Prediction of Migration Paths Using Agent-Based Simulation Modeling: The Case of Syria

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Abstract

The Syrian civil war, which started in 2011, has caused a great wave of forced migration in the Middle East. One of the most popular destination points for Syrian refugees has been Turkey. The purpose of this study is to predict the routes of refugees who leave the conflict areas in Syria to reach the refugee camps located in Turkey during a crisis. The study proposes an agent-based model to simulate the decision mechanisms of refugees in a highly uncertain environment. The model employs the A* algorithm to calculate the cost of each available destination point (refugee camp) for each agent, based on their risk preferences and starting locations, and allows agents to choose the camp with the minimum cost as the destination point. By use of the model, we simulate a moment of crisis namely the South Idlib bombardment (from December 2019 to January 2020) under four different scenarios that are generated considering the real-life data gathered from the newspapers of December 2019 and various other sources. The simulation results show the main pathways of Syrian refugees and give insights on the required camp capacities. The results are compared with the gathered secondary data to validate the proposed model.

Keywords
Forced migration, Syrian refugees, migration paths, agent-based simulation, risk preferences

1. Introduction
As the number of refugees worldwide has been increasing steadily in the last three decades, the refugee crisis has become a global prominent problem. Millions of people are forced to leave their homes due to armed conflicts, oppressions, and human rights violations every year (Castles 2006). Those who can cross international borders are referred to as refugees, and others are internally displaced people moving within the home country's borders. This study focuses on refugees. Since the mid-80s, refugee studies have concentrated on the relatively short-term migration waves that came to public attention and the minority of refugees that guarantee resettlement in affluent nations (Indra 1999). However, the issue of immigration is much more important than it seems. According to the June 2021 report

of the UN High Commissioner for Refugees (UNHCR), since 2010, the number of forcibly displaced people worldwide has doubled. At the end of 2020, this number reached 82.4 million due to persecution, conflict, violence, human rights violations, or events alarming public order. UNHCR (2021) reported 26.4 million refugees, more than a quarter of the total number of displaced people. Moreover, it is expected that the number of refugees and internally displaced people will increase dramatically due to the consequences of the imminent climate change.

The global trend towards the existence of refugees will never disappear since there will always be conflicts among individuals with different views (Mourao 2020). Some individuals may perceive these conflicts as significant threats to their quality of life and even their survival. An instance of armed conflict can cause a region to become extremely dangerous and can force individuals to leave their hometowns to search for safety. Individuals who are forced to leave their homes go through some decision steps during their immigration journey. It is important to understand and mimic these decision processes to predict pathways of migration. Predicting these paths enables relief aid services to be delivered to en route refugees. This study mainly focuses on observing the in-between (en route) phase of migration and predicting the migration pathways. For this purpose, this paper presents a simulation model to reconstitute the pathways of refugees trying to reach safety, which is based on capturing the interdependent behaviors of agents.

Traditional refugee-related studies concentrate on the beginning and ending points of migration. Humanity's migration history has been referred to as the movement between two fixed points, namely the origin and the destination (Schapendonk 2013). Some researchers adopted a sedentary perspective to explain the nature of migration, roots ruling over routes (Schapendonk 2013), (see Cresswell (2006), Schapendonk (2011), Urry (2007)). While the sedentary framework has found a place in the migration literature, scholars engaging with the mobile part of migration have interpreted it as a highly questionable concept. For example, Du Toit (1990) defines migration as a process, not a single act but a series of acts including anticipations, plans, and experiences. Discussions on migration mobility have changed the studies' course from the origin and destination to the journey. Studies on the *in-between* migration suggested that the destination may not be restricted to only one moment and a departure point (Schapendonk 2013). In other words, migration is impermanent since a destination can be designated to a place of another departure (Grillo 2007). For this reason, at every step taken along the migration pathways, refugees go through a decision process just like at their initial points of departure. Therefore, it is important to capture this decision process and understand how it leads to migration patterns in terms of spatial tracing.

The paper is organized into five sections. Section 2 provides an overview of agent-based simulation (ABS) modeling and its applications. The developed ABS model is explained in depth in Section 3. Section 4 describes model parametrization. Section 5 provides generated what-if scenarios of Idlib bombardment and the simulation results. Finally, Section 6 concludes the study with some insights and future work discussion.

1.1 Objectives and novelty of the study

This study aims to attain the main pathways of Syrian refugees from Syria to Turkey by simulating their migration movements using an ABS model. The simulation model generates each refugee's movements taking into account his/her personal preferences. The model is designed to reflect various decision-making processes of refugees during a crisis, i.e., a relatively short period of time. A high-intensity armed conflict limits our access to migration data to a great extent. To overcome the limitations arising from this, we have defined risk parameters for the environment and risk attitudes for refugees. Up to our knowledge, this is the first study to integrate risk preferences into an agent-based simulation model.

2. Literature review

This study develops an ABS model to find the widely used paths of Syrian refugees while migrating to Turkey from Syria. Because of this, the literature review focuses on the definition and main elements of ABS modeling, its application areas, simulation tools, and current migration simulation studies.

There are many different definitions of agent-based simulation (ABS) or agent-based modeling (ABM) in the literature. Since ABS is used with similar techniques in many different application areas, it is understandable that there is no precise definition. However, in all application areas, commonly, the working principle of the ABS is based on autonomous agents. Macal and North (2011) define the ABS as a model for simulating dynamic processes involving autonomous agents. Onggo (2016) adopts a definition that includes the interactions of autonomous agents with their environment and among themselves within the framework of internal rules. An autonomous agent reacts independently to situations it encounters during the simulation. Hence, an ABS model does not model a central mechanism that coordinates agents' behavior. Instead, ABS models interactions of a set of autonomous agents, each with its own attributes and behaviors, in a given environment (Macal and North 2011). ABS differs from other commonly used simulation models such as discrete event simulation and system dynamics through this modeling method. A standard agent-based model consists of three main elements: agents, agent interactions, and agents' environment (Macal and North 2011).

There is no universally accepted definition of an agent in the ABS literature (Macal and North 2007, Macal and North 2011, Onggo 2016). Onggo (2016) defines the term agent in its simplest form as an entity that makes its own decisions to achieve its objectives. Macal and North (2011) define an agent through its *autonomy, modularity, sociality*, and *conditionality* properties. Onggro (2016) suggests a spectrum of complexity to define an agent's attributes. In this spectrum, there is a homogeneous set of agents with simple attributes (speed) and behaviors (moving) at one end and a heterogeneous set of agents with complex attributes (memory) and abilities (learning) at the other end (Onggro 2016). An agent can perceive, act, reason, and react based on preset rules under specified properties. Woolridge and Jennings (1995) offer a comprehensive list of agent properties. All agents with the same properties and capable of performing the same activities constitute an agent type.

What makes the ABS model preferable is not the wide range of agent attributes; rather, it is the ability to simulate agents' interactions (Chan et al. 2011). The interactions may generate macroscopic patterns, known as emergent behavior. ABS offers an opportunity to simulate the local interactions of heterogeneous agents that generate the emergence behavior and develop design mechanisms to benefit from coherent regularities of agent actions (Chan et al. 2011, Onggro 2016). In our study, agents interact with their environment and make independent decisions, evaluating the properties of the environment. The environment is a virtual space that agents can interact with, and it can be in various forms, such as a network, a 2D or 3D area, or a Geographic Information System (GIS) map. Agents move in the environment according to the rules specified by the modeler. ABS allows us to model and visualize complex behaviors in a physical environment. In our model the environment is mainly a map and a bombing action occurring sporadically.

ABS has attracted the attention of many researchers from various disciplines. Its applications range from modeling email-based social networks (Menges et al. 2008) to tsunami evacuation (Puckett 2009), and to analyzing threats to financial stability (Bookstaber 2012). Recently, Haki et al. (2020) proposed an ABS model that explores how information system architecture evolves and its outcomes in various organizations. Hebert et al. (2018) developed an ABS that identifies the migration pathways of Syrian refugees from Syria to neighboring countries. This is one of the recent studies in the migration literature using the ABS model. Klabunde and Willekens (2016) review decision-making rules of agent-based models in the human migration literature, discuss the challenges of using ABM in migration studies and offer suggestions on overcoming these challenges.

Our study shows similarities with a recent study in the migration literature. Hebert et al. (2018) use complex systems theory and the ABM method to simulate the movements of refugees. The study's primary purpose is to observe migration pathways under the refugee crisis generated by the Syrian civil war (Hebert et al. 2018). The study considers three decision steps; the decision to leave, the choice of a destination and a path, and the decision to stay on the destination. Hebert et al. (2018) developed an agent-based model to simulate a long-term migration from March 2011 to December 2015. The severity of the conflict is associated with the region's current death tolls. In ABM, agents choose a destination and a means of transport once they decide to leave their homes, with respect to their wealth. Since the study focuses on the long-term effects of the Syrian civil war, the developed ABM offers countries, cities, and refugee camps as alternative destinations. All destination options are characterized by a set of attractiveness indicators such as security, life expectancy, trustworthiness, and more (Hebert et al. 2018). Agents who reach their destinations either stay there or become refugees again. Hebert et al. (2018) implemented the developed agent-based model using NetLogo, as in our study.

On the other hand, our study focuses on the short-term effects of a large-scale conflict such as a bombing. The unavailability of data to set parameter values is a primary problem in migration studies (see Hebert et al. 2018). We tried to solve this problem by assigning comparable parameters to the agents and the environment, namely risk preferences to agents and risk and tolerance levels to the patches (the environment). Unlike the study in the literature, we observed our model through four different possible real-life scenarios. We have also given users the freedom to set parameter values using the NetLogo user interface to try out what-if scenarios. Thus, we developed a flexible migration simulation model with novel parameters considering ABS definitions in the literature and current migration simulation models.

3. Model

This section describes the details of the ABS model that aims to find the main pathways of Syrian refugees to refugee camps in Turkey. The model makes use of the NetLogo program (Wilensky 1999). The model defines refugee groups as agents, and agents follow autonomy, modularity, conditionality, and mobility properties mentioned in the literature review section. A Syrian administrative map is created, and the data sets are generated based on the current risk profile of each governorate via the ArcGIS Geographical Information System software. A NetLogo environment is created by assigning the risk levels to patches.

The ABS model scans every patch and generates an agent that originates from that patch each tick if the risk score of the patch exceeds the adopted tolerance level. An agent calculates his/her distance to each available refugee camp and chooses the camp with the minimum distance as the destination point. If the predetermined camp capacity becomes full at any time point, the agent returns to the destination selection process by removing the previous target camp from the set of alternative destination points. The model may define obstacles on migration paths to restrict the movements of agents with specific risk preferences. Hence, agents check possible obstacles and decide their next moves accordingly. Agents leave the system when they reach their destination camp. A detailed flowchart is provided in Figure 1 describing the process.

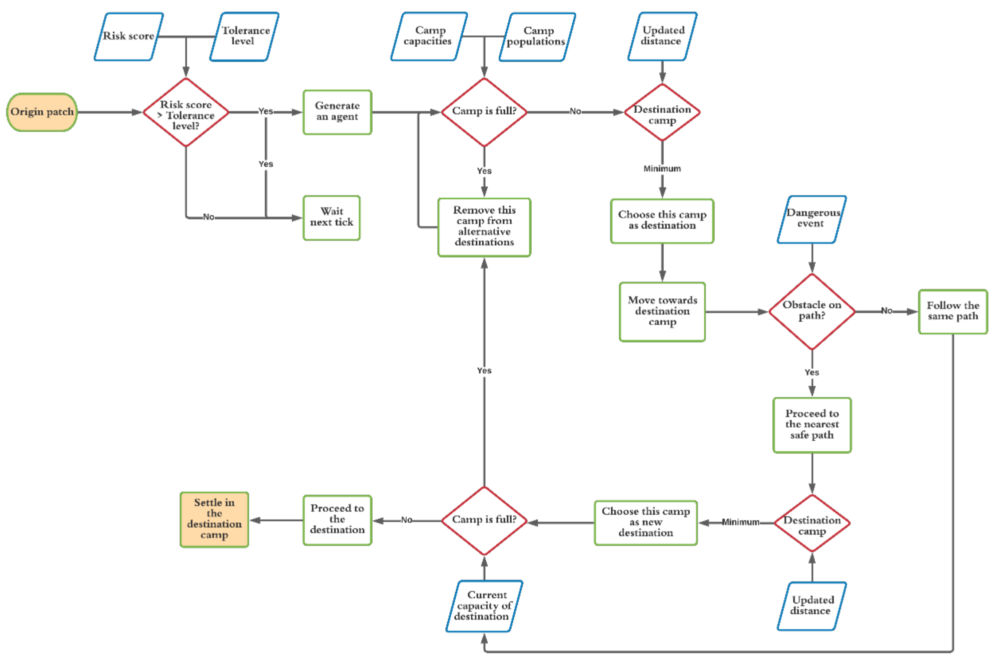

Figure 1. The flowchart of the proposed ABS model

The following subsections describe each step of the model in detail. Subsection 3.1 lists the assumptions of the developed ABS model. Subsections 3.2 and 3.3 explain the input generation stages and the migration decision of the agents. Subsection 3.4 describes the agents' choice of the destination camp. Finally, Subsection 3.5 represents the agent walking rules.

3.1 Assumptions

The proposed ABS model possesses the following assumptions. The set of possible destination points is restricted to the refugee camps located in Turkey. Although only 1.75% of Syrian refugees in Turkey stay in camps (Refugee Association 2020), setting the camps as the only target locations during a crisis simulation seems to be a valid assumption since the refugee camps are the closest safe settlements to the border-crossing points. The model assumes that each agent knows the environment, i.e., risk scores of patches, camp locations and available capacities before departing. This procedure is defined as *perfect information*, i.e., agents have complete knowledge of camp and patch attributes. At the beginning of the simulation, all camps are assumed to be empty or having a fixed pre-occupied capacity and can serve at full remaining capacity.

3.2 Generation of map and datasets

We created an administrative map (see Figure 2) covering governorates of Northern Syria and Turkish cities hosting official refugee camps via ArcGIS. The map includes main roads, highways, and refugee camps. We have generated three datasets to create the environment of agents. These datasets contain Turkish cities, refugee camps, and Syrian governorates. Turkish cities are assumed to be risk-free; hence, no risk attribute is included. The dataset for camps includes the name, capacity and population information of each refugee camp.

In addition to the name and population, the Syrian dataset includes an average risk score and tolerance level for each governorate. Each governorate's risk score is determined as the average number of conflicts in the region between July 2018 and November 2019 based on the Armed Conflict Location & Event Data Project (ACLED) database that provides the total number of conflicts in Syria for each governorate. The risk score of each patch is initialized to the calculated risk score of the region. The model includes a danger parameter which can be specified by the users using the NetLogo interface and the risk score of each patch is randomized to the extent of the specified value. Additionally, the risk score of a patch increases drastically with bombardments.

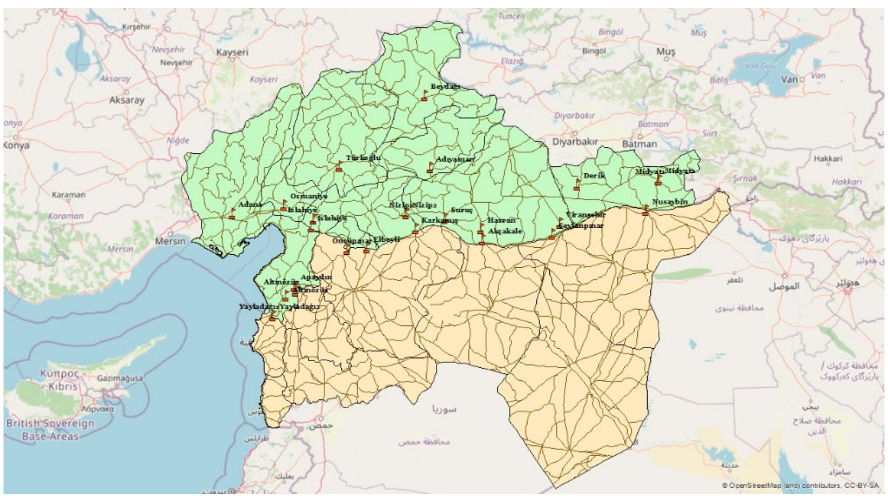

Figure 2. The map of governorates of Northern Syria and Turkish cities hosting official refugee camps

3.3 Tolerance levels and decision to leave

The leaving home decision of an agent depends only on average risk scores and tolerance levels; therefore, these parameters significantly impact the model's accuracy. A comprehensive literature review is conducted to determine initial tolerance levels. There are recent studies that interpret fleeing from the conflict area as a safer option than staying in the area or participating in the conflict; thus, some researchers define migrants as risk-averse agents (Mironova et al. 2014 and Mironova et al. 2019). On the other hand, Mironova et al. (2014, 2019) investigate the average tolerance level of individuals living in conflict areas during the Syrian civil war, not through an analytical approach. They conclude that an individual living in a conflict area has a higher tolerance level than an individual living in a safer place (Mironova et al. 2014 and Mirovona et al. 2019). We have defined tolerance levels between 1 (most risk-averse) and 5 (most risk-seeking), in line with the literature. Then, we have rescaled the risk scores to the 1-5 range to make these two parameters comparable. As of December 2019, the start date of the simulation, Idlib was the riskiest region with a risk score of 4.2, and we have determined the mean tolerance levels of patches in Idlib as 4.3. Tolerance levels of other governorates are determined based on their average risk scores compared to that of Idlib.

The model updates risk scores as new conflicts come through and the updated risks affect the decisions of agents who have not yet started to move. Likewise, tolerance levels may reduce over time, resulting in migration eventually.

Agents decide to migrate according to the relationship between patch properties. Migration decision is reflected by generating new agents on the patches whose risk scores are higher than their mean tolerance levels. The model defines an agent generation probability for each patch for all ticks by employing a sigmoid function. The sigmoid function results in a non-negative probability (p) in different magnitudes depending on the difference between the patch's risk score and tolerance level (see equation (1)). Hence, if the tolerance value is less than the risk score, the model has a non-negative probability of generating an agent in that patch. Agents enter the simulation at their generation ticks, and the model records and stores the agent's starting patch and period information. The decision to leave implies the question of where to migrate.

$$p = {}^{1}/_{1 + e^{danger\ score\ - tolerance\ level}} \qquad (1)$$

3.4 Destination choice

Agents are assumed to have access to up-to-date camp capacities and populations and decide on their initial destination camps using this information (see 3.1 Assumptions). Each agent forms a list of alternative destination camps (with available capacity for each). Each agent calculates a cost for each alternative camp based on the shortest path found by the A* algorithm (Hart et al. 1968). The camp with the lowest cost is identified as the destination of that agent. Agents may encounter obstacles on the path to their target camp. The model runs the A* algorithm to recalculate the shortest path costs of each alternative camp for each agent in every tick to prevent agents from stopping when they encounter obstacles. If the camp population becomes equal or greater than the camp capacity during the agent's movement, the model runs the A* algorithm to determine a new destination based on the agent's current patch as the origin. By this way, the agents adopt the environment. Since the model simulates short-term migration movements, there is no such case having a full camp empty again.

3.5 Agent movement rules

As an agent departs his/her origin to reach the destination camp, an agent moves towards the destination following the shortest path possible determined based on obstacles in the environment. The obstacles limit the possible paths of agents depending on their risk preferences. For example, an armed conflict or a bombardment increases the area's risk score, making that region a high-risk region. In addition to high-risk regions, the model can also define medium-risk regions. A risk-seeking agent may pass through a high-risk region, while a risk-averse agent considers medium-risk regions as obstacles. The obstacle integration into the model forces agents to get away from the danger zone as soon as possible and follow the closest safe path. Agents leave the system when they reach their target camps. The model updates the camp populations as an agent reaches a camp. By utilizing camp population updates, we can also determine the occupancy rates of the refugee camps.

4. Model parametrization

There are *static* and *user-specified* parameters in the model. The static parameters are the tolerance deviation level, the risk scores of patches within the danger zone, the amount of decrease in the risk score as an agent move away from the bombing center and the radius and the location of the bombardment. The tolerance deviation level specifies the maximum deviation amount from the mean tolerance, i.e., the parameter ensures that tolerance values are above or below the mean tolerance level according to agents' risk preferences. The bombardment zone is defined as circular, and the bomb's effect decreases by a fixed amount as agents move away from the center. Hence, the risk score reaches its maximum level in the center. The risk scores of patches within this circular zone are already defined in the model.

Users can set the values of the *user-specified parameters* from the NetLogo interface. User-specified parameters are the danger parameter (danger-parameter), the tolerance decrease parameter (tol-decrease-param), the distribution of risk attributes, the walking speed (walk-speed) and the tick of the bombardment. The risk scores of patches take a value within the range of [avg. risk score - danger parameter, avg. risk score + danger parameter]. The user specifies the amount of decrease in agents' tolerance levels in each tick with the tolerance decrease parameter. There are three user-specified parameters to control the distribution of risk attributes of agents: standard deviation (std-risktype) and thresholds for risk avoidance (low-threshold) and liking (high-threshold). An agent's probability of having a certain risk attribute comes from a normal distribution. One of the parameters determines the standard deviation of the normal distribution. The other two parameters are utilized to specify threshold values for risk avoidance and liking. The parameter for the walking speed of agents determines the number of patches an agent can walk in a tick. The maximum distance a healthy man can walk in a day is accepted as 25 km; correspondingly, the default walking speed is determined as four patches in the simulation model. However, the user can specify the number of patches by the criterion defined on ticks. Also, the walking speed can vary according to environmental conditions, such as weather, dangerous events, transportation means, and more. Users have control only over the occurrence tick of the bombardment. The user can "bombard" an area by clicking the "Bombard" button from the interface at any simulation tick.

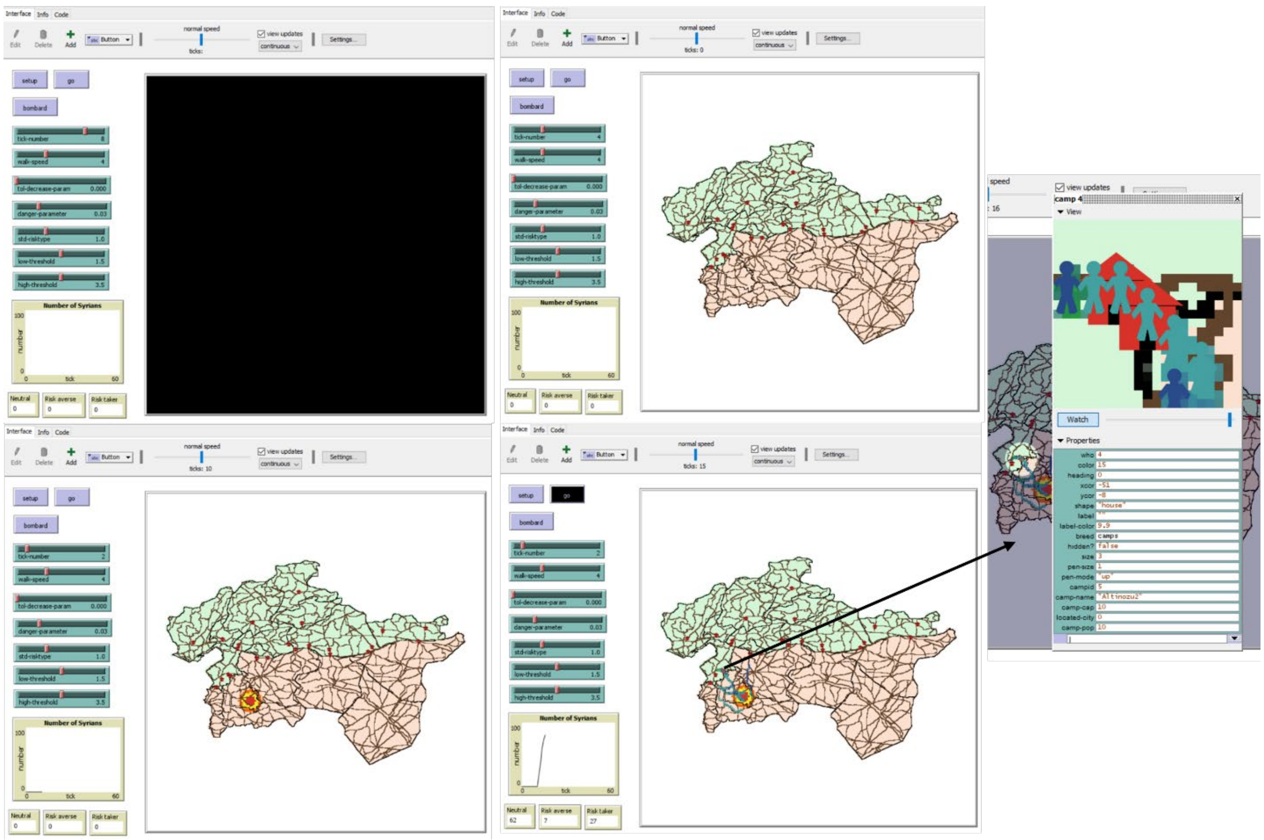

Figure 3. User interface of NetLogo for the developed ABS model

5. Scenarios and results

This study generates four scenarios that are variants of the developed ABS model. A tick in the NetLogo simulation corresponds to a day in real life. The study focuses on simulating the pathways of refugees during the South Idlib bombardment, which took place between December 2019 and January 2020. Hence, we have run the simulation model for one month, i.e., 30 ticks in each scenario. In each scenario, an agent represents a group of 1,000 refugees. Also, we have kept the environment the same and offered 26 refugee camps located in 10 cities in Turkey as potential destinations of agents. We have generated the camps, in line with their names, locations, and capacities provided in the reports of AFAD (Bursalıoğlu 2016). Table 1 shows the user-specified parameter values of each scenario.

The first scenario (the base scenario) aims to observe the catastrophic effects of a bombardment. We have set initial tolerance levels of all patches higher than their risk scores. The bombardment causes a sudden increase in the risk level of the bombing zone. Thus, agents originate only from the danger zone. In this way, we have eliminated long-term migrations from the crisis simulation. After simulating the bombardment, the risk scores of the patches within the zone start to decrease. The decline in risk scores continues unless a different conflict occurs in the same patches. We have simulated this scenario with various decrease parameters until reaching a satisfactory conclusion about its value. This value is 0.005.

In **the second scenario**, we have employed the tolerance decrease parameter. The user sets the value of this parameter from the user interface. The tolerance levels of patches within Syria decrease by the assigned value in each tick. The tolerance decrease parameter is 0 as default. However, for this scenario, we have set it to 0.003. The decrease in tolerance levels causes migration originating from different regions (medium-risk region) in addition to the bombardment zone (high-risk region). Therefore, the number of agents generated in the simulation increases.

The third scenario is designed to reflect the unpredictable environment of a conflict. In this scenario, several dangerous events occur in patches within Syria. We have increased the value of the danger parameter from 0.03 to 0.09. The increasing randomness of risk scores defines dangerous events. In this way, every patch has a non-negative probability of generating an agent. In other words, regardless of the region's risk level and the simulation time, migration can originate from any patch depending on its risk score and mean tolerance level.

The fourth scenario is generated to observe the differentiation in the paths of agents with different risk-taking preferences. We have reconstituted the environment and defined danger zones on the main paths observed from the previous scenarios. Danger zones consist of high-risk and medium-risk regions and act as obstacles depending on the agent's risk preferences. Thus, we can observe the most preferred paths of each agent type.

Table 1. Values of user-specified parameters for each scenario

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
danger-parameter	0.03	0.03	0.09	0.03
tol-decrease-param	0	0.003	0	0
std-risktype	1	1	1	1
low-threshold	1.5	1.5	1.5	2
high-threshold	3.5	3.5	3.5	4
walk-speed	4	4	4	4

5.1 Results

We ran the simulation model for 30 ticks (days) for each scenario. The bombardment occurs in the 10th tick in each run. Until the bombing, we have observed the changes in the environment. In Scenario 2, the tolerance levels of patches decrease for ten ticks. This tolerance decrease caused agents to migrate from regions with medium risk levels such as Tartus, Ar Raqqah, and Hamah. In Scenario 3, we have defined random dangerous events across Syria. These events originated migration from medium-risk regions by increasing the risk score above the tolerance level even before the bombing in Idlib. For the base scenario (Scenario 1), the simulation model generated 55 agents in the first three days after the bombardment. Fifty-five agents, i.e., refugee groups, correspond to 55,000 refugees. The run time of the base scenario is 28 mins and 55 seconds for 30 ticks, and it generates a total of 242 agents (see Figure 4). In Scenario 2, the number of agents produced increases to 700, and the run time reaches an average of one hour. In Scenario 3 and 4, we have tracked 415 and 285 agents, respectively. In the fourth scenario, we have observed that the high-risk and medium-risk obstacles limit the paths of risk-averse and risk-neutral agents. These two agent types eliminate a camp from the alternative destination list if an obstacle blocks the path leading to this camp. Thus, destination points become specific to each agent type, and main pathways are formed according to the risk-taking preferences of agents.

We can observe the main migration paths formed in each simulation scenario in Figure 5. Agents' risk-taking preferences specify the color of a path. In the simulation model, we have represented risk-averse agents in green, risk-neutral agents in cyan, and risk-seeking agents in blue. The red region represents the bombing center; as the color of the area changes from red to orange, the intensity of the bombardment decreases gradually.

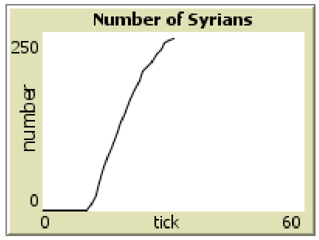

Figure 4. Number of Syrian refugees in the system vs. simulation time for the base scenario

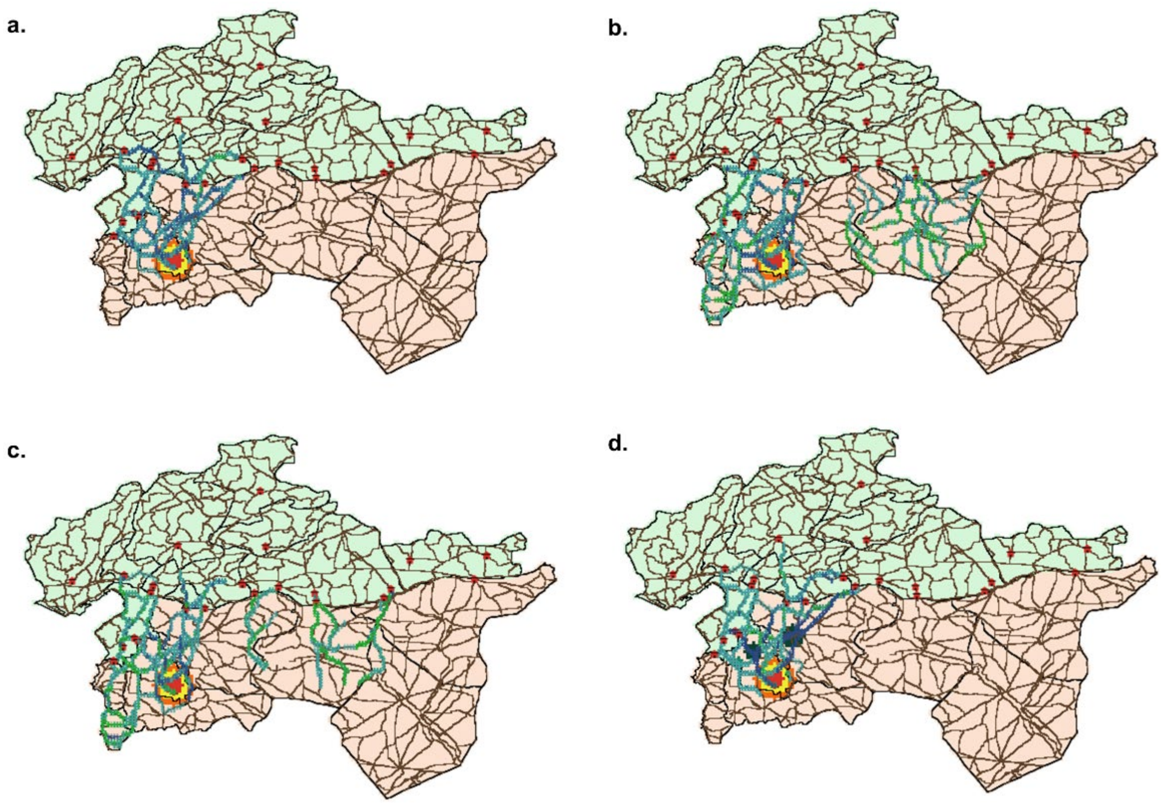

Figure 5. Resulted migration paths according to a. Scenario 1, b. Scenario 2, c. Scenario 3, d. Scenario 4

Table 2 shows the occupancy rates of refugee camps for each scenario. Here, 6 camps in Hatay (Altınözü 1, Altınözü 2, Apaydın, Islahiye, Yayladağı 1, Yayladağı 2) fill up first in every scenario. This result can be explained by the proximity of Hatay to the bombing zone, Idlib. The agents generated in the bombing patches near Aleppo plan their pathways through Aleppo. This route makes the Elbeyli and Öncüpınar camps in Kilis popular in all scenarios. The second (tolerance decrease) and third scenario (random dangerous events) cause a migration wave originating from Raqqa. This migration wave increases the population of Şanlıurfa camps. Also, in these two scenarios, the migration movements originating from Tartus cause the Hatay camps to be filled in a shorter time and the agents to head towards other available camps.

Table 2. Occupancy rates of refugee camps for each scenario

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Adana	0%	0%	0%	0%
Adıyaman	0%	0%	0%	0%
Altınözü 1	100%	100%	100%	100%
Apaydın	100%	100%	100%	100%
Altınözü 2	100%	100%	100%	100%
Akçakale	0%	100%	100%	0%
Ceylanpınar	0%	15%	100%	0%
Viranşehir	0%	0%	30%	0%
Harran	0%	25%	100%	0%
Islahiye	100%	100%	100%	100%
Türkoğlu	0%	0%	5%	5%
Karkamış	0%	13%	100%	13%
Elbeyli	100%	75%	100%	100%
Beydağı	0%	0%	0%	0%
Midyat 1	0%	0%	0%	0%
Midyat 2	0%	0%	0%	0%
Nizip 1	93%	0%	6%	53%
Nizip 2	0%	0%	6%	53%
Nusaybin	0%	0%	0%	0%
Öncüpınar	100%	100%	100%	100%
Osmaniye	87%	0%	53%	26%
Yayladağı 1	100%	100%	100%	100%
Yayladağı 2	100%	100%	100%	100%
Islahiye	100%	100%	100%	100%
Derik	0%	0%	0%	0%
Suruç	0%	0%	6%	0%

5.2 Future improvements

The run time of the current ABS model is long. Therefore, the model needs to be simulated in a simplified environment. There is a trade-off between the run time and the details involved in the model. A simpler environment has the potential to increase the simulation speed, allowing to run all the scenarios with more replications. In addition, simplification of the environment will allow the development of a more comprehensive pathfinding algorithm. We intend to develop a new algorithm employing utility functions that depend on the agents' risk preferences. to the best of our knowledge, this algorithm will integrate utility functions into a migration simulation for the first time in the literature. For this reason, the details lost from a simpler environment are planned to be included in the ABS model with the new algorithm.

5.3 Validation

Although the exact number of refugees who crossed the Turkish border during the Idlib bombardment is not known, we can estimate the approximate numbers based on the official statements from the corresponding period. On December 19, the Turkish Presidency declared that approximately 50,000 Syrian refugees entered Turkey from the northwest region of Idlib within three days following the bombardment (Al Jazeera 2019). In addition, United Nations observers stated that at least 18,000 people left the bombing site on December 21, 2019 (Al Jazeera 2019). The outputs obtained from the simulation model coincide with the statements. Hence, we can conclude that the model successfully predicts short-term conflict moments even though we have limited access to the exact migration data. As future work, we may confer with Migration Management to validate our path and camp population findings.

6. Conclusion

We developed an agent-based simulation model that includes the environment's risk attributes and the agents' risk-taking preferences. We ran the developed model with four different scenarios based on the Idlib bombardment. We obtained the total number of migrating agents, the population and occupancy rates of the camps, and visual outputs of the main migration pathways. We validated the outputs by comparing them with the official statements of experts. Visual examination of the model outputs and comparison with the data collected from secondary sources enabled us to understand the competencies and deficiencies of the model. We observed that the model captures the short-term effects of armed conflicts satisfactorily. Therefore, the camp population outputs may not match real life, but the decision-makers can use obtained results as upper limits for required camp capacities and develop response plans.

The model has a long run time and future efforts may focus on shortening it. The model can be tested with various agent and environment attributes. In this way, the effect of different attributes on forced migration pathways can be identified. We developed a flexible model to generate different scenarios from the NetLogo user interface by adjusting user-specified parameters. In addition, the model can produce new scenarios by changing the location and size of the conflict. Moreover, the model can generate other new scenarios by changing the static parameters, for example, changing the bombardment location or its radius. Parameter values can be set to more realistic values with a more comprehensive literature review or access to primary data to increase the model's accuracy.

Acknowledgements

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