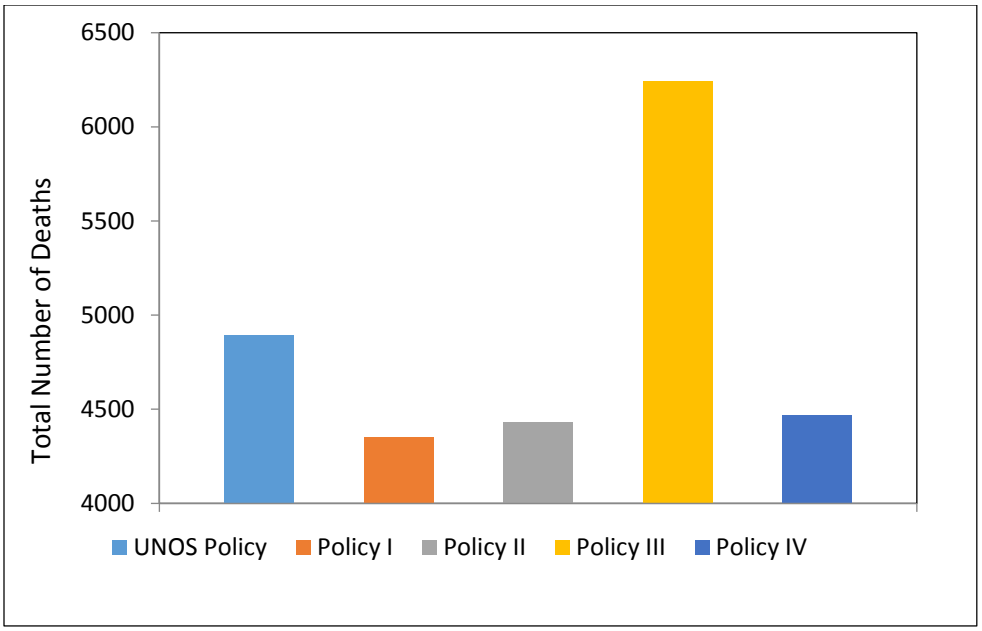

Figure A.13. Total Number of Deaths for 10 Percent Increased Patient Arrival Rates

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