Exploring Financial & Geographical Advantages in Waiting List for Organ Donations

Christine Harvey

December 15, 2015

Abstract

Your abstract.

1 Introduction

Around the world there are hundreds of thousands of people in need of a life-saving organ transplant [1]. This shortage of organs is a large problem in the United States with over 120,000 currently waiting for a transplant [1]. If a patient is unable to receive a donation from a living person, they must join the waiting list for an organ transplant from a deceased donor.

In the Unites States, there are currently no limitations on a person registering at multiple transplant centers in various DSAs [3]. The lack of restrictions in regards to multiple registrations is something that many believe gives an unfair advantage to those with the financial means to travel anywhere in the country to receive medical care or a potential transplant.

The research project completed for this course project developed a model of patients, in the United States on the waiting list for a kidney transplant. These patients are added to one or more queues, representing the Donor Service Areas. Some agents have greater abilities than others to register at transplant centers in more than one donor service area. The model will be able to analyze the advantages of multiple registrations and attempt to determine the actual degree of advantage gained from a patients having multiple registrations.

Section 2 describes the background of the problem. The model outline and implementation are discussed in Section 2. Section 3 covers the model experimentation conducted to address the social science problem investigated in this work. Section 4 describes the results in the model. Finally, Section 5 discusses the conclusions drawn from the model and research conducted.

2 Background

The waiting for organ transplants is a problem many see on various television shows, especially those taking place in a hospital setting. For hundreds of thousands of Amerians, this is much more severe and consuming difficulty. Over

120,000 Americans are currently on the waiting list for an organ transplant in the United States[1]. Various illnesses, conditions, and diseases can cause a person's organs to shut down. Modern medicine allows working organs to be transplanted from one functioning body into another. Certain patients can be treated by receiving a new organ and they are referred by a physician to be placed on the national transplant waiting list, managed by the United Network for Organ Sharing (UNOS) [1].

The UNOS waiting list manages the waiting period for heart, lungs, liver, kidney, pancreas, and intestine. When a person passes away under circumstanses conducive to organ donation, the medical team investigates whether the person has consented to become an organ donor. If the deceased is an organ donor, the medical team examines the individual's body and determines which organs are medically suitable for transplant to somone on the waiting list. The harvested organs are then donated and allocated according to the UNOS policy and procedures.

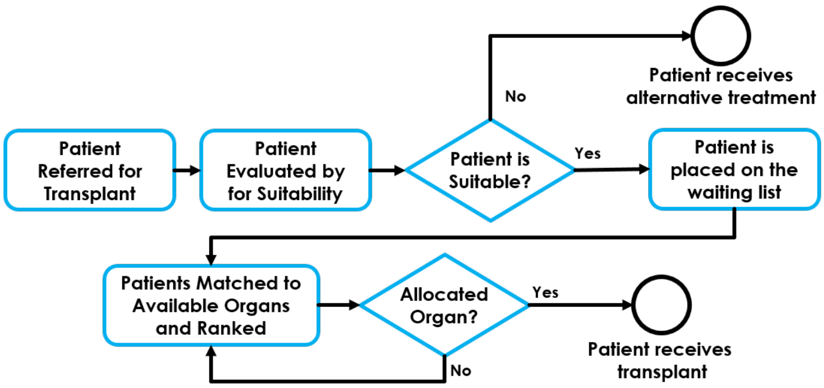

Figure 1: Description of the Organ Transplant system from the initial referral for a transplant by a doctor through the patient receiving a transplant or going on to receive alternate treatment.

While on the waiting list, a patient must to wait until an appropriate match is found. When an organ becomes available, there is a priority ordering given to patients based on a variety of factors including the quality of the match, the health of the potential recipient, and the amount of time a patient has been waiting. The waiting list process is briefly described in Figure 1. Therefore, the waiting list does not operate as a list or queue in the traditional sense. Many different factors account for the order in which a person receives and organ, but in the most generic sense, and in public opinion, the system operates as a queue. In most cases, outside of more severe circumstances, organs are first allocated within the Donor Service Area (DSA), then throughout the region, and finally across the entire country if there are no suitable candidates available in more local regions [2].

There are 58 DSAs and 11 regions in the country, therefore registering in another DSA could prove to be an advantage for a person listed in an area with a higher median waiting time. [6]. The shortest median waiting time for a kidney transplant across DSAs in 2009 was 0.50 years compared to the longest median waiting time of 5.22 years [7]. According to research published in the Journal of Transplantation this difference is related to number of patients suffering from End Stage Renal Disease, number of patients listed for transplant, organ procurement rates [7].

Due to this large range in waiting time, patients may register within multiple Donor Service Areas. UNOS manages a central repository and database for organ donation. A candidate for organ donation may have multiple registrations with the different Donor Service Areas. The lack of restrictions in regards to multiple registrations is something that many believe gives an unfair advantage to those with the financial means to travel anywhere in the country to receive medical care or a potential transplant.

One of the most well known instances of multiple registrations on the Waiting List is former Apple CEO, Steve Job's ability to obtain a kidney transplant at a hospital in Tennessee, despite being a resident of California [5]. This caused public outrage and many considered this a "loophole" existing for the rich that Jobs and others use when they're faced with the realization they are unable to directly pay for their desired treatment [5]. More recent studies have shown that patients with the ability to have multiple registrations may be more likely to receive a transplant[4].

3 Model

The model designed to emulate this system consists of agents or patients that are in need of an organ transplant. These patients are added to a waiting list in their primary location, which is determined stochastically. If patients are "advantaged", they may also join additional waiting lists, which is also determined stochastically. The probabilities for which waiting list a patient joins can be uniformly distributed or specified in the model inputs.

The model begins with an initial number of patients on the waiting list. Every time step, patients at the top of each waiting list are selected to receive a transplant. Each waiting list has a different number of patients per year that are transplanted, this number can be assigned randomly or specified in the model inputs. Once a patient is selected for a transplant, they are removed from all waiting lists. Patients that have been waiting too long for a transplant without being selected, die and are removed from all waiting lists.

A brief graphical description of the waiting list structure and the advantage a patient may have is shown in Figure 2a. This listing of three regions shows the the patients waiting for an organ at each location. One of these patients, Patient I, is registered in both Region 2 and Region 3. If each waiting list transplants the first two patients.

Figure 2b shows the outcome if the first two patients on each waiting list were to receive a transplant. If each of these top two on each waiting list received a transplant, Patient I is selected in Region 3, much sooner than if they had only queued in Region 2. This patient is removed from the queue in Region 2, but received a transplant before Patient K, who was only waiting in one queue.

Region 1: [A, B, C, D]
Region 2: [E, F, G, H, I]
Region 3: [J, I, K]

(a)

Region 1: [A, B, C, D]
Region 2: [E, F, G, H, ~~I~~]
Region 3: [J, I, K]

(b)

Figure 2: (a) Visualization of the concept behind the model design for queues patients. Each region in the model has a separate waiting list for patients. (b) Description of the allocation of organs to the top registrations on each of the waiting lists.

The model tracks the number of patients waiting, selected, transplanted, and deceased. Overall for each list the model also tracks the total number of primary listing transplants, secondary listing transplants, deceased patients at the primary listing, and the number of primary listing patients that were transplanted elsewhere.

The model is further explained in the following subsections. The Overview, Design concepts, and Details (ODD) protocol will be used in a modified version to describe the model in full detail in this section [12].

3.1 Overview

3.1.1 Purpose

The purpose of this model is to explore the outcomes when certain patients have advantages in access to healthcare. In this example, patients with additional resources or other indeterminate benefits over other agents, such as geographic location, are able to register in multiple regions for an organ transplant. The concept of multiple listings is unique to the United States due to the geographical expanse of the country and the large size of the national waiting list.

The model is meant to explore how allowing multiple listings may affect the system to gain a better understanding of this practice. The model was designed to represent how the transplant waiting list in the United States functions in regards to multiple registrations for a donor organ.

3.1.2 Entities, state variables, and scales

The model contains one type of entitity, patients on the waiting list for an organ transplant. Patients are characterized by a variety of attributes with the goal of representing candidates for organ transplantation with the minimal amount of detail.

A patient's main feature is their current state. Patients are either waiting, selected, transplanted, or deceased. The cycle which patients traverse through these phases is described in Figure 3. When patients are first added to the model they are in the Waiting stage. Patients that reach the top of one of the waiting lists are marked as Selected for a transplant and are removed from all lists. Selected patients receive a Transplant at their time step. If a patient is not selected, and has been waiting for too long, they transition into the Deceased state.

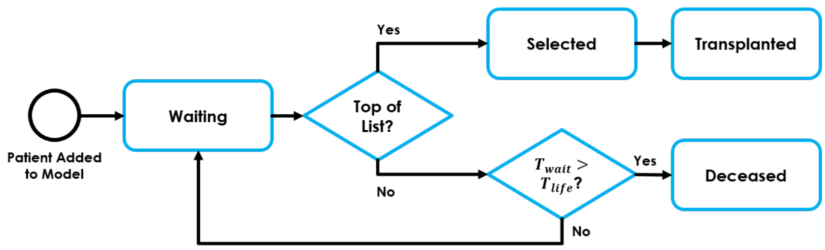

Figure 3: Overview of the states of a patient in the model.

Patients also have several other descriptive attributes to track their status in the model in addition to their overall state. Patients in the model have a unique identifier, a lifespan, a counter for their time on the waiting list, a list of regions where they are registered, and a primary location of registration. The unique identifier corresponds to the order they were added to the model.

Every patient is initialized with a predetermined lifespan which is a randomly generated number uniformly distributed between zero and an upper bound determined by the model. As every time step passes, the patient's waiting time is incremented by one. Once a patient's waiting time reaches their lifespan, the patient state changes to Deceased. The patient's regions of registration are also given when the patient is initialized, this is a list of one or more waiting lists that the agent has registered in. Advantaged patients will have multiple regions listed, these patients are marked as having the "advantaged" property in the model. The first of these regions will be the patient's primary region. This corresponds to a candidate's home listing location in the main version of the model.

The other feature of this model is the waiting list queues. These queues are represented a lists of lists. Each queue contains patients ordered in the ranking that they joined the waiting list. Each queue in the waiting list has a corresponding rate of patient transplantation. These values can be specified when creating the model. Every queue also has a probability that a patient will initially join the region's queue. This allows the model to distribute agents in a way that can resemble a certain geographic distribution of donor service areas or similar queues in a realistic environment.

There are no spatial resolutions within the model. It is assumed that patients are restricted to their waiting list region unless they are advantaged. The only temporal resolution within the model is to the time step which can be considered to represent a month.

3.1.3 Process overview and scheduling

At every time step of the model, two major actions are taken: the model step updates and runs followed by the patient's step function. This simple process is outlined in the pseudocode below:

```
#### Model Step ####
collect data
for queue in queues:
    select agents for transplant
    update seleted agents: state = "Selected"
add new patients to queues

#### Patient Step ####
for patient in all_patients:
    time_waiting = time_waiting + 1
    if patient is "Selected":
     state = "Transplanted"
    else patient is "Waiting" AND time_waiting >= patient_lifespan:
        state = "Deceased"
```

First, the model step submodel is activated. In general, does several major steps which are described in furthe detail in the Submodels section. First, data is collected for the next step in the model, updating the overall counter variables and data frames. Then, this method selects the agents that will be transplanted. According to the transplant rates for each of the region queues, the first patients up to the rate that are not already transplanted or deceased will be selected for transplant. Patients that have been selected experinece a change in state to "Selected".

Once the patients to be transplanted have been selected, new patients are added to the list according to the corresponding submodel. These patients are distributed among waiting lists accoring to the same initial parameters, using the queue distribution probabilities and the advantage probabilities. Then, the time step is incremented by one. If there are no longer any patients on the waiting list or if the number of time steps exceeds 120, the model completes.

After the model step has completed, the patietns each individually perform their own step function. First, the agents all age by one, incrementing their time waiting attribute. If a patient has been selected for transplantation by the model step, the patient's state is now changed from "Selected" to "Transplanted". Otherwise, if the patient is still in the "Waiting" state and their time waiting is greater than or equal to their lifespan, their state is updated to "Deceased.

Time is modeled as discrete steps, each time step can be thought of as roughly representing one month in time. The variables used in testing and experimenting with this model roughtly correspond to running the model over a 120 time step period, or ten years.

3.2 Design concepts

3.2.1 Basic principles

This model follows several basic general concepts and theories related to the real-world allocation of organs in the United States. The model follows the concept that the country is split into multiple Donor Service Areas. Generally (there are many exceptions that apply to small groups), these organs are first allocated within the Donor Service Area (DSA). This is why the Waiting List model makes use of multiple queues that can each be used to represent a DSA in the model universe. Along with the implementation of multiple queues, patients also have the ability to join multiple queues, if they are "advantaged". A patient may joing multiple listings in the model as they are in the Untited States according to current policies and practices.

These queues are represented at a fairly simple level of complexity. The model does not account for specific rules in the transplant system that give preference to certain individuals such as healthier adults or pediatric patients, who receive additional waiting list credit in the United States. The model also does not account for matching patients or for any sort of matching quality. Adding matching metrics to the model would greatly increase the complexity of the model design and implementation. This complexity would account for restrictions such as blood type matching or high-compatability matches. For the purpose of this particular study, determining the outcomes and affects of multiple listings in the system, matching metrics were not crucial to the model design.

The model does account for a certain level of complexity in regards to the queues. Each queue may have it's own transplantation rate, which is the number of patients tranplanted at each time step. Queues may also be programmed with their own Waiting list additions probability. This is the likelihood that a new agent will be added to the queue. This functionality allows the model to explore areas corresponding to specific Donor Service Areas or other queueing scenarios.

The goal of designing this model is to provide insights to these basic principles and to gain a greater understanding on how allowing multiple listings affects the overal transplant system and the outcomes of the system. The model should provide some insights and give evidence to some of the ethical concerns surrounding multiple listings.

3.2.2 Emergence

The model was designed to study the overall state and outcomes of the transplant system when patients waiting for a donor organ are allowed to register multiple times andor outside of their home Donor Service Area. Depending on the occuranes of advantaged candidates as well as the propertities of the queues, the results effects of multiple registrations is expected to vary. If all waiting list queues are of a similar design, the effects are expected to be minimal. When large differences exist in the transplantation rate and the size of the queue, the affects of mutliple registrations are expeted to be larger. This includes the waiting effetions on local populations as well as the rate of patient deaths at a local level.

Other results that would be more strictly designed by the model regulations would be the number of primary location transplants compared to alternate location transplants in the model. It is expected that the number of alternate location transplants will rise as the number of advantaged patients rises but the extent that this will take place is not deterministic.

3.2.3 Adaptation

Individuals do not inherently have adaptive traits in the model. Patients are assigned to a primary waiting list queue based on the intiial region probabilities provided at the initalization. Patients that are "advantaged" are allowed to register for multiple queues, appending themselves to the model. If the model is in Smart listing mode, the patients select their alternate ques based on which queue has the highest transplant to queue length rate. Putting themselves in the queue that seems most advantageoue. If the model is not in smart listing mode, agents choose their secondary listing stochasticaly from a uniform distirbution of the remaining options outside of their primary listing location.

3.2.4 Objectives

In the model a patient's goal is to receive a transplant, an individual is successful if they recieve a transplant from any location before reaching the end of their projected lifespan. If the model is in Smart Listing mode, individuals may give preference to transplant centers with the highest transplantaiton to waiting list size rates. Otherwise, individuals do not use any criteria to make decisions since the locations are determined stochastically.

Patients in the model want to actieve what they're able to at the most basic level, which is registering with their local, primary waiting list. Agents with an advantage are allowed to choose alternate registration locations which allows them to optimize their outcomes by selecting alternate regions with high rates of transplantation compared the the size of the waiting list. An Agent's reward is receiving an organ transplant.

3.2.5 Learning

In this model agents do not currently have the ability to change their adaptive traits over time. Agents remain on the same waiting lists that they initially chose until they receive a transplant or become die.

3.2.6 Prediction

Patients in the waiting list model have a slight capability to predict which alternate listing will have the best outcome. If the model is run in smart listing mode, the agent can use the knowledge of waiting list queue size and the transplant rates to make their decision regarding the location they should choose for registration.

No internal models are used to estimate the future conditions. Hidden predictions are only included in the ability of the model to add additional patients each year.

3.2.7 Sensing

In Smart Listing mode, patients use knowledge of the current waiting list queue size and transplantation rates to weigh in on their decision for which additional centers to register. These factors heavily influence the decisions the agent makes when deciding on additional listing. Agents can perceive the length of waiting list queues and transplantation rates. In the real world, all of this information is publically available and it is safe to addume that an advantaged patient would have access to adn investigate these additional opportunities. In the case of this model, individuals that are advantaged and searching for additional registration regions, the agents are assumed to know these variables.

3.2.8 Interaction

Direct interactions do not take place in the model. Agents interact with one another through sensing the best waiting queues to join in the Smart Listing mode and gauging the likelihood of receiving a transplant on that waiting list. Another form of indirect interaction takes place when the queue is determining which of the top agents will be transplanted. Patients will become deceased before reaching the top of the list, these patients are skipped over and removed form the list when the reach the top, allowing for patients further down to receive the organ. If there are advantaged patients present in the model, patients may be transplanted on another queue. If a patient is transplanted in a different region, corresponding to another waiting list queue, this patient is removed from the waiting list and the next patient in line may then be eligible for the transplant.

3.2.9 Stochasticity

Nearly all of the proceses besides the selection of agents for transplantation are controled by stochastic processes. The patient designation for the primary listing queue is randomly chosen by either uniform probabilities or by designated probabilities if the model design includes them in the specification. The patient's alternate waiting lists are also determined stochastically in a uniform method by default or using a ranking system to determine the patient's best options if the model is in Smart Listing mode.

For the initial patinets added to the model, the amount of time they have spend waiting for a trainsplant is stochastically determined using current waiting list properties and probabilities. More inforation on these initial values is provided in the Inputs section. The range of a patient's initial waiting time is determined using the probabilities available from the UNOS data, then the waiting time is assigned using a uniform distribution of integers to the patient within their given range.

Whether or not a patient has an advantage in the model and can register for multiple waiting lists is randomly determined based on the probability of having an advantage. A patient's lifespan is also chosen from a uniform distribution ranging from 0 to a maximum number of years a patient can spend waiting.

The final implementation of stochasticty in the model is in the ordering of the waiting list queues. Processing the queues in the same order every time to determine which patients receive a transplant would cause issues when patients have multiple listings. Patients registered on multiple lists would always receive a transplant from the first list in the order. Shuffling the order of the queue processing for transplant selection allows this to normalize and remove advantages over time.

3.2.10 Collectives

Agents in the model that are waiting for a transplant are a part of one or more waiting list queues. These collectives are represented as a list of lists, where each sublist represents a region's local waiting list queue. This collective is defined by the model as the structure in which waiting to receive an organ transplant occurs. Patients in the model are agent objects and are represented in at lease one of the queues at all time while waiting for an organ transplant. Once an agent has been selected for transplantation, received a transplant, or died, the patient is removed from the queue.

3.2.11 Observation

Python's Mesa module allows the model to use the DataCollector to track patient states in the model over timečitemesa. Tracking these statistics allows for simple and quick visualizations of the process and aggregate values of the model over time. The statistics managed by the DataCollector are specified to be recorded at the start of each model time step.

In addition to the DataCollector of patient states, the model also tracks several important lists that track the number of agents in each of the queues meeting certain criteria. These lists store the values for each of the lists and they are recorded and printed out when the model is finished. These output variables are also computed using various functions that return the cumulative values at the end of the model. These statistics only record data for the primary listed, or local, patients in their region, with the exception of the count of alternate patients listed. These lists include:

- Patients transplanted that were a primary listing in the queue
- Patients transplanted that were an alternate listing in the queue

- Patients with a primary listing in the queue that receieved a transplant elsewhere
- Patients with a primary listing that died before receiving a transplant
- Patients with a primary listing
- Patients listed as alternate

These output statistics are extremely useful when running the model in batch mode to get an overview of the model outcomes across varying parameters.

3.3 Details

3.3.1 Initialization

The initial state of the model is defined in the initalization method of the Waiting List model. The model takes in multiple input parameters, most of which are optional. The number of regions, number of initial patients, and number of additional patients to be added each year are the first three parameters that need to be defined. These mandatory items are followed by optional fields.

```
def __init__(self, regions, initial_patients, additional_patients,
             transplant_rates=[8, 5, 2, 2],
             queue_probabilities=[.5, .3, .15, .05],
             advantage_prob=0.05, output=True, max_lifespan=96,
             smart_listing=True):
    ...
```

The transplant rates for each center can be specified in a list corresponding to the number of transplants that should occur at each time step. The queue probabilities may also be specified to determine the allocation of new patients to each primary listing area. The advantage probability specifies the number of patients that have an advantage and may be listed at multiple centers. The maximum lifespan is set to 96, corresponding to roughtly 8 years on the waiting list. Additionally, there are two flags for the model. The output flag determines if text output will be given then the model is run, making the model cleaner to run in batch mode and more descriptive for standard runs. The final flag is for Smart Listing mode. This feature allosw the patient to look at the available alternate listing queues available and to determine which one has the best potential outcomes for the patinet based on patient transplant rates and the overall size of the waiting list.

3.3.2 Input data

These variables and initial parameters are derermined based loosely on data from the OPTN Website [1]. The initial parameters are meant to be varied and modified with educated assumptions to explore the model. All of these parameters are meant to be adjusted to explore the model further. For example, the model can be run with the following initial parameters to emulate the corresponding waitng lists, shown in Table 1.

Table 1: Initial parameters to be used in the model statistically representative of four Donor Service Areas.

Parameter	Value	Description and Motivation
regions	4	Chose four areas to represent the DSAs
initial_patients	1600	Size of the current waiting list for the four selected areas.
additional_patients	4500/12 = 375	Transplant additions minus the living donor ones (based on number of additions)
transplant_rates	[61, 37, 19, 26]	Determined by the Deceased Donor Transplant Rates per month in the chosen four DSAs
queue_probabilities	[0.42, 0.26, 0.11, 0.21]	Determined by the Deceased Donor Transplant Rates per month in the chosen four DSAs
advantage_prob	0.05	Probability that a candidate will be able to list multiple times
output	True	Turn on the output statistics printing
max_lifespan	96	Corresponds to a maximum waiting time of 8 years
smart_listing	True	Determines whether the patent will intelligently determine where to make their alternate listings.

The initail parameters given in Table 1 are based on aggregate information from data reports on the OPTN website [1] for the following DSAs:

- CAOP-OP1 OneLegacy
- ILIP-OP1 Gift of Hope
- INOP-OP1 Indiana Donor Network
- MNOP-OP1 LifeSource Upper Midwest OPO

Input data is also used to generate the waiting times for the initial patients on the waiting list. At the start of the model many patients, realistically will have already been waiting for some time. The probabilities displayed in Table 2 shows the probabilities that are used to assign waiting times to these initial patients.

3.3.3 Submodels

The model contains several submodels that represent the processes covered in the Process Overview and Scheduling section. The first of these submodels is the Patient Step submodel. At each time step, the patient move one step forward in time. First, the patient's waiting time increments by one. Next, if the patient is in the Selected stage, the patient transitions to the Transplanted Stage. If a patient is still in the Waiting stage, and they have been waiting for

Table 2: Number of patients currently on the waiting list by time spend waiting for a transplant. This is data specific to kidney transplant patients. Data was generated using the advanced reporting tools on the OPTN website [1]

Months	**[0,1)**	**[1,3)**	**[3,6)**	**[6,12)**
Candidates	3,912	7,815	9,897	17,037
% Candidates	3.1%	6.1%	7.7%	13.3%
Months	**[12,24)**	**[24, 36)**	**[36, 60)**	**[60, Inf)**
Candidates	27,153	20,471	23,217	18,405
% Candidates	21.2%	16.0%	18.2%	14.4%

longer than their expected lifespan, the patient will move to the Deceased stage.

The next submodel in the design is the overall model step function. This is run at the start of every time step, before the patient's step. Every time the step function is run it completed a variety of actions relating to the overall model, particularly in regards to adding new agents to the simulaiton and selecting candidates for transplantation.

First, this submodel schedules the next step for the model to take, following the agent's next steps in the simulation. Then, the data collection process takes place. Next the agents that will receive a transplant are selected by the submodel. First the order of the waiting list queues needs to be randomly shuffled. This ensures that certain waiting lists won't always be transplanted before others. This is especially important for multiple listings, once a patient is selected on one list they are skipped over for a transplant in another region. Therefore whichever region selects patients first will be transplanting multiple wait-listed patients more frequently than any other list. More detail is given on this shuffling in the Stochasticity section.

For each of the queues, the model selects the first patients in the list up to the region's particular transplant rate, $N_{transplant}$. Patients that are not eligible for a transplant, such as already selected patients, already transplanted, patients, or patients that have died while waiting are passed over and removed from the queue. The fist $N_{transplant}$ patients for the queue transition to the "Selected" stage.

Once the patient selections are completed for all queues, then new patients are added to the waiting list. These patients correspond to the input value given in the model initalization. The counter for the time steps is incremented. Finally, if there are no longer any patients in the "Waiting Stage" or if the number of time steps has exceeded 120, corresponding to ten years, the model finishes.

The final submodel in the model is the function to add new candidates to the model. This is run when the model is initialized for the initial number of patients and again during the model's step submodel. The number of candidates is taken as an input value to the submodel. Each patient is first added to a selected primary region's waiting list. This region is selected based on the queue probabilities specified as an input the the model. Once a patient is added to a primary region, it is stochastically determined if they will be listed at more than one queue based on the model probability parameter for patient advantage. If the patient is selected as being advantaged, they are randomly added to a random number of additional queues, uniformly distributed in the range $[1, N_{regions}/2]$. An advantaged patient has the ability to have an additional registration at anywhere from 2 regions to half of all regions.

Then, the patient is assigned and based on the order they are generated a given a lifespan, corresponding to a random normal distribution based on the average lifespan of a kidney transplant-eligible patient on dialysis [13]. The patient is creates using the Patient Class and the new patients are added to the model's schedule. Finally, the patients are added to the end of their assigned waiting queues.

These submodels were all tested initially with small data sets of 20 or fewer agents to verfiy that the agents were being properly assigned reasonable characteristics for the model. These small test sets were also used to validate that the implementations were properly working and agents were moving through stages in the correct order. In addition to small group testings, the model was run for larger, realistic values as described in the Inputs section. These results were visually analyzed to confirm the patterns were similar to that seen in the real world and that the overall aggregations were in overall agreement with the generally expected values from the data available on the OPTN website. Several overall statistics remained true for the model agreeing with popular opinion on the subject. Allowing for multiple registrations does not necessairly allow for more transplants to take place, but it does change who receives those transplants. Death rates and waiting list sizes remained consistent for varying parameters of the model as is expected and recorded in the real world based on UNOS data [1].

3.4 Model Implementation

This model was designed using the programming language, Python Version 2.7. The Mesa package for Agent-Based Modeling was incorporated into the model to assist with scheduling the agents in the model and to assist with visualization [8]. Jupyter was also used to develop the model in an interactive manner, compatible with web browsers. This method enabled the ability to make quick changes to the model [9].

These tools were chosen for several reasons over alternatives such as NetLogo, MASON, or a standard Python implementation. Like NetLogo, Python is an ideal scripting language for prototyping models [11]. MASON is Java-based, making them a more intensive and time-consuming to program in than Python [10]. The advantage to the chosen method over NetLogo, and MASON is the ability to easily navigate and implements waiting queues. Python has an easy-to-manipulate list functionality that can provide representation of the multiple Donor Service Area Waiting Lists. There is no agent movement that needs to be watched during the model, therefore built-in GUI capabilities are unnecessary.

Mesa allows for easy scheduling of actions that will take place at every time step. Mesa also has built-in data collection tools that allow the developer to track the states of agents in the model over the course of the simulation [8]. These two capabilities are the most important features of agent-based modeling tools that are needed to create this model.

Jupyter notebooks allow the developer to create easily accessible and fluid code in an interactive Markdown format [9]. The Jupyter notebooks are run in the web browser with a python back-end where code, documentation, and visualizations can all be viewed in one location. In developing this model, the ability to edit the code and immediately check the results and spawn visualizations representing the model was critical to easy development as well as verifying and validating the model.

4 Model Experimentation

systematic experimentation with the model

5 Results

presentation of model results, and

6 Conclusions

what was achieved with it

References

[1] The Organ Procurement and Transplantation Network, "OPTN Website," 2015. [Online]. Available: http://optn.transplant.hrsa.gov/. [Accessed 04-October-2015].

[2] The Organ Procurement and Transplantation Network, "OPTN Policies," 2015. [Online]. Available: http://optn.transplant.hrsa.gov/media/1200/optn_policies.pdf#nameddest=Policy_08. [Accessed 04-October-2015].

[3] The United Network for Organ Sharing, "Questions & Answers for Transplant Candidates about Multiple Listing and Waiting Time Transfer", 2015. [Online]. Available: https://www.unos.org/wp-content/uploads/unos/Multiple_Listing.pdf. [Accessed 04-October-2015].

[4] American Heart Association, "Wealthiest – not sickest – patients may have edge in organ transplants", 2015. [Online]. Available: http://blog.heart.org/wealthiest-not-sickest-patients-may-have-edge-in-organ-transplants/. [Accessed 12-November-2015].

[5] Cox, Lauren, "Steve Jobs' Reported Liver Transplant Stirs Debate", 2009. [Online]. Available: http://abcnews.go.com/Health/Economy/story?id=7902416. [Accessed 04-October-2015].

[6] Health Resources & Services Administration, "Organ Procurement Organizations", 2015. [Online]. Available: http://organdonor.gov/materialsresources/materialsopolist.html. [Accessed 14-November-2015].

[7] A. E. Davis, S. Mehrotra, L. M. McElroy, J. J. Friedewald, A. I. Skaro, B. Lapin, R. Kang, J. L. Holl, M. M. Abecassis, and D. P. Ladner, "The extent and predictors of waiting time geographic disparity in kidney transplantation in the United States.," Transplantation, vol. 97, no. 10, pp. 1049–1057, May 2014.

[8] Project Mesa Team, "Mesa: Agent-based modeling in Python 3+," 2015. [Online]. Available: https://github.com/projectmesa/mesa/. [Accessed: 02-Dec-2015].

[9] Project Jupyter, "Jupyter Notebooks," 2015. [Online]. Available: http://jupyter.org. [Accessed: 04-Dec-2015].

[10] S. Luke, C. Cioffi-Revilla, L. Panait, K. Sullivan, and G. Balan, "MASON: A Multiagent Simulation Environment," Simulation, vol. 81, no. 7, pp. 517–527, 2005.

[11] U. Wilensky, "NetLogo," 1999. [Online]. Available: http://ccl.northwestern.edu/netlogo/. [Accessed: 02-Dec-2015].

[12] V. Grimm, U. Berger, D. L. DeAngelis, J. G. Polhill, J. Giske, and S. F. Railsback, "The ODD protocol: A review and first update," Ecol. Modell., vol. 221, no. 23, pp. 2760–2768, 2010.

[13] Saran R, Li Y, Robinson B, et al. US Renal Data System 2013 annual data report: epid. of kidney disease in the US. Am J Kidney Dis. 2015;66(1)(suppl 1):S1-S306.