2016 年美赛 F 题特等奖论文

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2016
MCM/ICM
Summary Sheet

(Your team's summary should be included as the first page of your electronic submission.)
Type a summary of your results on this page. Do not include the name of your school, advisor, or team members on this page.

Our team was tasked with modeling refugee immigration policies in light of the current European refugee crisis. We developed a metric to determine the capability of a country to host refugees by assessing economic and physical information about a country relative to other host countries, resulting in a proportion that translates to a number of refugees being hosted, or capacity.

We analyzed the flow of Syrian refugees to and through Europe using agent-based modeling. We studied resource distribution amongst certain countries when their capacities were designated using our metric, implemented system dynamics and considered several countries' attitudes towards hosting of refugees as well considered the inclusion of other, non-European countries as hosts for Syrian refugees. Our model also supports testing of sudden influxes of refugees, addition of other countries outside Europe, ideal compared to realistic support from certain countries, and the effects of contagious disease on the system. The model is also scalable, and can handle large numbers of refugees. Not only did our model reflect realistic and interesting results when different factors were considered, but it also provided information useful in policy planning. Using the agent-based model, we determined a fair distribution of resources and optimization of refugee flow that accepts over 93% of the total refugees over 91% of the time with 95% confidence.

We also developed a separate deterministic rate-based model that considers additional exogenous events and explored the effects of endogenous and exogenous events using system dynamics. This model incorporates stock and flow structure and feedback loops in a rate-based simulation. Using this system dynamic model, we studied the balance of endogenous setbacks with both negative and positive exogenous events, such as a negative anti-immigration bomb threat or a positive piece of viral media. These factors were considered and directly affected the rates of refugee entry into Europe, represented in a quantitative model of the effects of real-life qualitative conditions. We studied the delaying effects of an endogenous issue, such as an issue with Eurodac, the fingerprinting identification system used when processing asylum application, and found that positive exogenous events of certain magnitudes could counter these delaying effects. With certain quantitative values of positive exogenous factors, we were able to return the overall simulation to have 95% of 1 million refugees be accepted to Europe when an endogenous delay was continuously affecting the process.

By incorporating known numerical values about refugee movement into both stochastic agent-based modeling and rate-based deterministic modeling, we shed light on the most influential factors in refugee migration and developed a policy to fairly settle one million Syrian refugees in safe-haven countries.

Letter to the United Nations

Dear UN Representative,

We, the ICM-RUN (RefUgee-aNalytics) team, were tasked with helping the UN develop a better understanding of the factors involved with facilitating the movement of refugees from the countries of origin into safe-haven countries. Through the creation of a metric to determine countries' capacities to host refugees, and the programming and development of two mathematical models and their testing and analysis, we have created a plan which will allow for near optimal distribution of one million refugees throughout Europe.

In order to achieve our primary goal of facilitating refugee resettlement, we analyzed the abilities of countries within Europe as well as Turkey to handle the flow of incoming refugees. From our calculations we determined maximum capacities for different hosting countries, and found that the bulk of resources such as food, water, and immediate medical care will be most effective if prepositioned in Turkey, France, Germany, and Italy. Furthermore, refugee families should never have to be separated, and so we created flexibility in our capacity determinations that will allow family members to stay together.

According to our plan, dedicating small portions of the budget to causes other than providing resources for immediate needs will also be beneficial for the refugees. We recommend that projects designed to make escape routes for refugees safe and not life-threatening, such as Italy's Mare Nostrum plan, be re-implemented so that the daunting journeys refugees currently undertake will not be so dangerous.

An emergency fund should be dedicated to creating positive media attention that will counteract the potential effects of negative events (such as a terrorist attack) on public opinion. This could facilitate viral campaigns or promotional advertisement encouraging people to volunteer or otherwise assuring the European public that hosting refugees is not a dangerous risk. Increasing public awareness and sympathy for the refugee cause will increase the support for this plan, and will hopefully encourage the participation of other countries. Despite the distance of countries such as China and the US from Syria, the area of concern, the capacity of such countries to make the process more efficient is invaluable. Aside from acting as host countries, both own resources and have many potentially willing volunteers and supporters. While there is an increase in cost associated with transporting refugees to these two countries over a long distance, our model indicated that there would be a more than 12% decrease in cost of prepositioned resources if 10% of refugees were directed to be resettled between China and the US.

Not only does our plan seek to save millions of lives of refugees, it is also beneficial to the original inhabitants of hosting countries. Much of the burden that falls on safe-haven countries is caused by illegal immigration, which refugees have often resorted to when a country does not provide resources for their survival. Properly distributing resources and improving the registration process will mean that refugees will be able to more quickly integrate into society, precluding attempts to illegally cross borders.

We hope you will adopt our policy recommendations to maximize the safety and movement efficiency of the refugees fleeing from violence while being fair to hosting safe-haven countries.

Sincerely,
ICM-RUN

2016 ICM Problem F: Modeling Refugee Immigration Policies
"ICM-RUN to Safe Countries"

Introduction

“"To say 'yeah, you know we have refugees all over in Europe but they all want to go to Germany and therefore we are not concerned' is effective, but wrong. ***And therefore I think we need a fair and just distribution****."*

- Martin Schulz, European Parliament President, quoted from a BBC Article

"They will come -- the problem is how are you going to deal with the issue?... ***I mean, it's just like a mathematical formula, what's going on in Syria****.”*

- Orcun Ulusoy, University of Amsterdam, researcher of human rights and migrant-border relations, quoted from NPR

Recent conflict in the Middle East has caused an increase of migration to Europe. Refugees travel to Europe over multiple water routes, with a few routes experiencing heavy traffic, namely the West, Central, and Eastern Mediterranean [3]. Travel over these bodies of water and crossing international borders contains risk for refugees, but an estimated one million refugees entered Europe 2015 to escape violence or threat of death elsewhere [3]. In accommodating these refugees, European countries have established a quota system to deal with the over 715,000 asylum applicants; however, only a small percentage of requests are granted and many refugees that are legitimately fleeing life-threatening conflict situations are delayed in resettling to a safe haven country or denied asylum entirely. In the past, burdening of countries has varied in the quota systems used for small-scale distributions of refugees already present in European countries. Those who are burdened the most worry about their ability to host the high number of refugees assigned to them and wish for the movement and resettlement of refugees to be fairer.

Restatement of the Problem

The recent increase in Syrian refugees entering Europe involves many different factors and system components. Using known information about routes, asylum data, approximated data and other numerical information collected by the United Nations High Commissioner for Refugees (UNHCR) as well as other groups assisting refugees, model the flow of refugees to and through safe-haven countries. Additionally, explore the dynamics of your model and consider factors that affect refugee behavior, the cooperation response and abilities of countries, exogenous and endogenous events, scalability, as well as different complications and non-ideal aspects of the refugee situation. Based on this model and other relevant information, develop a policy in support of the refugee model outlining conditions that would ensure optimal migration pattern. The objective is to use mathematical modeling to create a policy plan that will provide for the resettlement of refugees and spread the burden as fairly as possible between hosting safe-haven countries.

Assumptions, Decisions, and Findings

1. **Our plan of action will deal with refugees as defined by the 1951 Geneva Convention**. Millions of people throughout the world are not classified as refugees, but are in dire need of humanitarian assistance. The UN refers to these people as People of Concern. Of the 10.8 million People of Concern who have been affected by the Syrian Civil War, only 4 million are classified as refugees; the other 6.8 million are internally displaced, meaning that they have had to leave their homes because of the threat of violence. However, because we are developing a plan for hosting countries to resettle and integrate refugees into society, we focused on dealing with the persons who fall under the term refugee based on internationally agreed upon definitions [1].
2. **Syrian refugees are the main population of concern.**
   In 2015, more refugees fled from Syria than any other country in the world. The Syrian Civil War has created a mass emigration crisis with more than twice as many asylum seekers heading to Europe from Syria compared to Afghanistan, the second country on the list. As a result of this drastic increase, the UNHCR has devoted special attention to the humanitarian needs of people of concern in Syria. With no visible resolution to the war in the near future, it is likely that the Syrian crisis will continue to dominate the refugee scene. For these reasons, our team decided that a plan focusing on Syrian refugees would be most useful to the UN in the next few years.[2]
3. **The plan we developed mainly concerns European countries and Turkey.** As of now, around 4 million Syrian refugees reside in neighboring countries in the Middle East, a number far greater than the population of refugees in Europe, which is estimated to be a little more than a million. These countries, which include Turkey, Lebanon, Iraq, and Egypt, have taken in far more refugees though they are not classified as "developed countries." As a result, the UN has enacted a regional plan through 2017 in order to assist these countries. On the other hand, the refugee situation in Greece is continuing to deteriorate and "could still bring down Europe" [3,4]. However, because of Turkey's close relationship to the EU and its role as the main path refugees take on the way to Europe, it plays a major role in our plan [5].
4. **Hungary and Greece will not accept additional refugees in a realistic scenario.** The combination of its recent economic collapse and the huge influx of refugees crossing the water from Turkey have virtually incapacitated Greece, and it is safe to assume that it will not be able to provide for many more refugees in the near future. Hungary, which has been the route of choice for many refugees going to Germany, has expressed that they do not support the refugee resettlement plans proposed by the EU. While these two countries have been essential in refugee movement and would ideally participate in the plan we have developed, assuming that they would be capable or want to help further would be ignoring reality [4,6].
5. **Refugees do not choose which countries they are settled in, they are told this by the UNHCR and other organizing groups.** We know that ideally everyone would be able to choose where they want to go, but this is not possible because of the state of crisis. Saving more lives and being fair to hosting countries overrides this in relevant immigration policies [7].
6. **We will consider the three most popular routes to Europe.** The vast majority of Syrian refugees attempt to reach Europe by taking land routes to Turkey, Syria's next door neighbor, and subsequently sailing to Greece. Others take the most dangerous route - traveling by land to the North African coast and then sailing over the Mediterranean - and a very small number cross over to Spain after reaching Morocco. Though refugees may take many variations of these routes, we

condensed their travel to these main 3 routes for the purposes of modeling. While sources report there are 6 routes through which refugees enter the European Union, two are from non-EU European countries to EU countries (the West Balkan and Albania to Greece routes) and one is primarily frequented by Asian refugees (the E Borders route) [3].

Modeling Refugee Immigration

Overview of Modeling

When considering possible distributions of refugees, it is important to assess the refugee holding capacities of various countries in order to avoid overburdening them or exhausting their local resources in our solutions. Therefore we created a metric of capacity to find the number of refugees a country should hold when considering refugee distribution. Our metric takes into account a country's economic and physical ability to support refugees. Then, we used this metric to set the modeled capacity for each of the countries considered in our first model.

We first created an agent-based model of the refugee movement. The given problem of refugee movement naturally leads to use of agent-based simulation as a modeling tool. In agent-based modeling, each agent is given information and reacts according to only what they know, and the complex system is created through the interactions of many individual agents. Agent-based modeling is commonly used to model dynamic behavior, such as schools of fish or erosion of cliffsides, and is easily applied to refugee immigration to create interesting and informative movement simulations [8]. In our agent-based model, we used agents to represent the countries, the refugees, and the routes between countries. We incorporated refugee- and country-oriented logic in our programming and included data found through research to supply information for the refugees' path choices and decisions for the countries, whether or not they accept individual refugees. The end result was a dynamic, time-dependent complex system that incorporates stochastic and real-life data, representing the displacement, resource-consumption, and settlement of Syrian refugees into countries across Europe.

Next, we created a system dynamic simulation and used this to explore the effects of endogenous and exogenous factors on the movement of refugees leaving Syria through various routes and then being processed for asylum in different countries. This incorporated quantitative real-life data reported on the travel routes as well as numerical values representing qualitative factors: "European hospitality", or the public attitude towards accepting refugees, endogenous events such as technology malfunctions were represented by a delay in the processing time, and exogenous events such as threats or trends in media were values that modified the "European hospitality" aspect of this system dynamic model. We created a system dynamic simulation of Syrian refugees being accepting into Europe using interacting feedback loops in a stock and flow model of movement and incorporated quantitative modification due to endogenous and exogenous changes.

Metric of Country Capacity for Refugee Distribution

We developed a metric to determine a country's capacity to hold refugees. This is used when calculating the proportionate distribution of refugees from a country or countries outside the group amongst the countries within the group of all the countries being considered for resettlement. Below is the equation used to determine the country's metered capacity:

$$Country\ A's\ capacity\ = \frac{\frac{GDP\ PPP_A}{GDP\ PPP_{Total}} + \frac{Population_A}{Population_{Total}} + \frac{Land\ Area_A}{Land\ Area_{Total}}}{3} * total\ refugees$$

We thought that both the economic and physical aspects of a country should be considered when determining its refugee capacity. If a country were economically weak or incapable, we should not designate a large group of refugees to live there. If a country had a smaller population size, it would naturally not have the population subset of volunteer or work force needed to support many refugees. Additionally, if a country were wealthy and populous but very small (such as Luxembourg), our metric would not direct it to hold more refugees than it is geographically capable of. After we selected GDP, population, and land area as parameters, the elder two were verified as important factors when relocating and resettling refugees as they are both also considered in the European Union's equation for refugee redistribution as well the UNHCR analysis of countries' relative hosting of refugees [9, 10] .

Application of the Metric

We considered fifteen European countries: France, Spain, Switzerland, Germany, Belgium, the United Kingdom, Norway, Sweden, Austria, Italy, Hungary, Serbia, Bulgaria, Greece, and Turkey. We applied the metric to reliable and updated data for each country and used this to calculate the capacities implemented in Model 1. When extending Model 1 to include China and the United States, we considered the two of them combined to take on 100 refugees instead of applying the same metric as was used for European countries. Due to to their large distance from Syria, it would not be rational to base their responsibility to host refugees on their land areas or to consider them on the same level of responsibility or capability as European countries. Including land area in the metric for two of the largest countries in the world would result in a huge proportion of refugees being resettled there. This inclusion would drive up costs exorbitantly because the cost of transporting refugees across the Eurasian continent or an ocean would be very high. Not only are European countries closer to Syria, but all with the exception of Turkey operate under European Union asylum laws and the Dublin Regulation.

Shown below are the capacity values used for our agent-based model, which is scaled down to 1000 refugees instead of 1,000,000. The US and China were each set with capacities of 50 refugees, or 5% of the total pool.

Table 1: Capacity distributions for Netlogo agent-based model.

TR	IT	HU	BG	SE	RS	FR	CH	DE	GR	BE	AT	GB	NO	ES
138	94	32	27	73	23	129	48	121	37	39	45	96	73	100

Official country abbreviations are used. See Appendix Table 9 for country abbreviations and Appendix See Appendix Table 10 for values used when applying the metric to countries.

Model 1: NetLogo - Refugee Movement

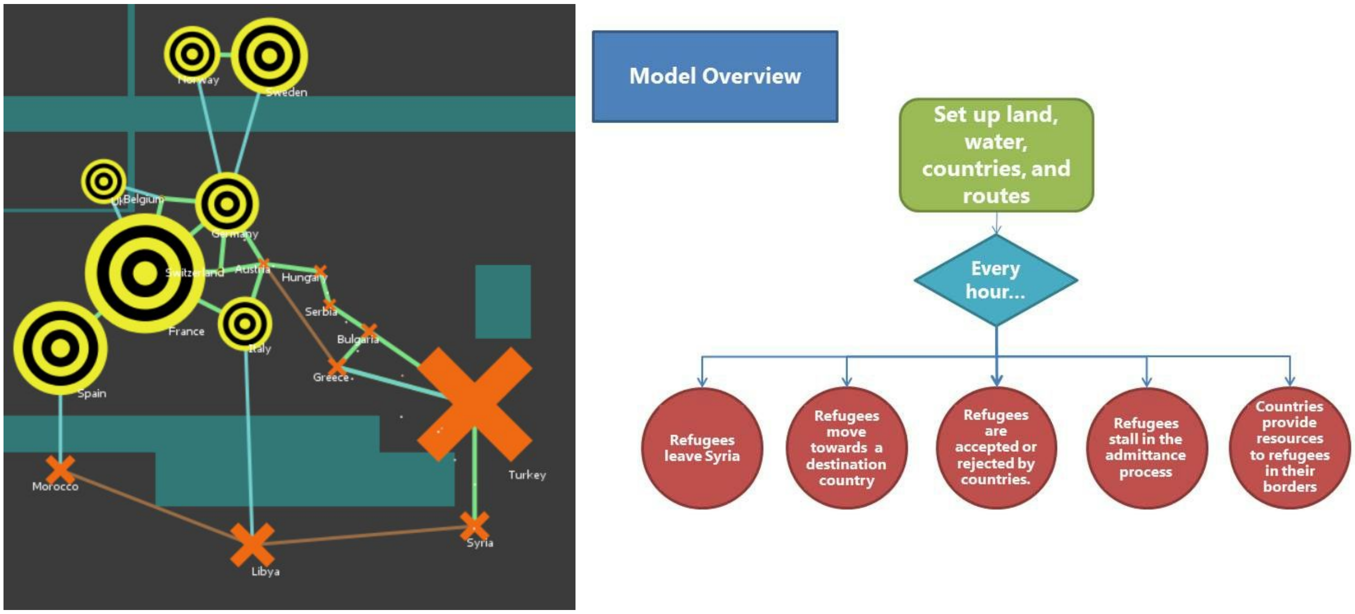


Figure 1: 1a) Screenshot of Netlogo map. 1b) Overview of NetLogo agent-based model.

We created a NetLogo program to model the resource expenditure and movement involved in refugee resettlement. The model sets up a map including European safe haven countries and other relevant countries primarily using three objects of interest: countries, refugees, and routes. NetLogo operates by executing actions every tick, over time, and we scaled all movement, distances, and rates so that every tick is the equivalent of an hour. Select patches of the background are colored blue, indicating relevant bodies of water. Yellow targets indicate countries potentially accepting refugees. Orange X's indicate countries that are not accepting refugees and Morocco, Libya, and Syria start off not accepting refugees as they are not the countries where refugees ultimately want to be admitted to [3]. Green links indicate border connections between countries. Blue links indicate water routes. Brown links indicate land routes. Every refugee in the program represents 1000 persons.

In setup of the program, the patches are colored, and the countries and routes are created. While the program runs, the refugees are created in Syria and leave at a rate of 3 refugees a day, representing 3000 people, the reported rate of refugees leaving Syria [3]. They use the logic referenced in Appendix Figure 10 to choose a country to travel to, and start traveling to that country. Once they reach the country, they have a chance of being accepted by the country, detailed in Appendix Figure 9, and if they are, they are removed from the program. Countries change their willingness to accept refugees in the process detailed in Appendix Figure 11. If a refugee is not accepted, they are temporarily stalled for a random duration of up to 30 days, then choose another country and continue traveling. Refugees who leave a country and return later to the same country have another chance of being accepted. Countries provide resources to all refugees passing through their borders, and to the refugees they admit. 'Resources' is our simplification of many diverse factors that could include food, water, shelter, medical attention, or transportation. For our purposes, refugees who do not gain 'resources' for long periods of time will 'die', and countries are the only providers of 'resources'. Countries will stop accepting refugees if they reach capacity, or if they run out of resources. The model runs until 95% of the default initial 1000 refugees have settled into a country, or all the refugees have perished from sickness or lack of resources.

Model 1 Flexibility

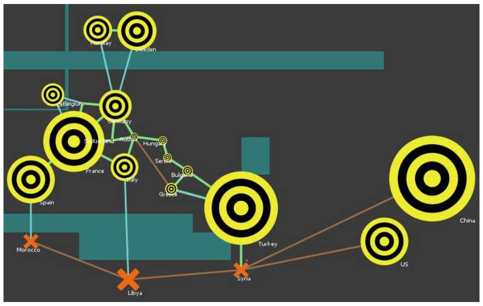


Figure 2: China and the US
The settings of our NetLogo model include toggles for including China or including the US, shown as two additional yellow/black targets on the right of the figure to the left.

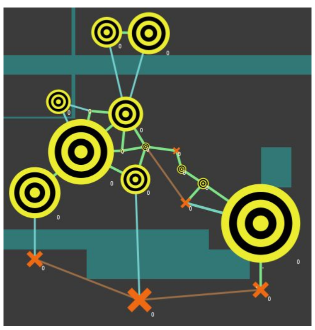


Figure 3: Realism
The settings include a toggle for realism. With the realism toggle set to 'True', Hungary and Greece do not accept refugees, as they have publicly announced they will not, as seen in insert-reference, and the processing time for refugees is set to the estimated average, as in insert-reference. Unless specified otherwise, all data has been collected with realism set to 'True'.

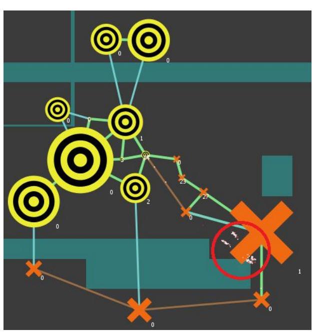


Figure 4: Sudden Influx
A button allows us to simulate exogenous events that lead to sudden influxes of refugees. In the image to the left, sudden influxes can be seen circled by red. The streaks circled are large groups of refugees seeking asylum.

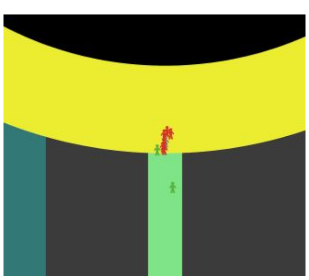


Figure 5: Disease
In the figure to the left, infected red refugees arrive, stall in Turkey, and the disease spreads throughout the entire group of refugees, infecting the health green refugees. Sliders adjust the the initial chance of being sick, the rates of disease spread, the average duration, and the recovery chance.
Unless specified otherwise, all data has been collected with initial chance set to 0.

Further Details of Model 1

We considered all the major countries in Europe when creating our model, but chose to include 15 countries, considering each country's capacity for refugees and their prior interest and activity in accepting refugees [10]. Similarly, we included major routes and water channels to Europe, leading us to include Morocco and Libya [3]. While running the model the countries are aware of their neighboring countries and whether or not those neighboring countries are accepting refugees, and refugees who look to travel over water are assumed to have found a boat or raft in order to do so. When countries reach their destination, they have a chance of being rejected, and if they are, they do not know for a period of stalling in which they sit in the country and wait for the result. This waiting time is distributed evenly over a range up to the maximum processing time set by insert-reference. A refugee's health has a chance of decreasing slightly with every tick. While refugees are in a country and draining that country's resources, they recover health, and the country's resources decrease by an amount proportional to the refugee's health gained. Even if the country is no longer accepting refugees, they will still pass out food and give shelter to those passing through if they resources remaining. Sliders to the side of the model visual indicate the country's resources, and slowly decrease as the model runs. The data from all the sliders, as well as count of accepted refugees and initial conditions, can be sent to an Excel file for data analysis.

Model 2: Vensim - Consideration of Human Factors

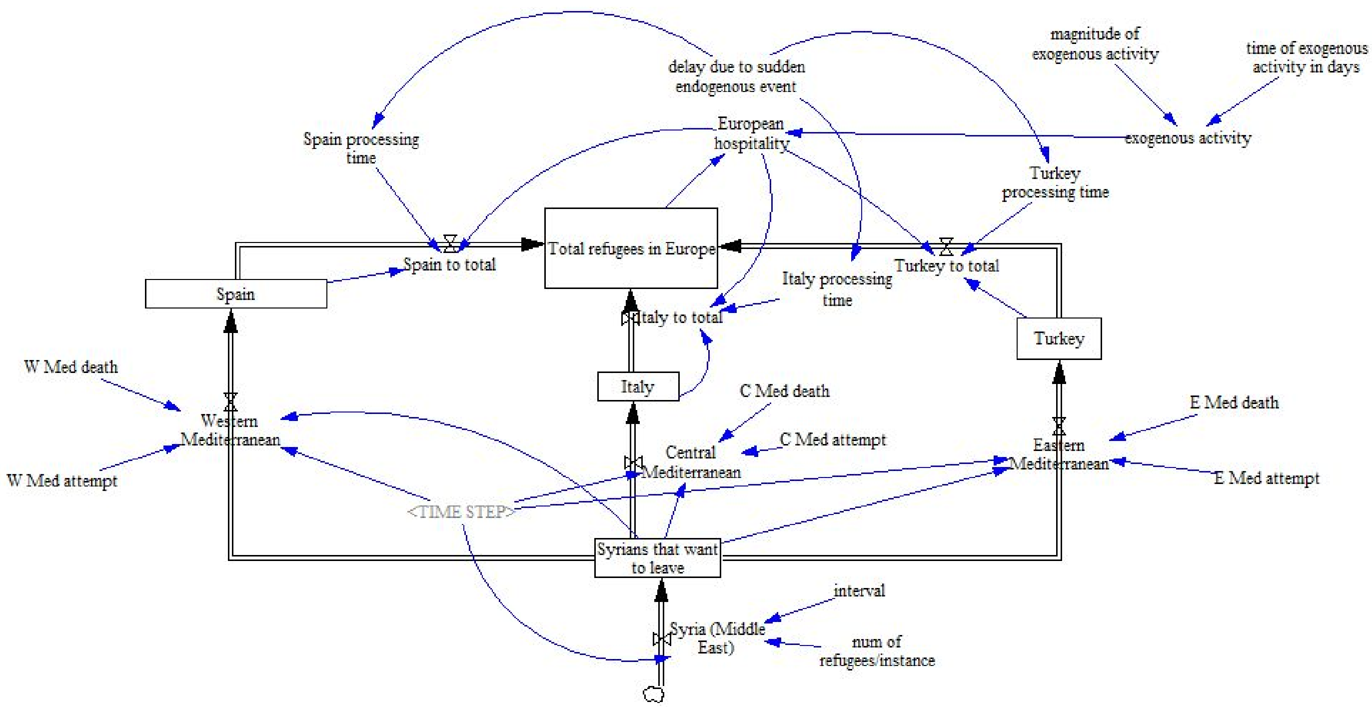


Figure 6: Vensim system dynamic model

We created a system dynamics model to explore the effects of exogenous and endogenous events on the rates of refugee processing and status approval from Spain, Italy, and Turkey - the three main entry points through which Middle Eastern refugees enter Europe. We focused on Syrians that want to leave the

Middle East and be granted asylum as refugees in Europe. The majority of these people travel through Spain, Italy, and Turkey via the Western Mediterranean, Central Mediterranean, and Eastern Mediterranean routes, and would then be processed in Europe [3].

Using Vensim box variables, proportional values found through research and known routes of travel, we constructed a system dynamic simulation. Syrians enter the box variable of "Syrians that want to leave" every day (Figure 6). From this box variable, appropriate numbers of people leave for Spain, Italy or Turkey each day that Vensim iterates. Once Syrians arrive in these three countries, the processing time for an application for asylum and the number of Syrians, values determined through research, determines the "Spain to total", "Italy to total", and "Turkey to total" rates, which model the rate of people applying and being processed and accepted as refugees under the Dublin Regulation (Spain and Italy) or the United Nations High Commissioner for Refugees [9]. Each of these rates is also modified by "European hospitality", a simple ratio from 0 to 1 that represents the effects of the changing European public attitude on the rate of accepting refugees. This variable is a function of the refugees in Europe and would affect the rate of countries registering and welcoming refugees into Europe. As the total refugees in Europe increase, the numerical value of European hospitality decreases; this affects the rates by decreasing the rate of asylum acceptance.

This model serves as a quantitative tool to assess the effects of qualitative events - not only would Europeans' public attitude change due to increased presence of refugees in Europe, but exogenous and endogenous factors affect the refugee acceptance process. As the Vensim model iterates over time, exogenous activity is timed to occur at a specific day during the iteration. The exogenous event has either a positive or negative effect on European hospitality, which then affects the rate of refugees from countries to the "total refugees in Europe" box variable.

The arrows in Vensim indicate that one variable affects another. For example, below is the code for the rate "Italy to total":

$$IF\ THEN\ ELSE(Italy\ >\ 0\ ,\ European\ hospitality * Italy * (1 - (Italy\ processing\ time)/365)\ ,\ 0\ )$$

In order to realistically model the flow of physical humans, the rate will only act to move people from Italy to the box variable "Total refugees in Europe" if there exist refugees in Italy. If the variable Italy = 0, there are no refugees in Italy and the "Else" is used so the rate "Italy to total" is 0. When Italy > 0 there are refugees in Italy, so the rate "Italy to total", which has units of People/Day, is created based on the processing time for an application such that the longer the processing time, the fewer people are moved from Italy to "Total refugees in Europe" each day. In addition to the duration of the processing time, the level of European hospitality is a ratio from 0 to 1 that also affects the rate "Italy to total". This format of coding was also used for the rates of "Spain to total" and "Turkey to total", including their respective processing times. European hospitality itself is modified by exogenous activity.

The "delay due to sudden endogenous event" represents an addition of some number of days to the processing times - such an event could be a technical issue with Eurodac, the biometric database used in processing asylum seekers, a delay in the official bodies that review asylum applications, or some other UNHCR-wide internal delay.

Further Details of Model 2

Model 2 contains data obtained from recent sources for the attempt and death rates for each of the three main routes used to leave Syria and enter Europe as well as the reported or self-set processing times for these countries' asylum application processes. The rate of Syrians entering the box variable of Syrians that want to leave was calculated from the estimated value of a million Syrians entering Europe in 2015 [3]. However, unlike the case in 2015, in Model 2 every person must enter the "Total refugees in Europe" through a rate process designed to model the approval process of asylum seekers. In actuality, not every single Syrian applies for asylum in the first EU country they enter (as is stated in the Dublin Regulation) and there are reported cases of refugees that apply for asylum in multiple countries - when Spain takes too long to process their case, they may move on to France and seek asylum there [11]. Additionally, there is no delay time when Syrians are 'transported' between countries' box variables. In other words, a Syrian will enter "Syrians that want to leave" in a day, then travel to a country within a day, then the next day be considered to be granted asylum status in Europe, repeatedly, until they are admitted or the rate becomes 0 because European hospitality is 0.

Results and Discussion

Model 1: NetLogo - Refugee Movement

Determining Resource Distribution

We ran 30 trials for every set of varying initial conditions tested in our NetLogo model. First we tested how much each country would use up if we allowed them unlimited resources, and tracked how many Resource Units were consumed while all refugees free-flowed through our network without worry that a country would stop accepting them because their resources had run out. All extraneous features (disease, addition of the China or the US, optimism) are turned off.

Table 2: Resources used in Netlogo model when resources are unlimited.

When Run with Unlimited Resources			
Country	**Resources Used (RU)**	**Country**	**Resources Used (RU)**
Turkey	369.35	Germany	52.72
Italy	107.41	Greece	130.06
Hungary	1.38	Belgium	3.71
Bulgaria	33.71	Austria	41.32
Sweden	76.04	UK	89.18
Serbia	26.35	Norway	77.34
France	137.23	Spain	71.25
Switzerland	51.94	Total	1269.05

We noticed by averaging our 30 runs of unlimited resources to each country that Turkey consumes, on average, almost two times more than the next country, France. 29.1% of the total resources expended were consumed in Turkey.

The first distribution we tested was splitting the average total resources used throughout all the countries evenly. However, this did not result in all the refugees being accepted by a country for any of 30 test runs, and thus this data is not presented in our paper, and the strategy of distributing resources evenly is determined to be a bad strategy. Many countries ran out of resources and stopped accepting refugees, and the rest of the refugees had nowhere to go.

Next we scaled resources consumed to the capacity of each country. This strategy ran successfully 4 out of 30 runs. For those runs, the average resources left over is indicated below. The other 26 trials failed to relocate 95% of the refugees.

Table 3: Resources left in Netlogo model with initial distribution based on capacity

Capacity Based Resource Distribution - 4/30 successful trial averages			
Country	**Resources Left**	**Country**	**Resources Left**
Turkey	0.00	Germany	13.28
Italy	8.67	Greece	0.00
Hungary	2.23	Belgium	6.56
Bulgaria	0.00	Austria	.40
Sweden	10.03	UK	21.55
Serbia	0.00	Norway	9.83
France	82.70	Spain	26.41
Switzerland	3.36	**Total**	185.01

In the next simulation, we set the resource values to the average of how much each country consumed + the standard deviation of that country's resource consumption. 24 out of 30 runs were successful in relocating all the refugees. For those runs, the average resources left over is indicated below.

Table 4: Resources left in Netlogo model with initial distribution based on expected consumption

Consumption Prediction Based Resource Distribution - 24/30 successful trial averages			
Country	**Resources Left**	**Country**	**Resources Left**
Turkey	44.46	Germany	3.55
Italy	5.17	Greece	1.35
Hungary	3.44	Belgium	4.80
Bulgaria	2.83	Austria	3.21
Sweden	3.02	UK	8.35
Serbia	3.70	Norway	1.50
France	4.99	Spain	5.94
Switzerland	4.67	**Total**	100.98

66% more runs were successful, and the total resources leftover has decreased by 54.58%. Since we ran 30 trials, we are guaranteed by the Central Limit Theorem to have a normal distribution of sample means . Constructing a 95% confidence interval using our 80% success rate creates the interval:

$$.80 - 1.96\sqrt{\frac{.80\times(1-.8)}{30}} = .66 < \textit{success rate} < .943 = .80 + 1.96\sqrt{\frac{.80\times(1-.8)}{30}}$$

Therefore, we can say with 95% confidence that this resource distribution will successfully allocate 95% of the Syrian refugees across Europe between 66% of the time to 94% of the time. Because we defined success as allocation of 95% of refugees, the success rate has been calculated without consideration of runs that allocated 94% or lower. However, five out of six of the unsuccessful trials successfully allocated over 93% of refugees. If we change our definition of success to consider 93% as our cutoff, $29/30 = .97 = 97\%$ of trials ran successfully, and the 95% confidence interval is

$$.97 - 1.96\sqrt{\frac{.97\times(1-.97)}{30}} = .91 < \textit{success rate} < 1.00 < 1.03 = .97 + 1.96\sqrt{\frac{.97\times(1-.97)}{30}}$$

With a definition of success being at least 93% of refugees successfully relocated, we can say with 95% confidence that our resource allocation allows for success over 91% of the time. Our best resource distribution is therefore as follows:

Table 5: Best resource distribution found through testing of Netlogo model

TR	**IT**	**HU**	**BG**	**SE**	**RS**	**FR**	**CH**	**DE**	**GR**	**BE**	**AT**	**GB**	**NO**	**ES**
420	105	5	45	80	30	140	80	130	5	35	55	85	80	80

*Official country abbreviations are used, see Appendix Table 10 for a table of country abbreviations.

Dynamics of the System

Taking this OPTIMAL resource distribution, we ran trials testing extraneous dynamics, exogenous events, and scalability.

Table 6: Settling times with the best resource distribution found, affected by extraneous dynamics

	Realistic	Optimistic	w/China	w/US	w/China and US
Mean settling time for 95% of refugees	324.8	323.6	324.3	324.5	324.1
Time p-value*	-	7.3e-11	0.00138	.0396	5.42e-5
Mean total resource units consumed (RU)	1261	1197	1176	1182	1106
RU p-values*	-	.0122	1.661e-7	1.76e-7	2.07e-16

*p-values were calculated from comparison with "realistic" data

We isolate the impacts of removing Hungary and Greece and increasing stall times on overall resource usage and time taken to settle 95% of refugees. The results confirmed our expectations in that the difference between measured optimistic and realistic model finishing times was statistically significant ($p < 7.3e-11$), so the difference in mean was not due to the random nature of our model's behavior. However, the means of the finishing time were 323.6 days and 324.8 days, which are realistically not different at all (0.36% difference), indicating that the time lost by excluding Hungary and Greece from our realistic plan as well as having more realistic stall times does not make our plan temporally unfeasible. The difference in cost, on the other hand, is both statistically and realistically significant ($p < .0122$, 5.2% difference) because even a very small change in resource units is large because when our model is scaled up, the values become much larger, and the monetary value of even a small percentage of the resources will drastically impact a limited budget. Adding the US to the model decreased overall expenditures by 6.3%. Adding China to the model decreased overall expenditures by 6.7%. Adding both the US and China decreased overall expenditures by a whopping 12.3%. When considering the size of the UNHCR's budget, which is usually around 7 billion dollars, these savings are very substantial and can instead be redirected to other endeavours, such as incentivizing other countries to take in refugees or contributing towards an emergency fund for unpredictable events [12].

We next looked at the disease attribute of our model and ran 30 trials of different levels of infectiousness and initial chance of starting out sick. Shown below are the results:

Table 7: Testing variations of infectious diseases in the Netlogo model

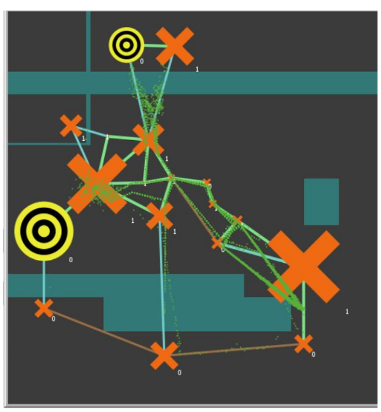
	20% infectious, 20% initially sick	20% infectious, 80% initially sick	80% infectious, 20% initially sick	80% infectious 80% initially sick
Accepted Refugees	636	410	585	401

The effect of disease are devastating on the population of refugees and the sick refugees drain country resources much faster than healthy refugees. All of the countries run out of resources and must shut down early. If a refugee survives being sick and becomes immune, there is a chance that they will not be able to settle into a country because they have all shut down from lack of resources. Increasing the percentage of refugees who are initially sick has far more effect than increasing the infectiousness of the disease, indicating that refugee clumping while they are stalled in a country does not spread the disease drastically, but that having many sick refugees does impact the end result of the model significantly. Therefore, when considering a population of refugees that are initially sick, it is imperative that all values, of capacity and spread of resources, be reevaluated.

Adding in sudden influxes of refugees into the system has no visible impact. Each refugee handles their own situation and the system as a whole does not stop working. There is no significant change in average settlement time for each refugee and the system runs rationally, taking in as many refugees as it can.

Scalability testing

During average performance of the model with 1000 refugees, the program runs at roughly 1286 ticks a minute. In testing the scalability of the model, we added refugees until we had 10,000 running, and recorded the time between each tick, for 30 ticks. The performance was heavily impacted, with an average of 19.07 seconds between each tick. However, we did not run into any serious problems like crashes or overflows. The test was run with all other applications closed, on a ASUS ROG G501 laptop running an i7 processor.



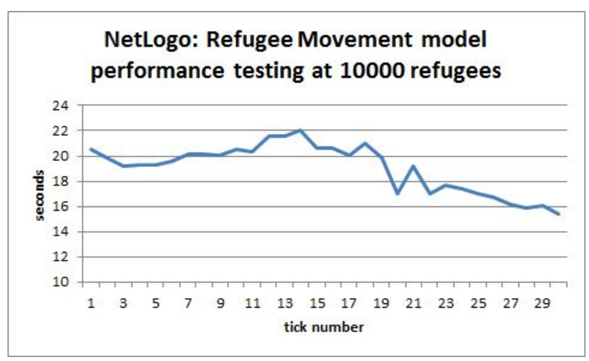


Figure 7: NetLogo - Refugee Movement model with 10,000 refugees

Conversion of Model Elements to Monetary Units

In order to fully understand the implications of the model, it is necessary to translate the Resource Units used in our model to real-life costs. The European Commission plan for relocation of Syrian refugees already in Europe (in Hungary, Greece, and Italy) calls for 6000 euros (about 6500 USD) to be given to a country for every refugee they host [9]. In contrast, the United States provides 925 USD for each person resettled by a NGO within its borders [13] The total number of resource units used by 1,000 refugees in our Netlogo model was 1261 units. For the follow calculations, we treated one ‘resource unit’ as the settlement money for one refugee, but it should be noted that in the model refugees use some portion of resource units when passing through a country (dependent on their health) and use more resource units when they are accepted to and stay in a country. Scaling up and using the value granted through the European Commission, the total cost for 1,000,000 refugees would be around 7.8 billion euros. We selected 5000 euros as an approximate equivalence value for a single resource unit through logical analysis of what each of the two real-life values means. The 958 USD provided by the United States Federal government is intended to cover housing, food, and pocket money for the first 30 days of resettlement, while the 6000 euros is a sum the EU pays a country in exchange for taking on one additional refugee. The elder is not sufficient and is too low to represent the money or cost of resources given to refugees, as - especially those fleeing from a war zone - would also need medical care, vaccination, identification or work registration, and other costs not included in the items considered by the US Federal government. On the other hand, the 6000 euros very likely could be more than the quantity used to settle a refugee. Given that the monetary ‘compensation’ from the European Commission acts as incentive for countries to accept resettled refugees under the EC’s plan, it could contain a small surplus such that a country ‘gains’ money by taking on a refugee. As a result of this logical analysis, we decided to also determine the total cost of resource units used using 5000 euros per unit. Doing the same conversion but using an equivalence of 5000 euros to a resource unit yields a total cost of 6.5 billion euros. While this is a large approximate value, it should be noted that this sum would, based on our Netlogo model, save a million lives and provide homes, food, and other resources for innocent civilian refugees.

Model 2: Vensim - Consideration of Human Factors

Our Vensim model was run for Trial 1 with no consideration of the effect on refugee movement due to changes in European hospitality and no delay from endogenous events or modification due to endogenous events in Model 1. After this trial, all other simulations were run with European hospitality considered. See Appendix Figures 11 and 12 and Appendix Table 11 for more detail on this model.

Table 8: Results of Vensim model trials

Trial	European hospitality?	delay due to sudden endogenous event (days)	exogenous activity magnitude + timing (ratio modifying hospitality)	Days running until all refugees (95% of total) are accepted to Europe
1	Not considered	0	0	350 - 375
2	considered	0	0	525 - 550
3	considered	0	-.3 at 300 days	600 - 625
4	considered	0	-.7 at 300 days	975 - 1000
5	considered	0	.3 at 300 days	450 - 475
6	considered	0	.7 at 300 days	425 - 450
7	considered	30	0	550 - 575
8	considered	70	0	650 - 675
9	considered	30	.2 at 300 days	525-550
10	considered	70	.6 at 300 days	525-550

The data collected from the Vensim model indicate trends between the European hospitality variable, which represents public attitude towards accepting refugees, endogenous and exogenous activities and the total days necessary for refugees to be accepted to Europe. Our first trial had no consideration for public attitude - essentially, refugees were accepted at the same rates, as European hospitality was not considered and did not modify the rates leading into the total count. This trial reported that at least 95% of the refugees were accepted in 350 to 375 days, or close to a year from the start of the simulation. Next, in the control trial the European hospitality does modify the rates of "Spain to total", "Italy to total", and "Turkey to total", and no endogenous or exogenous events occurred. The simulation completed in 600 to 625 days, or a little less than 1 ¾ years.

Interestingly, some sources indicate that it may take months or even years for an application for asylum to be considered . It should be noted that the real-life data is clearly the result of many factors that were not included in this model (resources of the processing offices, backlog, scheduling of interview, etc), while our Vensim model reports this extended time due to the sole variable of European hospitality, a variable that is functional quantitatively in our model but is multifaceted and qualitative in reality. The European hospitality variable is our numerical modification representative of human sentiments that affect the entry rates for refugees into Europe. I

In addition to considering a representatively quantitative variable for public attitude, we also considered exogenous and endogenous activity affecting refugee movement. As expected, there is a decrease in the time when positive exogenous events occur, and increases in the time to completion when negative exogenous events are introduced, or when a endogenous event causes a delay in processing time.

We also ran numerous trials in order to assess whether positive exogenous events could counteract the effects of a delay due to endogenous factors. When there is a 30 day delay, the exogenous factor must be of magnitude .2 - representative of a 20% increase in the exogenous facet of European hospitality - in order for refugees to be accepted within 525 to 550 days, or the same as the control trial. When there is a 70 day delay, the exogenous factor must be of magnitude .6, which is a factor of 3 times more impactful than the .2 magnitude exogenous event.

While realistic public attitude like European hospitality, as well as endogenous events and exogenous events, cannot easily be quantified, it is interesting to study the trends and balances that appear when they are considered in a model of policy involving ever-changing human behavior. By including quantitative representations of these human elements, our Vensim model adds a an element involved in the immigration of refugees that significantly affects the implementation of policies and resettlement plans in the real world.

Policy Recommendations

The foundation of the policy we have developed from our model results is in accordance with the mission of the United Nations High Commissioner of Refugees which is to "safeguard the rights and well-being of refugees" [14]. In essence, we have decided that the preservation of human life and dignity supersedes other factors in consideration of the appropriate course of action. Based on this belief, we have formulated a plan to resettle the Syrian refugees that have entered the European continent and Turkey. In this policy, non-refoulement (a victim seeking asylum should never be returned to his attacker) and preventing against discrimination are priorities, so the purpose of the plan is to give all those seeking a life away from violence and war a place to live without discrimination [15]. Since it is potentially discriminatory to distribute refugees to different regions based on race or religion, both have been excluded from consideration.

In order to be fair to the current inhabitants of hosting countries, our team developed a metric that takes into account size, population, and economic stability in order to determine the number of refugees each country should take in order to spread the burden equally. These capacity values, which are given in Table 1 (scaled down for refugee count of 1000, but easily scaled up to 1,000,000) should be set as the requirements for the number of refugees each country should be able to take in. Because keeping families together is important, we recommend that family units be considered as a whole and only sent to countries with room for all of the family members. To facilitate this, we also recommend increasing the aforementioned capacities by 5% which should be used only to allow families to stay together. Through incorporating these capacity values into the NetLogo model described in our report, we have found proportions that resources should be distributed in which are shown in Table 5. These values are different from capacities because resources are necessary to care for refugees not only when they have settled semi-permanently in a country, but also when they are moving to these designated countries. Since Turkey and the countries in the Southeastern regions of Europe are closest to Syria and have the greatest traffic, they will need the greatest amount of resources to provide temporary necessities such as food, water, and medical care. Resource allocation will also be affected by unpredictable events such as the onset of a contagious disease. Our model is flexible incorporates this possibility, and capacity/resource distribution values can be quickly recalculated if necessary.

For this plan to be feasible, the UN will have to have continued financial support from its donors. Most of the budget will be directed towards providing the designated amount of resource units to each of the participating countries. A smaller portion will be set aside for improving the communication systems and bureaucratic infrastructure that will be necessary for quick and efficient international information exchange. Minimizing the extensive time it takes to register refugees and to make contact with other countries about available space will mean that refugees will get to settle down sooner, and that money will be saved since fewer resources are consumed in the meantime.

This model is very stable, but in the case of unusual exogenous events that would interfere with the plan, we recommend that the UN divert a small portion of the budget into an emergency fund. An example of external events that would negatively impact the system is the recent terrorist attacks in Paris. Many countries shut down immigration for a period of time after the attack due to suspicions of Syrian migrants, causing many refugees to be totally blocked from entry. An event such as this would cause a negative spike in the acceptance of refugees because public support for helping refugees could drastically decrease. As demonstrated in our Vensim model, the negative effects of such an event can be combatted by the introduction of a positive exogenous event. In this situation we would recommend that the emergency fund be used to support the development of positive exogenous factors, which can have beneficial impacts on public opinion. For example, the popular blog *Humans of New York* has millions of followers, and its campaign on Syrian refugees had a significant impact on American awareness and support of the refugee cause.

Another issue demanding the attention of the UN is safety of the routes taken to get to Europe and to travel through it. When registration policies are inefficient and European countries are trying to discourage people from coming through their borders, refugees are given no choice except to turn to smugglers and other illegal methods of gaining entry to safer grounds. When refugees have to use these methods, they put themselves in grave danger while funding criminals, leading to an unnecessary loss of life. Recently the bodies of 71 refugees were found in an abandoned truck, likely belonging to a smuggler [16]. Furthermore, even in less tragic cases, the thousands of dollars that refugees spend on obtaining fake passports and paying for dangerous boat trips could instead be going towards funding their resettlement. Previously, Italy funded a project called Mare Nostrum that made routes for refugees safer and saved 140,000 lives. This project was discontinued in 2014, but we would recommend that the UN revitalize such efforts which make up an enormous part of the difficulties that refugees face as they are attempting to seek asylum [17].

Strengths and Weaknesses

Model 1: NetLogo - Refugee Movement

- **Strength 1: The model is flexible, time-dependent, and dynamic.** The model is flexible enough to consider many factors such as resources, disease spreading, exogenous events that strain the system, capacity, and every refugee's decisions all at once, and the agent-based modeling structure allows easy addition of further metrics or shifts in the dynamics of the crisis. Furthermore, the tick-based logic of NetLogo guarantees that the simulation is time-dependent and everything is guaranteed to run at the same rates relative to each other, working together to create a dynamic complex system.

- **Strength 2: The model contains stochastic elements.** Our model 1 is not deterministic, meaning we are able to have several runs that produce several different results. Rather than using a constant value and producing one number without knowing how far it could deviate from the actual value, risking error through incorrect constants or overlooked variables, we create several runs with some random choices spread out, creating a data set of total run times for each set of conditions. Because of this, we can see the implications of change in these choices, and how much it affects the end result, and report accurately.
- **Strength 3: The usage of agent-based modeling closely represents human behavior.** As each refugee is free to make their own stochastic decisions, the paths of the refugees emulate the paths of real-life human refugees traveling through Europe. They make informed decisions similar to the travelers they represent and the countries react to them in a realistic manner as well. The behavior is not uniform, nor is it arbitrary, creating a model representation of the actual situation in Europe and Syria. Running many trials allowed us to see overall trends even though the decisions made by each refugee were different every time.
- **Strength 4: The model considers multiple aspects of refugee support.** A country not only provides Resource Units to a refugee that is accepted and granted asylum to stay there, but also supplies resources to refugees that apply and are declined or are passing through and cannot be fit in the country's capacity. This is representative of the actual resources need by refugees traveling to and across Europe - they do not only need resources to settle, but need immediate food, shelter, treatment, and other resources as they are traveling.
- **Weakness 1: The model is strict in exactly what the countries and refugees know.** Countries have an information grid exactly equal to their neighbors, and are unaware of the status of countries beyond that. Similarly, refugees are only aware of the countries one country away from them, and only aware of the paths stemming from the country they are currently at. Turkey cannot tell refugees that Switzerland has available room for them, and a refugee at Austria would not know if France is still accepting refugees before traveling to, for example, Germany.
- **Weakness 2: The model assumes durability and accessibility of resources.** In addition to assuming all refugees who choose to travel by water have access to a boat, we assume front-ending countries with the amount of resources they require is sufficient to model consumption of resources over time, ignoring food decay or shelter spots opening and closing over time.

Model 2: Vensim - Human Factor Consideration

- **Strength 1: The model incorporates general public sentiment.** The changing value of European hospitality represent human sentiments. While there is no simple quantitative measure of this variable nor of its influence in refugee movement, it realistically does affect our system. Including varying numerical representations of these complex human aspects adds to our understanding of the dynamics of refugee movement.
- **Strength 2: The model allows for endogenous delays and sudden exogenous events.** In reality, the actual duration of application processing is likely longer than the reported value, due to backlog, lack of resources or manpower, or other realistic internal issues that arise. Exogenous events can be distilled to a net negative or positive influence on rates of asylum acceptance.

While in reality these are qualitative events, their influences can be seen in quantitative complex systems analysis.

- **Strength 3: The stock and flow structure emulates the movement of refugees from Syria to Europe.** The ability to have 'levels' or stocks of refugees that amass in Spain, Italy, and Turkey and to separate these box variables from the stock of refugees in Syria and the flow of refugees between these variables results in a compartmental model representative of the sections or areas in an individual refugee's journey where they enter a larger pool. Additionally, the level of 'stock' or the number of refugees in a box variable affects the rate at which they leave for a new destination.
- **Weakness 1: Mathematically, the accepting countries are equally affected by changes in public attitude and endogenous/exogenous events.** Spain, Italy, and Turkey are all modified by the same ratios when European hospitality or endogenous/exogenous events occur. If there were a bombing in France, Spain or Italy would likely respond with a more negative reaction in acceptance rate compared to Turkey, as the elder two are closer in proximity to France and could feel more concern that refugees entering through their processes could be connected to a negative exogenous event in France. In reality, Spain, Italy, and Turkey would have different reactions depending on the public sentiments of other countries, and multiple endogenous and exogenous events of different magnitudes.
- **Weakness 1: The model does not incorporate delays and realistic times for exogenous events directly into the rate of refugee movement.** Processing time is a variable that affects a country's rate of accepting refugees into Europe, but refugees are hindered by probability or rates, instead of delays in time such as delays in obtaining transportation from Syria to Spain/Italy/Turkey or delays when waiting for paperwork to be processed once in those three countries. Additionally, there may be some delay in the effects of exogenous events - a social media trend might take a couple days before it reaches peak, but it will affect the rates of entry both before and after the peak.

Combined

- **Strength: Our models incorporate real data collected from recent sources.** By basing the rates of route selection, refugee deaths, and processing times found through research, our model is more representative of the actual situation than if arbitrary values were used in each case. Additionally, our metric for resource distribution was applied to current country data.
- **Strength: Our models considers non-ideal complications and realistic modifications.** Our models allow for changes and depletion of resources, changes in public attitude and countries' acceptance rates of refugees, and other facets that add to the complex nature of the refugee crisis.
- **Weakness: Our models do not incorporate certain factors, such as wealth or religion, that are reported to affect refugee movement.** From reading news articles we recognized that many Syrian must pay smugglers or fees for traveling, and in other cases some countries have adopted policies of seizing valuables from refugees or claiming they cannot accept refugees of certain religions.

Future Work

In future studies of refugee movement, not only should agent-based modeling be used to study refugee movement, but also the movement of aid and asylum groups such as UNHCR, the IOM, and other Non-governmental organizations.

More extensive study of the impact of different levels of disease could be continued. Our testing verified the need for reevaluation of resources and country capacities, but we have not extensively tested what the new resource distributions would be, and the monetary expenditure compared against the strength of a sickness.

Model 1 could be adjusted to allow countries to accept refugees past their capacity, if the situation is dire, allowing for more flexible testing. However, many precedents and research on existing behavior would have to be set before any realistic adjustment to the model could be made.

Additionally, Model 2 should be expanded using statistical or numerical data from trend analytics or social media studies regarding different countries' public attitudes towards refugee hosting. This problem is a very current issue, and will continue to grow and change in complexity and involvement of many interesting and interacting factors.