Model Description

'Blood Donation Analysis.py' is a Python file using the Mesa agent-based modeling module. Unedited, it generates 200,000 agents who can interact over 365 time-steps simulating a full year. Agents have 12 attributes to determine how they interact in the model (See Table 1).

Attribute	Description
MSM	A Boolean determining whether agent is an MSM
HIV	A Boolean determining whether agent has HIV
Blood	String defining agent's blood type
Clueless	A Boolean determining if HIV-infected agent has been diagnosed
DaysSinceInfection	Integer representing the number of time steps (days) since initially infected with HIV
RBCBank, PlateletBank, PlasmaBank	Float indicating the volume of unexpired red blood cells, platelets, and plasma agent has donated, respectively
DonationDay	A list of the timesteps (days) at which the agent will donate blood or blood products
RBCTime, PlateletTime	Number of time steps since the agent donated red blood cells or platelets, respectively
FalsePositive	A Boolean determining if the agent was diagnosed with HIV despite being uninfected

Table 1: Agent attributes and their descriptions.

Monte-carlo methods are used to determine the values of the agents' attributes in order to match the observed HIV prevalence rate among MSM and non-MSM, observed proportion of blood types, observed proportion of HIV sufferers who are undiagnosed, and the observed rate of blood donation. To simulate the interactions of agents that donate blood with those that require blood transfusions, the ABM's agents are designed to donate blood and require transfusions at the rate described in the 2013 AABB Blood Collection, Utilization, and Patient Blood Management Survey.

Donor agents can use one of three types of blood donation and there are three types of blood components that are transfused for different purposes[1]. The three blood components are:

1. Red Blood Cells (RBC): This is the most commonly transfused blood component. It is either separated from whole blood for use or directly collected through a "Power Red" donation.
2. Plasma & Cryoprecipitate: Mainly used to deliver clotting factors to patients with a risk for uncontrollable bleeding. Collection involves separation from whole blood.
3. Platelets: Used to mitigate the risk of uncontrollable bleeding. Can be separated from whole blood or through a plateletpheresis donation.

[1] Joint United Kingdom (UK) Blood Transfusion and Tissue Transplantation Services Professional Advisory Committee. Blood Components. https://www.transfusionguidelines.org/transfusion-handbook/3-providing-safe-blood/3-3-blood-products

And the three types of blood donations are:

1. Whole Blood (WB) Donation - Blood is collected directly from a donor
2. Power Red Donation – Only RBC are collected from a donor
3. Plateletpheresis - Only platelets are collected from a donor

Each of these types of blood donations yield a different set of blood products. The volume of blood products is quantified in "units", where each unit of RBC and Plasma is 300 mL and one unit of platelets contains $3 \, x \, 10^{11}$ platelet cells[2,3]. The volume of blood components collected by each donation type is illustrated in Table 2.

Donation Type	RBC Collected (units)	Plasma Collected (units)	Platelets Collected (units)
WB	1	1	0.2
Power Red	2	-	-
Plateletpheresis	-	-	1.8

Table 2: Volume of blood components collected for each donation type.[4]

For additional complexity, a donor's blood type must be ABO compatible with the blood type of a potential recipient of that blood for RBC and plasma transfusions[5]. Platelet transfusions do not require ABO compatibility, and any donor's platelets can be transfused into any other agent. Table 3 illustrates ABO compatibility given a transfusion recipient's blood type. Agents are designed such that the proportion of each blood type matches the general U.S. population[6].

Recipient Blood Type	Accepted Donor Blood Type (RBC)	Accepted Donor Blood Type (Plasma)
O+	O-, O+	O-, O+, A+, A-, B+, B-, AB+, AB-
O-	O-	O-, A-, B-, AB-
A+	O-, O+, A+, A-	AB+, AB-, A+, A-
A-	O-, A-	AB-, A-
B+	O-, O+, B+, B-	AB+, AB-, B+, B-
B-	O-, B-	AB-, B-
AB+	O-, O+, A+, A-, B+, B-, AB+, AB-	AB+, AB-
AB-	O-, A-, B-, AB-	AB-

Table 3:The blood types of transfused blood products that can be accepted by a recipient based on their blood type[7]. ABO compatibility is dependent on the blood product being transfused.

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[2] American Association of Blood Banks. *The 2013 AABB Blood Collection, Utilization, and Patient Blood Management Survey Report*. 2013. Page 15.
[3] Elzik, ME. Correlation of Transfusion Volume to Change in Hematocrit. February 2006.
[4] American Association of Blood Banks. *The 2013 AABB Blood Collection, Utilization, and Patient Blood Management Survey Report*. 2013. Page 15.
[5] UTMB Health. Blood Component ABO Compatibility Chart https://www.utmb.edu/bloodbank/blood-bank-transfusion-services/component-therapy/blood-component-abo-compatibility-chart
[6] Penn Medicine. Blood Type Frequency. http://www.lancastergeneralhealth.org/LGH/Our-Services/Blood-Bank/About-Us/Blood-Type-Frequency.aspx
[7] Australian Red Cross. Matching Blood Groups. https://mytransfusion.com.au/about-blood/matching-blood-groups

Roughly 2.1% of the population presented to donate blood or blood components in 2013.[8] With 38% of the population being eligible to donate, this implies that only 5.7% of eligible potential donors presented themselves to donate, and this ratio of actual donors to eligible donors is assumed to be true in the ABM.

Since there is a lack of data regarding the frequency of blood donation, the number of blood donations a donor makes each year is assumed to be represented by sampling a negative binomial distribution. Most of the time, it would be good practice to assume a pareto distribution for a topic like this since it's expected that a small minority of people will make most of the donations in accordance with the Mathew principle. However, as will be discussed later, there is a minimum time between donations of 56 days, which limits the number of blood donations per year per agent to six[9]. A negative binomial distribution will still allow some donors to make many more donations than average, but still be constrained by the six donations per year per agent limit. The expectation value of this distribution is the ratio of total donations and total donors from the 2013 AABB Blood Survey and is approximately 2.27 $\frac{Donations}{Donor}$. Similarly, 32% of donors in 2013 were first time donors, implying that the mode of the distribution is low; either one or two donations per year[10,11]. We assume a mode of the distribution to be one, though the results are robust, and the ABM concludes similar results whether a mode of one or two is chosen. From these assumptions, the parameters of the negative binomial distribution are calculated as $r = 4,\ p = 0.7592$, and is shifted one coordinate to the right.

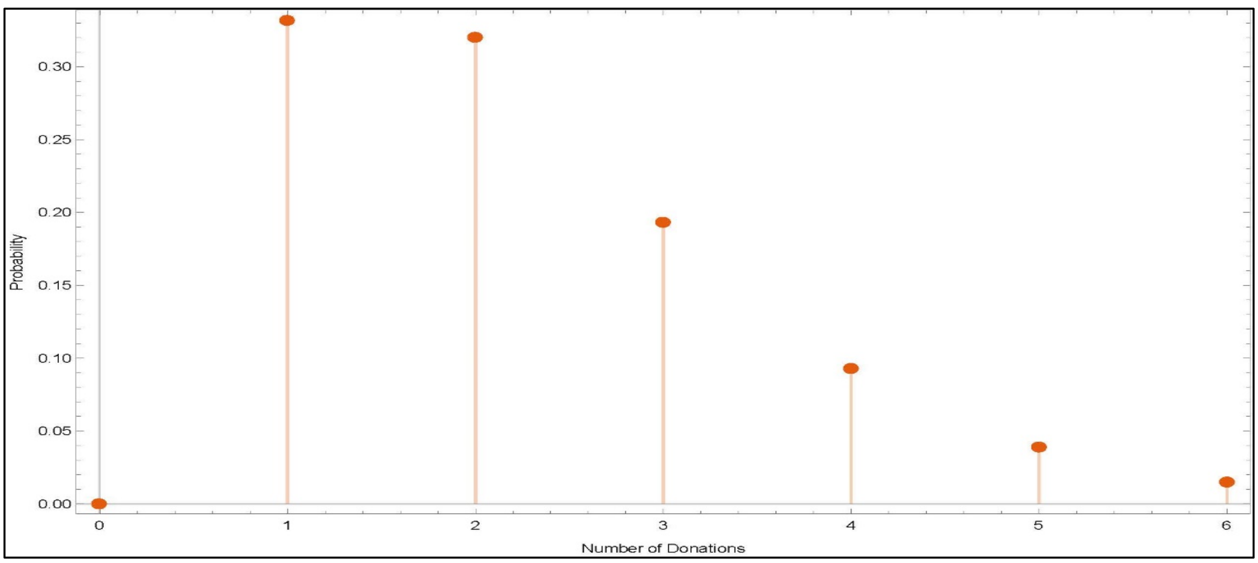

Figure 1: The probability distribution that determines the number of donations a donor makes in the ABM

The time of year is also an important consideration since the number of donations made is dependent upon the season. More people present to donate blood in the summer and late fall than at other times of year, and so the probability of donating on a given day of the year is proportional to the supply of blood for that day. A 5-th order polynomial fit is made of the function 'O positive 2013' in Figure 2 and is normalized so that the area underlying the

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[8] American Association of Blood Banks. *The 2013 AABB Blood Collection, Utilization, and Patient Blood Management Survey Report*. 2013. Page 43.
[9] American Association of Blood Banks. *The 2013 AABB Blood Collection, Utilization, and Patient Blood Management Survey Report*. 2013.
[10] Ibid. Page 43.
[11] Leila Kasraian. Relationship between first-year blood donation, return rate for subsequent donation and demographic characteristics. 2012.

curve equals one. The R^2 of this fit is .9413, indicating that it is very close to capturing all the variation of the 'O Positive 2013' curve. This normalized function is then used as the probability distribution to determine when agents will donate.

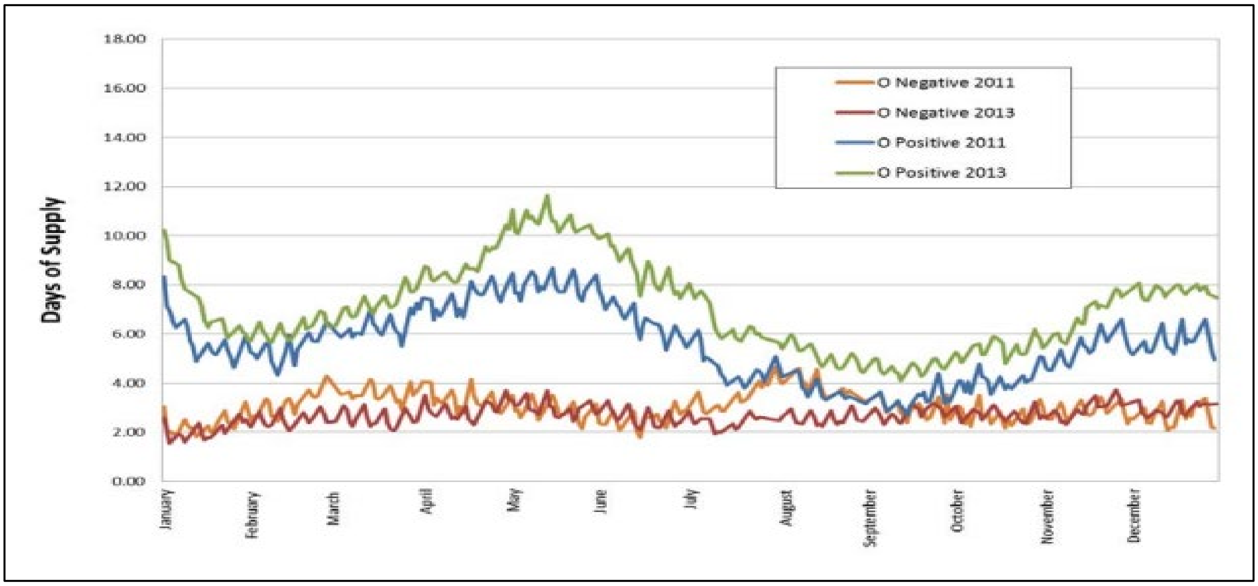

Figure 2: Observed days of group O blood supply 2011-2013.[12]

There is a legally mandated minimum amount of time between donations, and so an agent may only donate once every 56 days.[13] If sampling the probability function for the days an agent will donate yields more than one donation in a 56-day period, the probability distribution is sampled again.

Blood products decay and are unusable after some period of time. Platelets expire and are no longer usable 5 days after donation, red blood cells expire 42 days after donation, and plasma expires one year after donation[14]. The days elapsed since an agents last donation are measured, and their blood products are removed from the model if not transfused within their expiration time. This means that there is an optimum transfusion strategy that is taken by the model to minimize the number of expired components, which involves transfusing the oldest, non-expired blood component from most abundant ABO-compatible blood type.

The relationship between MSM and HIV incidence is estimated by the Centers for Disease Control here. The model initiates by matching the rate of HIV infection amongst its agents with the observed HIV infection rate in the United States. Additionally, MSM acquire HIV at a much higher rate than the general population.

[12] Ibid. Page 19.
[13] American Association of Blood Banks. *The 2013 AABB Blood Collection, Utilization, and Patient Blood Management Survey Report*. 2013.
[14] Ibid.

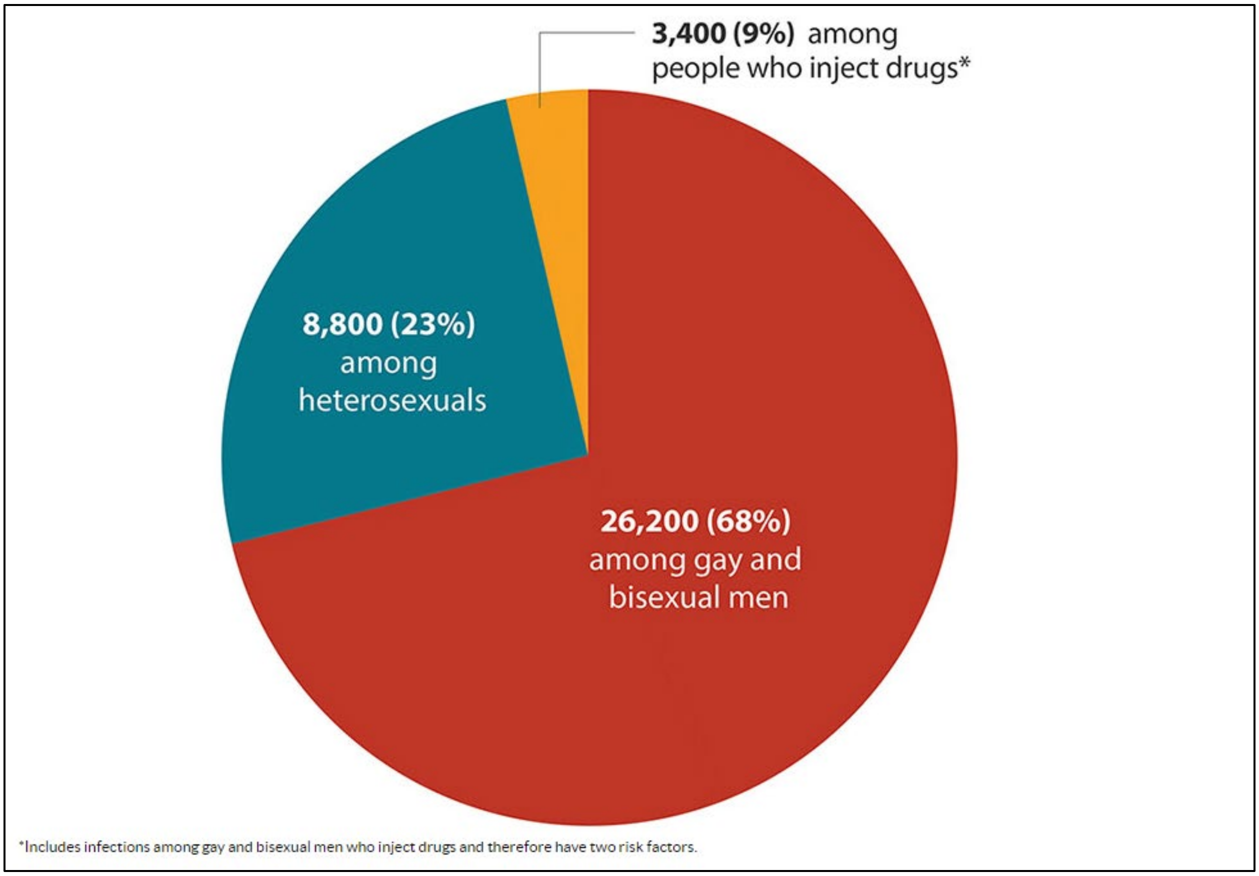

Figure 3: New HIV diagnoses per year as distributed between MSM and the Heterosexual population.[15]

From CDC estimates (Fig. 3), the probability that an MSM agent acquires HIV at a given time step is $\frac{HIV\ infections\ amongst\ MSM}{Total\ U.S.Population * Days\ of\ the\ year} = \frac{26{,}200}{315{,}000{,}000 * 365} \approx 2.28x10^{-5}\%$ and the probability for a non-MSM agent is $7.65x10^{-6}\%$. Everyone who acquires HIV, but did not start the model with HIV, is undiagnosed and the parameter Clueless = True.

Agents are initialized with HIV to match CDC estimates of HIV prevalence[16,17]. From this, the probability of being MSM ***and*** having HIV and not being MSM ***and*** have HIV is 0.1917% and 0.1509%. The conditional probability of having HIV given being MSM, **P(HIV|MSM)**, and having HIV given not being MSM, **P(HIV|~MSM)**, are dependent on the proportion of the population that is MSM. Estimates range from 2 – 5% of the population being MSM, and so the probability of being MSM, **P(MSM)**, is determined by sampling a uniform distribution between 0.02 and 0.05. By definition the HIV prevalence probabilities are $\boldsymbol{P(HIV|MSM) = \frac{P(HIV \cap MSM)}{P(MSM)}}$ and $\boldsymbol{P(HIV|{\sim}MSM) = \frac{P(HIV \cap {\sim}MSM)}{1-P(MSM)}}$**.**

Despite every blood donation undergoing an HIV test, HIV-infected donors have a chance of registering a false negative on an HIV test. The probability of a false negative test result as a function of time spent infected is given in figure 4.

[15] CDC. HIV in the United States at a Glance. https://www.cdc.gov/hiv/statistics/overview/ataglance.html
[16] CDC. Estimated HIV Incidence and Prevalence in the United States 2010–2015. 2016.
[17] CDC. HIV among Gay and Bisexual Men. 2017.

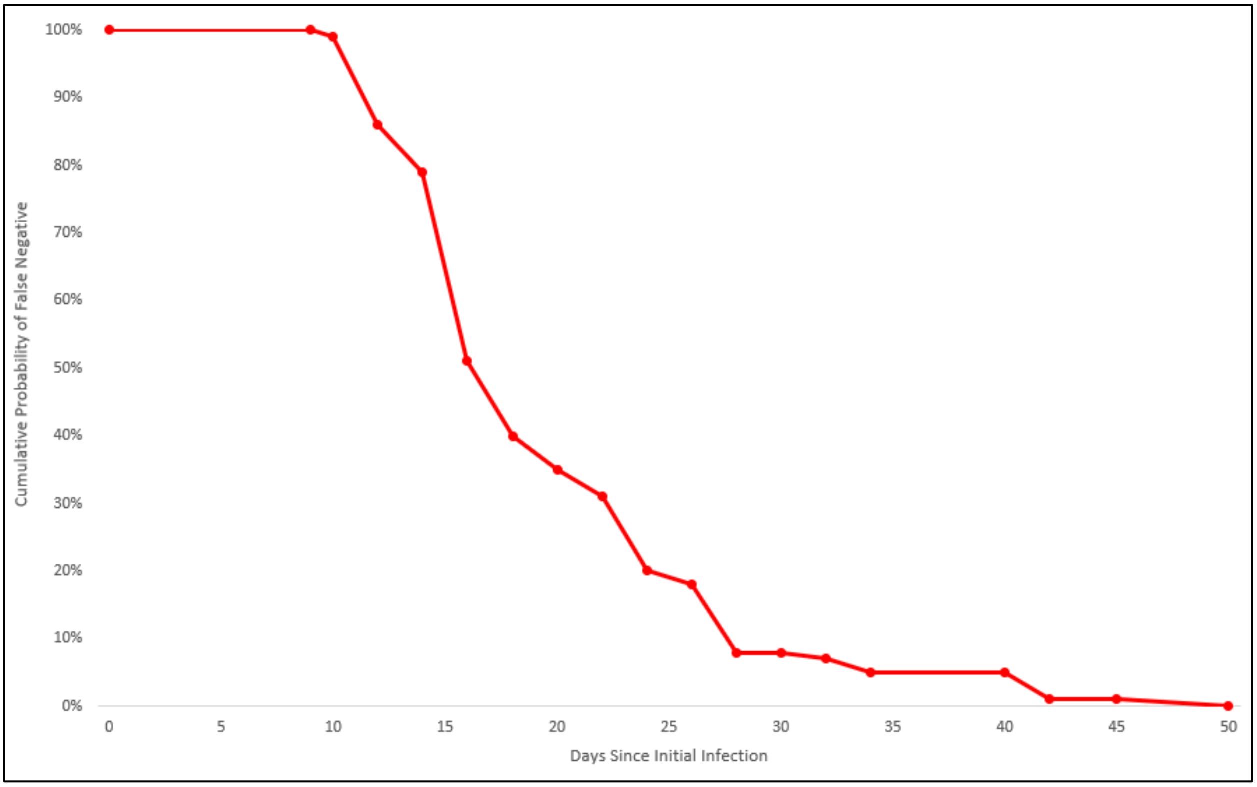

Figure 4: Probability of registering a false negative test result as a function of days since infection for a fourth generation HIV test.

After 50 days, this probability stays constant at around 0.01%. When an infected agent makes a donation, the probability that donation will make it into the general blood supply is given by figure 4.

Lastly, agents require transfusions of plasma, red blood cells, and platelets. The total number of blood components transfused is given in the 2013 AABB Blood Survey as 13.6 million units of RBC, 2.2 million units of platelets, and 1.8 million units of plasma. The quantity of RBC's transfused per person is 2.72, while the quantity of platelets and plasma provided per person in not provided. To account for this, the number of units of plasma and platelets transfused per person is determined by sampling a discrete uniform distribution from 1 to 4, given the high uncertainty in the estimate.

If an agent is transfused with HIV-infected blood, then there is a 90% of contracting the disease. At the model's conclusion, the number of HIV infections from transfusion is calculated.