AN AGENT-BASED MODELING AND SIMULATION TOOL FOR ESTIMATION OF FORCED POPULATION DISPLACEMENT FLOWS IN IRAQ

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ABSTRACT
Forced displacement and migration is on the rise globally. As a result of wars, insurgencies, political persecution, complex emergencies, and climate change, more than 65 million people worldwide are considered as forcibly displaced. This rising number has created significant challenges for humanitarian agencies. Therefore, understanding the causes, movement patterns, and migration flows of displaced populations has attracted researchers. While traditional migration models can be used, more sophisticated and advanced models are required to capture various factors influencing the displacement process and the complex interactions and behaviour of various agents that force people to make displacement decisions. Agent-based modeling (ABM) has emerged as a preferred modeling method for complex social and environmental problems including forced displacement and migration. ABM in the context of forced migration allows for a more accurate and detailed simulation by including dynamic interactions of migrants and humanitarian actors. This paper presents an agent-based model developed to understand the nature of forced displacement in Iraq caused by recent conflicts.

Keywords: Agent-based modeling, displacement tracking, forced displacement, internal migration

1. STATE OF THE ART

Since the end of World War II, global conflicts have generated an increasing number of refugees and internally displaced persons (IDPs), resulting principally from conflicts or persecution within states (Anderson, Chartuvedi and Cibulskis 2007). According to the UN Refugee Agency (UNHCR), formerly known as the United Nations High Commission for Refugees, the total number of people forcibly displaced worldwide in 2015 reached a total of 65.3 million (UNHCR 2015). An estimated 12.4 million of these were newly displaced in 2015 as a result of conflict or persecution. After Syrians who constitute the largest number of displaced persons (11.7 million), Afghans, Colombians, Congolese, Iraqis, Nigerians, Somalis, Sudanese, South Sudanese, and Yemenis, each with more than 2 million displaced people, are the next largest groups (UNHCR 2015).

Various factors contribute to forced displacement. Threats to personal safety and security are of primary importance in leading people to abandon their homes (Davenport, Moore, and Poe 2003). Besides violence and culture, other relevant factors like domestic economic situation at home and abroad may influence internal displacement (e.g. flow path selection). Previous studies have found that networks and cultural communities provide people with information about migration possibilities (Shellman and Stewart 2007).

The displacement of large numbers of people in times of crises represents a challenge for humanitarian agencies (Hailegiorgis and Crooks 2012). Provision of basic needs and services for displaced people, delivering critical aid such as shelter, food, and medical health in dynamically changing environments (i.e. unpredictable number of people, in scattered locations) are very difficult undertakings.

Until recently, forced displacement has been primarily considered a political phenomenon; therefore, it has been ignored in migration literature (Schmeidl 1997).

Computational studies investigating the refugees' movements are scarce in the academic literature. However, extensive research has been done both on evacuation, which focuses on smaller space and time scales, and migration modeling, which focuses on much larger space and time scales (Groen 2016; Uno and Kashiyama 2008; Smith and Brokaw 2008).

Nowadays, ABM is intensively applied in several domains, such as engineering, biology and social science. In the last ten years, several researchers have been demonstrating its potential to advance our understanding of complex systems (Andersson, Chartuvedi, and Cibulskis 2007; Collier and North 2012; Asakaura, Aoyama, and Watanabe 2011). However, ABM has only fairly recently been applied in humanitarian research. Therefore, there are very few references in the literature compared to more classical methods such as Linear Programming, System Dynamics or Discrete Event Simulation (Menth 2016). Sokolowski, Banks, and Hayes (2014) introduced a methodology for crafting the environment and agents to

represent the Syrian city of Aleppo and the displacement of its citizens due to the Syrian conflict. The model replicates the refugee behavior taking place within Aleppo by capturing the dynamic interaction taking place between rebels and government troops.
However, existing research shows that ABM can capture interactions among individuals, and, therefore, is well-suited for modeling sociological and psychological behavior and interactions of humans (Johnson, Lampe, and Seichter 2009). Interactions between individuals often produce nonlinear effects at the population level (Klabumde and Willekens 2016). The ABM simulation approach is capable of capturing these interactions. In fact, the major advantage of ABM for the analysis of social systems is the capability for modeling both explicit and implicit social interactions. In the case of forced migration events as a result of these interactions, individual decisions and behaviour may change, since these interactions are very dynamic (i.e., in time and space). This represents a huge advantage for modeling by means of ABM technology to produce simulations and shape the resulting networks, which expands its applicability and effectiveness with the integration of geographic information systems (GIS) technology (Crooks and Wise 2013).
The model presented in the current work integrates in a single platform individual decision making by the civilian population, as influenced by insurgent and military actions as well as resources provided by the humanitarian agencies. Moreover, the level of influence on population behavior (displacement flows) is estimated in accordance with real data (gathered from extensive field records) as a function of the risk level perceived and considering the observed destination preferences. Agent-based modeling of these dynamic interactions in a GIS environment allows a better simulation of the system. Thus, the model proposed herein differs from previous work, and could be a more effective tool for analysis and decision making required for humanitarian logistics planning and deployment.

2. CASE STUDY

Violence and conflict have caused unprecedented displacement in recent years, particularly in the Middle East. A large number of Iraqis have been affected. The UN Refugee Agency reported that 203,700 new asylum applications were filed in 2015 by people who have fled from Iraq (UNHCR 2015). However, the greater numbers of affected Iraqis have been internally displaced, forced to relocate to other regions within Iraq. For instance, from January to July 2014, there were an estimated 1.2 million internally displaces persons (IDPs) in Iraq (ECHO 2014). Presence of armed groups performing intimidation and terror acts at specific regions, still forcing individuals and entire families to find safer areas where their ethno-religious group constitutes the majority. Armed clashes between the multinational Forces and Iraqi Security Forces on the one hand, and ISIS insurgents on the other, have also produced population displacements (Couldrey and Morris 2007). The movement occurred predominantly in and between urban areas – with more than 70% fleeing Baghdad. At least 10 of the 18 Iraqi provinces have now tried to place entry restrictions on their internal borders to Iraqis displaced from elsewhere in the country (Margesson, Bruno, and Sharp 2009).
Within many areas in Iraq, conditions are deteriorating and are leading to more permanent problems. Seven out of the eighteen Iraqi provinces host more than 80% of the total identified IDPs (IOM 2016): Baghdad (16%), Anbar (16%), Dahuk (15%), Kirkuk (13%), Erbil (8%), Ninewa (6%) and Sulaymaniyah (6%). Figure 1 is a slide prepared by European Commission – Humanitarian Aid & Civil Protection (ECHO) showing the movement of people displaced in Iraq in January-July 2014 (ECHO 2014).

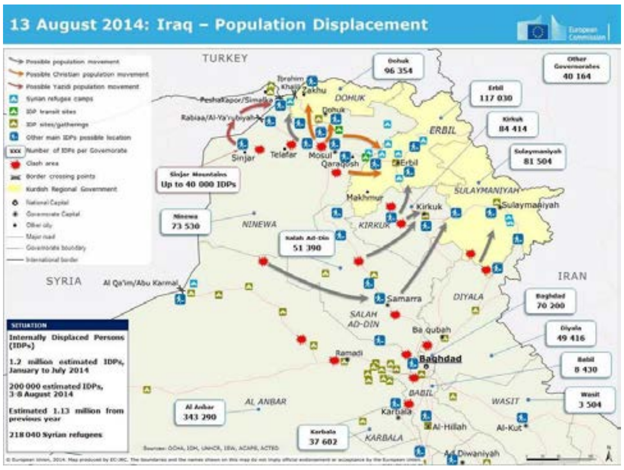

Figure 1: Movement of People Displaced in Iraq from January to July 2014

Based on the availability of data and on the fact that violence and conflict continue to take place in Iraq, the present work seeks to produce a broadly applicable computer simulation that will be used to capture the behaviour of civil populations, military forces, and humanitarian agencies.
The model can be used to analyze the forces that are driving refugee flows and conditions. The impacts of government policies can be examined and used to conduct policy experiments to see how refugee communities might respond to alternative courses of action.
By executing the computer model with different initial values for its parameters and inputs, patterns and regularities can be discerned from the results (Andersson, Chartuvedi, and Cibulskis 2007).
The approach used to reach this objective consists of the following:

- Extracting real data from the Displacement Tracking Matrix (DTM), an information management tool used by the International Organization for Migration (IOM).
- Identifying and analyzing events that cause forced migration.

- Developing an agent-based simulation tool to capture the behaviour of displaced people, insurgents, and military forces.

3. DESCRIPTION OF THE MODEL

ABM has been chosen because in addition to the above mentioned advantages, their application avoids unrealistic restrictions and assumptions, imposed on the system if being modeled under other approaches as system dynamics, where aggregate data is used. ABM can be used to conduct policy experiments to see how refugee communities might respond to alternative courses of action (Anderson, Chartuvedi, and Cibulskis 2007).
ABM has been chosen as it allows:

1. Virtual simulation of the consequences of decisions,
2. Integration of multiple theories regarding the phenomena under analysis,
3. Representation of agents with multiple decision strategies,
4. Modeling of heterogeneous actors who can modify their behavior over time.

We have used AnyLogic simulation software 7.3 (AnyLogic 2016), which allows GIS environment to be embedded and used in the simulation and proves to be very important in large scale forced displacement simulation. Implementing ABM in the GIS environment, it is possible to model the emergence of phenomena through agent interactions over time and space (Crooks and Wise 2013). Based on this approach, the overarching objective of our project is to simulate the flows of displaced people and calibrating the model using empirical data from the Displacement Tracking Matrix (DTM), which represents one of the contributions of the current work.
The simulation model's components are:

1. Agents,
2. Input section,
3. Map and visualization,
4. Output section.

The agents include:

- Governorates,
- Insurgents,
- Families displaced,
- Iraqi security forces,
- Foreign peacekeeping forces,
- Iraqi commanders.

The Governorate is the environment in which agents act and interact. In the specific case of Iraq, 18 different governorates have been considered, even if the focus is on the eight most significant, in terms of people displaced.
insurgents respresent a minority group who are forcing political change by means of a mixture of subversion, propaganda and military pressure, aiming to intimidate the broad mass of people to accept such a change. They seek to destroy the state by violent action designed to disrupt the normal functions of control (UK Army Field Manual, 2007).
In the model, insurgents goal is to capture major cities and therefore their destinations could be several.
The families are the civil population of the Governorates. Families,based on the movement of insurgents, decide if staying in their place or moving toward other governorates where they feel safer. Figure 2 shows the decision tree for the families.

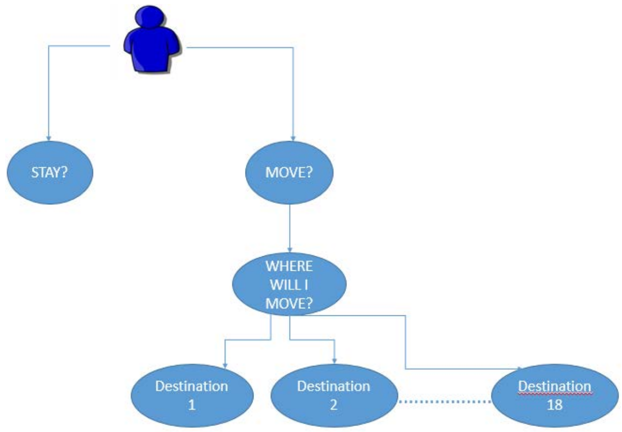

Figure 2: Decision Tree for the Families

The initial decision of the families is dependent upon the value of a Risk Index which has been calculated for each governorate. The Risk Index is a function of a number of dynamic variables (e.g., push and pull factors of displacement). These variables are:

- Presence of national military,
- Presence of international forces,
- Presence of insurgents,
- Number of civilian casualties,
- Access to transportation infrastructure,
- Local behaviour,
- Presence of humanitarian organizations,
- Level of poverty,
- Presence of relatives.

As the values of push/pull factors change, the overall index will fluctuate and the number of families displaced for each governorate will change. The higher the value of Risk Index, the higher the population displaced. Figure 3 shows the number of displaced people as a function of the Risk Index (as implemented in the model).
Iraqi Security Forces are the existing military forces in Iraq who battle against the insurgents. The main Iraqi Security Forces organizations belong to the Ministry of Interior (MOI) and the Ministry of Defense (MOD), although other ministries control smaller, specialized security forces (The Washington Institute 2004). Based on the actions of the insurgents, Iraqi Security Forces

may undertake several possible actions (which may be chosen by the users).

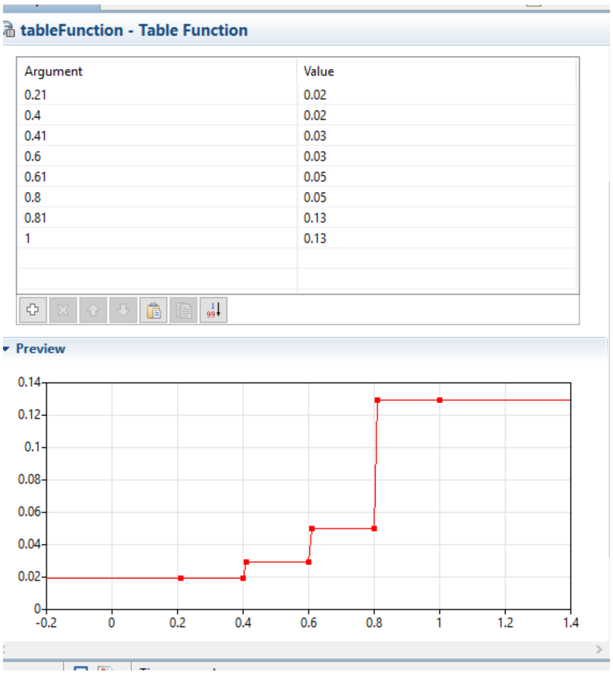

Figure 3: Displaced Population Function

Foreign Peacekeeping Forces are the U.S.-led coalition forces who battle against insurgents in Iraq. The coalition forces in the model are from USA, UK, Canada, Australia, Italy, Denmark, and Germany. Based on the rules of engagement (Rules of Engagement 2007), four categories of strikes against insurgents have been implemented in the simulation model:

- Troops into contact,
- Pre-planned strike,
- Fleeting target,
- Time-sensitive targets.

For each strike, U.S. military forces can use several resources:

- Aircraft,
- Any organic direct fire weapons,
- Mines.

In this simulation, the B-1 Lancer bomber aircraft, bombs of 1kiloton, and Claymore mines have been used. The US strike authorities remain subject to the expected level of collateral damage (Rules of Engagement 2007). If the insurgent (target) is in a High Collateral Damage Zone, which means that there are more than 30 families within a 1 kilometer radius, a strike requires the approval of the Secretary of Defense. If the target is in a Low Collateral Damage Zone, it requires the approval of the Commander of Iraqi Multi-National Forces, while if the target is in a No Collateral Damage Zone it requires only the approval of the Division Commander. This is the behaviour of the Agent ‘Commander’ in the model.

The map section shows the evolution of the flow of displaced people over time. The input section allows the user to set up a number of different parameters, such us the initial population, different types of agents, and the value of Risk Index for each Governorate. Finally, the output section reports the main simulation results, including the number of people displaced from each governorate and the final destination of these displaced people. Figure 4 shows a partial view of the interface for the Input Section, with sliders to input the Security Risk Index for each governorate (values shown are for demonstration only).

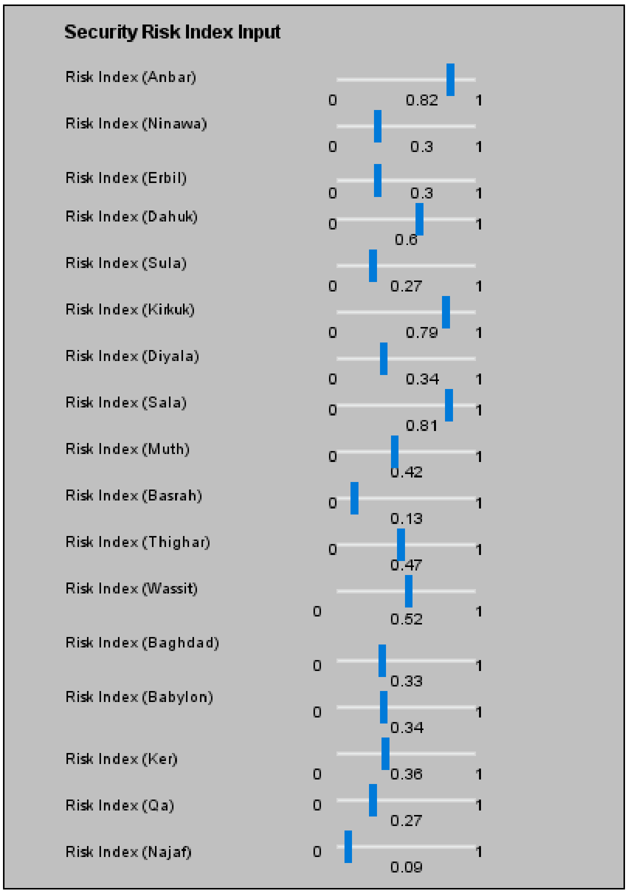

Figure 4: Graphical Interface for Input Section

Figure 5 shows the simulation model visual and map section that includes the eight principal governorates (Al Anbar, Ninewa, Kirkuk, Diyala, Saladin, Baghdad, Babil, Erbil) with their real population (Joint Analysis and Policy Unit 2015), and the flow of people displaced for each governorate. Furthermore, this figure also shows the movement of insurgents, the principal basis of foreign military forces (Ninewa, Saladin, Diyala, Baghdad, and Kirkuk) and the pre-planned attack with aircraft made by U.S. military forces against the insurgents. In the Model Setup section, the user can add different agents to the simulation model, and, based on the movement of the insurgents, could choose, through several buttons, which kind of military strike could be undertaken.
Figure 6 shows the most important results of the simulation that could be accessed at run—time. The

main results are also saved in a database file that can be accessed at the end of the simulation.

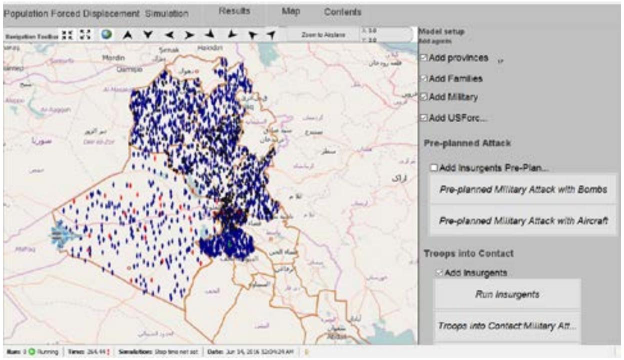

Figure 5: Simulation Model Animation Graphical Interface

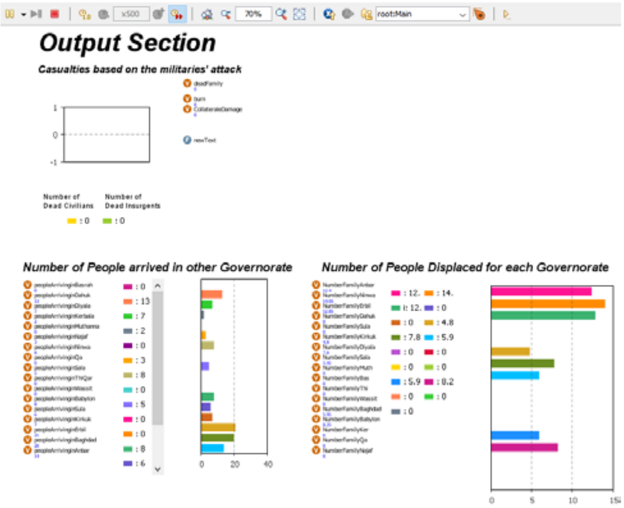

Figure 6: Graphical interface for the Output Section

4. SIMULATION RESULTS

The simulation model introduced in section 3 has been used to model the flow of IDPs. Multiple simulation runs have been executed for each governorate and the results are summarized below.

These experiments have been performed for eight governorates. In this work, results are reported for the Governorates of Al Anbar and Erbil only. The simulations results correspond to the values for 4 weeks of simulated time.

Selection of these two cases is based on the fact that, according to the DTM dataset, Al Anbar is the worst affected governorate in terms of people displaced, while Erbil is the least affected Governorate.

The governorate of Al Anbar is situated in western Iraq. With a total population of close to 1.5 million, it is the largest governorate in the country in terms of land area. Over the past decade, Al Anbar saw multiple waves of displacement due to the offensive of insurgents. The experiment about Al Anbar has been done with a Risk Index value of 0.81. Table 1 reports the results of simulation with the number of people displaced in the Governorate of Anbar.

Table 2 reports the probabilities of choosing different destinations for the displacement from Al Anbar. In this specific period, 39.4% of the families displaced from Al Anbar choose another district in Al Anbar as destination, while 27.3% of the families displaced from Al Anbar move to Baghdad and 12.1% to Erbil.

Table1: Number of Families Displaced from Al Anbar based on the Highest Value of Risk Index

Risk Index Value	% Displaced	Number of Individuals Displaced	Number of Families Displaced
0.81	13.0%	193,440	32,240

Table 2: Probability of Destination for Families Displaced from Al Anbar

Destination Governorate	Probability (%)
Al Anbar	39.4%
Baghdad	27.3%
Erbil	12.1%
Kirkuk	9.1%
Sulaymaniyah	6.1%
Babylon	1.0%

Situated in northwest Iraq, with a total population of just over 1.5 million, Erbil hosts the capital of the region of Kurdistan which is administrated by the Kurdistan Regional Government (KRG). As the economy and security of Erbil are generally better than many other areas of Iraq, this governorate continues to be a common destination for displaced populations. Erbil is the least affected governorate in terms of people displaced.

The Erbil experiment has been done with a Risk Index value of 0.21. Table 3 reports the simulation results with the number of people displaced in the Governorate of Erbil. Table 4 reports the probability of destination for the displacement from Erbil. In this specific period, 98.9% of the families displaced from Erbil choose another district in Erbil as destination, while 1% of the displaced families move to Salah al-Din.

Table 3: Number of Families Displaced from Erbil based on the Lowest Value of Risk Index

Risk Index Value	% Displaced	Number of Individuals Displaced	Number of Families Displaced
0.21	2.0%	30,840	5,140

Table 4: Probability of Destination for Families Displaced from Erbil

Destination Governorate	Probability (%)
Erbil	98.9%
Salah al-Din	1.0%

The model is able to estimate these results for all the Iraqi Governorates. During the simulation, the model updates the situation in each Iraqi Governorate based on the evolution of the Risk Index. Based on the different strike of US coalition forces against insurgents, during the simulation is computed the total amount of casualties (i.e., killed civilian and insurgents).

5. CONCLUSION

The main goal of this study was to extract real data from the displacement tracking matrix (DTM), an information management tool used by the International Organization for Migration (IOM); to identify and analyze events that cause forced migration and develop an ABM Simulation tool to capture and reproduce the behaviour of displaced people and military forces.

To this end, a specific agent-based simulation model has been proposed: the simulation model is characterized by the most relevant actors in Iraq (Insurgents, Families, Iraqi Security Forces, US coalition forces). The agents of the simulation model are characterized by variables, parameters and statecharts that define their behaviour. The simulation model implemented, is able to generate an animation to show the behaviour of the agents during the simulation, the different experiments can be defined using the input interface for seting up the parameters and the results can be obtained from the output interface.

Based on the real data, the proposed model is able to recreate the situation in Iraq, focusing on the simulation of the behaviour of families/individuals inside each governorate of Iraq.

In order to identify the causes of displacement, a Risk Index has been developed, which take into consideration the most important push factors of displacement.

In the last section of the paper, a scenario has been simulated and some of the main indicators and results are presented, showing the usefulness of the simulation outputs to be used to estimate the flow of people displaced from each iraqi governorate.

The model can also be used as a tool for training the commanders of Military Forces and to support their decisions, for the evaluation of the impact of these in terms of estimation impact on the civil population.

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