Summary

The refugee crisis is dynamic with many factors involved. We address two phases in refugee movement, which have distinct priorities.

Phase 1 refers to the flow of migrants from the Middle East and North Africa to Europe entry points. These movements are almost always illegal and orchestrated by human smugglers. Authorities have *minimal control* over the safeness and distribution of traffic during this phase. The task is to estimate the number of fatalities along each route, so that search-and-rescue operations can be planned. Adapting the general accident prediction mode, which takes into account route distance, traffic volumes, and constant risk factors on these route, we derive a route-specific formula to estimate the expected fatalities for 2016.

Our main focus, Phase 2, is the relocation of registered refugees from hotspots near initial entry points to host countries. We develop an original iterative allocation algorithm that calculates the number of refugees to be relocated from each hotspot to each host country. The solution is obtained via linear optimization and accounts for the capacity of host countries, processing rates at the hotspots, and costs of supporting refugees during their temporary stay at hotspots, among other factors. The model is designed to be run regularly, with revised parameters, to account for the dynamicity of the factors involved.

Our algorithm is designed to favor long term optimization instead of stepwise cost. When distant countries such as the US are added to the list of potential hosts, relocation of refugees to these countries help to reduce long term cost, though the cost of transportation could be more expensive in short term. It is best that the rate of refugee processing at hotspots match the rate that host countries can take in.

We also propose two additional measures to supplement this algorithm: the Availability Index which corresponds to host countries availability to support refugees during the months of resettlement and the Urgency Index which indicates the degree of need for resources at local hotspots to help NGOs in their distribution. This can be used to calculate maximum capacity, instead of using self-reported data (currently the case), which can lead to an unfair distribution of responsibilities.

Based on our models and results, concrete policy recommendations are developed to advise EU governments and NGOs in coping with the crisis.

ICM-RUN Strategic Team/ February 1, 2016

Policy Recommendation with Regards to the European Refugee Crisis
Attn: UN Commission on Refugees,

In light of the scale of the current refugee crisis, we propose the following:

Reduce fatality counts It should be noted that primary movement of migrants to initial entry points in Europe is mostly illegal. Since authorities have little to no control over its volume and safeness, the task is to station search and rescue missions along the six common routes. We estimate the expected fatalities along the Central Mediterranean route to be the greatest of all routes. The UN should advise authorities at entry points about the estimated fatalities for each route to direct rescue resource.

Optimize relocation scheme

We propose a scheme to fairly relocate registered refugees in Europe host countries. To this end, a planning committee under the European Union should be set up to coordinate the process.

For host countries:

1. Governments and media should bolster public support for refugee intake by promoting the idea of refugees as a resource. Many European countries are facing the imminent plague of an ageing population, which comes with it issues of pensions, sluggish economies, and financing welfare states. While refugees need much support in Phase 2, in future, they can be help Europe alleviate its pressing population problem.

2. Host countries can help speed up relocation if they set fewer criteria (skills level, age, gender, etc.) for the refugees they take in.

For entry/hotspot countries:

1. The current bottleneck in the process is screening at hotspots. International assistance in this area, e.g. to set up more spots, provide more staff, or streamline the process would be tremendously helpful.

2. Refugees upon first arrival need a lot of support for shelter, food, and basic healthcare. Security concerns follow closely after. As far as possible these resources have to be prepositioned.

For NGOs, more emergency aid should be allocated for countries with high urgency indices. NGOs can pool resources to maintain a regularly updated database of this index.

Given the scale of the crisis, providing enough resettlement capacity to meet the demand is more important than all else. Distant countries like the US and China should also be involved in these efforts. Even though transportation costs may be large initially, it helps to address the pressing issue, which is cumulative support cost at Europe hotspots.

Modeling the European Refugee Crisis

ICM Contest Question F

Team # 53504

February 2, 2016

Contents

1 Introduction

1.1 The European Refugee Crisis

Research literature makes a distinction between two types of refugee movement: *primary movement* to "initial places of safety", and *secondary movement* from such a place to "newer destinations for the purpose of claiming asylum" [7]. To model the refugee crisis in Europe, we have refined that categorization and identified three key phases:

Phase 1. Primary movement :

The flow of asylum seekers and refugees from conflict zones to Europe entry points. Almost all[1] these migrants are illegally smuggled by human traffickers in frail, overcrowded boats [2]. Governments and NGOs thus have little, if any, control over the safeness and distribution of movement at this stage. The efficacy of EU plans to attenuate human trafficking activities is met with doubt[2].

As such, efforts should be focused on estimating fatalities along each route, so that in the short term, rescue operations can be directed and information published to assist potential migrants in their decision.

Phase 2. Short-term secondary movement (within the next 3-5 years) :

Initial relocation of registered refugees from frontline hotspots [3]. to European host countries. Relocation volumes would be based on the capacity of host countries, processing rates at the hotspots, and costs of supporting the refugees.

Phase 3. Long-term secondary movement (beyond 5 years) :

By this time, the refugees are expected to have become functioning members of society. Given the young composition of refugees fleeing West Asia (over 50% are currently under 18[3], they would be a tremendous resource to combat Europes ageing population woes. However it is no longer within the humanitarian concerns of the UN and is beyond the purview of this paper.

[1] The average cost for a boat journey is USD 1200 per person [3], which is more expensive than a plane ticket from Turkey to any European country. Any rational person would take the plane, which is by far the safer and cheaper option, if they could legally get to Europe.

[2] "There is real uncertainty on whether the operation will ever be able for either legal or political reasons to get to the core of its mandate" (Thierry Tardy, a senior analyst at the EU Institute for Security Studies, in an interview with CNN) [4]

[3] EU-run 'hotspots' are set up near heavy migrant entry points to "identify and fingerprint migrants and refugees" [1]

1.2 Defining the Problem

The phases above have distinct priorities and will be addressed separately.

Phase 1 is discussed in Section 2. For each route, we fit real-life data in the past two years into a existing accident prediction model to find the relevant parameters. We then used the interpolant function to predict fatalities by route in 2016.
Phase 2, addressed in Section 3, receives much more focus, because the authorities have greater control over this phase. Our goal here is to:

- devise an allocation algorithm for relocation in order to minimize costs of maintaining crowded refugees campsites and financing the relocation;
- simulate the algorithm on real-life data;
- develop supplementary measures to further optimize the algorithm.

Section 4 analyzes the changes in our models when faced with issues of scale and exogenous events. In addition, by analyzing the relative significance of each parameter, we identify the set of factors that should be targeted to optimize the outcome. In the last section, we describe sets of concrete policy recommendation for the Europe governments and NGOs that will support refugee movement patterns.

2 Phase 1: Primary movement

We focus our analysis on the movement of asylum seekers to Europe via sea traveling. Human smugglers illegally transport thousands of migrants via six main routes (see Fig. 2) and the primary mode of transport is boat.
If such movements were orchestrated in a legal manner, models could be developed to optimize for safety and efficiency. Unfortunately, this is not possible. The humanitarian duty of governments and NGOs is to distribute search-and-rescue resources where they are needed. To this end, our modeling objective is to estimate the number of potential fatalities along each route.

Figure 1: Major migrant routes to Europe

Assumptions

- Certain factors are important safety Refugees are transported in inflatable rubber boats of approximately equally low quality[4]. The effect of low boat quality is the same along all routes.
- The speed of travel is constant (hence a proportional relationship between distance traveled and time spent on sea).
- Each route has a fixed set of risk factors.

[4]Human traffickers buy cheap, low-quality boats because they are aware of efforts by EU authorities to confiscate these vehicles.

Symbol	Description
Q_i	traffic volume along route i (people/year)
M_i	number of accidents per unit distance for route i
N_i	expected number of accidents in a year for route i
β_i	elasticity constant of effect of traffic volume on number of accidents for route i
α_i	proportionality constant for route i
x_k	measure of risk factor
γ_k	coefficient constant corresponding to x_k
X_i	risk exponent for route i; $X_i = \sum_k \gamma_k x_k$

Table 1: Notations for Phase 1 models

Parameters considered

- *Traffic volume along each route*: High demands for a route increases the risk of overcrowding, which decreases the megacentre of the boat and increases the risk of capsizing.
- *Risk constants for each route*: These can be empirically determined and indicate the peculiarities of each route (ocean currents, normal visibility conditions etc.).

Methodology

Step 1: Theoretical basis

To predict the number of accidents on common migrant routes, we adapt the general model for accident prediction for single roads. According to a report by RIPCORD-ISEREST [6], nearly all modern accident prediction models conform to the following form:

$$\mathbb{E}(M_i) = \alpha_i Q^{\beta_i} e^{\sum_k \gamma_k x_k} \tag{1}$$

where:
Q_i is traffic volume in a year (number of people traveling on route i)
β_i is elasticity constant or effect of traffic volume on number of accidents
x_k is risk exponent
γ_k is coefficient constant

Since for each route, x_k remains constant throughout the entire length of the route, i.e. $e^{\sum_k \gamma_k x_k} = X$. Then for each route i, equation (1) becomes:

$$\mathbb{E}(M_i) = \alpha_i Q_i^{\beta_i} e^{X_i} \tag{2}$$

The expected number of accidents along route i with known distance can then be approximated as:

$$N_i = \left(\alpha_i Q_i^{\beta_i} e^{X_i}\right) \cdot d_i = d_i \left(\alpha_i e^{X_i}\right) Q_i^{\beta_i} \tag{3}$$

Step 2: Model fitting

We fit the model with real-life data from the past two years (2014 and 2015) for the three common migration routes[5] to estimate the risk exponents for each route.

Ideally, we would perform a power fit. However, the lack of accessible monthly data on the number of fatalities and rescue efforts along the routes only allows for solution from a system of linear equations. While we estimate the number of accidents using annual data on total number of deaths recorded, real-life application of this model should take into account the number of accidents that would happen without rescue efforts in place.

Results and Analysis

Migration Route	Parameters	
	β_i	$\alpha_i e^{X_i}$
Central Mediterranean	-9.827	6.764E+51
Eastern Mediterranean	-0.209	83.921
Western Mediterranean	-3.370	3.866E+13

Table 2: Fitted parameters for Phase 1 accident model

Our results indicate that the Central Mediterranean route has the highest risk exponent, and thus is the most dangerous route at the moment. While Eastern Mediterranean route is the current most popular route[6], it also has the shortest distance[7] among the three routes and the smallest risk exponent.

A very important factor in predicting fatalities is the cyclical fluctuation due to seasonal changes, which, as a yearly estimate, our model cannot

[5]Data for other routes are not readily available.
[6]880,820 arrivals in 2015
[7]100km

account for. We could not model this due to a lack of readily available monthly data for each route. Nonetheless such data can be easily measured. Once such information is obtained, more accurate monthly models can be developed in the same manner.

Incorporation of model into projected flows of refugees

As the dynamicity of factors that affect how migrants decide to move through the region causes the patterns of movement to change with time[8], we think it is not necessarily meaningful to attempt to project the exact number of migrant arrivals via each route with the limited data that is accessible to us[9]. However, if incorporating the projected arrival data estimated by the EU, our model can estimate the expected number of fatalities that allow for adequate search-and-rescue efforts to be implemented.

3 Phase 2: Short-term secondary movement

Conditions affecting refugee relocation from frontline hotspots to host countries, which we will revisit later, are subject to unexpected, drastic changes. It is neither practical nor useful to give absolute values of relocation volumes over extended periods of time.

As such, we seek to develop an allocation algorithm that would be run monthly[10], with revised parameters, to calculate relocation volumes over incremental periods. The main objective of the algorithm is to minimize the costs of resettlement procedure.

Assumptions

- Centralized planning is done by the European Union. There is absolute compliance by member states with respect to the EUs decisions.
- Our algorithm gives a number of refugees to be moved from each hotspot to each host country. We assume that the current host-matching

[8]East Mediterranean route saw an increase of tenfolds of migrant arrivals from 50,830 (2014) to 880,820 (2015) while Central Mediterranean saw a slight decrease from 170760 (2014) to 157220 (2015).

[9]The number of migrant arrivals in 2015 exceeded projected number by the EU in 2014 by a large number.

[10]In practice this granularity can take any value

Symbol	Description
h_i	hotspot i
n_i	number of refugees at h_i
s_i	the maximum number of refugees that can be processed in one month at h_i
c_{h_i}	monthly cost of supporting a refugee at h_i
n_j	nation j
a_j	the maximum number of refugees that can be accepted in this month at n_j
c_{ij}	transportation cost of relocating from h_i to n_j
x_{ij}	number of refugees to be relocated from h_i to c_j that month

Table 3: Notations for Phase 2 models

process (which considers the host countries and the refugees preferences), can always find enough matches in time to fill this designated number.

- Secondary refugee movement is entirely controlled by legislative authorities: refugees can only move from one nation-state to another if there is explicit legal permission. This is in line with current restrictions on refugee movements.

Parameters considered

- *Maximum number of places that each host country can offer in the upcoming period*: This is dependent on the resources (mainly land and financial) and public support towards refugees in that country.
- *Maximum number of applications that a hotspot can process in the upcoming period*
- *Cost of supporting one refugee per day at each hotspot*: Upon entry, refugees rely entirely on humanitarian support for basic sustenance. This cost covers shelter, food, basic daily allowance, and other miscellaneous expenses.
- *Transportation cost of relocating each refugee*: The EU currently bears this cost.

Methodology

Step 1: Theory setup

We use linear programming to minimize the total expected cost to the EU, which includes (1) the cost of supporting refugees that remain at temporary hotspots and (2) the total transportation cost of relocation. The cost function is calculated as:

$$f_{\text{cost}} = \sum_i \left(c_{h_i} \cdot \left(n_i - \sum_j x_{ij} \right) \right) + \sum_i \sum_j x_{ij} \cdot c_{ij} \tag{4}$$

The total number of refugees moved to a nation should not exceed that country's capacity. Similarly, the number of refugees leaving a hotspot cannot exceed the processing capacity of that hotspot. Together with the non-negative sanity constraints, we have the following set of constraint equations:

$$\begin{cases} \sum_i x_{ij} \leq a_j & \text{for } j = 1, 2 \ldots \text{number of nations} \\ \sum_j x_{ij} \leq s_i & \text{for } i = 1, 2 \ldots \text{number of hotspots} \\ x_{ij} \geq 0 & \text{for any } i, j \\ n_i - \sum_j x_{ij} \geq 0 & \text{for } i = 1, 2 \ldots \text{number of hotspots} \end{cases}$$

Step 2: Algorithm simulation

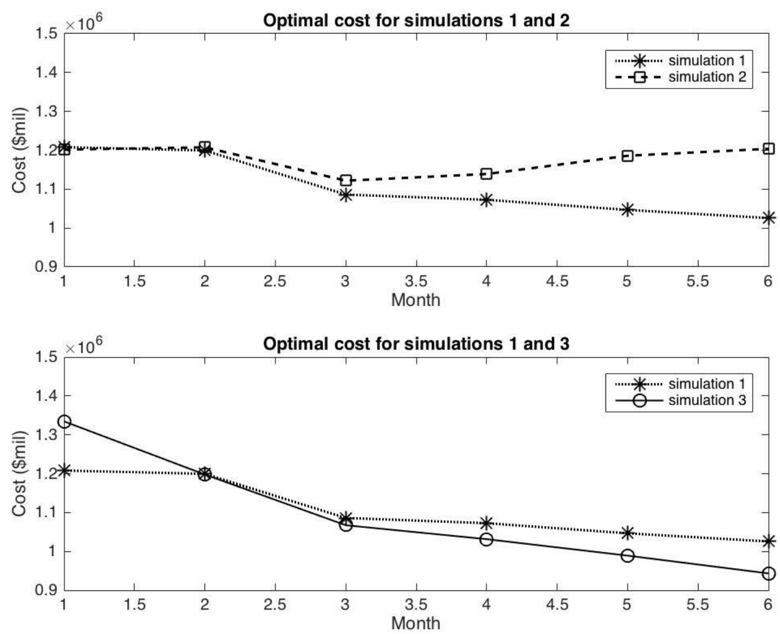
We carry out simulations of the algorithm using the GNU Linear Programming Toolkit (GLPK) and original Bash scripts, with 2 hotspots (Greece and Italy) and 4 host countries (Germany, France, Netherlands, Sweden). Almost all data used are real-life data from reliable sources.
To get accurate solutions, the parameters of the model are meant to be revised after each time step. To run the iterative simulation, We make additional regarding each parameter:

- a_j (the monthly capacity of each country) is assumed to remain unchanged. We obtained this number by dividing the capacity for the year, as announced by the countries, by 12.
- s_i (processing rate at hotspots) is assumed to remain unchanged as well.
- c_{h_i} The cost of supporting a refugee is currently 35/refugee [5]m or \$1140. We assume this would fluctuate within a small range (due to changes in needs for heat, density, or disease outbreaks etc.). At each step we pick c_{h_i} randomly from $\{1020, 1120, 1220\}$.

- c_{ij} (transport cost of relocation) is uniformly fixed at 500, which is the amount allocated by the EU[5].
- n_i (number of refugees at a hotspot) does not change, i.e. the rate of new arrivals is roughly equal to the rate of migrants being relocated or having their applications rejected.

Step 3: Improving the algorithm - ***Acceptance capacity versus processing capacity***

Figure 2: Simulations 1, 2 and 3



Intuitively, it would be most efficient if $(\sum a_j = \sum s_i)$. We test the hypothesis by running 2 simulations (upper part of Fig. 2). Simulations 1 and 2 are run with identical parameters, except that $\sum a_j$ and $\sum s_i$ are equal in simulation 1 and slightly different in simulation 2.

Optimal cost can be improved significantly if there is equality between the total amount of countries capacity and the total amount of refugees can be processed at hotspots. This makes sense because the cost due to staying of the refugees will be cumulative. Thus, we want to move as many refugees as possible. Any difference between them will cause a waste of resources. Another constraint can be added to our linear system

$$\sum_{i,j} x_{ij} = \sum_{i} s_i = \sum_{j} a_j \tag{5}$$

Criteria (5) in itself does not make sense, but when added to the system, it will help the linear programming algorithm approach long term optimization.

In focusing on the long run, the improved system with criteria (5) can avoid another pitfall. Given only the initial set of constraints in Step 1, if we add to the matrix countries that are far away such as US or China, they will never be chosen because of the high transportation cost. With (5), though it may cost more in one month, the long term cost is reduced because capacity to take in refugees is better made use of. We demonstrate this in the lower part of Fig. 2. Simulation 3 is run with exactly the same parameters as simulation 1, with the addition of criteria (5) as a countries and two distant countries (Us and China) in the list of hosts.

Toward more fairness: Availability Index

In the simulation above, we assume that maximum capacities are self-reported by the countries and faithfully so. However, since countries are responsible for supporting refugees in the short term, self-reporting can lead to an 'unfair' distribution of responsibility. Thanks to the tight cooperation within the EU, stricter rules can be imposed. We propose using an *availability index* to calculate the relative ability of host countries to receive refugees:

$$\text{avail}_{c_j} = \frac{\left(\text{GDP per capita}_{c_j}\right)^{\alpha}}{\left(\text{population density}_{c_j}\right)^{\beta}} \times \left(\%\text{ public support for refugees in } c_j\right)^{\gamma} \tag{6}$$

This index takes into the account the resources that clearly influence a country's ability to support refugee resettlement: land and financial capital. With this, the capacity for refugee intake can be calculated to be proportional to the index.

This index, as a supplement to our main model, is rather underdeveloped. There will also be clear difficulties in estimating the exponents. However once established, it has the potential to be extremely useful.

Directing emergency aid: Urgency Index

In our simulations on real data, the number of people relocated at each step is equal to the maximum processing capacity of the hotspots. Processing is clearly the bottleneck in this process. The influx of refugees means a tremendous strain on local resources (shelter, food, healthcare, among others) at these places. We propose the *urgency index* to estimate the urgency of resource needs at these places:

$$\text{urgency}_{h_i} = \frac{\left(\text{refugee population}_{h_i}\right)^{\alpha} \cdot \left(\text{population density}_{h_i}\right)^{\beta}}{\left(\text{local allocation for refugees + EU allocation + NGO aid}_{c_j}\right)^{\gamma}} \tag{7}$$

Though not used directly in the allocation algorithm, this urgency measure can identify the spots that need the most help, so that EU and NGOs can direct emergency aid there.

4 Analysis - Sensitivity and Scalability

Refugee relocation is indeed subject to many unpredictable factors.

- At the simplest level, more hotspots can be opened up by the EU, or more countries will agree to resettle refugees.
- Terrorist attacks like the recent one in Paris can result in large drop in the number of places that host countries offer up for refugees.
- Weather conditions such as volcanic eruptions in Ireland can render transportation costs to neighboring countries prohibitively expensive.
- Processing rates at hotspots can increase (by receiving more support) or decrease (because of events triggering security concerns).

Nonetheless, a notable strength of our algorithm is that it is designed for change. All the factors above have been encoded as parameters into the model, and their changes will induce changes in the outcome for subsequent iterations.

It is clear from our simulations on real data that the current limiting factor on the rate of refugee relocation is the processing rate at the hotspots and the capacity offered by host countries. Even if the population of asylum seekers stranded at these hotspots were to increase by a factor of 10, the rate cannot increase further. In that case our relocation scheme will remain the same, but there is a much greater need to relieve the resource strain near entry points. The solution would be to set up more hotspots near heavy entry points and find ways to speed up processing. In the meantime, our urgency index can help governments and NGOs to distribute their resources.

5 Policy Recommendations

5.1 Reduce fatality counts

In phase 1, it should be noted that primary movement of migrants to initial entry points in Europe is mostly illegal. Since the authorities have little to no control over its volume and safeness, the task is to station search and rescue missions along the six common routes. UN can advise the authorities of different entry points about the risk factor and projected flow of refugees associated with each route so that the availability of rescue vessels and of helicopters[11] matches the expected need.

5.2 Optimize relocation scheme

- Our model offers a scheme to fairly relocate registered refugees in Europe host countries. Optimization is only possible with a lot of centralized planning and coordination between such countries. To this end, a planning committee under the European Union should be set up.
- For host countries:

  Sufficient public support for refugee intake is crucial in determining how many places a host country can offer. Governments and media can bolster this by promoting the idea of refugees as a resource. As briefly noted in our introduction, many European countries are facing the imminent plague of an ageing population, which comes with it issues of pensions, sluggish economies, and financing welfare states. While refugees need much support in Phase 2, in Phase 3, they can be help Europe alleviate its pressing population problem.

[11] Helicopters are used in rescue efforts to transport urgent medical cases to hospital

Our model assumes that we can always match enough refugees with hosts to meet the stipulated relocation volume. However, this is not always the case. Host countries can help attain the optimum solution if they set fewer criteria (skills level, age, gender, etc.) for the refugees they take in.

- For entry/hotspot countries: Volumes of refugee relocation can grow much faster if the screening process at hotspots is faster. This is in fact the current bottleneck in the process. International assistance in this area, e.g. to set up more spots, provide more staff, or streamline the process would be tremendously helpful.

  Refugees upon first arrival need a lot of support for shelter, food, and basic healthcare. Security concerns follow closely after. As far as possible these resources have to be prepositioned.

- For NGOs, more emergency aid should be allocated for countries with high urgency indices. NGOs can pool resources to maintain a regularly updated database of this index.

- Given the scale of the crisis, providing enough resettlement capacity to meet the demand is more important than all else. Distant countries like the US and China should also be involved in these efforts. Even though transportation costs may be large initially, it helps to address the pressing issue, which is cumulative support cost at Europe hotspots.

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