Using GIS to Predict Human Movement Patterns in Complex Humanitarian Emergencies: A Test Case of the Syrian Conflict

by

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To Michael Campbell and Topher Campbell,
thanks for sticking with me through this process.

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List of Abbreviations

GIS	Geographic information system
GISci	Geographic information science
SSI	Spatial Sciences Institute
USC	University of Southern California
CHE	Complex Humanitarian Emergency
NGZ	No Go Zone
HRC	Human Relief Chains
WAB	Web App Builder
PLO	Palestinian Liberation Organization
IDP	Internally Displaced Persons

Abstract

There are Complex Humanitarian Emergencies (CHE) happening worldwide. Currently, 68.5 million displaced persons exist around the world resulting from these CHEs. This project seeks to develop an Arcpy script for predicting movements within these crises to help government and non-government agencies manage resources. This project is intended to predict large-scale flows of people to allow agencies to prepare for an influx of displaced persons and organize shelters, food, clothing, medical personnel, and other necessities. ArcPy within ArcGIS Pro will give non-trained users an easy format to view spatially relevant processes and information about the CHE that they may be unable to share with the public. Additionally, this project looks at theoretical models of human movement that are most relevant to the circumstances of the CHE and should help speed communication between GIS and non-GIS professionals. This project uses the Syrian refugee crisis as a test case because of the large-scale movement and long duration involved.

Chapter 1 Introduction

A Complex Humanitarian Event (CHE) is an event, such as a natural disaster, war, or man-made disaster, that leaves people in crisis and in need of humanitarian efforts and relief (Pakes, 2008). Disasters are becoming more frequent and stronger, wars are global and are lasting longer, and droughts and economic instability are causing harsh conditions (Coleman, 2006). These increasingly severe events are extending the impacts of CHEs to an increasing number of people as the world's population continues to grow (Hall, 2017). Many of these events require that impacted individual's basic needs are met. A few examples of such needs include safety, medical services, food, shelters, clothing, and clean water. As the spatial and temporal scale of a CHE changes, so too do the needs of those impacted. Someone who is affected by a hurricane may need a week's worth of supplies, while those leaving during a regime change may need supplies and support for several years.

There are 68.5 million forcibly displaced persons (FDP) worldwide; this includes 40 million internally displaced persons (IDP), 25.4 million refugees, and 3.1 million asylum seekers (UNHCR, 2017). These numbers do not include the approximately 10 million stateless people who have been denied any nationality with associated rights and protections. Over half of FDP are children. A recent report stated that one person is displaced every two seconds (UNHCR, 2017). The FDP crisis is not a small problem. Often it is assumed that refugees leave their homes for a short time and then return to them. That is not always the case, as the average time a refugee is displaced is 19 years (Xu, 2015). Many refugees are forced to leave their home country and live permanently in other countries, while others return to their country of origin but are not able to return their city of origin. Some organizations feel that if a refugee does not return to their original home, that it is a failure (UNHCR, 2008).

It is essential, however, to consider that many people do not live in their original homes their entire lives. Therefore, it would be more appropriate to determine a situation a success if the life of refugees can be or has been improved. This project serves as the first step in developing a set of tools to aid in the return or resettlement of FDP and IDP citizens by providing support information for decision-makers. This project does not intend to solve the entirety of the problem, but to provide aid to those who are working on the problem.

1.1. The Syrian War as a Test Case

In 2011 violence in Syria began; it is a continuation of the protests associated with the Arab Spring and the start of a civil war within the country (Britannica, 2017). The longevity, visibility, and the number of people affected are the reasons this CHE was chosen as a case study for the project. This CHE also involves a large number of refugees who are both internally and externally displaced. When this conflict began in 2011, people moved away from their homes in response. At first, they traveled short distances to neighboring towns or to stay with family, but soon they were traveling further and leaving the country. There was and continues to be bombs and guns; even hospitals are targets (Shaheen, 2017). Situations like the Syrian CHE leave decision-makers and refugees with many questions that need to be addressed. Where will these people go? What will happen to them once they arrive? Will there be food, clothing, toiletries, a place to sleep? Will they find work as doctors or engineers? Can their children finish their university studies? Figures 1 and 2 show photos taken four years after the violence started in Syria. These people have left with what they can carry and made their way to France. However, France was unprepared for the influx of refugees and asylum seekers (Holmes, 2016), despite being a first world country with many resources. Of course, there are other things at play such as politics, but if France had been prepared, it is possible that the policies would have been very different.

Figure 1 Refugees on the streets of Paris. (AFP Photo/Nimani, 2015)

The recent response to refugees by many countries legitimizes these questions. Many times, refugees are not welcome in both their home countries or new countries where they seek refuge. Why? Simply put, refugees are challenging, because they have needs like food, shelter, sanitation, and medical attention. In addition, they are perceived to have no positive impact on the host countries.

Figure 2 Refugees walking from France to Croatia (AFP Photo/Francois Guillot, 2015)

Preparedness could have been the difference between French citizens gaining a few neighbors and tent cities developing along major streets. Figure 2 is a photo of people leaving France attempting to find another country to provide assistance. This departure from France is a further loss for them after losing everything to the ravages of war. Violence and natural disasters continue to increase in severity and frequency, resulting in a world now grappling with a crisis of how to better respond to the vast humanitarian need.

1.2. Motivation

This problem affects people. It is fundamental to recognize the needs of these people and how to provide for them. Many times, women and children make up the majority of those who are migrating, and they are the most vulnerable group (Jahngiri, 2012). Unfortunately, some governments have not prepared for women because they do not want the experience to be “too comfortable” with the risk of the women choosing to remain in the host country instead of returning to their home country. These “comforts” include avoiding sex trafficking, rape, prostitution, successive pregnancies, unwanted pregnancies, STD’s, and many other atrocities (Gasser 2004). It is not only imperative to have food and water available for evacuees and refugees but also to provide safe places. Medical teams who can assess the needs of women who are often pregnant or with small children are needed in these areas, but the medical expertise is not always accessible. CHEs are traumatizing experiences for everyone involved. It is an important part of the assistance effort that people trained to respond to traumas are available (Newnman 2016).

When a CHE happens, whether it is long-term like a war or short-term like an earthquake, there will be an economic impact. An estimated 2.5 million jobs were lost due to 9/11 around the United States as a whole, not just in New York. (Sullivan, 2003). After a recent earthquake in China, people in affected impoverished areas took jobs in other parts of the country unaffected by the earthquake. While some of these people commuted, others moved and changed to the new locations. This earthquake had an economic impact for at least two years past the initial CHE (Yuan, 2016).

From all of this, the primary motivation for this project is to assist in reducing the suffering of these people. Many of them, especially children, are vulnerable. This project, and future ones like it, are intended to aid those on the ground and those in government positions in making decisions that will be beneficial and compassionate.

Chapter 2 Literature Review

2.1. CHE Planning and Response

There are three main phases to a CHE; (1) pre, (2) during, and (3) post. The timing of these stages can range from predictable to spontaneous and from a few days to years (Williams, 2017; Hu, 2016). Because of these differences in the timing of stages, responses to CHEs vary as well. In some areas, like the southeastern United States, hurricane season is an annual event, in which CHE of this type has a warning period. The consistency of the CHE allows planners to prepare for these events year-round and focus on how, when, and why people evacuate (Yin, 2014). Agencies involved in hurricane preparation know that not everyone will evacuate, so they must prepare to respond during the incident. One method of preparation is to place supply depots along possible evacuation routes in case people essential supplies while evacuating both during and after the storm (Lodree, 2009). When planning for these stations, it is crucial to know which routes for people will remain accessible and what locations along these routes are the best places to establish supply depots. GIS has been used to create predictive models that include areas where streets are no longer accessible (Horner 2011). The 2018 hurricane season for North Carolina was particularly rough. Two hurricanes, Florence and Michael, affected the state in succession, an example of how subsequent events can have compounding effects on a CHE.

There are CHEs other than natural disasters that can be anticipated, allowing for necessary planning and preparations to be made. The European Union (EU) foresaw the current Syrian refugee crisis that started in 2014 and preemptively established a fund for 2014-2020 to help resettle refugees within Europe. These resources, along with domestic aid, were meant to offset costs associated with the predicted influx of refugees. The money was partially successful, but significant border closures limited the ability to apply the funding in a meaningful way.

(Newnham 2016). The timeframe for the fund is not complete, so it will be a few years before analysis will allow for an actual discussion of its effectiveness. Unfortunately, even when there are new settlements and people can relocate there are many other stressors involved. Many people in these situations do not feel that their lives have any worth other than contributing to the success of future generations (Yako, 2014). In Canada, the city of Toronto prepared for refugees by using GIS-based site suitability to find the best areas to resettle refugees. The criteria used included access to affordable rent, language classes, employment opportunities, and schools. In this example, decision-makers chose outcomes that benefited both the refugees and established citizens of Toronto (Vaz, 2016).

In contrast, Lebanon was opposed to refugee camps from the Syrian crisis within its borders due to recent historical events. Lebanon has become the home to many Palestinian refugees who live in camps. These camps are now mostly controlled by the Palestine Liberation Organization (PLO). This has created an environment where Lebanese police cannot safely enter (Dunne, 2017). The loss of control is in part due to the continuation of the camps over an extended period and no attempt by the government to integrate Palestinian refugees into Lebanese society. As a result of this experience, Lebanon has officially closed and restricted its border with Syria. However, people are still fleeing into the country, and the lack of preparation prevents both illegal and legal immigrants from finding work or housing. One result of this lack of preparation and development is unsanctioned tent cities in fields or along roads. In addition, this has resulted in a non-working population who are draining the resources of Lebanese citizens (Sanyal, 2017).

While it is helpful to predict and prepare for a possible event, during a CHE it is essential to know how to aid people who have immediate needs. In the past, it was almost impossible to have instant information about what was happening and where. Social media has provided unparalleled access to near real-time information. Both Twitter and Flickr are a great way for emergency professionals to find out what is happening, where it is occurring, and even how severe the situation may be. Twitter was especially useful in response and circulation of essential information during Hurricane Sandy. This hurricane was one of the largest on record when it struck the US northeast, including areas, like New York City, where there are large numbers of Twitter users (Yoo, 2016). Semantic searches can insert results into a GIS-linked database (Zhang, 2017), further connecting the nearly instant information from social media to the necessary response professionals.

The post-CHE phase is a complicated time. In some cases, such as a storm or earthquake, the first two stages can last for a short time, but the post period can last much longer. The first 72 hours are critical, and humanitarian relief chains provide needed food, clothing, diapers, formula, and other supplies (Tofighi, 2016). Medical care, with a particular emphasis on psychological and trauma care, are among the necessities to assimilate into a new life or return home (Newnman 2016).

Because these situations are complex; the pre, during, and post needs and methods are sometimes mixed. The Toronto relocation study happened during the pre-phase, before the arrival of refugees, and the actual relocation occurs post arrival. In the during and post CHE phases it is important to respond with sufficient supplies. Adding to the complexity, sometimes there are waves within a CHE, especially in the case of war. There may be days with no fighting, in which there will briefly be a post phase as people leave and a pre-phase as organizations plan for the next influx. Due to the ever-changing conditions of these situations, it is vital for experts to have information readily available during all phases of the CHE.

2.2. Collaboration

Both synchronous and asynchronous communication have become part of everyday interactions. Blogs, forums, Skype, Twitter, online education, and other media allows communication regardless of geographic location and time. A person can comment on a blog written five years ago or talk “face-to-face” with a coworker in a different time zone. Many types of collaboration are essential to this project because it is rare that all stakeholders and parties can be in the same location. There are generally several stakeholders addressing a CHE, and in order for them to collaborate and efficiently respond, they need to be able to communicate quickly and precisely from various locations and settings.

2.2.1. History of Collaborative Software

Research and companies have made a variety of shareware and groupware also called Computer Supported Cooperative Work (CSCW) systems products to facilitate collaboration, for both synchronous and asynchronous communication. One of the goals of CSCW is to allow the computer not only to solve problems, but aid in human interaction to solve those problems (Ellis, 1991). Types of collaboration can be sorted into four main categories as shown in Figure 3.

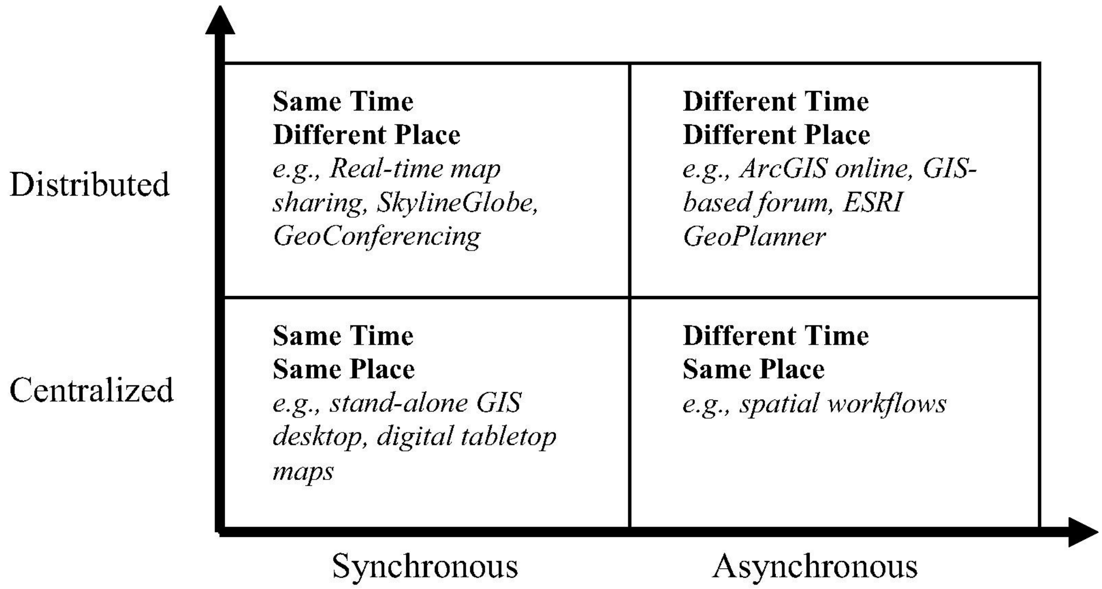

Figure 3 Time and location classifications (Armstrong, 1993; Sun, 2016)

One of the problems with early collaborative software was turn-taking. Turn-taking is when the file is accessible to multiple users, but only one active user is permitted to edit the file at a time (Sarin,1988; Greenberg, 1990). In an attempt to solve that problem, “locking” was used (Stefik, 1987). “Locking” allows users to “lock” only the sections they were actively working on while letting other users edit within the same file. The “lock” allowed multiple users to work on the same file, but not in the same sections of that file. Operational Transformation (OT) allowed users to each have a copy of the file and then send updates to other users’ files. The establishment OT allowed users to work on the “same” file simultaneously and give updates periodically (Ellis, 1989). In the mid-2000s Google introduced Google Docs which allows users to edit and comment on the same document simultaneously. Since then, there has been an expansion in CSCW programs that allow for simultaneous, document sharing, and manipulation as well as video conferencing.

2.2.2. Collaboration within GIS

At the start of GIS collaboration attempts, many GIS were added into current CSCW software or used in conjunction with that software. An example is GroupArc (Churcher, 1999) which used GroupKit, an existing CSCW and Arc/Info to allow collaborators to visualize spatial topics while discussing and collaborating in real time. A problem with this approach was that every collaborator needed to have a copy of the software downloaded to their computers. Having multiple copies is problematic because it can be cost prohibitive as well as challenging to maintain updates. Another project in this era was Spatial Group Choice (Jankowski, 1997) which used the CSCW version of Microsoft Windows for Groups and Group Choice with ArcView 2. The limitations here are similar in that each collaborator needed to have access to all of the software and operating systems in order to share information.

As the internet advanced, so did GIS collaborative platforms. Researchers not only wanted to have collaborations on the same documents, but they also wanted it to be synchronous. A primary goal of future programs was to facilitate a way for all collaborators to see what the other collaborators were seeing. One of these platforms, called GCC_CONNECT, was explicitly created to aid in crisis management or CHEs (Cai, 2005). This platform had a similar goal to this thesis, allowing collaborators in different locations and capacities to be able to make decisions using available the data quickly. However, the majority of the work presented for this software was focused on developing a multi-user, shareable architecture with the ability to share geographic analysis. There are also other challenges such as bandwidth availability and connections which may limit the number of people available to participate in the collaboration.

GIS is currently addressing the lack of a collaborative medium with the use of changing technologies. Desktop GIS applications are still needed and very useful, but GIS has branched out into both internet and mobile apps (Maguire, 2006). However, many of the desktop GIS functions allow for rapid prototyping of new applications, which makes developing new collaboration methods a multi-stage process involving desktop, online, and mobile GIS. Currently, interactive GIS-based products are frequently used, finding location-based weather, directions, traffic information, travel plans, dinner options.

2.2.3. Challenges in Collaboration

There are currently two main collaborative challenges in GIS as a field: (1) expertise exchange between fields of study and (2) the lack of collaborative mediums (Schafer, 2005; MacEachren, 2005). GIS exists as a field in its own right; however, many projects within the field pair with other areas of research. Often within collaborations, participants share some degree of knowledge between the involved fields without being an expert (McGee, 2007).

Other inter-field collaboration issues include differences in semantics, metadata, and methodologies. GIS experts and hospital workers sometimes have problems relaying information due to a lack of uniformity. Granell discusses that during a health outbreak, even within the same type of organization, such as hospital to hospital or county to county, there are often different methodological approaches (2014). There are different organization levels, EMT, hospitals, health agencies, and citizens working to create the best outcome. Minimizing confusion is an essential aspect of collaboration (Granell, 2014). As large amounts of accessible data held in geoportals and geodatabases data become available, the metadata and the keywords (semantic search) should be standardized to avoid difficulties when searching for data. Agencies should create a standard for metadata that is required. Enforcing data consistency reduces data redundancies that occur when users duplicate datasets that already exist, but cannot be easily found (Hu 2015).

One of the primary purposes of this project is to give non-experts within the GIS field a tool that they can efficiently use. Although Google Maps uses GIS elements at its core, like digitization, photogrammetry, and satellite data, few untrained people recognize this component. Instead, they merely type in their destination and wait for directions, utilizing a GIS without noticing. Ideally, this system will allow for seamless collaborations in which the user does not need to understand the background GIS processes in order to use the system effectively.

2.3. Networks and Agent-Based Modelling

Where, why, and how people will move is a question that geographers have tried to answer for years. Tobler's First Law of Geography states that things that are closer are more related than those that are farther apart (Tobler, 1970). The friction of distance states that the further something is, the less likely someone is going to go there (Mayhew, 2009). For instance, a person is more likely to shop at their neighborhood grocery store than at a grocery store hours away.

Within the CHE, users who help people, whether in the pre, -during, or post time periods, want to make sure during all stages of the event that the most amount of people are safe and that supplies are available quickly. One of the ways to ensure this is modeling how, why, and when people will either evacuate, migrate, or shelter in place during a situation. Agent-based modeling is one way to study active systems and the individuals within the system (Kelly, 2003). Some of the factors that determine behavior are family size, economics, transportation availability, and education levels (Yin 2014). For instance, a wealthier family is more likely to evacuate early and stay at a hotel outside of the range of the hurricane, whereas poor minorities are likely to go to a shelter or stay in their homes. However, knowing where people will go isn't the only reason for agent-based models. Disease is often found at refugee camps and the ability to predict an influx of disease can aid in prevention and management (Crooks, 2014).

2.4. Current Response Methods and Collaboration

For CHE response teams, both civilian and military, the term “field” means anywhere the disaster is happening, this can vary in size depending on the size of the CHE. The field is often defined by where the CHE is not, or where life starts functioning normally (Arziman, 2015). Forward teams go ahead of the main group to asses medical and supply needs. They also look for ways to mitigate further adverse health effects. Usually, these teams are small, the Australian Disaster Response forward teams (AUSMAT) consist of 1-4 civilians (Robertson, 2011). These forward teams then report back to their organizations, NGOs or government, to report what they have found so other teams can be organized and mobilized. Besides forward teams, other response teams are found in the organizations, whether NGO or government, and these teams are grouped into clusters. These clusters function to ease communication roles between members of teams. Inter-organization coordination and communication is essential but can be complicated when there are many people involved. Lack of communication can result in loss of life and resources (Kaynak 2014). The US has adopted the Incident Command System in 1970 for all disasters. This system relies on the deployment of intervention teams, which consist of planning, logistics, security, and finance persons. Each team uses a single command structure with a limited, manageable scope of control. For instance, the security person oversees security, and they are the one making all the security decisions (Arziman, 2015). Figure 4 gives an overview of the command structure.

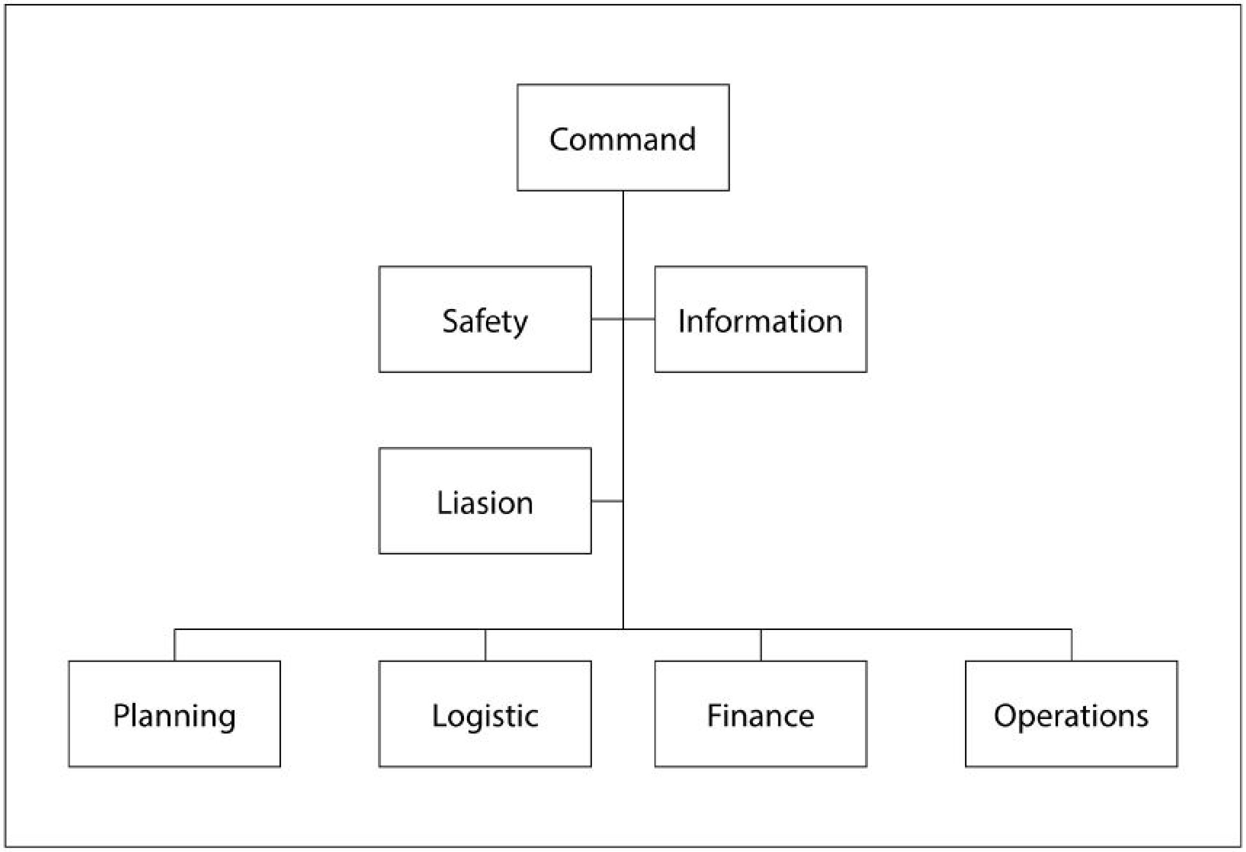

Figure 4 Command Flow Chart (Arziman 2015).

This project works well for these small groups as well as larger ones that follow. The small groups can benefit from having a map of predicted areas of interest. They can go to those locations and then asses the needs of future larger endeavors. They can also relay information back about more possible locations that can be run through the simulation.

Chapter 3 Methodology

3.1. Research Design

This project is intended for use at the organization level, rather than providing a route for individuals trying to leave a situation. The targeted organizations for this application include both government agencies, such as FEMA, departments of health and human services, and non-government /humanitarian organizations like the UN, UNICEF, and Red Cross/Crescent. The primary purpose for this project is modeling movements of people as groups for agency response, not for individuals to map a safe route.

3.2. Platform Selection

The selected platform for this project has a list of four criteria that need to be met in order to be useful to the targeted organizations. The first criterion for a successful implementation of this project is that the platform needs to be consumed by an audience that has a wide range of GIS expertise. Any outputs from the project need to be accessible not just to the analyst producing the results, but to a broader audience involved with planning and preparation of sites for incoming people. To accomplish this the resulting analysis needs to be available as a web-based display. The second criterion is that the platform needs to have enough processing power to run multiple spatial calculations and maintain the integrity of the resulting datasets. The third criterion is that the cost of modeling movement must be low. Since the events can happen quickly and affect a large area and number of people, it is important that the modeling and any possible reassessments can happen at low cost in both time and money. The final criterion is that the platform should be robust, with current support systems in place and future support expected for the foreseeable future. Four different platforms, Google Maps/Earth, ArcGIS WebAppBuilder (WAB), ArcGIS GeoEvent Server, and ArcGIS Pro were examined using these four criteria.

Google Maps/Earth were considered together as a possible platform for the project. The main appeal for using Google Maps/Earth for this project is their common usage among the general population. The outputs from either part of the Google platform are formats that are easily shared with many collaborators and allows for an integration of data from multiple users as either inputs or outputs. However, the Google platforms fail on the second criterion in that they do not have enough spatial processing power to run the analysis in a way that can incorporate the individual data sets into a single output. Google does pass on the remaining two criteria, as many of the functionalities are free and support for both Google Maps and Google Earth is expected to continue for some time.

The next platform that was considered for this project was WAB. Since this platform is a web-based, highly flexible and customizable tool; it had much initial appeal as the primary platform for the project. It passes the first criterion in that it can be made available to a broad audience and has a customizable interface that allows non-GIS users to interact with the model in a natural way. WAB almost passes the second criterion. While WAB can easily handle each individual calculation, at the time of its testing, it had trouble combining multiple tools or widgets. In order to run the project through WAB both the buffer and overlay widget needed to be run at the same time, which was not possible during the initial testing. WAB does not pass the third criterion of cost. Many of the widgets and performing spatial analysis using WAB consumes credits. While some credits are included as a part of annual licensing of Esri software some of the processes that were run started to increase as the project expanded in scale greatly. Since to goal of this project is to provide a tool the users could run over an unknown number of days/weeks/years any credit cost would limit the usage of the project. This may be resolved with Esri's program for non-profits which offers cost-saving measures (Esri, 2018). WAB has a lot of support and development currently occurring and so passes the fourth criterion, and future versions of this model may be converted to WAB as processing costs decrease and functionality increases.

The third platform, GeoEvent Server appears to meet all of the criteria listed above, however, due to personal logistics and local internet firewalls, this platform could not be operated remotely. I did not have access to a local version of GeoEvent Server, but it is anticipated that this platform will be a viable option for future projects.

ArcGIS Pro was selected as the platform of choice because it manages to meet all four of the criteria needed for successful implementation. ArcGIS Pro allows for direct export of maps to ArcGIS Online, so any results from analysis can be directly shared with collaborators. The maps from ArcGIS Online can even be embedded into HTML code for access across any type of webpage. ArcGIS Pro has extremely flexible spatial analysis capabilities through the use of ArcPy Python scripting. ArcPy allows for almost every functionality within ArcGIS Pro to be coded into Python scripts, which can be run either within ArcGIS Pro itself or through a separate Python interpreter. ArcGIS Pro also passes the third criterion of cost as many of the target organizations for the project either already have ArcGIS Pro available or can get the software for government or non-profit pricing considerations. ArcGIS Pro is also currently under full support and development from Esri as the future replacement of the current desktop software and thus passes the final criterion.

3.3. Data Sources

This project is the development of a proof of concept model that in future stages will incorporate live data streams. In order to show the success of the model, a data set was compiled of recent real events from Syria from multiple web-based sources. These events range from January 2015 to April 2018 and include over 550 individual events that are potential triggers for forced migration. Included in this data set is the date and location of the event, if violence or death occurred during the event, and finally the source of information for the event. Also, weather data from the National Oceanic and Atmospheric Administration was compiled from the same time frame for all weather stations in the nearby area. The weather data includes the location of the station as well as the recorded maximum and minimum temperatures and any precipitation. The data is available daily for the time frame of the project. The final initial data source was obtained from ArcGIS online and includes a Digital Elevation Model of the area around Syria and the land borders of the surrounding countries. This data was gridded to 750-meter resolution and is used as the primary source of slope and landcover calculations to aid in understanding the overall topography of the study area.

3.4. Methods

3.4.1. Travel Method

The model examines the likelihood that individuals will walk a set distance from an event location over the course of a week. Walking was chosen because it is a travel method that is available to almost everyone and can be used when access to a vehicle is not possible, practical, or safe. The development of events in Syria has shown that walking is an important travel method for these types of events, as individuals have walked to refugee camps and cities throughout Europe. Several drivers to the distance individuals will walk were added in, including the distance to the nearest refugee camp, slope, water, weather, and level or type of violence. Any of the variables that do not change from a day to day basis were precalculated beforehand as described in section 3.4.3. Travel likelihoods are calculated on a daily basis for up to seven days to give planners an idea of how quickly refugees will be arriving in the area.

3.4.2. Justification for ArcPy scripting

One of the greatest strengths of using scripting through ArcPy is the added flexibility to incorporate the many tools that already exist within ArcGIS toolbox. Initially, the project was intended as a series of interconnected tools within ArcGIS Model Builder, with a focus on the Least Cost Path and Weighted Overlay tools. However, these tools can only use raster data, and each daily iteration must be entered manually. This significantly reduced the efficacy of the tool for this study. The Raster Calculator only works for iterations within ModelBuilder works if the file name remains the same and can run with live/ changing data. ArcPy scripting allows for customization and a combination of tools and outcomes with logical if statements. This was used to make weights that were then added to the Raster Calculator.

3.4.3. Preprocessing

Using ArcGIS Pro three pre-processing rasters were created. These files are created before running the Python script because the information from these calculations remains fixed throughout the study area. The first of these files is a binary file raster file used as a mask to exclude large bodies of water from the final calculation. The second file is a raster that calculates the distance to the nearest relocation camp over the entire study area. This raster is then reclassified to an inverse ordinal ranking system based on days of travel (1-7) to the nearest relocation camp, to indicate a travel preference toward places of safety. This variable is considered a "pull," indicating a preference to travel toward locations of perceived safety. In this case, both internal and external refugee camps were used to create the raster. People are more likely to go to places they feel are going to be safe and have supplies. Figure 4 shows the location of the camps, while Figure 5 shows the weighted raster. The final raster is a travel likelihood raster based on the ease of travel over the terrain based on slope. This calculation uses Irmischer's travel model to calculate the travel velocities over the study area. The travel velocities (given in m/s) are used as a proxy for ease of travel, with the assumption that people trying to leave in a hurry are more likely to choose terrain that is easier to travel. These values are then converted to dm/s in order to provide equal mathematical weight with the distance to camp calculation. Initially, Tobler's law was used to calculate the terrain's ease of travel. However, Irmischer's travel model (Irmischer 2017) was used instead (Figure 6). Irmischer compares his results to that of Tobler's and provides results that are more accurate. This method also divides the predictions by gender. For this project, the travel model of males over uneven terrain was used. The project goal is to see when people will start arriving at the relocation camps. Men are usually faster than women; in addition, women are usually traveling with children or groups which would be considerably slow their progress. Other groups such as the elderly and disabled were not accounted for because again, they would be moving much slower.

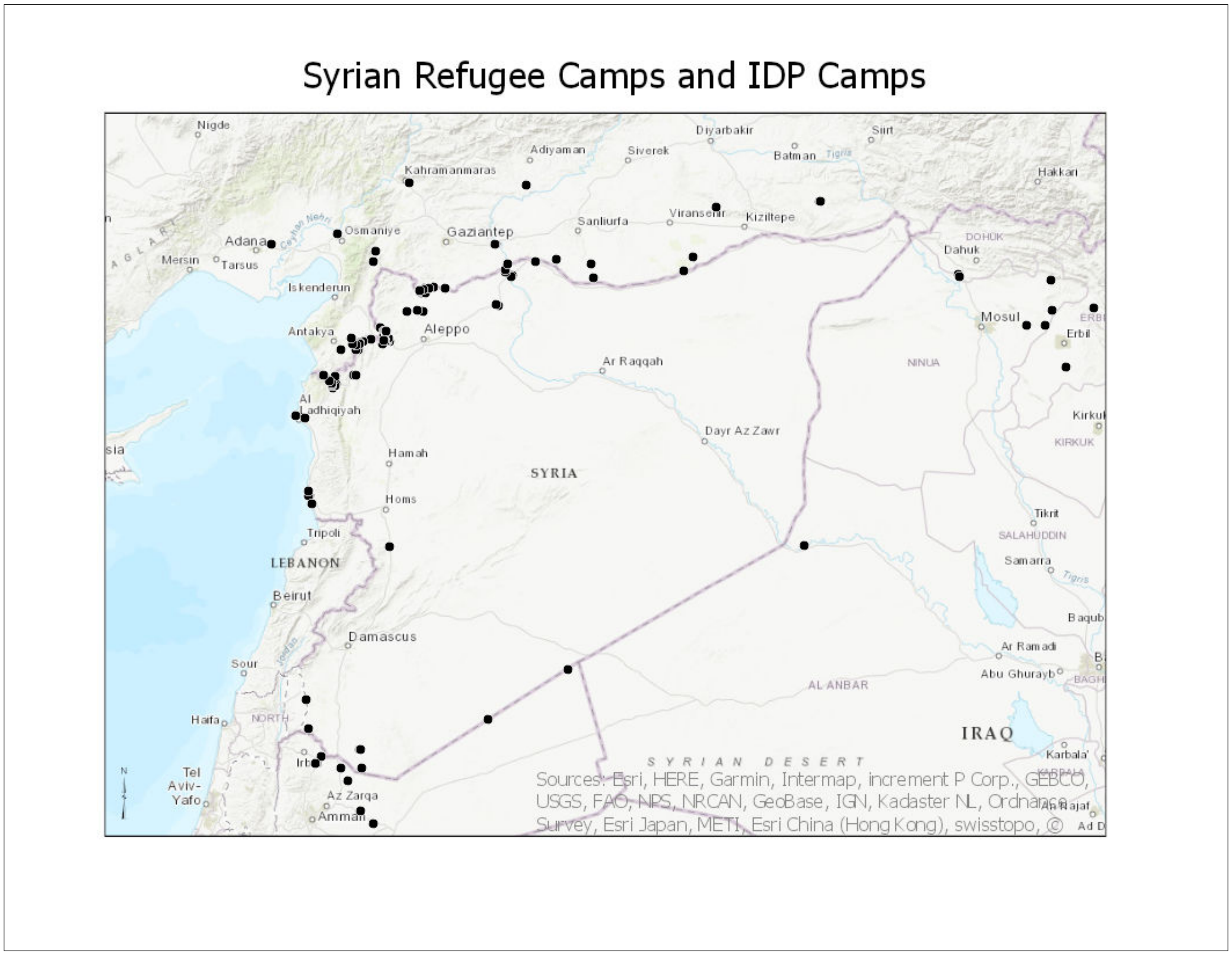

Figure 5 Location of refugee camps and IDP camp

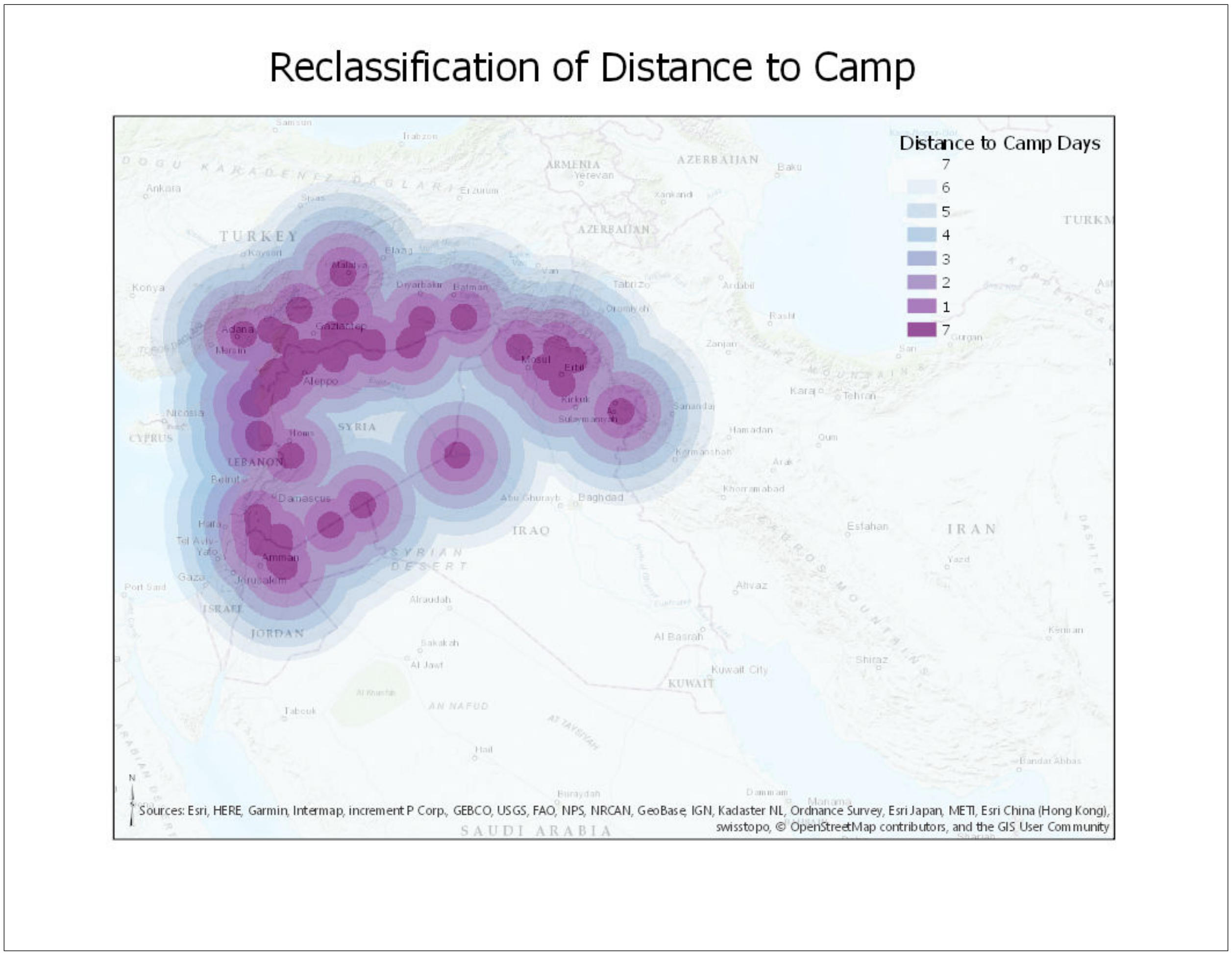

Figure 6 Distance to the camps, weighted by linear distance

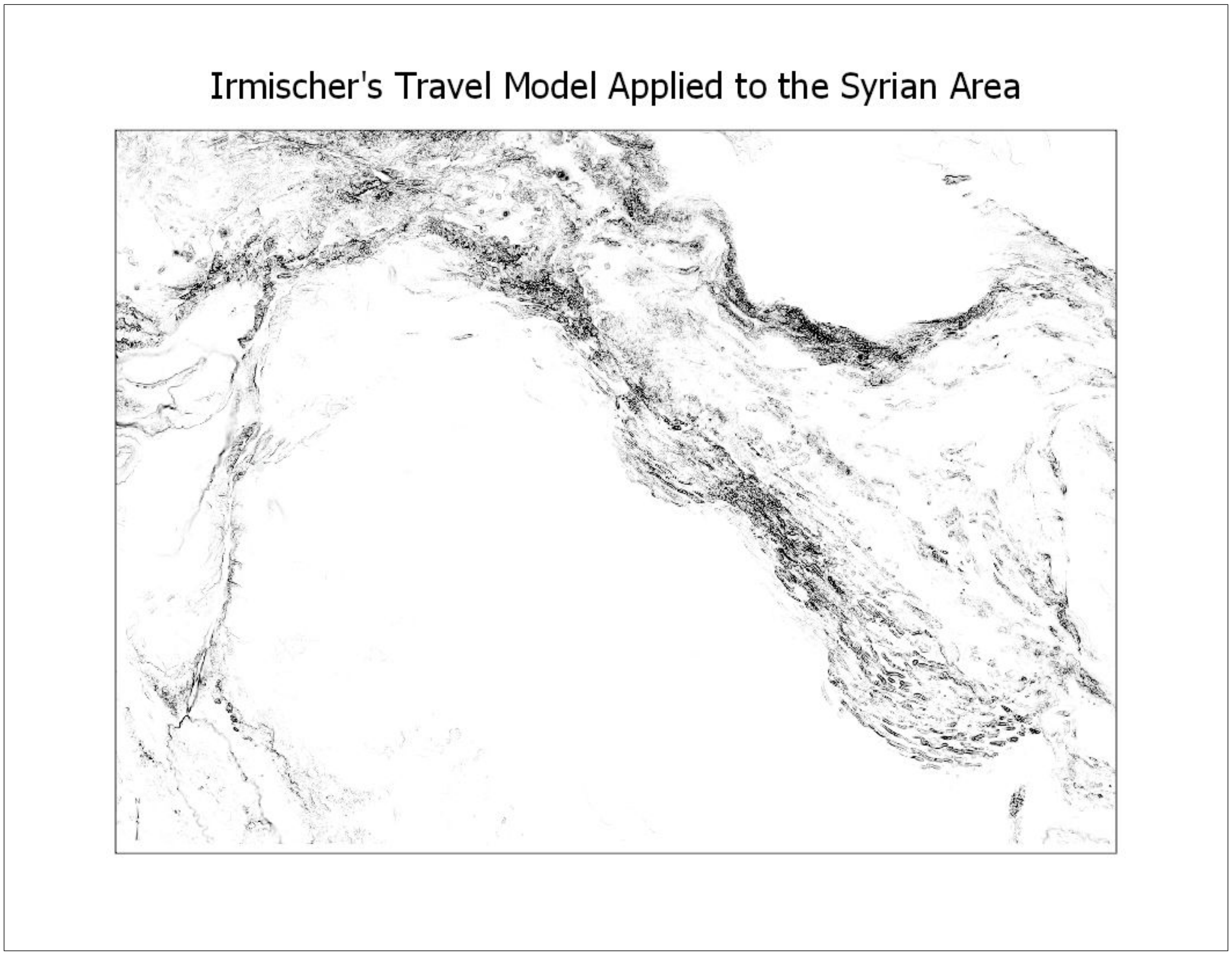

Figure 7 Irmischer travel mode applied to the Syria and surrounding areas

3.4.4. Python Script Process

The Python script has several stages that are linked together to perform the overall model calculations. The first step is to read in the data sources to define the variables used in the calculation. The defined variables include two feature classes and three raster datasets. The two feature classes are point features that define the event and the weather conditions for the day of the event. In order to simplify the project, these features were separated from their respective data sets for the full-time period. The three raster datasets include the previously run calculations for land coverage, slope, and distance to camp. In addition, the output data location needs to be identified before running the script.

The second process defines the travel weights to be used in the model. First, the weather feature class and event feature class are combined using a Spatial Join of the nearest weather station to the event. This creates a single file with both the violence level of the event and the current weather conditions. These inputs are used within a conditional statement to determine what the daily travel distance will be. The first set of variables considered are violence related. A binary query is established for violence yes/no and death yes/no. Not all events are violent such as protests, just as not all violence-related events result in deaths. These queries are ranked to determine how far people will travel following an incident. Protests, while indicative of social unrest, don’t warrant mass exodus and thus people who leave are less likely to travel as far. However, some people may choose to leave at this point. When violence and death occur, more people are likely to leave and will travel further. This project does not quantify the level of violence or death only if the event is violent or deadly.

The next variable is the weather. This proved to be the most complex of the variables and determined considerably the methods used. The parameters for this variable were, precipitation, heat, and cold. Precipitation included snow, rain, or hail in any recorded amounts. Heat was determined as anything over 95° F or 35° C, and cold was determined as anything under 32° F or 0° C. These temperature extremes would make travel more difficult. The temperature range proved to be the most difficult parameter to incorporate into the analysis.

The next step is a series of logical queries to determine the distance that will be traveled each day. The default daily travel distance is set to 16 km based on how far a healthy person can walk without distance training (Bumgardner, 2018). This default distance is then modified in the case of violent (18 km) or death (20 km) events, or negatively modified due to a high maximum temperature (14 km), a low maximum temperature (12 km), or precipitation (10 km). This distance is then set as the buffer distance in the Buffer tool and used in an iterative loop modeling the next seven days of travel. This buffer is then converted to raster format (Feature to Raster). Additionally, a fixed value is added to the raster based on if the event is either non-violent, violent, or if death is involved. This factor will be used as a part of a predefined colormap to indicate likelihood of people leaving.

The final step of the calculation is to use map algebra to combine the modeled travel distance with the land classification, travel model, and distance to relocation camp rasters. This step is contained within the iterative loop and applied individually for each day. This final raster is then converted to integer values to provide an ordinal classification and to allow for the addition of a fixed colormap (Add Colormap). This colormap contains a set of pre-coded classified coloring system to ensure that the data outputs are consistent. The colors chosen are to represent a scale of threat similar to what is seen at airports and other security areas. The full code is available in the appendix.

The calculated results are then automatically displayed as a map. All seven days are in individual rasters. These can then be exported in a variety of ways, however, for this project, a web map in the form of a StoryMap was chosen. A StoryMap was chosen because it is already in the format to accept the map and non-expert could easily update it.

Chapter 4 Results

Three events were chosen based on location, level of violence, and precipitation levels. Event one is in the city of Aleppo, Syria and took place on July 28, 2016. This event was non-violent, and there was no death for this event, but there were tensions and changes in rebel and terrorist organization structure. There was no maximum temperature recorded that day, and the minimum temperature was 68 F or 20 C. There was also no precipitation recorded. The green color ramp in figure 8 reflects the event being of interest, but no violence or death.

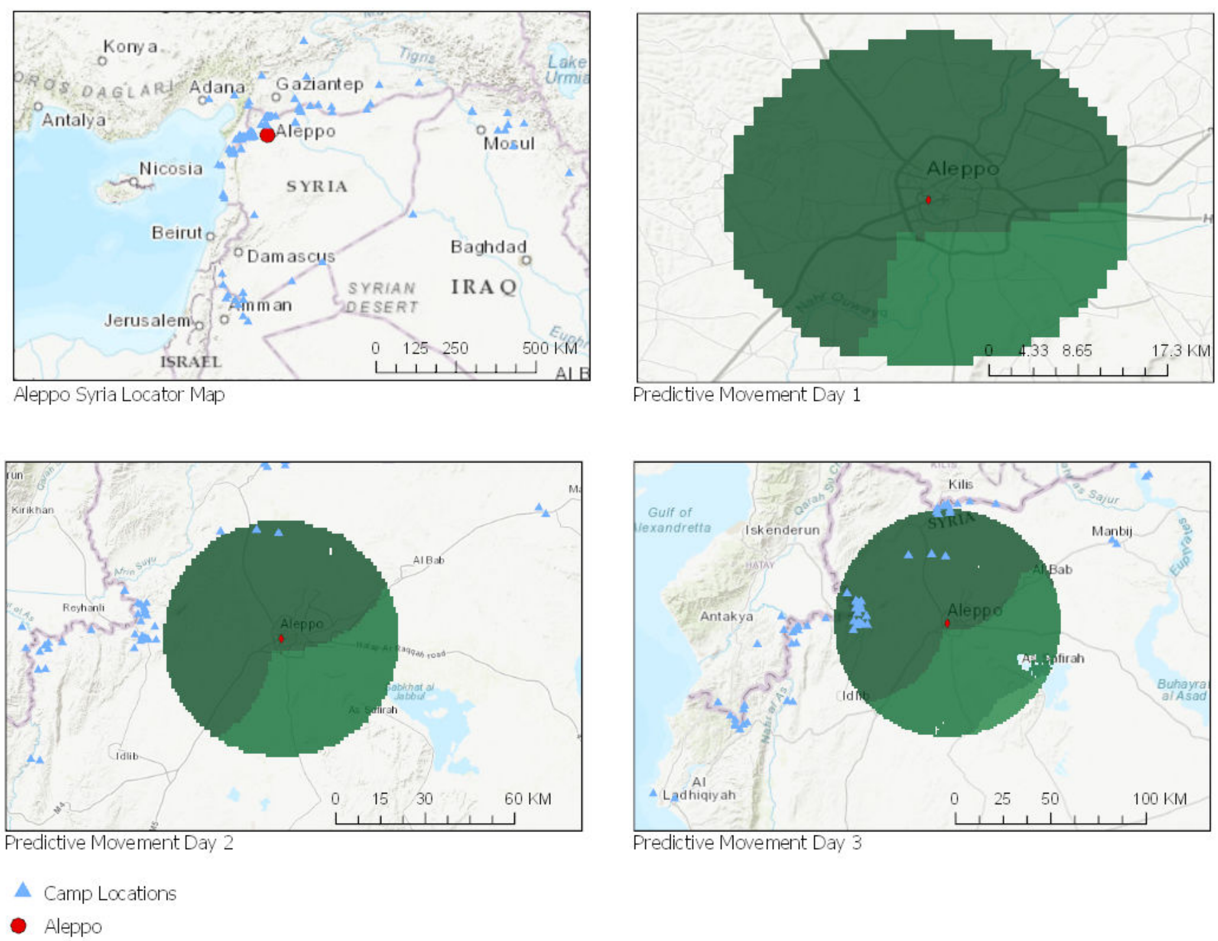

Figure 8 Predictive models for days 1-3 and a locator map of Aleppo

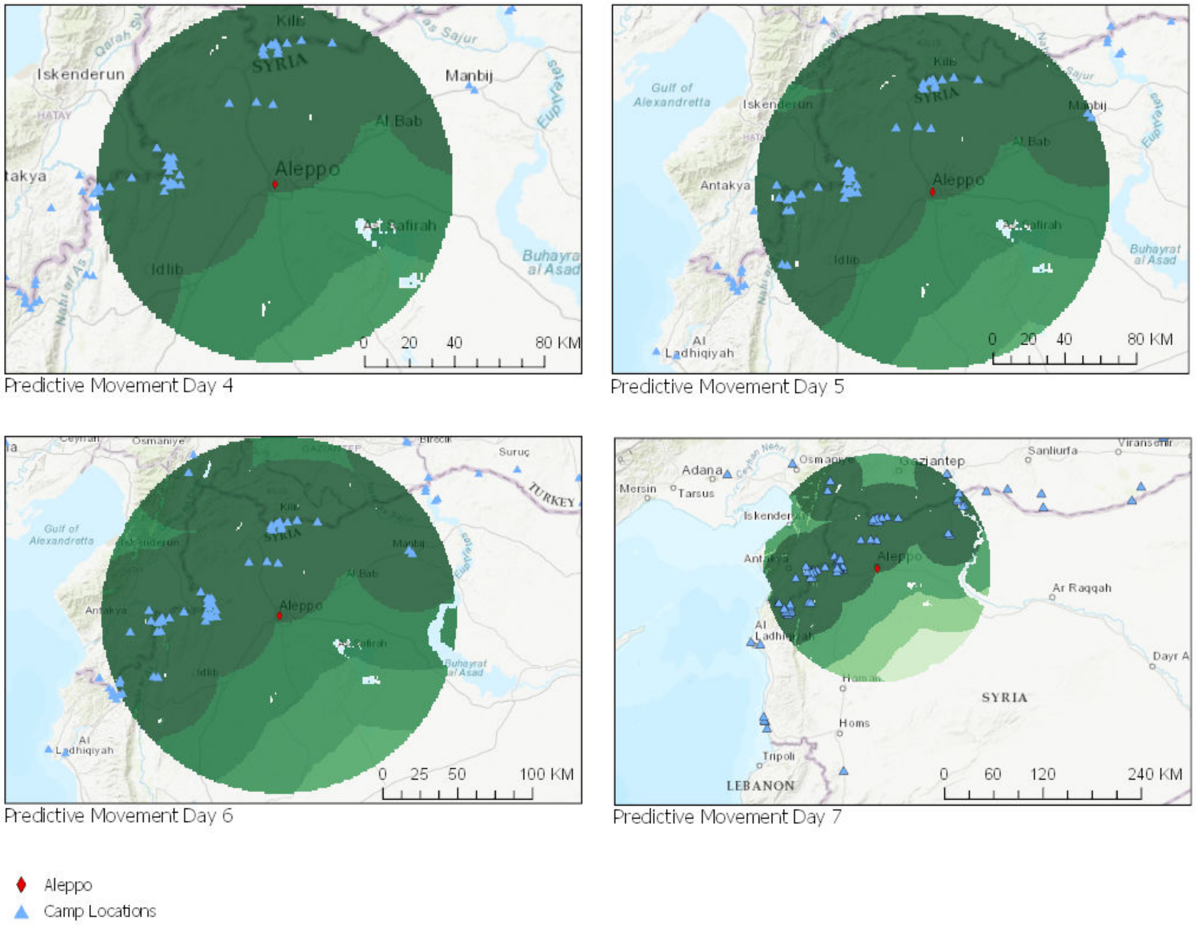

Figure 9 Predictive models for Aleppo days 4-7

As noted in figures 8 and 9, the darker the color more likely people will move in that direction. The blue triangles are the camp locations, both internal and external. The darkest areas are around the camp location bands.

The next event located in Harasta on June 18, 2017. The maximum temperature for that day was 97 F or 36.1 C, and no minimum temperature or precipitation was recorded. This situation had violence, rebels fired on aid workers, but no deaths were reported. The orange color ramp reflects the violence, but lack of deaths reported. The results are displayed in Figures 10 and 11.

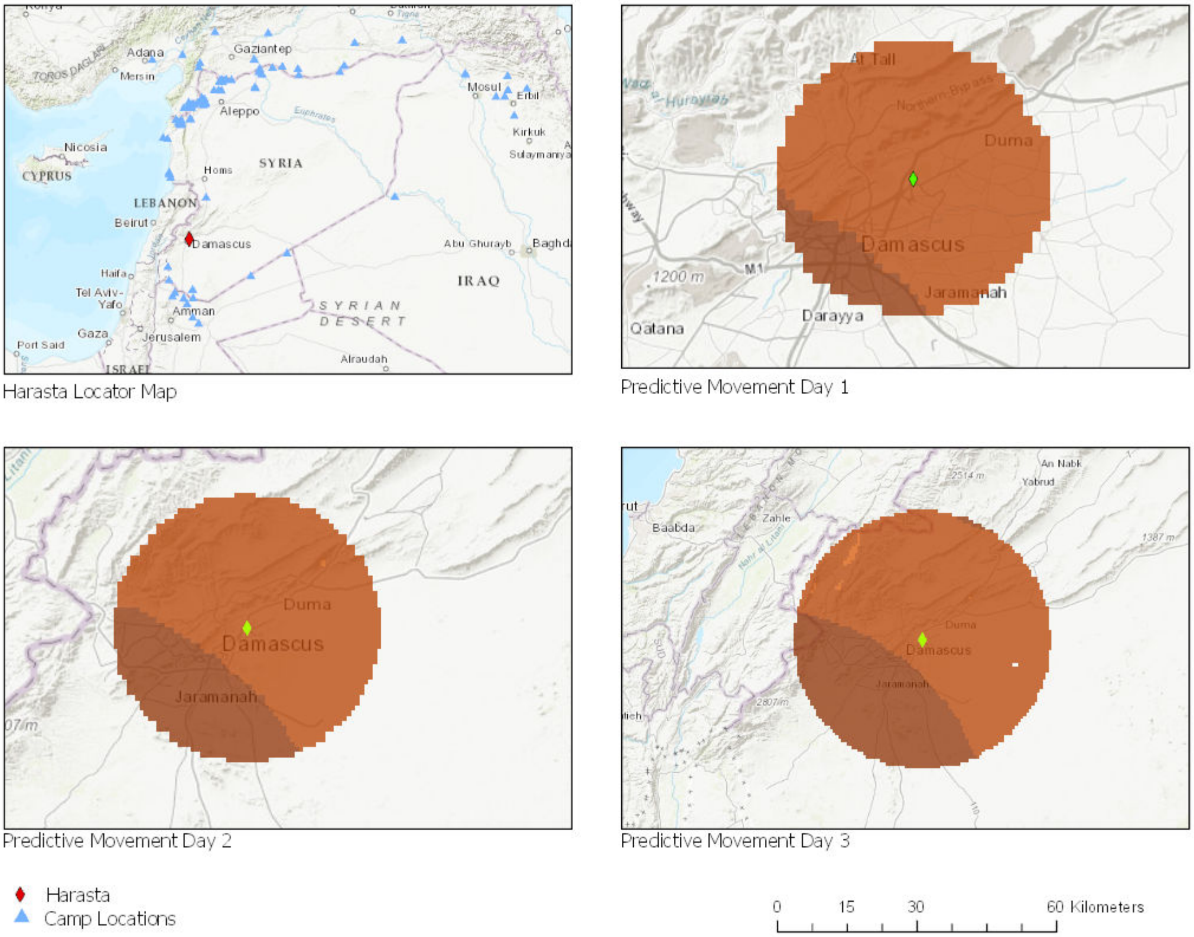

Figure 10 Predictive models for days 1-3 and locator map of Harasta

In Figures 10 and 11 once again, the darker the color are the areas that people are more likely to go. The buffer ring is smaller on this set of maps than the other two events. The reason for this is that the temperature was higher than the determined more manageable temperature. However, the darker areas indicate that travel is more likely toward the camps, which cannot be seen until maps from days 4-7.

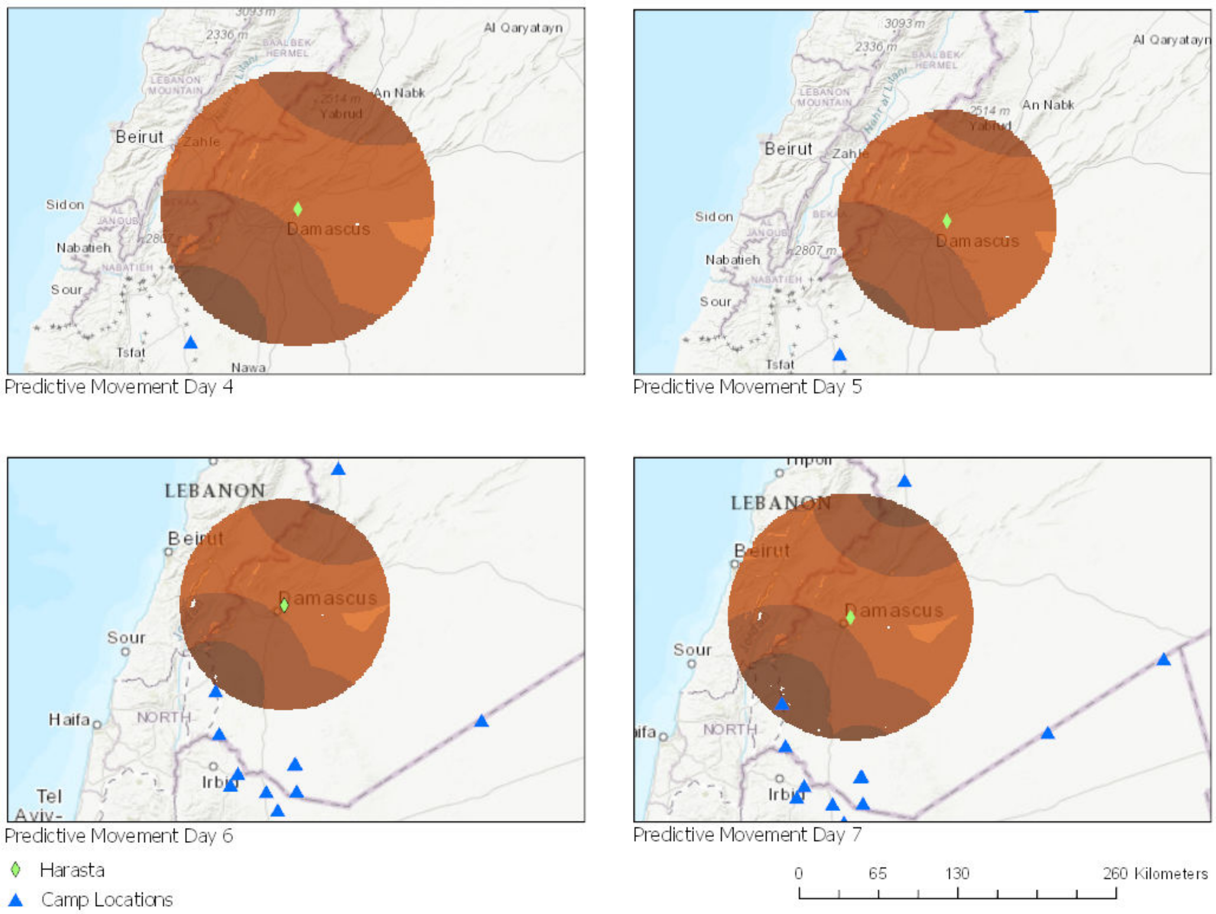

Figure 11 Predictive models of Harasta days 4-7

The third event, pictured in Figures 12 and 13, took place in the city of Flaita on January 2, 2015. This event was both violent and deadly as rebels were engaged with terrorists. The max temperature was 58 F or 14 C, no minimum temperature or precipitation was reported.

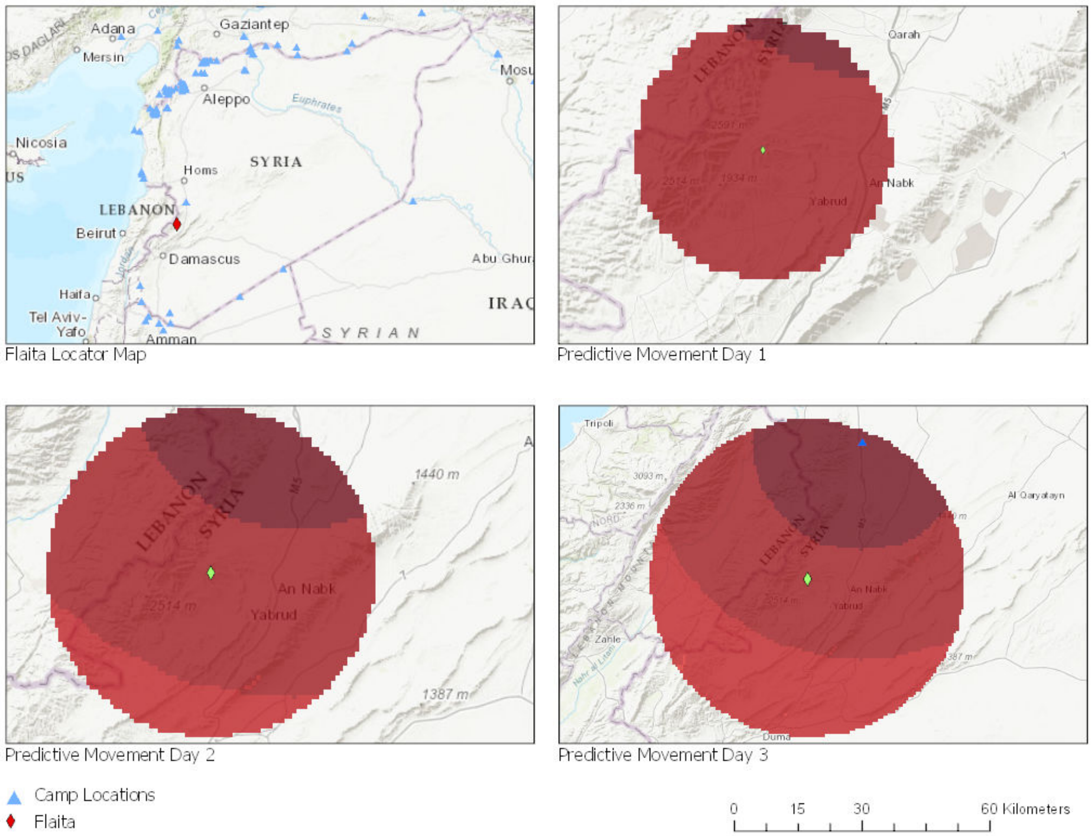

Figure 12 Predictive models for days 1-3 and locator map of Flaita.

Again, in Figures 12 and 13 the darker the color, the more likely the people are to go to that area. The darker color goes again towards the camps which can be first seen on Day 3. This buffer ring is slightly larger than the other ones. This is because death was involved which increases the rate at which people would leave.

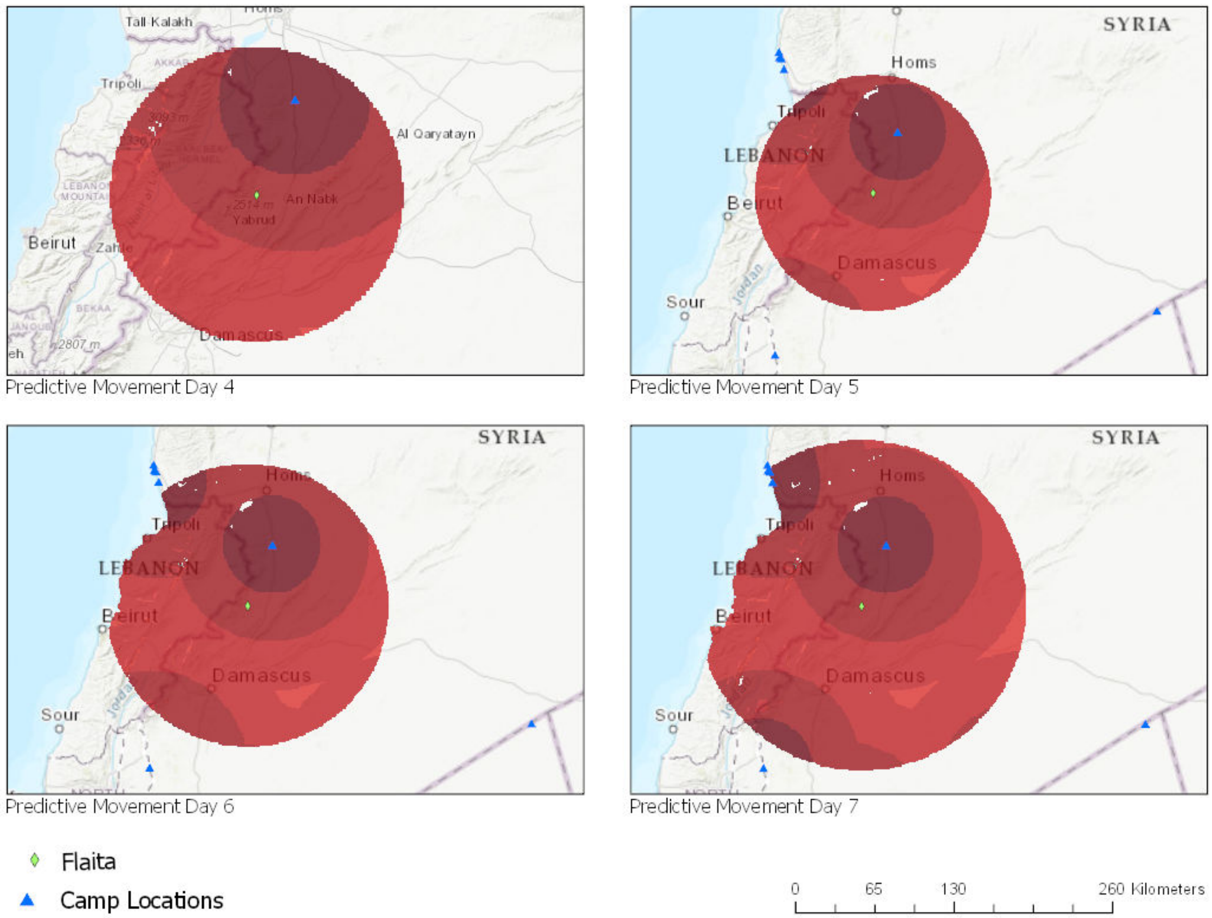

Figure 13 Predictive models of Flaita days 4-7

The maps can then be shared as a webmap and added to any number of platforms. Chosen for this project was Esri's StoryMap. This is for ease of adding information by anyone with editing rights. Also, it already is compatible, and the user can easily select maps to add to the StoryMap. The following figure 14 is a sample StoryMap.

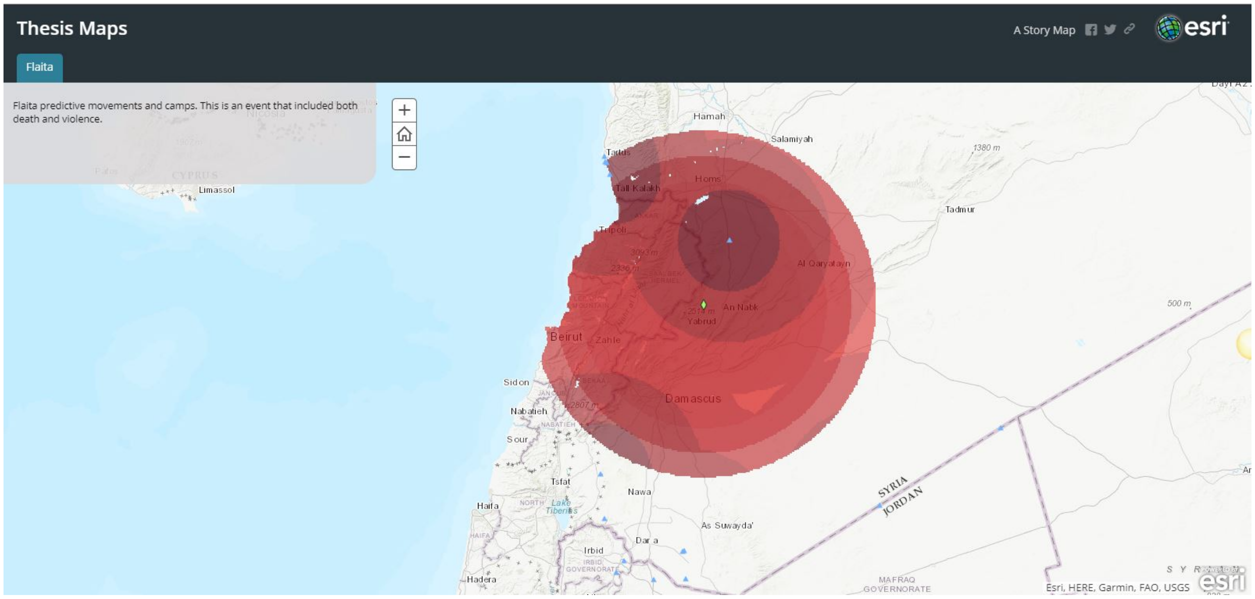

Figure 14 Sample StoryMap of Flaita

Chapter 5 Conclusions and Further Research

The primary application of this project is for small forward teams operating at CHE sites and nearby areas. The output of the project is intended to provide timely information to aid in the decision making that these teams participate in to assist displaced persons. This project has been successful because it provided a tool that covers the four criteria mentioned in the methods section. The first of the four criteria is that it is consumable by a large audience. The maps that are produced can be displayed on a webpage, pdf, email, or other formats as needed. One of the aspects that will be addressed in any future expansion of this work would include web-based interactivity and participatory GIS. The second of the four criteria is Does the method allow for sufficiently complex calculations to produce a useful output? Arcpy is robust enough to do the calculations necessary for the complexity of the problem. The third of the four criteria is cost. The tools used in this script are part of a typical deployment of an ArcGIS account used by large organizations such as an NGO or government. The cost in time is also low due to the current version of the script being short. Each iteration took less than 5 minutes to run once all the data had been entered. The final of the four criteria will support for the platform continue for a significant amount of time was also met using Arcpy in ArcGIS Pro. ArcGIS Pro has been proven to be robust in the past, with ESRI support being comprehensive and helpful. Additionally, there is increasing support for online app development.

Future platform selection could reconsider at Esri's WAB and Esri's GeoEvent Server. Cost for WAB may be prohibitive if used for daily functioning, however, because CHEs are not daily events it remains a platform that has potential. GeoEvent Sever could be cost prohibitive, but the fee is annually and not based on usage. Importantly, Esri offers special pricing for NGOs and other service-based organizations (Esri, 2018). This could lower the cost enough to be a viable option. A future project could compare the platforms for cost, efficacy, and user-friendliness. Currently, this project could only really be implemented by someone with knowledge of Modelbuilder and Python, in the future creating something that could be used by anyone would be the goal. The more people able to use the tool, the more likely it is to be implemented.

There are new ways of creating models such as looking at cell phone data before, during, and after a CHE. Participatory data allows planners to see how people respond to an event. A finding of particular interests is that people tend to leave in waves after the event as jobs and housing become scarcer (Yuan 2016). This type of collected data falls under the participatory category, meaning that a user does not only query the computer for calculations, but also adds in information from cell phones, social media, government records, and other available sources. When this participatory data is semantically and ontologically consistent, it allows for a better model response (Goodchild, 2008). Increasingly fine-scaled predictions of human movement are available with more advanced computational capabilities and the ability to run sophisticated statistical analysis (Longley & Batty, 2007). However, many of the outputs are not easily understood or used by non-experts, including those who have little computer knowledge outside of using a web browser. Unfortunately, the vast majority of first responders and decisions makers involved in CHEs lack this expertise. This is due to having a focused their expertise in other fields, further exemplifying the need for collaborative efforts between fields.

Another future consideration is the cell size of the raster. The amount of detail for the elevation data for Syria is not as fine-scaled as other places in the world. Scale for the rasters is something that will be a consideration for other projects.

Adding other parameters such as violence happening in other locations, not just in the city itself, would be useful as people travel away from violence. Changing the travel parameters for women, children, large groups, elderly and disabled would be beneficial as well. Then a prediction could be made not only about the first wave of people entering areas, but when the next wave of people would enter.

Unfortunately, a CHE where this could be implemented would be ideal for further research and field testing of the application's efficiency. Until it is used and tested in an actual event by field teams, there is no way to measure its efficacy. Once this is field tested possibilities for other parameters besides weather and terrain can be entered giving more information to stakeholders. Organizations have been contacted determine to see if possible in the future.

When groups of people are displaced by a CHE, of any sort, there can be preparations made that will lessen the suffering of those who are displaced. This project and others like it can help government and NGOs know where refugees and IDP will be fleeing. This can help them prepare with resources and personnel there ready to help. When used in conjunction with already available good practices for providing aid in a CHE, it is hoped that this project can reduce the overall feelings of loss and helplessness that displaced persons exhibit in the course of their crisis.

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Appendix

Code

```
import arcpy

Irmischer = r"C:\Users\Colleen\Documents\Colleen_Thesis\Colleen_Thesis.gdb\Irmischer"
LandCoverage =
r"C:\Users\Colleen\Documents\Colleen_Thesis\Colleen_Thesis.gdb\LandCoverage"
DistanceToCamp =
r"C:\Users\Colleen\Documents\Colleen_Thesis\Colleen_Thesis.gdb\RCDistanceToCamp"
ColorMapFile = r"C:\Users\Colleen\Desktop\ThesisData\Colleen\TravelLikelyhood.clr"

EventInput =
r"C:\Users\Colleen\Documents\Colleen_Thesis\Colleen_Thesis.gdb\Harasta_20170618"
WeatherInput =
r"C:\Users\Colleen\Documents\Colleen_Thesis\Colleen_Thesis.gdb\Weather_20170618"

EventOutput =
r"C:\Users\Colleen\Documents\Colleen_Thesis\Colleen_Thesis.gdb\HarastaMovement"


Join_output_temp =
r"C:\Users\Colleen\Documents\Colleen_Thesis\Colleen_Thesis.gdb\EventJoin"
Output_temp =
r"C:\Users\Colleen\Documents\Colleen_Thesis\Colleen_Thesis.gdb\OneEventBufferDay"
OutputRaster_temp =
r"C:\Users\Colleen\Documents\Colleen_Thesis\Colleen_Thesis.gdb\RasterDay"

fields =['violence', 'death', 'MaxTemp', 'MinTemp', 'Precip']

arcpy.SpatialJoin_analysis(EventInput,WeatherInput,Join_output_temp,"JOIN_ONE_TO_ONE"
,"KEEP_ALL","#","CLOSEST")

for x in range(1,8):

        DayOutput = Output_temp + str(x)
        DayRaster = OutputRaster_temp + str(x)
        ColormapOutput = EventOutput + str(x)
        ColormapRange = 0
        ViolenceDistance = 18 * x
        ViolenceText = str(ViolenceDistance) + " KILOMETERS"
        DeathDistance = 20 * x
        DeathText = str(DeathDistance) + " KILOMETERS"
        DefaultDistance = 16 * x
```

```
DefaultText = str(DefaultDistance) + " KILOMETERS"
MaxTempDistance = 12 * x
MaxTempText = str(MaxTempDistance) + " KILOMETERS"
MinTempDistance = 10 * x
MinTempText = str(MinTempDistance) + " KILOMETERS"
PrecipDistance = 8 * x
PrecipText = str(PrecipDistance) + " KILOMETERS"

with arcpy.da.SearchCursor(Join_output_temp, fields) as cursor:
        for row in cursor:
                Violence = row[0]
                Death = row[1]
                MaxTemp = row[2]
                MinTemp = row[3]
                Precip = row[4]

if Violence is not None:
        if Violence == "yes":
                BufferDistance = ViolenceText
                ColormapRange = 20
        else:
                BufferDistance = DefaultText

if Death is not None:
        if Death == "yes":
                BufferDistance = DeathText
                ColormapRange = 40
        else:
                BufferDistance = DefaultText

if MaxTemp is not None:
        if MaxTemp > 95:
                BufferDistance = MaxTempText
        else:
                BufferDistance = DefaultText

if MinTemp is not None:
        if MinTemp < 32:
                BufferDistance = MinTempText
        else:
                BufferDistance = DefaultText

if Precip is not None:
        if Precip > 0:
                BufferDistance = PrecipText
        else:
```

```
BufferDistance = DefaultText

arcpy.Buffer_analysis(EventInput,DayOutput,BufferDistance)

arcpy.PolygonToRaster_conversion(DayOutput,"Day",DayRaster,"CELL_CENTER","Day",0.0058)

Colormaptemp = arcpy.Raster(DayRaster)/arcpy.Raster(DayRaster) * ColormapRange

Eventtemp = Colormaptemp + arcpy.Raster(Irmischer) + arcpy.Raster(DistanceToCamp) + arcpy.Raster(LandCoverage)

arcpy.Int_3d(Eventtemp,ColormapOutput)

arcpy.AddColormap_management(ColormapOutput,"#",ColorMapFile)
```