Optimizing the Size and Location of Short-Term Refugee Camps in Syria (BMCM Problem 1)

Sorin Vatasoiu, Martin Carlsen, and Julia Romanski

November 8, 2015

Non-Technical Summary

Regarding the imminent arrival of Syrian refugees in the week of November 9th, we at the United Nations High Commission for Refugees propose a short-term plan for housing and ensuring the safety of the estimated 100,000 refugees. We have constructed a mathematical model to optimally chose the locations and sizes of refugee camps in Syria. We focused on prioritizing safety and security for the refugees while keeping in mind factors such as sustainability as we continue to look for more permanent solutions. The model identified five locations to set up short-term refugee camps in Syria: one camp near Damascus, another near Al-Ladhiquiah, on the Mediterranean coast, two camps in the North, near the Euphrates River, and one in the Northeast, between Ar Raqqah and Al Hasakah. Each of these camps will have a capacity of 20,000 refugees.

The cost of the initial setup will amount to \$45 million while \$500,000/day will be needed to run the establishment. Assuming a duration of 6 months, we can expect the total project to cost about \$100 million.

Despite being a substantial cost, it is our utmost duty at the United Nations High Commission for Refugees to protect and support refugees in Syria during their resettlement. We firmly believe that these five camps will prove to be effective short-term solutions in dealing with the current situation and will provide internally-displaced Syrians with support, shelter, and safety, while more permanent solutions are investigated.

1 Introduction

The crisis in Syria has been ongoing since 2011, starting with revolts to oust President Assad. But the situation quickly escalated into an intricate web of power struggles between several groups throughout the region. From 2012, several rebel groups planned to oust the Syrian government and violence ensued in Damascus, the capital, and neighboring regions. The situation now has added dimensions in that multiple religious sects are involved along with the anti-government rebels. Notably, ISIS has also entered the picture, exacerbating the entire conflict. In the process, thousands of civilians have been killed and over four million have fled their homes. There are no signs of abatement as the refugee count continues to increase.[11]
The United Nations High Commission for Refugees is dedicated to providing support and solutions to refugee problems globally [1]. With a present focus on the conflict region of Syria, the UNHCR must deal with finding suitable refuge for the people of Syria. Both short-term and long-term solutions must be considered. Specifically, establishing refugee camps in suitable locations within Syria while more permanent resettlement plans are formed is a pertinent issue for the UNHCR. In this report, we have set out to answer this relevant and complex issue of determining ideal short-term camp locations within Syria through a mixed-integer program.

We define a refugee scenario as follows:

Def 1. *A **refugee scenario** describes the geopolitical situation of a region with a refugee crisis. It includes data by region on population density, conflict severity, and natural resource availability.*

We define the Refugee Camp Problem as follows:

Def 2. *The **Refugee Camp Problem** chooses the size and location of refugee camps for a given refugee scenario. It is a multiobjective problem; the goal is to minimize total cost (startup and maintenance), while ensuring camp safety and reachability for refugees and aid workers.*

We propose a Mixed Integer Program (MIP) Model for the Refugee Camp Problem. The Refugee Camp Problem is based on the more general Facility Location Problem, which has been well-studied in the literature. In the Facility Location Problem, one chooses locations for facilities, such as a factory or warehouse, minimizing the cost of building the facilities and the transportation costs between customers and facilities. In the Refugee Camp Problem, the camps can be seen as facilities and the refugees can be seen as customers. Similarly to the Facility Location Problem, we wish to minimize the distance between refugee camps and refugees, so that refugees do not have to travel too far to reach safety. We adapt the cost function to the refugee scenario, penalizing the placement of refugee camps near conflict zones, for example. Additionally, placing camps near areas with sufficient natural resources

to supply the camps is favored by the model.
Geographic data on population density, conflict zones, and natural resources in Syria was not available in tabular format, so we extracted the data from heat maps. Based on color intensity, we were able to estimate numerical values for population density and conflict severity. The Syrian population is concentrated in the West and the North, while the desert is sparsely populated. Generally, more conflict occurs in zones with higher population density. Population density and the availability of natural resources, a critical consideration when building refugee camps, are very closely tied. As a result, population density can be used as a proxy for resource availability.
Given a refugee scenario, the MIP model chooses the locations and sizes for the refugee camps that are to be built. We evaluate our model by a qualitative assessment, as well as by computing the total population served by each refugee camp. We take into account the service level of each refugee camp in the distance part of the objective function, but this suffers from imprecision due to discretization. In order to evaluate the performance of the model, we create Voronoi graphs to assign people to their closest refugee camp.
The remainder of the report is organized as follows: Section 2 reviews relevant literature in the field of refugee camp planning and Section 3 outlines the layout of a camp. Section 4 states the assumptions of the model, Section 5 contains the mixed-integer program model for the Refugee Camp Problem, as well as a method for collecting data and another for evaluating the results of the model. Section 6 presents the results of the MIP model, and section 7 discusses possible improvements to the model. Section 8 analyzes the data and concludes the report.

2 Literature Review

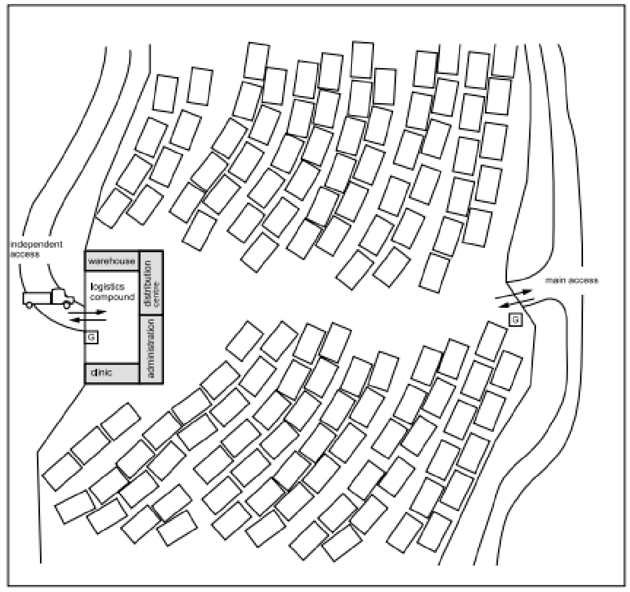
There has been a lot of research on the topic of refugee camps. Some results have become widely accepted as good guidelines such as the UNHCR suggestion to keep camp sizes under 20,000 [9]. In addition to UNHCR reports, there has also been significant research into the entire process of handling refugees including strategies on how to handle such crises, typical layouts of camps, and risk analysis of different refugee camp designs [6].

Cosgrave goes into detail about what factors contribute to refugee camp costs and effectiveness [7]. He discusses the implications of proximity to water and resources as well as safety as it relates to location and camp size. Cosgrave also finds a statistically significant positive correlation between infant mortality rates (which he argues reflect overall camp death rate) and camp size. Based on these results, he concludes that refugee camps should be capped at a size of 50,000.

3 Camp Layout

When considering the layout of the camp, there are certain important factors to consider. Internal security is a vital issue as the refugee camp's purpose is to act as a safe haven for the inhabitants. Therefore, proximity to conflict regions or local communities of differing religious or political views must be considered. However, this is taken care of under our model where proximity to conflict frequency is one of the parameters considered. Furthermore, due to the nature of the crisis, regions of conflict and regions of communities of differing religious/political views can be seen as the same. Although external safety will not be an issue after determining the optimal locations, internal safety will still be. We must ensure protection of the inhabitants from each other; aside from placement of security personnel, vulnerable targets to violence or mistreatment should be placed in visible areas with adequate lighting. Specifically, vulnerable targets include women, who may be targets to sexual violence, or children, who may be targets to fatal accidents due to their size and/or behavior. Therefore, shelters for women and children should be located in areas with more security and visibility. Moreover, it is also vital that they should not travel lengthy distances alone to retrieve supplies as it increases the likelihood of a violent incident. In light of this, distribution centers should not only be located centrally in the camp for ease of access, but specifically, nearer to the shelters containing women and children. This also solves the problem of increasing security and visibility near homes with women and children as the distribution center will be sizable with adequate security and lighting at all times.

Figure 1: Proposed Camp Layout (Source:[6])



Another aspect of internal safety is protection from natural hazards such as fires. Fires in a Syrian refugee camp would most likely be caused by human error. Therefore, it is of utmost importance to design the camp in such a way to slow down the spread of fire between shelters. Several precautions should be considered in the layout of the camp. General recommendations state that the distances between shelters should be twice the height of the buildings. This ensures that the fire will not spread to the other shelter in the absence of wind. Furthermore, fire breakers and a water supply should be set in strategic points in the camp to effectively prevent the spread of the fire. Moreover, shelters should have proper ventilation as smoke is equally dangerous.

It is important to have medical facilities in the camps as well. Despite the possibility of there being hospitals in nearby towns, medical facilities are necessary for emergency needs. One medical facility is needed for every 20,000 inhabitants. For ease of access in case of emergency, the facility should be placed in a central, visible area.

In line with treating medical issues, it is of utmost importance to take extensive sanitary measures to prevent an outbreak. This means a clean environment must be maintained. Dump sites should be chosen to be away from the shelters. Furthermore, each shelter should ideally have one toilet and standing water should be taken care of to prevent infestation [6].

Some factors we do not need to consider for the camp are recreational and educational facilities as it is a short-term settlement for 6 months. Moreover, we do not need to consider possibilities of expansion, again, due to the plan's short-term nature.

Another factor to consider is whether the 100,000 refugees should be displaced in one large camp or in several smaller camps. The answer to this question is arguable as both large and small camps have their advantages and disadvantages. However, simply put, the UNHCR policy recommends keeping camp sizes below 20,000 inhabitants [9]. This is also in line with the fact that one medical facility is required for every 20,000 inhabitants. Using a maximum capacity of 20,000 inhabitants in a single refugee camp, we may also quantify the following: we will need to supply the inhabitants with up to about 10 tonnes of food and about 300 tonnes of water per day. Also, the diameter of such a camp will be roughly 0.6km [7].

To summarize, the characteristics of our camp layout should be as follows:

- Several small camps with maximum capacity of 20,000 inhabitants each
- Assuming there are roughly 20,000 inhabitants, the diameter should be about 0.6km
- We will need to supply up to about 10 tonnes of food and about 300 tonnes of water per day
- External threats must be mitigated by optimally choosing a location far from conflict
- Internal threats must be mitigated through adequate security and proper placement of the distribution center as well as the women's and children's shelters
- Natural hazards, medical emergencies, and sanitary conditions must be kept in check through proper facilities and design

4 Assumptions

The model contains several assumptions. We list the assumptions along with possible scenarios where they may not hold.

Assumption	**Limitation**
Refugees prefer to go to the closest refugee camp.	People fleeing a conflict may prefer to go to a camp they perceive as safer from external threats even if it is farther away.
The percent of people evacuating is the same in each region.	Some areas of the country are safer than others, and may not need to evacuate at all.
Natural resource availability can be approximated by population density.	People prefer to live in areas with sufficient natural resources, but the higher the population density, the more natural resources get depleted.
Keeping the camp size below 20,000 people ensures internal safety.	Smaller camps are easier to police and reduce risk of sanitation issues, but it is unclear what the exact relationship is between size and internal safety.
We cannot build refugee camps for Syrians outside of Syria.	We make this assumption mainly based on political constraints, as we were not sure if the UNHCR had the jurisdiction and/or right to force neighboring countries to host refugees. For example, Lebanon has a strict "no refugee camps" rule (though refugees often find other accommodations [2].
Conflict intensity is constant over time.	The political climate is unpredictable. Areas that are currently safe may become unsafe in a matter of weeks.

5 Methods

Heat Map Processing

To properly model the effect of location on the effectiveness of refugee camps, we determined that two of the most important factors would be population density (Figure 5) and conflict density (Figure 6). To quantify these maps, we first filtered out irrelevant or noisy data like city names, country borders, and bodies of water. We were then left with a heat map of conflict and population across Syria. See Figures 7 and 8 for the filtered heat maps.

We saw that areas with either high population or high conflict had high pixel sums. In order to discretize our graph (to help reduce the size of the space that our optimization model will have to search), we divided our maps into 20-by-20 pixel square blocks. We then computed the average density of each block, thus regions of high RGB values created regions of high density. For conflict density, we have no quantifiable scale (it is just a high to low conflict legend), however, the relationship between total RGB and population density is non-trivial. For the six given colors in the legend, we plotted the associated density vs. the total RGB value to get the graph seen in Figure 11. Seeing a logarithmic relationship, we fit a log-linear model to this data set to arrive at the following relationship:

$$\log \rho = -0.0144 * \mathrm{RGB} + 11.10 \tag{1}$$

where ρ is the density associated with a total RGB of RGB. So, applying this log-linear relationship to the total RGB values in each block, we arrive at the resultant density bar graphs in Figures 9 and 10.

Mixed-Integer Program Model

We present a MIP model for the Refugee Camp Problem, based on the Facility Location Problem MIP model proposed by [3]. The map of the geographic region is discretized into squares, with $\mathcal{L}$ representing the set of location squares. The binary decision variables y_i indicate whether there is a facility in location i, while the binary variables $x_{i,j}$ indicate whether there is a refugee camp in location i serving refugees in location j. P represents the total number of refugees, and p represents the maximum camp size (subject to internal security considerations). For this case study, we use $P = 100,000$ and $p = 20,000$.

The cost can be divided into three components: startup cost, denoted by f, camp size-dependent cost, g, and distance cost, d. Let $p(i)$ be the population density in location i, and let $c(i)$ be the conflict density in location j. Population and conflict density are both scaled to range from 0 to 1000.

The startup cost includes the monetary cost of opening a refugee camp and the level of conflict in surrounding areas. As well, it includes a bonus, represented as a negative cost, for placing a camp in a location with good access to resources, as suggested by population density:

$$f(i) = C + c(i) + \sum_{j \in \mathcal{A}(i)} c(j) - p(i) \qquad \forall i \in \mathcal{L}$$

where $\mathcal{A}(i)$ is the adjacency set of location i. We take $C = 100$ for our model.

The cost that gets multiplied by the size of the camp is given by:

$$g(i) = \frac{\alpha - p(i)}{\beta}$$

where $\alpha \in \mathbb{R}^+, \beta \in \mathbb{R}^+$. The idea is that if $p(i)$ is high, natural resource availability is high as well, so the penalty for placing a camp in location i should be low. Conversely, if $p(i)$ is low (like in the desert), natural resources will be hard to come by, and we should penalize the placement of a camp in location i. Since $p(i)$ ranges from 0 to 1000, we take $\alpha = 1000$ to essentially invert $p(i)$, and take $\beta = 10,000$ so that $g(i)s(i)$ ranges from 0 to 2000.

Finally, the distance between two points is the scaled Manhattan distance $D(i,j)$. The Manhattan distance between two points (x_1, y_1) and (x_2, y_2) in the Cartesian plane is defined as $|x_1 - x_2| + |y_1 - y_2|$.

$$d(i,j) = \gamma p(j) D(i,j)$$

We take $\gamma = 1000$.
The MIP model for the Refugee Camp Problem is given below:

$$\max \sum_{i \in \mathcal{L}} f(i) y_i + g(i) s(i) + \sum_{i \in \mathcal{L}} \sum_{j \in \mathcal{L}} d(i,j) x_{i,j} \tag{2}$$

s.t.

$$\sum_{i \in \mathcal{L}} x_{i,j} \geq 1 \qquad \forall j \in \mathcal{L} \tag{3}$$

$$y_i \geq x_{i,j} \qquad \forall i \in \mathcal{L}, \forall j \in \mathcal{L} \tag{4}$$

$$x_{i,j} + x_{i+1,j} \leq 1 \qquad \forall (i, i+1) \in \mathcal{L}^2, \forall j \in \mathcal{L} \tag{5}$$

$$x_{i,j} + x_{i,j+1} \leq 1 \qquad \forall i \in \mathcal{L}, \forall (j, j+1) \in \mathcal{L}^2 \tag{6}$$

$$x_{i,j} + x_{i-1,j+1} \leq 1 \qquad \forall (i-1, i) \in \mathcal{L}^2, \forall (j, j+1) \in \mathcal{L}^2 \tag{7}$$

$$x_{i,j} + x_{i+1,j+1} \leq 1 \qquad \forall (i, i+1) \in \mathcal{L}^2, \forall (j, j+1) \in \mathcal{L}^2 \tag{8}$$

$$x_{ij} \in \{0, 1\} \qquad \forall i \in \mathcal{L}, \forall j \in \mathcal{L} \tag{9}$$

$$y_i \in \{0, 1\} \qquad \forall i \in \mathcal{L} \tag{10}$$

$$\sum_{i \in \mathcal{L}} s_i \geq P \tag{11}$$

$$0 \leq s_i \leq p \qquad \forall i \in \mathcal{L} \tag{12}$$

$$s_i \leq M y_i \qquad \forall i \in \mathcal{L} \tag{13}$$

The objective function (2) minimizes the cost. Constraints (3) ensure that all refugees are assigned to a camp. Constraints (4) require that if a camp is assigned to a group of refugees, then it will be constructed. Constraints (5) through (8) prevent camps from being constructed in adjacent zones. Constraint (11) ensures that the demand of all the refugees is met, while constraints (12) limit the size of each camp. Finally, constraints (13) ensure that refugees will only go to open camps. (M is an arbitrarily large number, taken to be $100,000$ in our case.)

Cost Model

To estimate the cost of building a proposed solution to this problem, we look at historical data on setup costs. In 2014, a \$63.5 million refugee camp that has a capacity of 130,000 was built in Jordan for Syrian refugees. Linearly extrapolating this amount, we get an average cost of \$448 per refugee. We can use this approximation so long as our camps have size within an order of magnitude of 130,000 since the majority of the setup cost will involve building costs per refugee [4].

As for the ongoing costs, we see that a Syrian refugee camp in Jordan that hosts 100,000 people costs \$500,000 per person per day to operate [5]. This gives us an average cost of \$5 per person per day over the next 6 months. Since all of our refugee camps will be in Syria, we convert this number using Syria's CPI (about 33) and Jordan's CPI (about 55) so our final operational cost will be $\frac{33}{55} \cdot \$5 = \$3$ per person per day [10].

Evaluating Model Performance

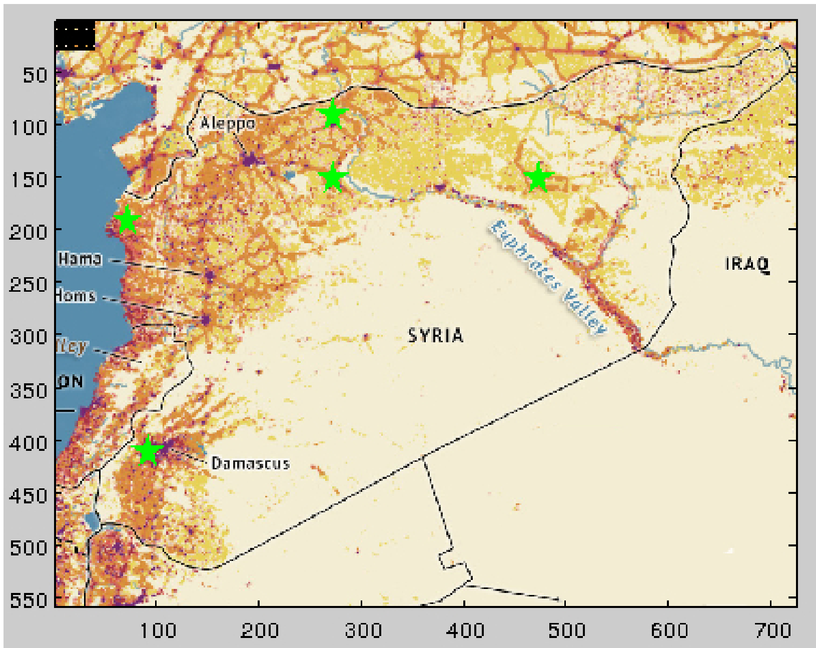
To evaluate the performance of our model, we look at where the camps are located relative to population centers and area of conflict. This is a sanity check to make sure that our model doesn't predict a camp distribution that is dangerous or impractical (like setting up a refugee camp in the middle of the Syrian Desert).

To do this, we look at a Voronoi graph (Figure 3) of the camp location vs. the map of Syria. A Voronoi graph partitions the image into regions based on distances to the nearest camps. So, for example, the closest refugee camp to anyone in region D is the camp site in that region (roughly at coordinates (250, 150)). This lets us gain some insight into which locations of Syria that each camp serves (i.e. locations from which a camp receives refugees) while also qualitatively assessing how well our model performs. We can also see where our model places refugee camps relative to centers of conflict (Figure 4). This lets us evaluate how safe the areas around refugee camps are.

6 Results

In this section, we present and evaluate the results of our MIP model. Data extraction from heat maps and model evaluation were done in `MATLAB` and the MIP model was created using `JAVA` 8 with `GUROBI` 6.0.

Figure 2: Refugee Camp Locations On Syrian Map (green stars denote camp locations) (Map Source: [8])



We see that our model puts the refugee camps at a safe distance from any serious conflict (see Figure 4). Also, since we have the population densities for each location on the map of Figure 3, we are able to compute an estimate of how many people each camp serves (assuming refugees go to the closest camp). We do this by summing all the densities in each region giving totals of:

Camp	Refugees Served
A	32,676
B	23,489
C	11,737
D	20,483
E	11,614

Figure 3: Refugee Camp Locations with Voronoi Graph of Population (Map Source: [8])

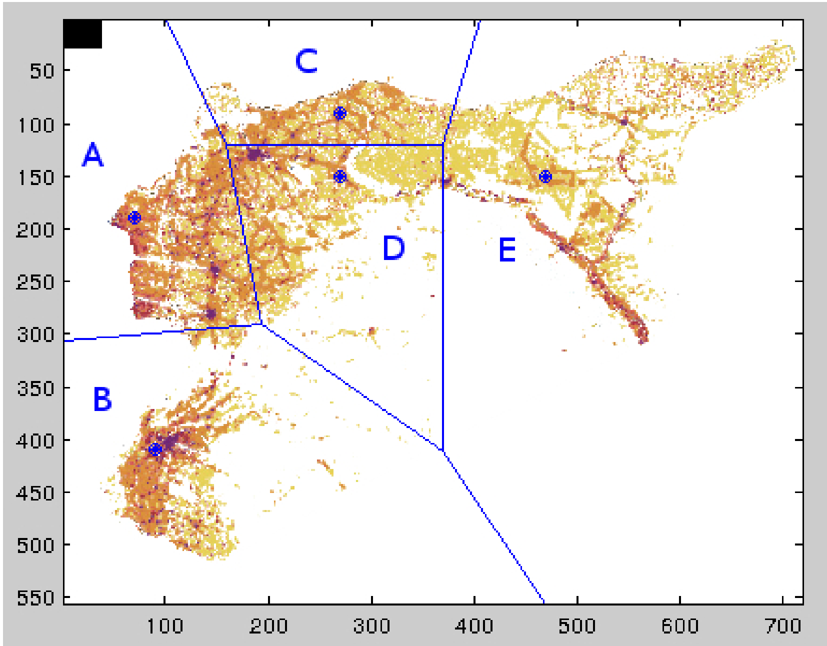
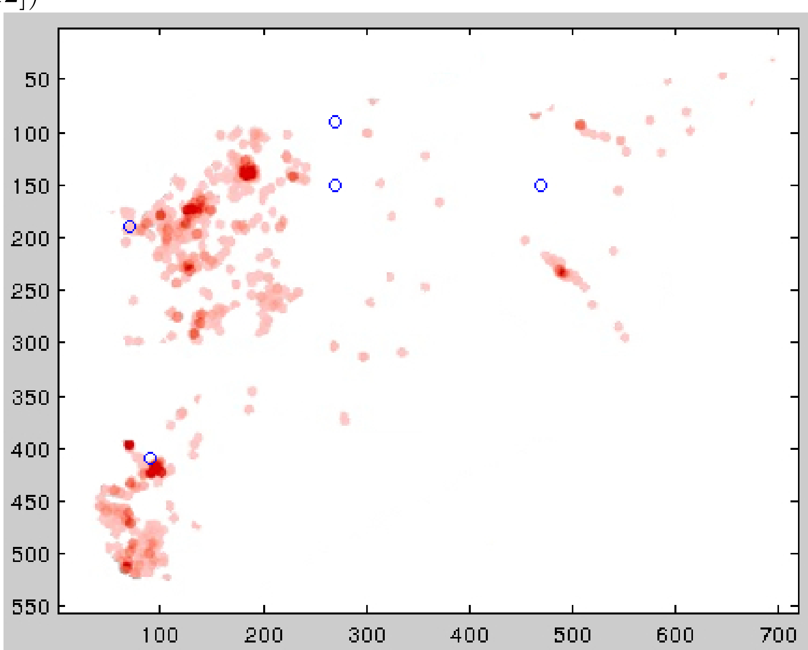


Figure 4: Refugee Camp Locations and Conflict Areas (blue circles denote camp locations) (Map Source: [12])



A nice fact about these proportions is that they are all within a factor of three of one another. This means that the camps are distributed in such a way that each camp services a roughly even proportion of the incoming refugees.

One slight oddity in our resultant camp distribution is how close camp B is to Damascus. Our initial intuition led us to believe that the camps would be located far away from large cities since they often see the most violence. However, it seems that the benefits of having a camp near a big city out-weighed the safety concerns. Such benefits include:

- Proximity to major transportation networks
- Proximity to food, water, and other supplies
- Service to many more people who seek refuge

The major disadvantage is clearly safety. Having a refugee camp near such a major center of conflict make external threats much more likely than separating the camp from the fighting.

Finally, we also arrive at an estimated cost for building all of this infrastructure and ongoing costs. Since our model outputs a 5-camp solution in which each accommodates 20,000 people, our setup cost is

$$\frac{\$448}{\text{person}} \cdot 20,000 \frac{\text{people}}{\text{camp}} \cdot 5 \text{ camps} = \$44,800,000$$

And our ongoing cost for the next 6 months is

$$\frac{\$3}{\text{person} \cdot \text{day}} \cdot 100,000 \text{ people} \cdot (180 \text{ days}) = \$54,000,000$$

So our estimated total cost will be \$98,800,000.

7 Improvements

There is much room for improvement on our model, ranging from seeking better data to adding more factors. A certain improvement would be to get actual population and conflict density data for Syria rather than inferring this data from heat maps. A lot of precision is lost by translating these discrete pixel values to continuous densities. Given more time, we could have discretized our maps far more finely, thus improving the precision of our results.

As for our Mixed-Integer Program model, we could have added more factors. We made several assumptions such as availability of natural resources being highly correlated to population density. If we had more time, we could have created a more in-depth model for availability of resources. Additionally, we could have looked into developing a more robust model of external safety, especially how proximity to conflict affects safety. Likewise, another improvement would have been a way of accounting for sanitation and other related issues and how they affect internal safety.

Our cost model is quite simple; it just consists of two linear models for setup and ongoing costs. This leaves a lot of room for improvement by perhaps considering locational cost dependence and more fine-grained costs.

8 Conclusion

This report outlines a plan for constructing short-term refugee camps in Syria to accommodate the estimated 100,000 imminent refugees. We introduce the Refugee Camp Problem, which is based on the Facility Location Problem, and propose a MIP model to choose optimal camp sizes and locations. The solution to the MIP model was to place five camps around the North and West of Syria. Four of these camps were located far away from high conflict areas, while the fourth was located close to Damascus, a large city with high conflict. This illustrates a tradeoff between the risks of placing a camp near a high-conflict area and the benefits of placing a camp near refugees and in close proximity to natural resources. The model is evaluated by constructing a Voronoi graph, which is used to determine the number of people that would travel to each camp location, assuming refugees choose the closest camp. The Voronoi graph can also be used to instruct refugees where to go, allowing camps to be kept at predicable sizes.

References

[1] *UNHCR: The UN Refugee Agency.*

[2] *Quick facts: What you need to know about the Syria crisis*, 2015.

[3] M. Balinski, *50 Years of Integer Programming 1958-2008*, Springer Berlin Heidelberg, 2008, ch. 6.

[4] M. Berger, *This is Jordan's Newest and Biggest Refugee Camp For Syrians Still Fleeing The War.*

[5] N. Colgrass, *Life for Syrian Refugees, at 500K a Day*, 2013.

[6] T. Corsellis and A. Vitale, *Transitional Settlement: Displaced Populations*, Oxfam, 2005.

[7] J. Cosgrave, *Refugee Density and Dependence: Practical Implications of Camp Size*, Disasters, 10 (1996), pp. 261–270.

[8] Geopolitics Weekly, *The Geopolitics of the Syrian Civil War.*

[9] S. Lischer, ed., *Dangerous Sanctuaries: Refugee Camps, Civil War, and the Dilemmas of Humanitarian Aid*, Cornell University Press, 2015.

[10] Numbeo, *Cost of Living*.

[11] L. Rodgers, D. Gritten, J. Offer, and P. Asare, *Syria: The story of the conflict*, 2015.

[12] SNAP, *Estimated Areas of Control as of 30 April, 2015*, 2015.

Appendix

Figure 5: Population Heat Map Across Syria (Population Density Map) (Source: [8])

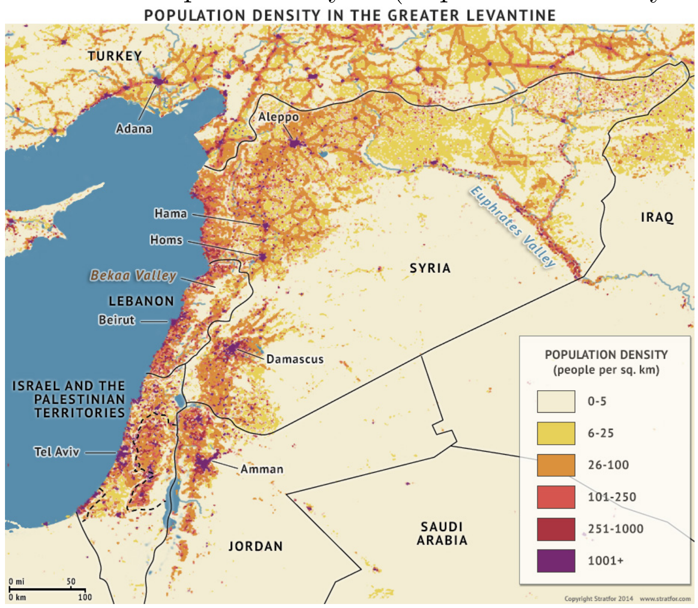


Figure 6: Conflict Heat Map Across Syria (Conflict Density Map) (Source: [12])

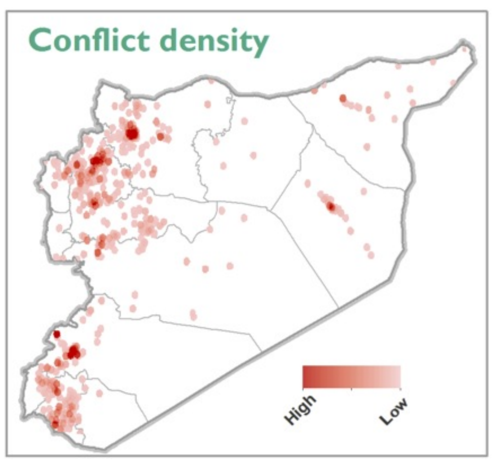


Figure 7: Filtered Population Heat Map Across Syria. Darker colors represents areas of high population density. (Map Source: [8])

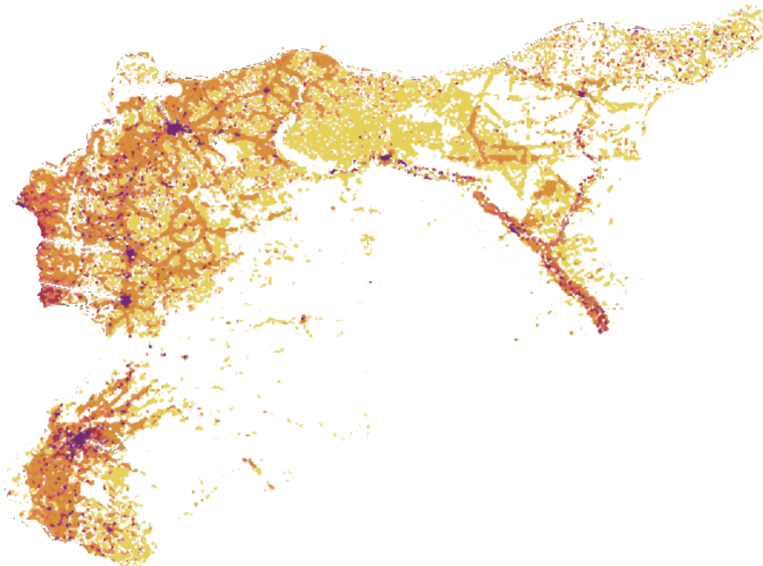


Figure 8: Filtered Conflict Heat Map Across Syria. Darker red represents areas of high conflict. (Map Source: [12])

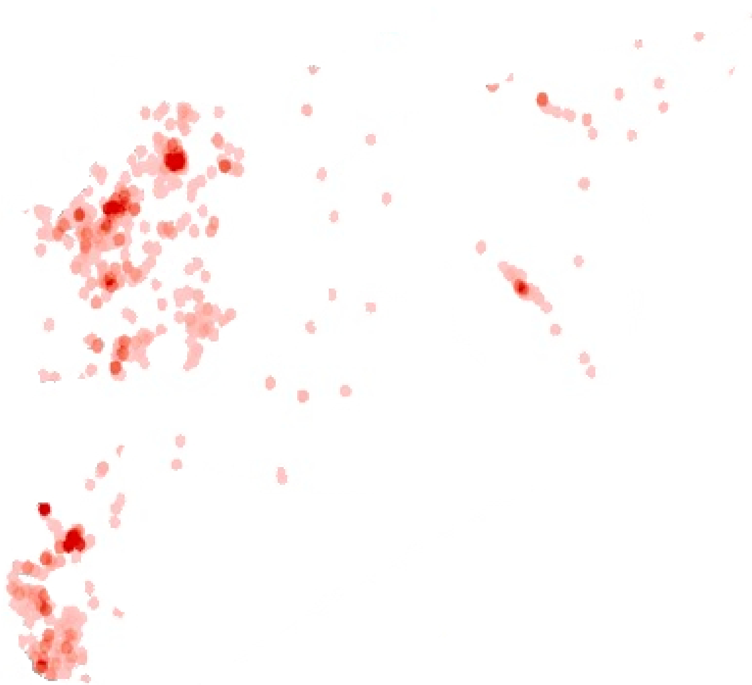


Figure 9: Population Density Across Syria. Areas of high population density are indicated by taller bars. Also, note that the coordinate 1,1 corresponds to the top left of Figure 7. (Source: [8])

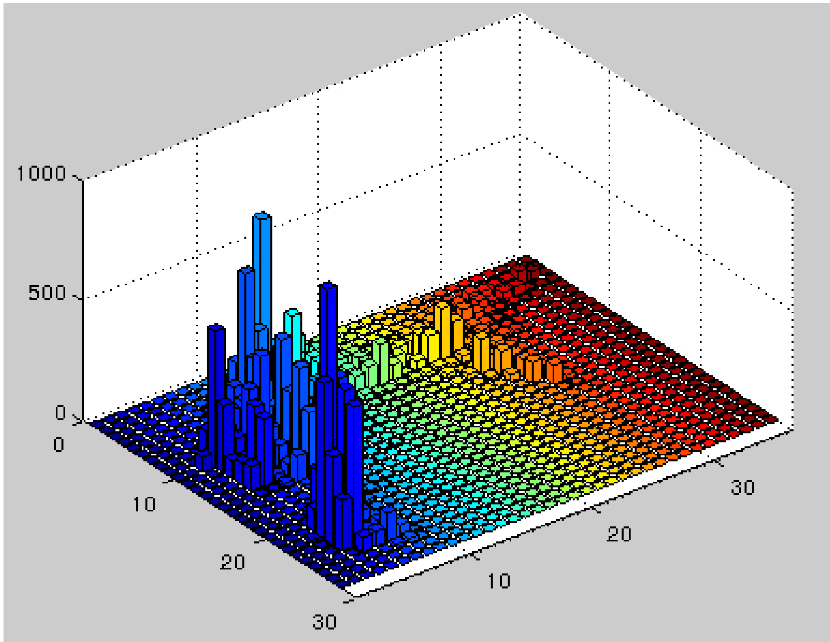


Figure 10: Conflict Density Across Syria. Areas of high conflict density are indicated by taller bars. Also, note that the coordinate 1,1 corresponds to the top left of Figure 8. (Source: [12])

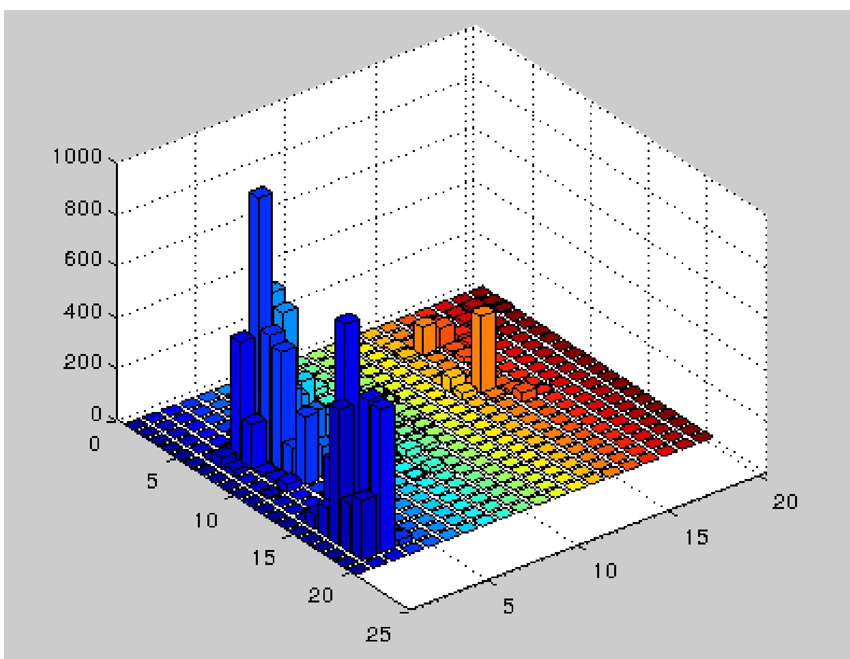


Figure 11: Log-Linear Relationship of Population Density vs Total RGB. $\log \rho = -0.0144 * \mathrm{RGB} + 11.10$ with $R^2 = 0.98$.