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WHERE ARE THEY HEADED NEXT? MODELING EMERGENT DISPLACED CAMPS IN THE DRC USING AGENT-BASED MODELS

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ABSTRACT

The paper describes a prototype agent-based model used to predict the spontaneous settlements that can arise among internally displaced forced migrants in the Democratic Republic of the Congo. The internally displaced persons—in the real-world and the model—are constrained by geographic and social forces that dictate their ability to locate and reach organized camps run by humanitarian organizations or instead group with others to establish small temporary settlements. This research is of interest to humanitarian response stakeholders who try to locate self-settlements in order to administer humanitarian assistance and prevent further loss of human life.

1 INTRODUCTION

The world is witnessing the largest forced displacement of human beings in historical record. In 2016 alone, the most recent full year for which the United Nations has figures, 10.3 million people were newly displaced from their homes (UNHCR 2017). While many are aware that globally we are facing an extreme refugee crisis, much less attention is given to internally displaced persons. Unlike refugees, internally displaced persons (IDPs) have not fled their country due to persecution, but rather have been forced from their homes and remain in their home country. Refugees have long been a concern of the international community, with international organizations and countries adopting frameworks for identifying and protecting those who flee across territorial borders in 1951 (UN General Assembly 1951). Not until the 1990s did the international community begin to take notice of the growing crisis of internal displacement, including the vast need for humanitarian assistance and legal frameworks to accommodate forced migrants with far less public visibility than refugees (Deng 1998). In fact, of the 65.6 million displaced persons globally, 40.3 million (61.5%) are internally displaced within their own countries (UNHCR 2017).

Like refugees, IDPs suffer from loss of property, documentation, and established social structures as they flee their homes and communities. They remain in their countries of origin, but may struggle to gain access to their rights and services, requiring continued humanitarian assistance to meet basic needs (Williams 2008). Coordinating the necessary humanitarian response and assistance required to meet the needs of IDPs is, in some ways, more challenging that refugee response. Countries experiencing internal displacement may resist intervention by international organizations and state-sponsored aid agencies on the grounds of preserving norms of sovereignty. Additionally, since they do not traverse international borders where crossings are monitored, IDPs may flee to uncharted locations, making them difficult for humanitarian actors to locate.

This paper represents the initial collaborative work between modeling and simulation researchers and a humanitarian organization with the mission of providing assistance to IDPs. The objective of the project is to build an agent-based model of IDPs as they evacuate their communities to attempt to predict locations where groups may settle away from conflict. The first steps presented here represent a simplified model of movement and discussion of the next steps to add the necessary social complexities to represent real-world situations. Geospatial data representing non-state armed group-controlled territories, known civilian population centers, and locations of mineral resource mines were provided by the United Nations Office of the Coordination of Humanitarian Affairs (UNOCHA). Behavioral rules of agents are relatively simple, but represent macroscopic effects of micro-level decision-making by IDPs and non-state armed groups.

2 BACKGROUND

Driving global trends, the Democratic Republic of the Congo (DRC) has about 515,165 refugees in neighboring countries as of early 2018 (UNHCR 2018), but an estimated 4.1 million internally displaced in addition to the several millions of people who are not displaced but require humanitarian assistance to survive (OCHA 2017)—89% of forced migrants from the DRC are IDPs. Civil unrest in the DRC dates back to the colonial era when colonizers exploited ethnic differences to secure and extract the vast mineral wealth of the country, particularly in the mountainous eastern regions (Turner 2007). Independence from colonial powers did not see the end of the turmoil; in fact, just the opposite. With Western powers intervening in early politics (Nzongola-Ntalaja 2002) and a succession of turbulent leadership changes (McCalpin 2002), the DRC continues to struggle to maintain order and advance humanitarian and development objectives. This is particularly true of the eastern regions of the country which are geographically distant to the capital in Kinshasa.

While many are familiar with the Rwandan genocide in 1994, the civil conflict in eastern DRC that rages on to this day—which was at least partially precipitated by the genocide—is far less known or understood. When the majority government came to power to end the genocide in Rwanda, the previous government fled in exile to eastern DRC, taking with it all of its military and government officers, military arms, and money (Prunier 2009, 1995; Lischer 2006). The sudden influx of refugees from the Rwandan genocide into eastern DRC disrupted already fragile balances of power between ethnic groups. In the particular regions bordering Rwanda, this influx of refugees even fueled rumors of a plan for the Rwandan government to take over the region (Turner 2007). This resulted in subsequent expulsions of groups of people from North and South Kivu provinces in the DRC, who had inhabited the region for generations, into Rwanda and Uganda (Mamdani 2001). Violence spiraled out of control as each action resulted in backlash from government authorities or conflicting ethnic groups, deepening the divide between the many ethnic- and land-based identities that make up eastern DRC. As the violence escalated, more and more groups created their own non-state armed groups to protect their interests, resulting in the myriad armed groups that operate in the region over 20 years later (Mamdani 2001; Autesserre 2008; IRIN 2007; Okumu et al. 2010).

While regional and local security issues, governance, and ethnic conflict underlie the ongoing civil conflict in eastern DRC, the vast mineral resources of the region exacerbate an already volatile situation. The mountainous regions of eastern DRC are not only home to some of the world's last species of gorillas and elephants, but also the location from which gold, coltan (used in most mobile phones), and diamonds are mined in large quantities. These vast mineral resources have invited localized conflict over territories, as well as foreign intervention to exploit the chaos for profit (Samset 2002). Tragically, a region of the world that is extremely rich in natural resources suffers an equally extreme "resource curse" (Ross 1999) with a large percentage of the population reliant on humanitarian assistance for survival.

The history of conflict in the DRC is very complex, and its nuances cannot be summarized in a short article. The backdrop for understanding this ongoing conflict in the eastern part of the country, however, is necessary to understand the difficulty of both the modeling task and its potential to improve humanitarian efforts. Though no forced displacement path of migration is simple, the DRC presents particularly difficult dimensions for humanitarian response. The geography is dramatic: dense, unforgiving jungles in which non-state armed groups often hide; volcanoes and tall mountains tower over valleys and rivers; and infrastructure such as roads are relatively undeveloped in many places. Guiding the decision of where to flee, the push and pull of animosity and hospitality between the large numbers of ethnic groups inhabiting the country are varied and complicated. One cannot flee conflict and simply find safety in the next town or village since the group(s) inhabiting those areas may not be friendly to one's own group. The vast numbers of internally displaced then are propelled in directions that are geographically and socially constrained. Rather than follow predetermined routes such as roads that lead to urban areas or established humanitarian camps, the humanitarian community must find ways to predict where pockets of IDPs settle in the unforgiving terrain of the eastern DRC in order to effectively provide humanitarian assistance to those in need of help.

3 STATE OF THE ART

The enormity of the global refugee crisis has attracted increasing scholarly attention of all kinds, including from modeling and simulation researchers. Where more traditional studies focused on statistical methods (Schmeidl 1997; Davenport et al. 2003; Moore and Shellman 2004), later attempts used modeling approaches to look at refugees and IDPs as variables in peacekeeping operations (Bailey 2001). Some scholars began to approach forced migration through the study of formalized models to look at cost and benefit factors that influence individuals' decisions to flee conflict (Melander and Öberg 2006). In the last decade, there has been a steady increase in the number of studies looking at forced migration-related issues from a modeling and simulation approach. In general, these follow three broad themes.

First, refugee modeling often centers around healthcare. This is unsurprising as forced migrants often face acute healthcare needs, and the health sciences have been early adopters of simulation methodologies. Anderson et al. (2007) proposed an early agent-based model (ABM) to study the impact of humanitarian policies on healthcare provision among refugees. Another similar model looked at the spread of cholera in crowded refugee camp conditions (Crooks and Hailegiorgis 2014). Related models have also used ABMs to explore safety in camps (Frydenlund and Earnest 2015) and collective identity shifts (Frydenlund and Padilla 2017).

Second, peace and conflict related models feature prominently in the study of forced migration, either as a dependent or independent variable. Some are not specifically simulation-based, but employ social network analysis or systems thinking to convey complex interactions of factors that influence forced migration (Wood 2008). These models often tackle issues relevant to stability operations during and after conflict, such as ABMs of ethnic conflict after military surges (Weidmann and Salehyan 2013) and models that reflect individual decisions to flee conflict zones (Sokolowski et al. 2014).

Third, forced migration models center on patterns of flight. This avenue of research has obvious practical implications for governance and humanitarian crisis management. Simulation research, including is practical application, often seems to be presented in journals less commonly viewed by practitioners in the specific case-study field, particularly in forced migration. One counter example to this is an ABM presented in the *Journal of Refugee Studies*—as far as we can tell, the only one—which presents a generic model of refugee flight patterns, but with the main intent to garner interest in the forced migration scholarly community for modeling (Edwards 2008). More recent work has led to creative approaches to modeling forced migration, such as using system dynamics models to understand protracted refugee situations (Vernon-Bido et al. 2017), crowdsourcing GIS data to understand response to catastrophe (Crooks and Wise 2013) and utilizing network theory to develop quick estimations of refugee flight patterns (Suleimenova et al. 2017a; Suleimenova et al. 2017b).

The pace of this research direction in forced migration, traditional qualitative and quantitative approaches as well as using M&S, has increased in recent years, but much work must still be done to unite the studies of motivations to flee as well as flight patterns.

4 THE MODEL

For this project, we constructed an agent-based model of forced migrants' movements in the eastern DRC province of North Kivu. The following description represents a model in the early stages of development.

Subsequent versions will include more terrain data, calibration and validation of the model using historic data for the project, and increasingly complex decision-making rules for agents. This iteration of the model represents an adaptation of the Boids Flocking Model (Reynolds 1987), which also allows the agents to prioritize flight from conflict and terrain elevation to influence the direction they will travel.

4.1 Data

The ABM uses geospatial data of mine locations, armed non-state armed group-controlled areas, village locations, and data related to terrain (elevation). With this approach, the distance of entities within the model can be represented in a relative scale that is more realistic to the actual distances observed in reality. Figure 1 shows the location of the GIS data in a macro view relative to the African continent. The total data are reduced to the area around the identified villages (represented in the dashed square). The right of Figure 1 provides a view within the dashed square. This is the modeled area, where the polygons represent the non-state armed group-controlled areas, and the points represent the identified locations of villages.

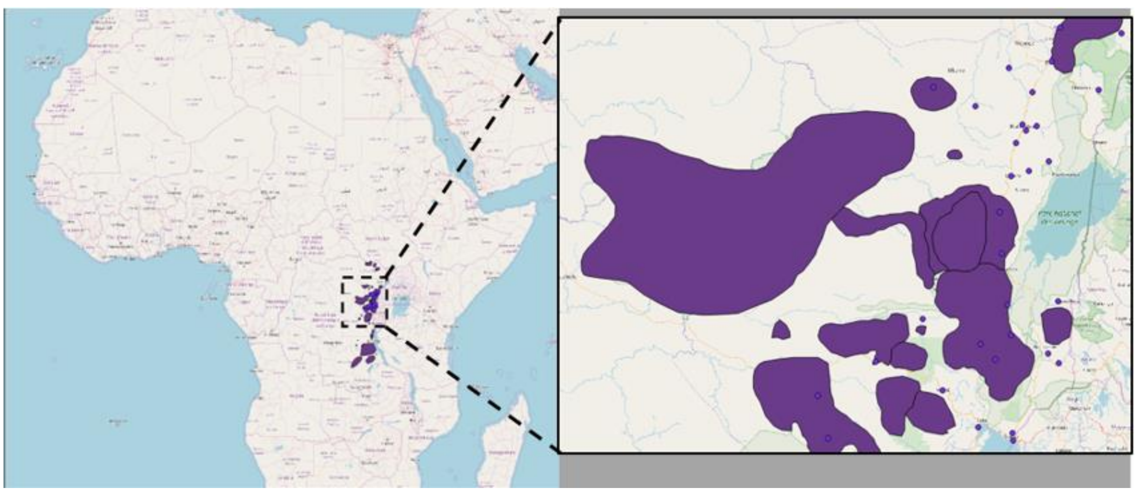

Figure 1: Macro and micro level view of geographic area, purple sections represent non-state armed group-controlled areas**.**

4.2 Entities

Entities in the model broadly include terrain—which conveys geographical and elevation data to the agents—and agents who can be either of the general population or members of a non-state armed group. These are explained in greater detail below.

4.2.1 Terrain

Agents get varying information from the environment. Namely, a location can be a:

- Conflict zone – occupied by non-state armed groups
- Village – starting locations for all agents which can become engulfed in conflict
- Mine – a location of mineral resources that can be extracted to fund non-state armed groups (attractors for non-state armed groups)
- Camp – a “safe” location operated by a nongovernmental organization like the UN where IDPs can settle (attractors for IDPs)
- General – terrain that has elevation data that IDPs traverse

In later models, adaptations to these environmental factors will be pursued. In the current iteration, camp locations are stationary and predetermined. Conflict zones and mines are placed in the model based on the GIS data of known real-world locations in North Kivu province.

4.2.2 Agents

There are two types of agents in the model. Congolese agents represent civilians who reside in villages within the province. When conflict approaches their village, these agents react by determining whether to flee or stay in place. The agents follow a simple algorithm that dictates their movements. First, the agents flee away from conflict in any direction necessary. Second, the Congolese civilians attempt to stay near other civilians for safety (flocking model). Third, the civilians, when far enough away from conflict (safe distance), will attempt to travel along the path of least resistance (downhill). If the civilians are close enough to "see" a camp run by a humanitarian organization, they will attempt to find refuge there. If they cannot see a camp, they will self-settle in locations where they find others, there is no conflict nearby, and the terrain is hospitable. If they are trapped between conflict groups, they will move sporadically attempting to find a safe area to escape.

Armed agents represent non-state armed groups that are endemic to eastern DRC. Non-state armed groups migrate slowly in an attempt to acquire resources necessary to fund their operations. These funds are not modeled directly, but non-state armed groups move towards mines or villages to expand their territory, thereby causing Congolese civilians to flee the conflict non-state armed groups cause as they move in to extract resources.

These representations are not realistic for eastern DRC. Most importantly, eastern DRC is very ethnically diverse, with non-state armed groups arising to defend these disparate ethnic groups. This layer of complexity is planned for future iterations, since this causes dramatic differences in whether and how civilians in eastern DRC actually flee. Modeling of ethnic diversity and relationships (friend and foe) between ethnic groups is currently under development.

4.2.3 Behavior

At the start of a simulation run, IDPs typically scatter away from conflict areas, then begin to group and move toward a nearby camp. Scattering reflects the agents' decision-making priorities to first flee away from conflict and second find others in flight with whom they can group for safety. These two processes are prioritized over the third objective, which is to reach a camp for safety. This can be seen in Figure 2 below where villages in this midst of conflict groups scatter, but villages where conflict groups are close tend to flee in a similar direction (following the flocking model). Agents' ability to "see" conflict and determine that conflict is "far enough away" to shift priorities from one behavior to another can be experimentally varied in the user interface. Though very simplified, the rules for agent behavior are as follows:

1. If conflict is within "conflict-vision" radius, flee away from conflict.
2. If distance from conflict is at least a "safe-distance" away,
3. Find other IDPs nearby to walk with (flocking behavior)
   a) Try to walk towards a humanitarian camp (blue circles in Figure 2) if it is close
   b) Otherwise, follow the path of least resistance (downhill, based on geographic terrain elevation values)

In this simplified prototype model, agents are triggered to flee (or not) by the start of the simulation. This occurs because some villages are located within armed non-state group-controlled areas and thus immediately seek to flee conflict. There is no natural end to the simulation at this point, nor is there any implication for IDPs to leave the safe zones unless conflict comes nearby at which point they would follow the behavior rules above. In future iterations of the model currently under development, the armed non-state groups change territory shape based on the pursuit of resources, which continues to disrupt the location of settlements. This will be detailed in future models and publications.

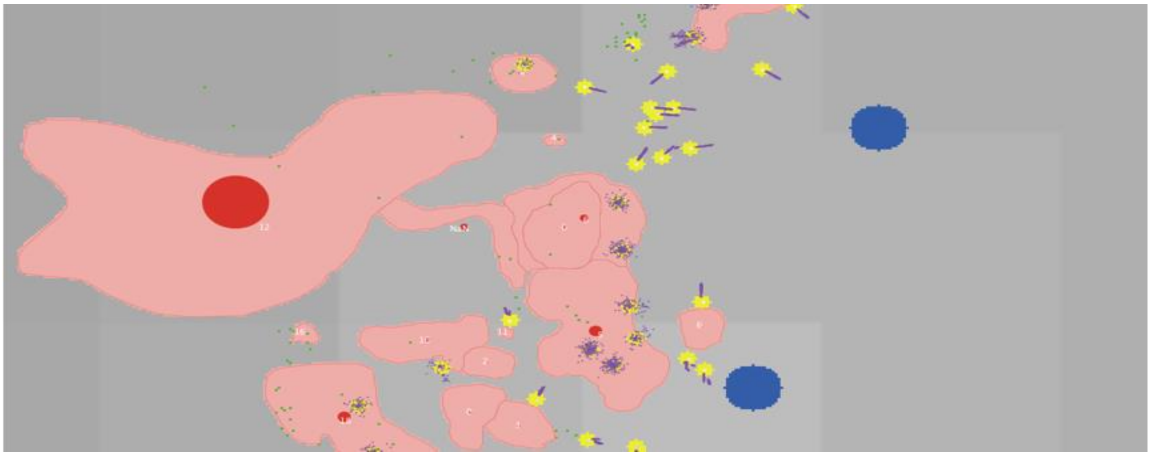

Figure 2: NetLogo interface at 3 time-steps (ticks). Red: armed non-state actor-controlled territories; yellow: villages; blue: UN location; purple: agents.

5 SIMULATION RESULTS

5.1 Experimental Design

The simulation was run to incorporate 27 parameter combinations with five repetitions each (135 total runs). Computational costs are quite high given the geographic parameters and the large number of agents in the model. These preliminary simulation runs were to test the plausibility of the model and direct future model development. Despite the use of a high-performance computing cluster, the model has proven too computationally intensive to manage a larger survey of the parameter space. The parameters were tested as follows:

- Population: 0.01, 0.05, 0.1 percent of the real-world village populations
- Safe-distance: 50, 70, 90 "patches" of distance the IDP wants between itself and the conflict
- Conflict-vision: 15, 30, 45 "patches" of distance that the IDP can view conflict

The flocking variables were held constant for all simulation runs. In initial model versions, locations of camps were randomly determined for each run, but these were fixed to minimize combinations of parameters necessary to evaluate the model. We allowed each simulation to run for 500 time steps. Figure 3 below shows an example simulation run illustrating that 250 time steps was not enough time for the IDPs to converge to points away from conflict, but at 500 resulted in more cohesive groupings.

5.2 Analysis of Output

A simple OLS regression was run to explore various models and determine the effect of parameters globally imposed on agents' decision-making (Table 1). The first two models look to see if the main variables (i.e. population size, preferred distance between agent and conflict, and ability to see conflict) influence the average distances of agents to conflict and their origin point respectively. Model 1 specifically models the average distance between each agent and the closest instance of conflict. Model 2 assesses the impact of those variables on the average distance between the agent and its origin point ("home"). In both models, the distance required before the agent feels "safe" has no statistically significant impact on how far they ended up away from conflict or home. The distance at which agents could see conflict, however, had a statistically significant effect on both the distance they ended up from the nearest conflict and their homes.

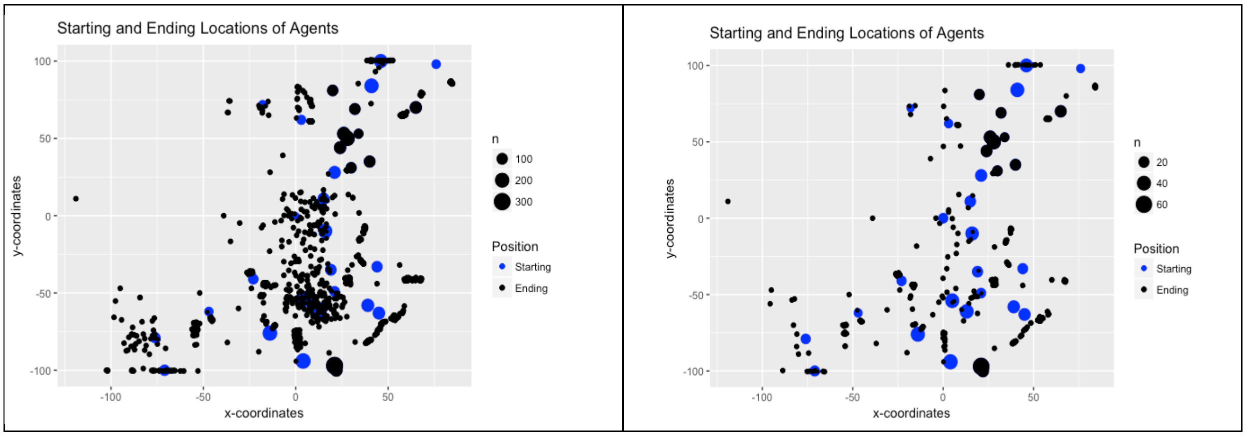

Figure 3. IDP movement at 250 (left) and 500 (right) time-steps.

As a prototype model, the statistical significance of these values provides only a starting point for understanding the impact on the agents' ability to flee in the model. We can see that as population increases, the average distance from home and conflict both increase somewhat. In the second two models, the dependent variable is standard deviation from conflict and home, respectively. Similarly, safe-distance does not impact the statistical model, but conflict-vision and population do.

Table 1: OLS regression output for four different statistical models.

VARIABLES	(1) Mean DC	(2) Mean DH	(3) StD DC	(4) StD DH
population	18.43***	-51.83***	-3.566***	-63.62***
	(2.579)	(6.067)	(0.610)	(7.215)
Safe-distance	0.000185	0.000377	0.000558	-0.000487
	(0.00706)	(0.0166)	(0.00167)	(0.0197)
Conflict-vision	0.588***	0.631***	0.352***	0.267***
	(0.00941)	(0.0221)	(0.00223)	(0.0263)
Constant	-3.635***	8.097***	0.911***	17.66***
	(0.589)	(1.384)	(0.139)	(1.646)
Observations	135	135	135	135
R-squared	0.968	0.871	0.995	0.580

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Looking first at the distance from conflict, we see that as population increases, the average distance from conflict goes up, but the standard deviation across all agents goes down. The agents are less scattered when more of them are in the model, presumably due to the flocking algorithms that encourage agents to migrate towards other agents. As the conflict-vision, or distance at which agents can see and react to conflict, increases the average distance from the conflict also increases (they flee farther) but so does the standard deviation (they flee in more disparate directions).

Turning to the distance from home, as the population increases we see large decrease in the average distance from home. In fact, as more people are added to the model, a larger number of people are not close enough to the conflict to decide to flee, which may explain this relationship. Increased population also dramatically decreases the dispersion of agents' distances from home (standard deviation). This is likely caused by the same phenomena: many new agents in the model will be far from conflict and find it unnecessary to flee, while others flee great distances, so adding agents may force this relationship to appear. Increasing the conflict-vision of agents, however, has a much smaller influence on the distance from home than population. Assuming a linear relationship, for every additional one "patch" of distance the agent could see conflict, it only moved an additional 0.63 patches farther from home. Similarly, conflict-vision increases the dispersion of agents slightly.

These effects can be broken apart for more nuanced analysis since each parameter combination was only tested at specific levels. Figure 4 shows us that, in a relatively linear way, increased ability to "see" conflict allows agents to flee farther, both from home and conflict. This is not particularly groundbreaking but allows us to generally see that the prototype model is performing as we might expect IDPs to behave in the real-world.

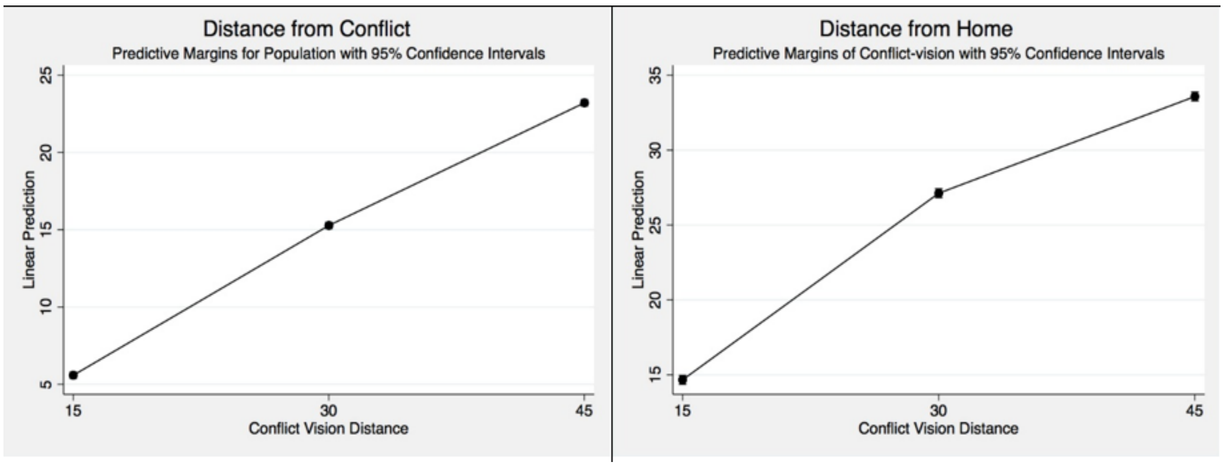

Figure 4: Effect of conflict vision distance on distance from home and conflict.

One area of concern for our model, which would eventually help to understand other parts of eastern and possibly western regions of the DRC, is that population appears to have some dramatic impacts on the simulation outcomes. This is problematic as we develop a prototype model since we are already stretching the computing capacity of the HPCs we use for running the simulations. As we move to add necessary complexity to the model, it is important to understand how much of the population we must represent to get an accurate picture of where groups of IDPs may assemble outside of officially operated camps. What we see in Figure 5 is that when we disaggregate the effects of population on distance from home and conflict, there appears to be diminishing returns in this effect between 0.01 and 0.1 percent of the population. For reference, based on the recorded populations in UNOCHA records for the villages in this model, 0.001% of the population is 81 people; 0.01% is 814 people; and 0.1% is 8,140 people.

These are by no means exceptionally large simulations, and yet they are quite computationally costly when the agents must interact with both the environment and other agents in the model. We anticipate a significant amount of detail must be added to make sure the model is accurate in representing conditions in the DRC, which requires us to work to streamline algorithms and processes in order to 'make room' for more complexity. What these initial runs tell us is that the relative difference in outcome when using 0.01% of the population and 0.1% is minimal. Future experiments will look more carefully at this gap to further narrow down the optimal population 'sample' to use for our simulated world.

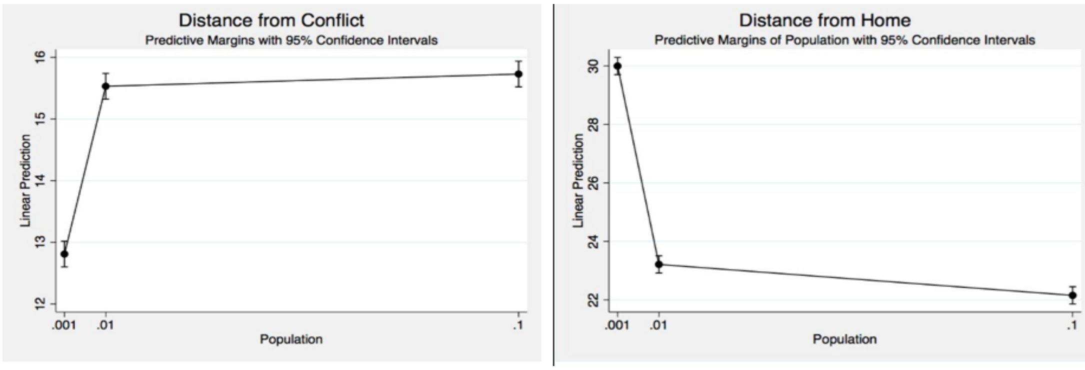

Figure 5: Effect of population on distance from home and conflict.

6 CONCLUSIONS AND NEXT STEPS

The prototype model presented here provides direction for future modeling efforts. Our next steps are two-fold. First is the matter of model development. We will further investigate the necessary population sampling required to adequately model the intended effect, as described in the previous section. Additional layers of geographic complexity (e.g. rivers as obstacles and water sources, density of trees as obstacles and firewood sources, network of passable roads) will be added to the model to further constrain or motivation agents' patterns of flight as well as non-state armed groups' decisions about resource acquisition. We will also implement first two different ethnic groups and associated non-state armed groups, and then expand this representation to incorporate numerous ethnic network structures (friend and foe) in the region.

The other important step in our development process is determining the best way to convey modeling and simulation results to practitioners in the field. If these modeling efforts are truly intending to make a difference in humanitarian operations, we must consider both the software options available to handle the complexity of this growing model as well as the meaningfulness of results as conveyed to practitioners in the field. This is an area of ongoing research that will be discussed in a future paper.

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