An agent-based forced displacement simulation: A case study of the Tigray crisis

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Abstract. Agent-based models (ABM) simulate individual, micro-level decision making to predict macro-scale emergent behaviour patterns. In this paper, we use ABM for forced displacement to predict the distribution of refugees fleeing from northern Ethiopia to Sudan. Since Ethiopia has more than 950,000 internally displaced persons (IDPs) and is home to 96,000 Eritrean refugees in four camps situated in the Tigray region, we model refugees, IDPs and Eritrean refugees. It is the first time we attempt such integration, but we believe it is important because IDPs and Eritrean refugees could become refugees fleeing to Sudan. To provide more accurate predictions, we review and revise the key assumptions in the Flee simulation code that underpin the model, and draw on new information from data collection activities. Our initial simulation predicts more than 75% of the movements of forced migrants correctly in absolute terms with the average relative error of 0.45. Finally, we aim to forecast movement patterns, destination preferences among displaced populations and emerging trends for destinations in Sudan.

Keywords: Agent-based Modelling · Simulation · Forced Displacement

1 Introduction

Agent-based modelling (ABM) is a computational approach that provides an opportunity to model complex systems. It can explicitly model social interactions and networks emerging from it. Its popularity is in part due to the decentralised nature of the approach, which allows a heterogeneous mix of many agents to act and interact autonomously, in turn leading to emergent behaviours in the system at higher levels.

The initial concept of ABM was introduced in the late 1940s. However, it has become popular in the 1990s as the use of ABM required computational advancements [1]. Today, ABM is widely applied to various research disciplines, such as biology, business, economics, social sciences, and technology, and practical areas including infrastructure, civilisation, terrorism, military and crowd modelling. There are also newly emerging application domains, such as cyber-security and the social factors of climate change [2].

In this paper, we concentrate on the domain of crowds involving human movement patterns and evacuation modelling. Schelling [3] was one of the first to

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represent people as agents and their social behaviour as agent interactions. Only after two decades, the idea of modelling human behaviour and their movement patterns in society and geography was broadened in literature [4]. More recently, human movement modelling has expanded using various ABM software tools, as well as variations in source code languages, model developments, and their level of scalability [5]. Although ABM models problems ranging from small-scale behavioural dynamics to large scale migration simulations [6], it is becoming particularly prominent for population displacement studies [7, 8]. It is already used in a wide range of refugee-related settings, such as disaster-driven migration, which incorporate changes in climate and demographics [9].

Modelling forced displacement requires an understanding of the type of migrants, methods structuring available data, modelling approach and measures of uncertainty associated with data [10]. It is also crucial to consider the course of movement of refugees and internally displaced persons (IDPs), including when they decide to leave, where they choose to flee and whether to stay or flee further from the first destination choice [11]. Hence, ABMs could be applied interactively to assist governments, organisations and non-governmental organisations (NGOs) in predicting when and where the forced displacement are likely to arrive [12], and which camps are most likely to become occupied in the short term.

The rest of the paper is structured as follows. In Section 2, we introduce an agent-based simulation development approach (SDA) that allows construction and execution of forced displacement simulations. We create a forced displacement model for the Tigray region in Ethiopia, which has an ongoing conflict crisis since the beginning of November 2020, using the proposed approach (Section 3). In Section 4, we discuss the obtained simulation results, validate the prediction against the UNHCR data and visualise forecast simulation results for camps in Sudan. Finally, we conclude our paper with final remarks and future work in Section 5.

2 Simulation development approach using Flee

Suleimenova et al. [13] proposed a generalised and automated SDA to predict the distribution of incoming forced displacement, who fled because of war, persecution and/or political instability, across destination camps in neighbouring countries. The proposed approach includes six main phases, namely situation selection, data collection, model construction, model refinement, simulation execution and analysis (see Figure 1).

In the first phase, we select a country and time period of a specific conflict, which result in large scale forced displacement. In the second phase, we obtain relevant data to the conflict from four data sources: the Armed Conflict Location and Event Data Project (ACLED, http://acleddata.com), the OpenStreetMap platform (https://openstreetmap.org), the United Nations High Commissioner for Refugees (UNHCR, http://data2.unhcr.org/en/situations) and population data. Third, we construct our initial model using these data sets and create, among other things, a network-based ABM model. Once we have built the ini-

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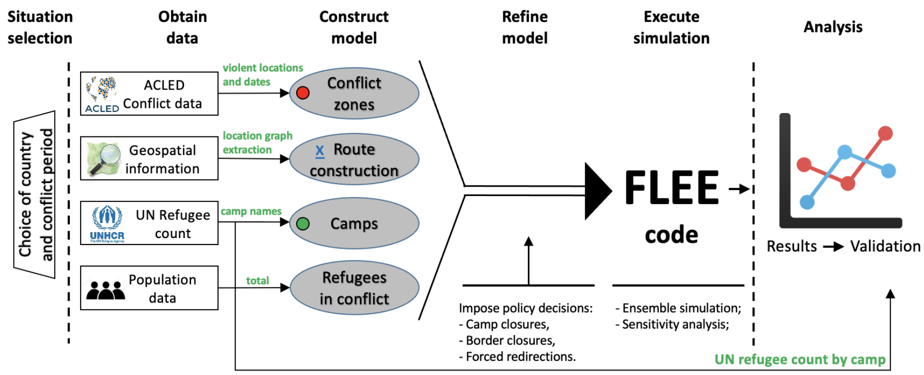

Fig. 1. A simulation development approach to predict the distribution of incoming forced population across destination camps.

tial model, we refine it as part of the fourth phase. Here, we manually extract information on camp and border closures, as well as forced redirection. The fifth phase involves the main simulation, which we run to predict or forecast, given a total number of forced population in the conflict, the distribution of displaced people across the individual camps. We run our simulations using the Flee simulation code (https://github.com/djgroen/flee). Importantly, Flee has the algorithmic assumptions (i.e. ruleset) for forced displacement simulations where each simulation step represents one day (see [13, 14] for a detailed description of assumptions). Once the simulations have been completed, we analyse and validate the prediction results against the full UNHCR forced displacement numbers and/or visualise the forecast results as part of the sixth phase.

To demonstrate the use of SDA with Flee, we construct a model based on the conflict instance of the Tigray region and execute simulations to predict the distribution of incoming refugees to the neighbouring country of Sudan, as well as forecast future trends to efficiently allocate camp resources.

3 Forced displacement in Tigray

The conflict in the Tigray region, which has about six million people, started on 4th November 2020, when Prime Minister Abiy Ahmed ordered a military offence against regional forces, namely Tigray People's Liberation Front (TPLF). The conflict is thought to have killed thousands and displaced more than 950,000 people internally according to UNHCR estimates, and of which about 50,000 people are displaced to Sudan. The majority have crossed at Hamdayet and Lugdi border points while the rest have crossed at Abderafi and Wad Al Mahi border points. Most of these refugees have been transferred away from the border points to the Um Rakuba and Village 8 settlement sites, and some refugees still remain at the border point waiting for other family members who may have gotten lost along the way, as well as in hope to return home soon.

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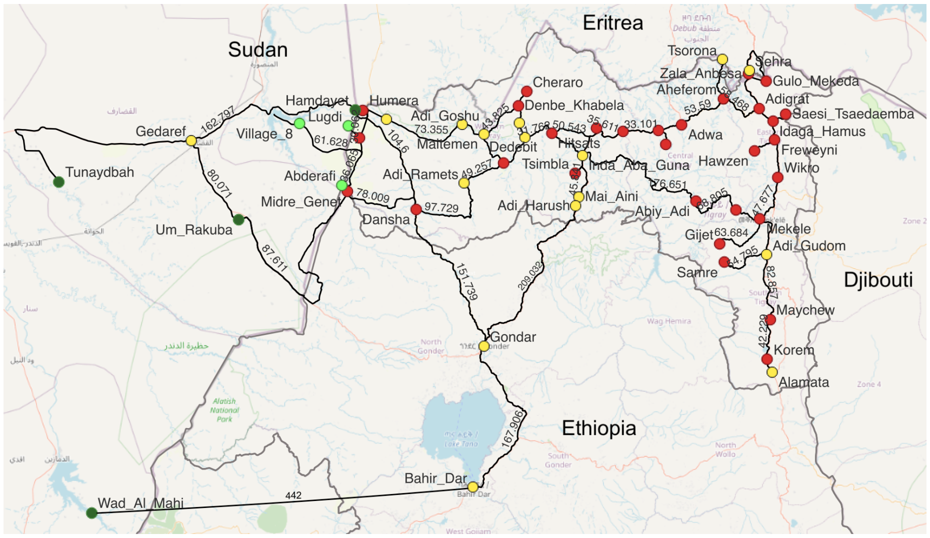

Fig. 2. Overview of geographic network model for the Tigray region with potential conflict zones marked in red, camps in dark green, forced redirected locations in light green and other settlements in yellow. Interconnecting routes are given in a simplified straight-line representation including their length in kilometres.

Ethiopia is also home to 178,000 Eritrean refugees, including 96,000 mainly accommodated in four refugee camps in the western part of the Tigray region. However, their conditions have been unknown due to the communications blackout. But, in recent days, many Eritrean refugees have reportedly fled to safer locations within Tigray and other regions in Ethiopia. In addition, it has been reported that some Eritrean refugees are among the more recent arrivals into Sudan. To have better insight and to define the ruleset for migration prediction and conflict forecast for this simulation instance, we have tried to follow up every reliable source including reports from UNHCR, UNOCHA, ACLED, etc. in addition to the latest news and updates from news agencies like the Associated Press (AP), Reuters, and BBC.

We created an initial model for the Tigray region using ACLED, OpenStreetMaps, UNHCR and other sources (see Figure 2). It includes 30 conflict locations, 18 towns, four camps in Sudan, which are Hamdayet, Um Rakuba, Wad Al Mahi and Tunaydbah, and three forwarding hubs, namely Lugdi, Village 8 and Abderafi. The latter locations are the main Sudanese border crossing points for displaced people emerging from Tigray. The two towns (Tsorona and Sehra) in Eritrea are hypothetically added to the model because UNHCR suggests that there are people arriving in Eritrea along the border with Ethiopia according to unverified reports.

When a conflict erupts, Flee predicts the resulting movement of displaced population along with a simplified travel network, and how many arrive at the

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camps. The prediction is based on assumptions that are summarised as follows. First, our simulation begins with 100,000 displaced persons and 96,000 Eritrean refugees residing in the Tigray region on the 4th November 2020. It does not include Ethiopian refugees in Amhara, Afar and Benishangul-Gumuz regions, as well as in Djibouti or Eritrea because we do not know their numbers at this time. Second, we model both refugees and IDPs, as IDPs could become refugees if the conflict intensifies. It is our first effort in modelling both types of forced migrants. Third, displaced persons travel on foot, at a speed of up to 40 kilometres per day. Moreover, persons may leave conflict regions two days before a conflict erupts due to the spread of danger warnings from nearby locations or families. Furthermore, any day of conflict in any Tigrayan settlement will create 10,000 displacements in our forecast. We validated this very simple heuristic with the displacement data in November, and found that it is 90% accurate on average over that period. Finally, distance to neighbouring locations is important in the choice of next destination for people, but a bit less so than in the original simulations by Suleimenova et al. [13], to reduce the chance that people keep going back and forth between very nearby settlements.

4 Results and analysis

We run our simulation for 146 days, from the nominal start date of the crisis, November 4th 2020, until March 29th 2021. We obtained the total number of refugees arriving in Sudan from UNHCR and validate the simulation results to gauge model performance. Subsequently, we introduce conflicts at random locations in the selected region of Tigray, at a frequency determined by the chosen level of intensity. To cover a range of potential future conflict patterns, we define 18 conflict scenarios based on five potential woredas (i.e. districts) of Tigray and three levels of conflict intensity. Specifically, we create future conflicts by placing randomized major conflict events in the 100 day forecasting period which starts on March 30th 2021. The three intensity levels are defined as follows: Low with 5 events, Medium with 10 conflict events and High with 15 conflict events. Each conflict event is assumed to take place in one location and to last anywhere between 2 and 20 days. The motivation behind this is to examine the importance of location and/or intensity of conflicts driving the number of arrivals in Sudan.

We illustrate our simulation results in comparison to the UNHCR data till the simulation day 146 in Figure 3, where the refugee population growth is underpredicted in three camps while overpredicted in Wad Al Mahi. The large mismatch in the Hamdayet, Um Rakuba and Tunaydbah camps is primarily due to their far proximity from conflict locations. In comparison, Wad Al Mahi is the furthest camp but the number of arrivals is only 700 refugees according to data. After day 146, we forecast the distribution of incoming refugees in Sudan for additional 100 days and observe a drastic increase in the numbers of refugees for Hamdayet and Um Rakuba due to their close proximity to conflicts.

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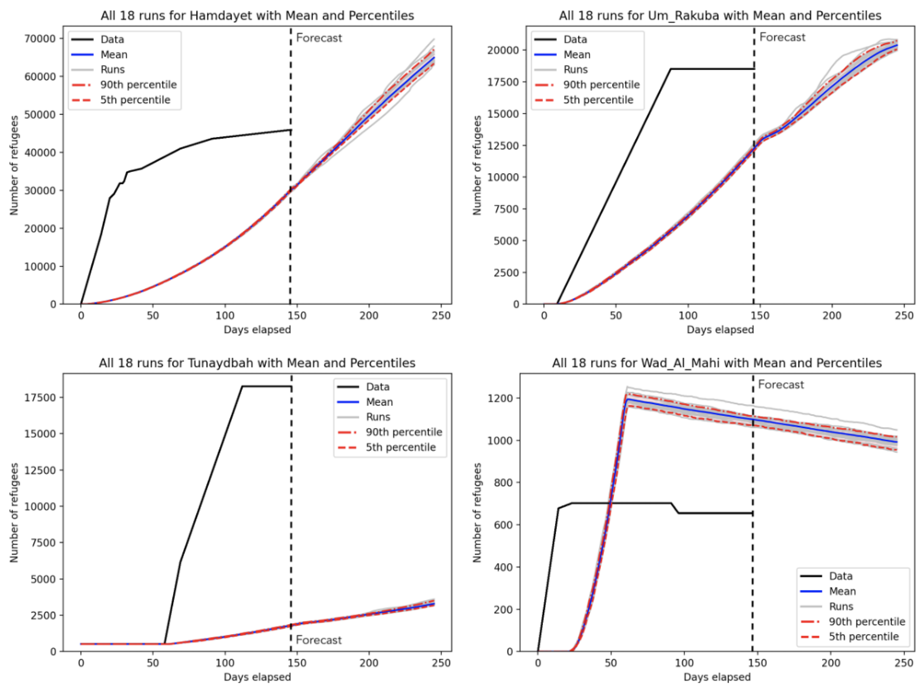

Fig. 3. Number of refugees for four camps as forecasted by forced displacement simulation for the Tigray conflict. The UNHCR data (black line) is represented for 146 days till the availability of the actual data.

5 Conclusion

This is our first attempt at forecasting arrivals in the Tigray conflict in North Ethiopia. Many aspects of our model are not mature yet, limiting the conclusions we can draw from this paper. However, we did identify that people displaced from conflicts further away tend to go to Eritrea, Djibouti, or simply other parts of Tigray in the short term (but may arrive in Sudan gradually over the longer term). Moreover, individual events in nearby towns, such as Humera, trigger an immediate spike in arrivals on our simulation. Events further afield do not trigger a spike in arrivals but do have a more gradual boosting effect on the number of arrivals over time. In future work, we will vastly increase the number of simulations, and use averaging techniques to make more precise forecasts with quantified uncertainty ranges. We will also review our IDP model, and aim to include realistic assumptions or any specific pressing questions that we should tackle with future forecasts.

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