An Exploratory System Dynamics Model of the Refugee Crisis in Northern Africa

by
Ivan W. Taylor[1],
Ali A. Sheikh

Abstract

The refugee migration in Northern Africa is the humanitarian crisis of our time. Millions of people are living in desperate conditions in refugee camps in Northern Africa and Southern Europe. These people are fleeing violence, famine, or poverty. Most are hoping to immigrate to a safe Western Nation, seeking a better life for themselves and their children. The United Nations (UN) recognizes that immigration may not be possible for millions of refugees, so the UN is hoping to either integrate the refugees in neighboring countries or reduce the violence in the crisis countries and repatriate the refugees [1]. One of the authors conducted two previous studies exploring the use of System Dynamics to examine the refugee crisis. One study used an exploratory System Dynamics model of the refugee crisis to compare various dynamic allocations of aid with the hope of reducing the suffering of those affected in the crisis countries and the neighboring countries. The other study specifically looked at alternative futures for the Syrian civil war using System Dynamics and examined the scope of the problems of immigration and repatriation it created. One of the authors, who has first-hand experience of the plight of refugees and knows many others who lived through similar experiences, conducted structural-confirmation tests on these models. Based on his suggestions, the new model was built which attempts to more generally address the root cause of the refugee crisis which is the civil wars.

1. Introduction

At the end of 2018, there were 70.8 million people forcibly displaced, 2.3 million more than 2017 [1]. Of these, almost 26 million people were refugees defined as those who fled their country of origin and cannot return. There were 41.3 million internally displaced persons who had to flee their homes but were still in their country of origin and 3.5 million asylum seekers were waiting to see if they will be accepted as refugees. 80% of these refugees were in countries neighboring their country of origin. The largest contributors to the refugee crisis were 6.7 million people from Syria, 2.7 million people from Afghanistan, 2.3 million people from South Sudan, 1.1 million people from Myanmar, and 0.9 million people from Somalia. Only 2.3 million internally displaced persons returned to their homes in 2018, while only 92.4 thousand refugees were resettled in third countries. We can see that the refugee crisis is bad and getting worse. This is the humanitarian crisis of our time. The United Nations High Commission for Refugees is seeking durable solutions to this refugee crisis [1]. These durable solutions include integrating the refugees in the neighboring countries hosting the refugee camps, resettling the refugees in

1 Policy Dynamics Inc., New Hamburg, Ontario, Canada, ivanwtaylor@gmail.com

third countries, and repatriating the refugees to their country of origin. In this paper, we will develop a general model of how repatriation might be made possible.

In 2007, Forrester [2] emphatically encouraged the members of the System Dynamics Society to attack the world's big issues or Grand Challenges. These grand challenges had three primary criteria: they affected the lives of millions of people, they are currently being addressed by actors with seriously flawed mental models, and they are addressable by System Dynamics and seemingly few other disciplines. We believe that the current refugee crisis meets these criteria and should be a major effort of the System Dynamics Society. However, it appears from the limited literature available [3, 4, 5, 6, 7] this is not the case.

System Dynamics involves interactions between Stocks and Flows. Stocks represent the accumulations of real-life objects while Flows are how these accumulations increase or decrease over time. The refugee crisis involves families crossing national borders which can be considered flows of people. Resources also flow into the affected countries to try to relieve the suffering. Thus, we felt that System Dynamics is ideally suited to the analysis of this problem. In complex systems, causal connections between entities can be separated in time and space which makes it difficult to intuitively understand the impact of changes to them on other entities without an explicit quantitative model. Using a quantitative System Dynamics model requires solving a system of highly interconnected first-order differential equations using numerical methods. One of the issues in the System Dynamics approach is defining the system boundary. It must be broad enough to capture the important cause and effect relationships but narrow enough to allow clear policy prescriptions that improve system performance. There are several types of System Dynamics models that have been useful in policy analysis. The work that will be considered in this paper could be categorized under the heading exploratory modelling.

Weil [8] discussed the need to have a sufficiently wide system boundary to convince policymakers of the realism of the model. On the other hand, Homer [9] suggests that some practitioners who promote exploratory modeling are less rigorous than “full-fledged scientific modelers”. He recognizes that “much of what we see at conferences is still exploratory, often appropriately so” but he wants it “to be identified as such and clearly differentiated from full System Dynamics”. Some of the first exploratory System Dynamics modeling came out of the RAND Corporation in the early 1990s [10]. In this work, an exploratory model was subjected to extensive sensitivity analysis to find robust policies for possible implementation in the long-term. Scholl [11] surveyed of members of the System Dynamics Society and found that a significant minority of the models being developed were considered highly complex and involved thousands of variables. More recently Pruyt, et.al. [12, 13, 14] have been conducting exploratory System Dynamics modeling along with gaming.

One of the issues in working with models is validation [15, 16]. In this paper, we examine two models of the refugee crisis that were developed by one of the authors and documented as chapters of books [17, 18]. Structural-confirmation tests were conducted on these models by one of the authors who has first-hand experience of the refugee crisis. This led to a new model that will be described at the end of this paper along with an application to a country in crisis.

In section 2 of this paper, we summarize the models originally documented as book chapters. In section 3, we discuss the structural-confirmation tests of the models and the issues discovered in the process. In section 4, we discuss the new model that was developed in response to the recommendations of the structural-confirmation tests and we calibrate the model to the refugee crisis in Syria between 2010 and 2019. In section 5, we provide some conclusions along with a discussion of further work required for the new model.

2. Brief Description of the Previous Models

2.1 Modelling the Allocation of Humanitarian Aid to Reduce Suffering

This System Dynamics model of the refugee crisis was written for a chapter of the book entitled, "Security by Design" [19]. It was extensively documented and the documentation is freely available online [20]. It was developed in Vensim and involved 15 interconnected sectors and 201 equations. There are 20 stock variables in the model, 28 normal parameters, 27 constants, and 23 effect (look-up) functions.

As an overview of the model, we provide the Vensim diagrams for three sectors that are central to the original approach. The first is the movement of refugees (shown in Figure 1). The people in the crisis country may be subject to violence, starvation, disease, or poverty and may choose to leave their country and become refugees. Some of the refugees may become desperate enough to attempt unconventional border crossings, such as traveling by boat across the Mediterranean Sea to Southern Europe. Others may be able to legally immigrate from the neighboring countries to a safe third country.

The principal policy lever in the model, assumed to be available to decision-makers, is the allocation of aid to either food, health services, diplomacy, peacekeeping, immigration, economic development, or border control (see Figure 2).

Of particular interest in this work was the problem of unconventional border crossings where refugee families chose to risk their lives to escape the refugee camps and travel to Europe. A detailed model of this decision process was developed and is shown in Figure 3. It was assumed to be based several influences, such as the availability of border crossing resources and the number of families who have successfully or unsuccessfully attempted unconventional border crossings, among other things.

The other 12 sectors use the results of the allocation of aid to establish various resources which may reduce the suffering and increase the safety of the refugees and internally displaced families.

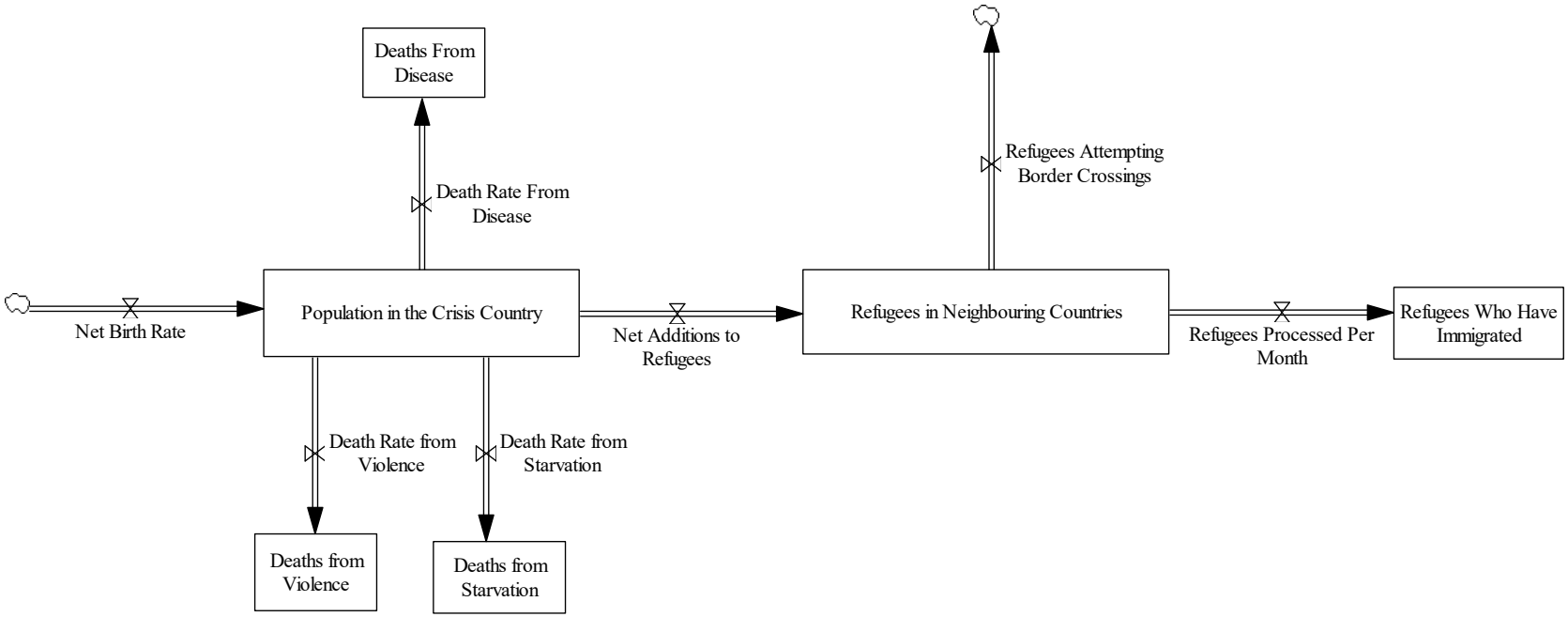

Figure 1: Stocks and Flows in Refugee Flow Sector of the Humanitarian Aid Model

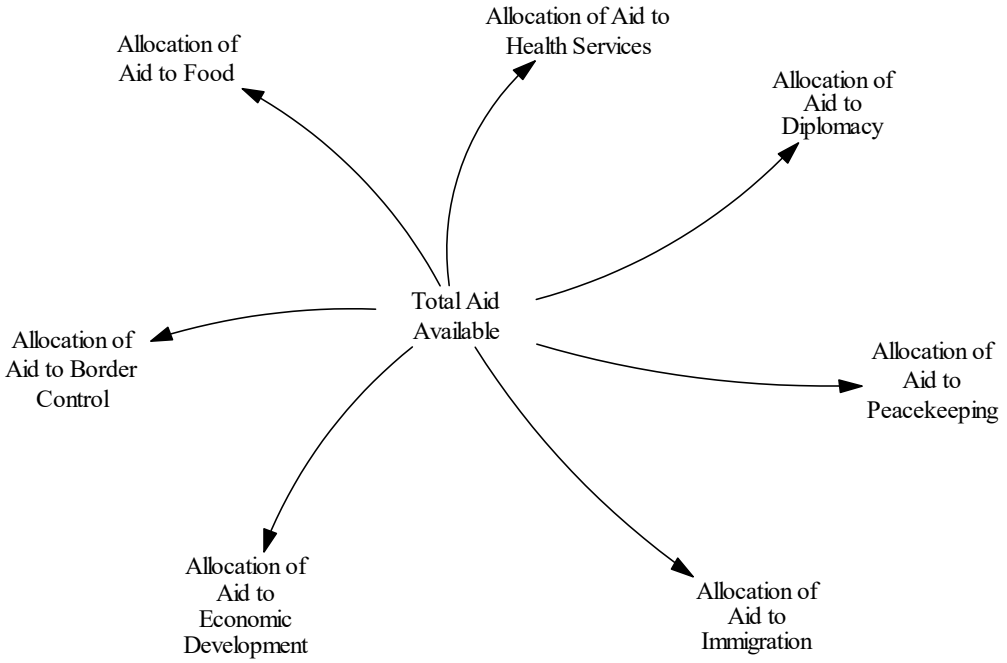

Figure 2: Allocation of Humanitarian Aid Sector

2.2 Modelling the Syrian Civil War

This model was specifically oriented to the situation in Syria which began with civilian protests against the regime and deteriorated into a full-blown civil war. In this model, the scope was reduced compared to the humanitarian aid model. A book chapter based on this model entitled, "Using System Dynamics to Examine Alternative Futures of the Syrian Refugee Crisis" [18] has been submitted for publication in an upcoming book entitled, "Refugee Crisis: Global Perspectives, Challenges and Issues" [21].

To provide an overview of the model, we present the Vensim diagrams for the two sectors, refugee flow (see Figure 4) and violence (see Figure 5). You can see that the refugee movement sector retains many of the same features as the humanitarian aid model; however, the concept of unconventional border crossings is not considered.

The violence model attempts to capture the nature of the Syrian civil war that began as a protest movement and deteriorated into a full-blown civil war between the regime and rebel forces. This sector is based on the predator-prey model [22] in which protests begin and then the regime reacts to quell these protests, but this causes rebels to organize and begin battles with the regime forces.

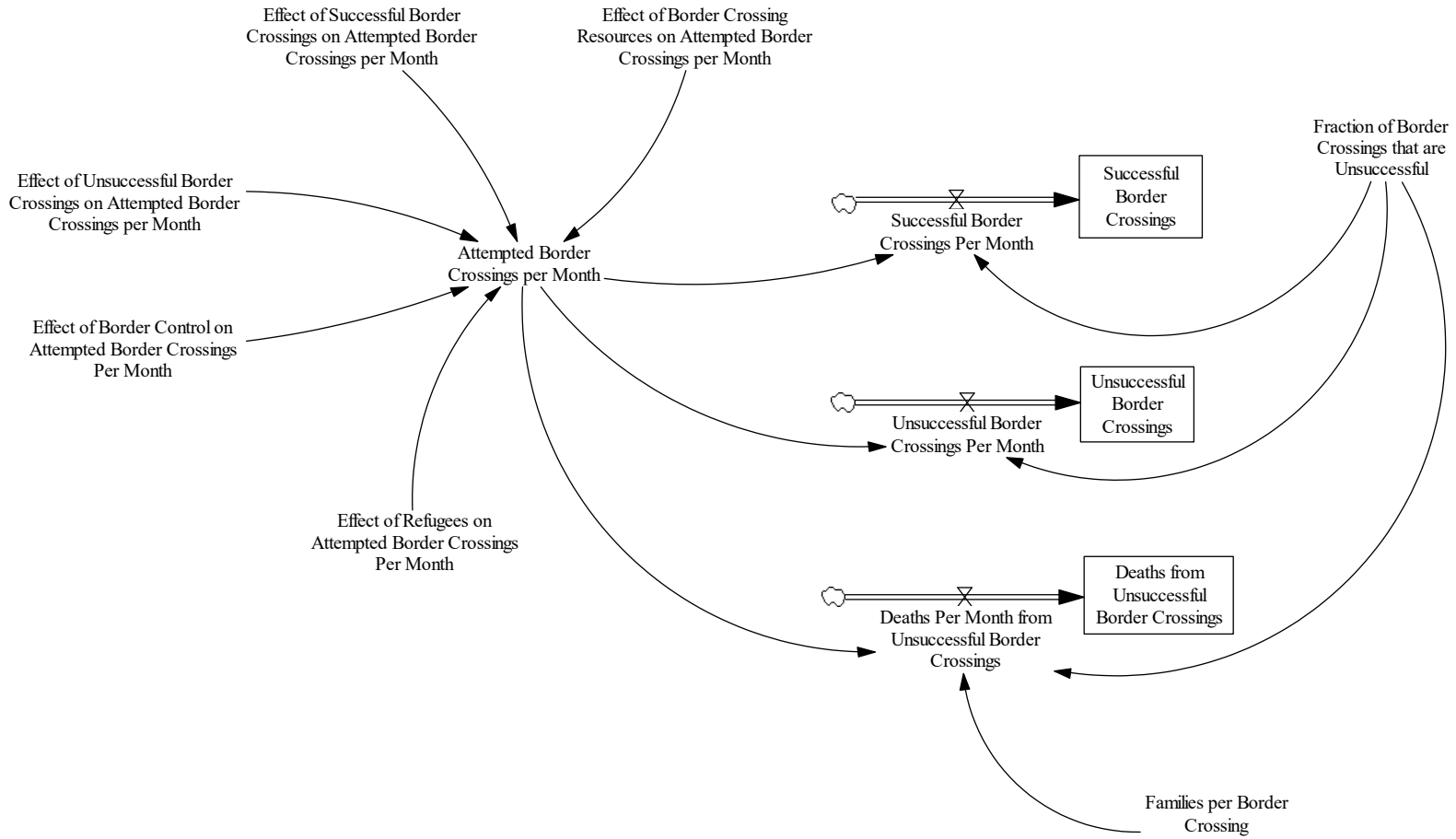

Figure 3: Simplified Stock and Flow Diagram of Border Crossing Sector

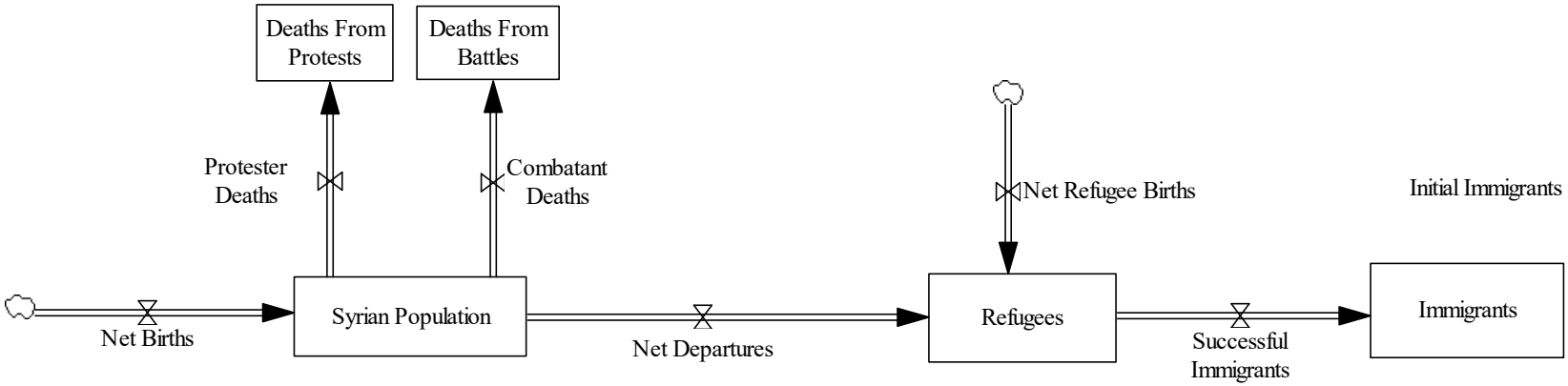

Figure 4: Stocks and Flows in Refugee Flow Sector of Syrian Civil War Model

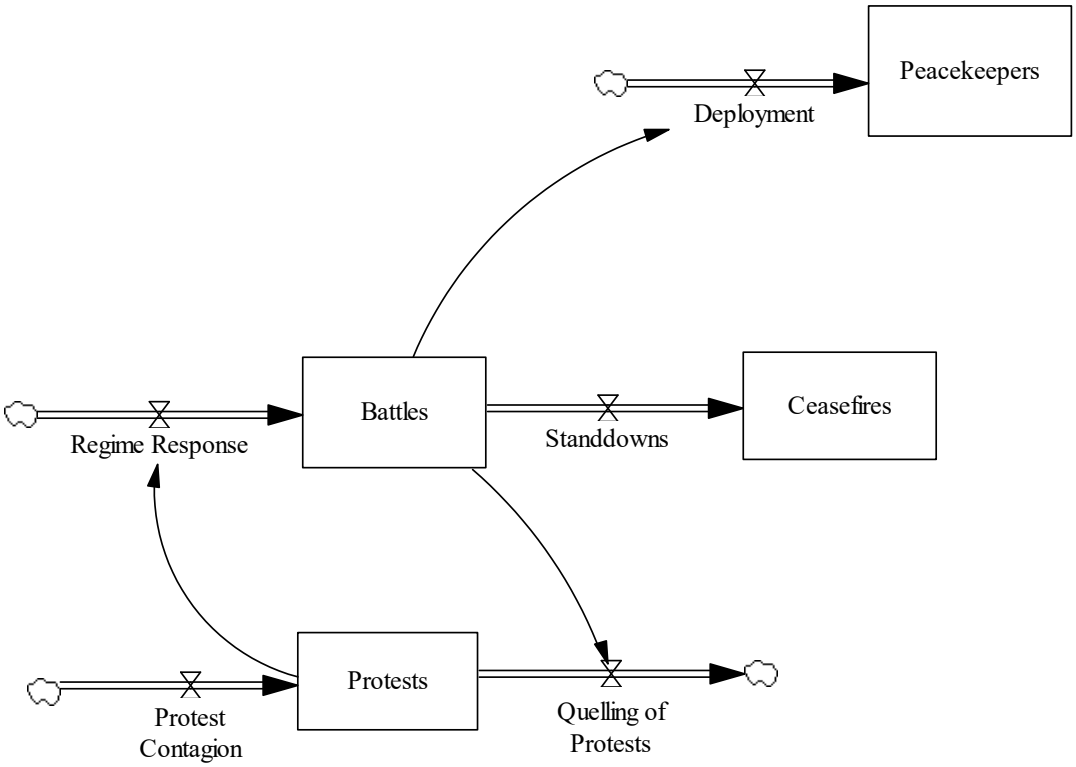

Figure 5: Stocks and Flows in Violence Sector of Syrian Civil War Model

3. Structural-Confirmation Tests of the Models

There are three steps in the validation of System Dynamics models. Barlas [15] describes them as direct structure tests (empirical and theoretical), structure-oriented behavior tests, and behavior pattern tests. Forrester and Senge [16] cover much of the same ground but describe their validation process as tests of model structure, tests of model behavior, and tests of policy implications. The primary concept of System Dynamics modeling is that structure drives behavior. So for these two models, we will conduct direct theoretical structure tests which involve qualitatively examining the structure of the models and walking through each mathematical equation and logical relationship comparing them with available knowledge about the real system. Barlas [15] calls this process structural-confirmation testing.

We will document the structural-confirmation testing of the two models discussed above. To determine if the models are a reasonable imitation of the real-world, one of the authors who has personal experience with the refugee crisis examined the individual stock and flow diagrams in the Vensim models along with the mathematical formulae and logical relationships with the help of the original author of the models.

3.1 Structural-Confirmation Test of the Humanitarian Aid Model

Although the structural-confirmation test was conducted on all 15 sectors, we will only discuss the work that was done on the three sectors which were the primary focus of this study.

Aid Allocation Sector

This sector contains only auxiliary variables (see Figure 6). Central to this sector is the total aid available per month. This value is based on the number of deaths in the crisis country and the fraction of the population at risk of violence. The number of refugees could be considered in this calculation of total aid available since the UN must provide aid to create and operate refugee camps. However, this value should be easily calculable based on the number of refugees in the neighboring countries, and we can assume this cost is not discretionary. So, the total aid available in the model would be considered the discretionary aid available once the refugee camps are provided for. This total available aid is allocated dynamically to seven individual types of aid: food, health services, diplomacy, peacekeeping, immigration, economic development, and border control. The desired fraction of the available aid allocated to each type is based on the current situation on the ground. The actual allocation of aid to a particular type is based on the desired fraction and a complex calculation based on the combination of all of the other desired fractions.

This sector provides elements of both short-term humanitarian aid and long-term nation-building. The allocation process is dynamic and quickly responds to the situation on the ground. This may be somewhat unrealistic because it assumes up-to-date perfect information whereas, in reality, it would take time to collect and analyze information about the situation on the ground before changing the aid allocation. This could be modeled using perception concepts similar to those in Forrester's Urban Dynamics [23]. The allocation process is fully automated and is based on a partial priority system. The priority approach might need to be re-evaluated. It might be better to allow the model to distribute the aid based directly on the need on the ground without any specific priorities. This could easily be changed in the model.

The original model was primarily focused on reducing the number of deaths caused by dangerous sea crossings; so, this was our first consideration. The desired fraction of aid allocated to border control was based on the number of deaths in unconventional border crossings. The desired fraction of aid allocated to food is based on the fraction of the population without enough food. The desired fraction of aid devoted to health services was based on the fraction of people with a disease in the crisis country. This needs to be corrected to include all of the people in hospitals and clinics which includes the people wounded in the violence, the people with a disease in the refugee camps, and the people needing medical aid because of the long, arduous walk from the crisis country to the refugee camps. The allocation of aid to diplomacy in the model was based on the fraction of the population at risk of violence. Similarly, the allocation of aid to peacekeeping in the model was based on the fraction of the population at risk of violence. This would need to be corrected because peacekeeping would only be activated once the violence has been reduced to the point where ceasefires have been put in place and peacekeepers are employed to monitor the ceasefires, protect the safe havens and provide security for the food aid delivery. Support to the immigration system was based on the number of refugees but in fact

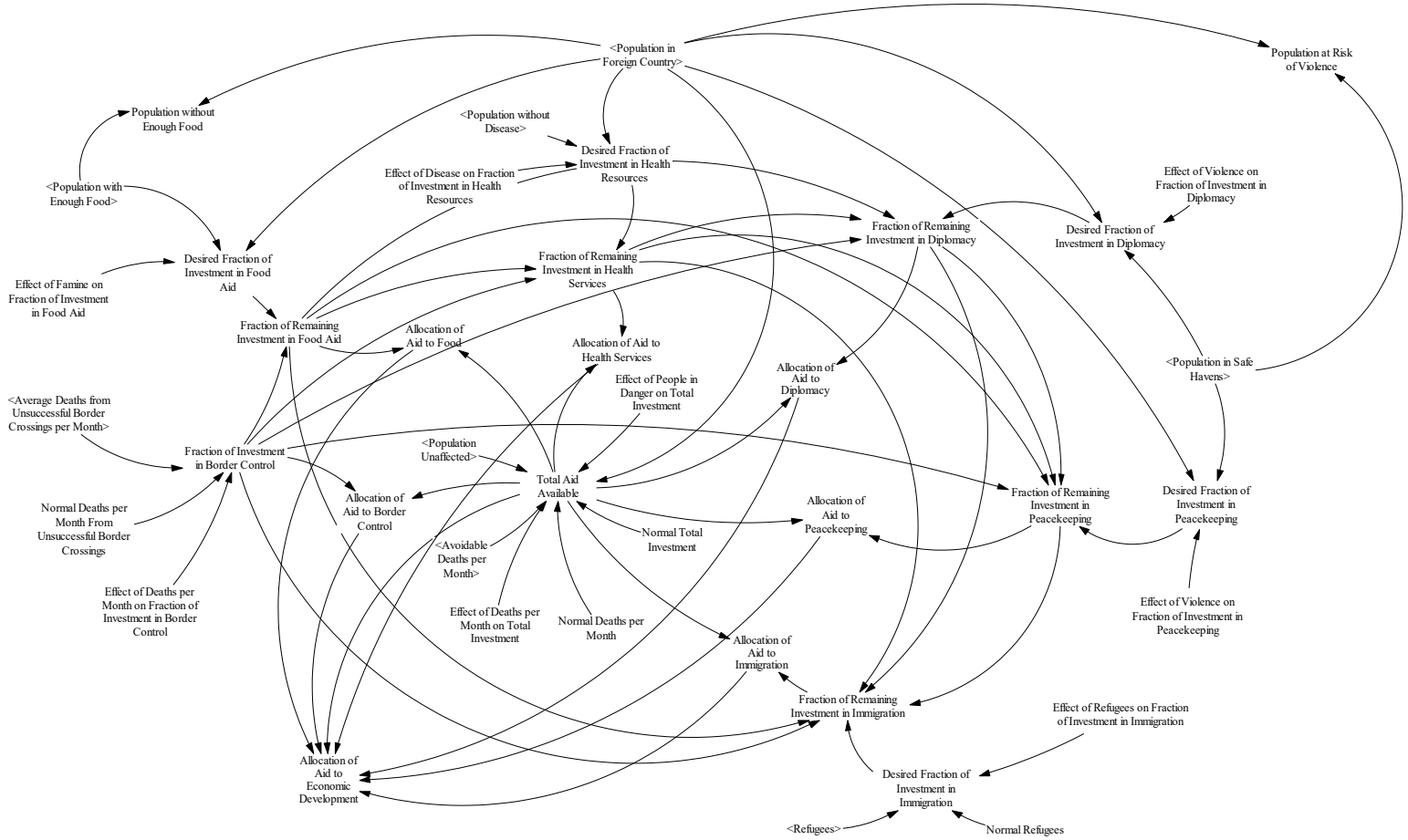

Figure 6: The Aid Allocation Sector in the Humanitarian Aid Model

should be based on the immigration quotas of the third nations. Finally, the current model calculates the economic development aid as the aid leftover after all the other allocations have been made. Again, economic development aid would likely not be activated until the crisis country was stabilized.

This automated calculation of total aid available and allocation of aid to the various types may be a shortcoming of the model as the user might wish to control either the total aid available every month or the individual allocation to the different types of aid. Also, this capability would be needed to validate the model based on real-world data. This interactive approach will be considered in future versions of the model. Finally, the other sectors seemed to assume that the aid allocation process may be based on an overly optimistic view of its effectiveness in reducing the suffering.

Refugee Movement Sector

The refugee movement sector is shown in Figure 7. It contains stocks for the population in the crisis country, deaths from violence, deaths from disease, and deaths from starvation in the crisis country, refugees in neighboring countries, and refugees who have immigrated to third countries. The population in the crisis country has one in-flow (net births), and four out-flows (the death rate from violence, the death rate from disease, the death rate from starvation, and the net additions to refugees). The refugees stock has the net additions in-flow and two out-flows (refugees attempting unconventional border crossings and refugees processed for immigration). Refugees who have immigrated has one in-flow. The central auxiliary variable in this sector relates to the time it takes to decide to leave the crisis country. This is modeled as a complex relationship between people at risk of violence, people with disease, people without enough food, and people without jobs.

The approach of looking at the refugee crisis on a country-by-country basis is a good one because each country would have different input parameters reflecting their particular situation and data to validate the model is available on a country-by-country basis. However, the measure of the population is "families" and should be changed to "people". The net additions to refugees currently flows in only one direction. There should be a flow back from the refugees stock to the crisis country because the refugee camps are supposed to be temporary until the refugees can return home safely (i.e. repatriate). There are many protracted situations with people in refugee camps for decades; therefore, there should be a net births in-flow to the refugees stock. Also, refugee camps are highly susceptible to contagious disease and therefore there should be a deaths from disease out-flow from the refugees stock. However, disease is not a major reason for refugee movement, so this should be removed from the decision to leave the crisis country. Economic migrants seeking a better quality of life are not considered refugees, so although unemployment may be part of the decision to leave the crisis country, these economic migrants can often be expected to be repatriated if their lives are not at risk. However, poverty can be left in the decision model because it causes movement out of a crisis country even if the people become illegal immigrants. Not having enough food would probably not be accepted as the reason to become a refugee. Instead, the UN would provide food aid and encourage them to stay in the crisis country. So, this should be removed from the decision to become a refugee. The people in the crisis country who live outside a safe haven are considered at risk of violence and

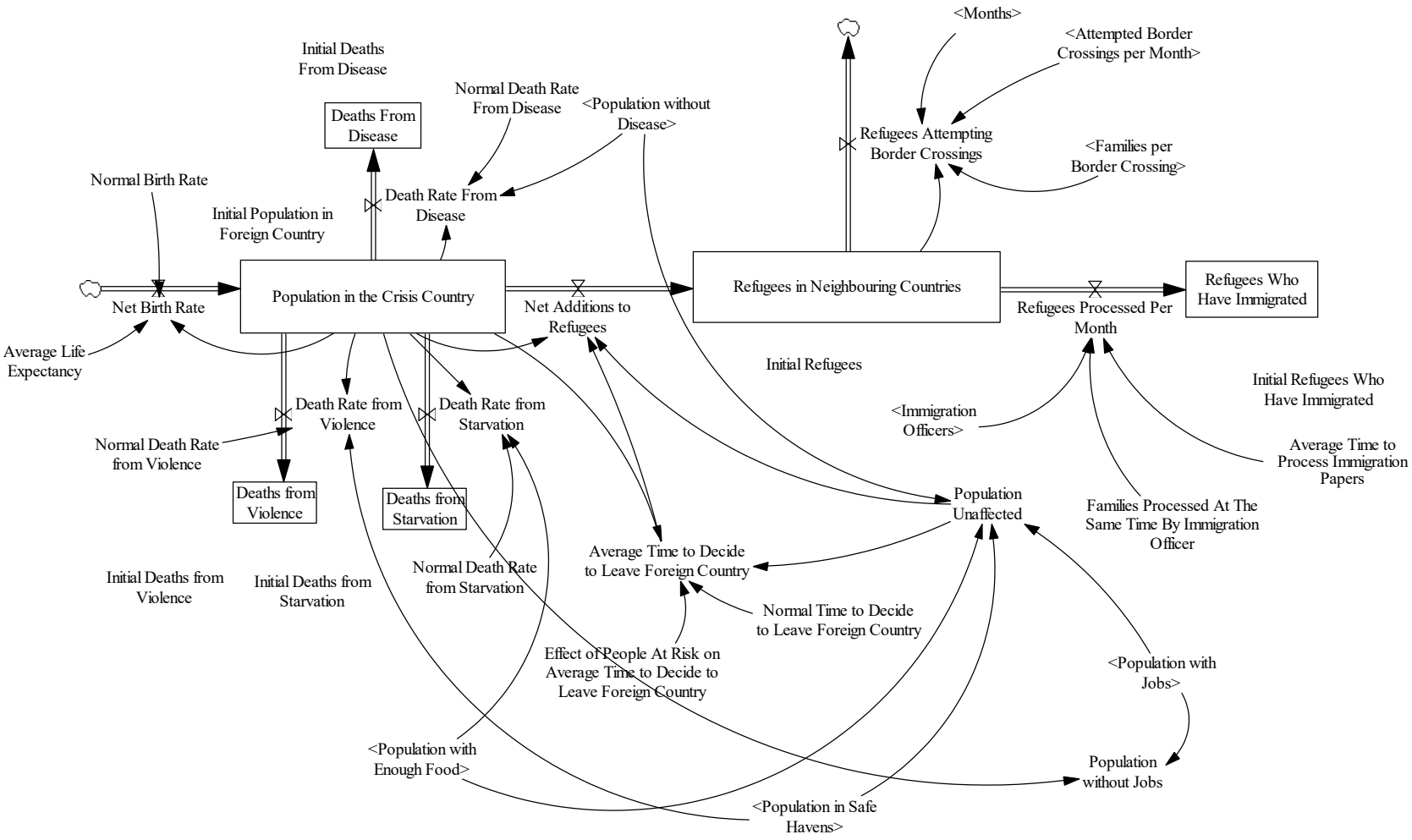

Figure 7: The Refugee Movement Sector in the Humanitarian Aid Model

some proportion of them will choose to become refugees. However, those internally displaced persons living in safe havens may also wish to leave the crisis country and although their lives may not be at immediate risk, it may be hard for the UN to determine whether they are in danger or not.

We should re-evaluate the out-flow from the refugees stock created by attempted sea crossings. There is a high probability that those refugees will be intercepted by border control ships and repatriated to their countries of origin so this flow should only include successful border crossings in which the refugees are allowed to re-settle in Europe and the number of refugees who die in their attempt to make a sea crossing.

There has recently been a situation of compassion fatigue in countries that were accepting refugees as immigrants. This should be modeled explicitly as a major reduction in the immigration rate as more and more refugees resettle in third countries.

Unconventional Border Crossing Sector

The sector that we developed was quite complex (see Figure 8). We tried to include the important factors in the decision by desperate refugees to employ untrustworthy smugglers in an attempt of a dangerous sea crossing. We considered the number of refugees who might be unable to immigrate legally, the availability of sea crossing resources, the rate of successful sea crossings that might encourage others, and the rate of unsuccessful sea crossings that might discourage them. Successful sea crossings are assumed to arrive safely in Europe and unsuccessful sea crossings are assumed to have sunk during the crossing. The successful or unsuccessful sea crossings are included in the sector as stocks. The fraction of unsuccessful sea crossings is influenced by the crowdedness of the sea crossing boats which in turn is based on the number of refugees and the number of sea-crossing boats. There is also a stock in this sector for the deaths caused by unsuccessful sea crossings.

As mentioned above, when the model was written the problem of unsuccessful sea crossings from North Africa to Europe was considered a situation that needed to be quickly addressed. There are two types of unsuccessful sea crossings. There are those involving the tragic loss of life if the boats do not make the voyage safely. These deaths were a highly visible part of the refugee crisis but in fact, we found when working on the model that they represented a very small part of the suffering of the refugees and the people in the crisis country. There are also sea crossings that are intercepted and refugees are returned to their country of origin. The model did not consider the chance of refugees getting caught and being deported or the backlash that arose in Europe against attempts at illegal immigration. It also did not consider the possibility that the refugees would be held in desperate conditions in the refugee camps that formed when they landed in Europe.

The problem of sea crossings seems to have been largely solved for the Europeans and is not causing the death and suffering it was circa 2015 [24]. Although this sector may not be as central to the refugee crisis as it once was, it should remain part of the model and should be brought up-to-date because refugee smuggling will likely continue to be a problem if only in other types of dangerous escapes from the crisis country.

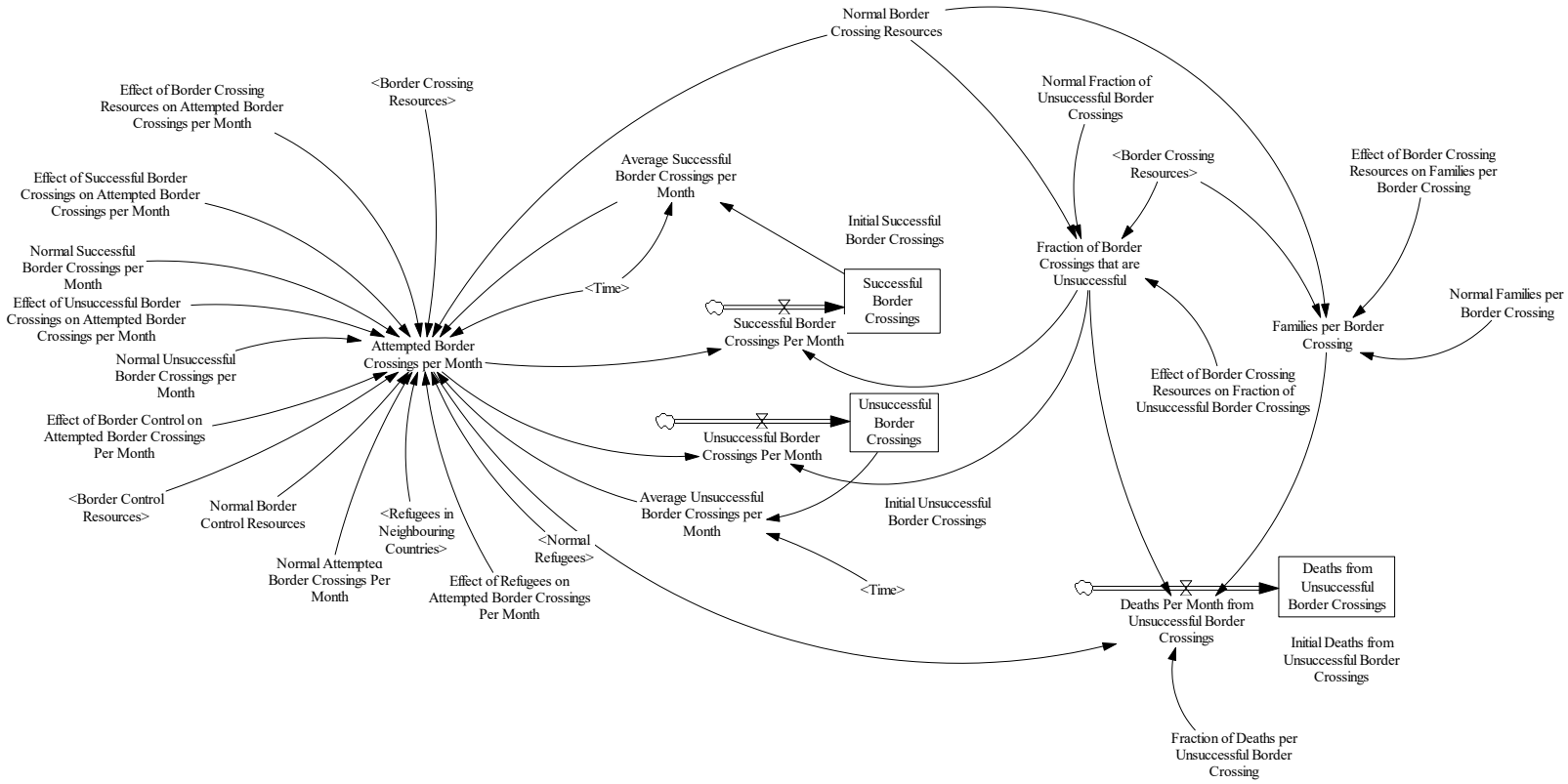

Figure 8: The Unconventional Border Crossings Sector in the Humanitarian Aid Model

3.2 Structural-Confirmation Test of the Syrian Civil War Model

The Syrian civil war has been one of the biggest contributors to the recent refugee crisis. Therefore, it was considered worthy of a separate study. The model developed to study this crisis was much simpler than the humanitarian aid model described above. It contained only two sectors: refugee movement and violence. The goal of this study was to develop insight into ways the refugee crisis caused by the civil war could be resolved in the long term. A structural-confirmation test was done on its two sectors.

Refugee Movement Sector

The refugee movement sector is shown in Figure 9. It contains stocks for the Syrian population, deaths from protests, deaths from battles, refugees, and immigrants. The Syrian population has one in-flow (net births), and three out-flows (protester deaths, combatant deaths, and net departures). The refugees stock has two in-flows (net departures and refugees net births) and one out-flow (successful immigrants). Immigrants has one in-flow. There are two new concepts in this sector. The immigration rate is based on the possibility of compassion fatigue which can have a significant effect on the number of immigrants accepted. And the net departures has two directions created by a refugee flow out of Syria caused by the protests and the battles and the flow back that can be initiated when a ceasefire is agreed to and enforced by peacekeepers.

This model is an improvement in several ways compared to the humanitarian aid model. In this model, the measure of the population is in "people" and there is a net births in-flow to the refugees stock. Although deaths from disease are not explicitly considered, it is included in the net refugee births. The decision to depart Syria is only based on the violence which is measured in terms of protests and battles. Attempted sea crossings are not considered in this model.

Violence Sector

The violence sector shown in Figure 10 has four stocks: protests, battles, ceasefires, and peacekeepers. There is assumed to be a positive initial number of protests when the model run begins. Then protests has one in-flow, protest contagion, in which protests in one location are assumed to encourage protests in other locations and one out-flow based on the regime quelling the protests with violence. The battles stock has one in-flow for the regime response to the protests and one out-flow based on the regime and the rebels standing down their forces when the ceasefires are in place. The ceasefires stock has one in-flow. It is assumed that the ceasefires are agreed to battle by battle. The peacekeepers stock has one in-flow for deployment which is activated once the number of battles reaches a level representing the peacekeeper deployment threshold.

In the structural-confirmation test of the violence sector, it was noted that ceasefires usually require the effort of diplomats who can negotiate with the warring parties. Furthermore, the warring parties are not self-contained. They are often supported with weapons and funds from outside countries. Diplomatic effort is also expended to negotiate with these outside countries to stop this support. Also, not all civil wars begin with protests. So, if this model were to be

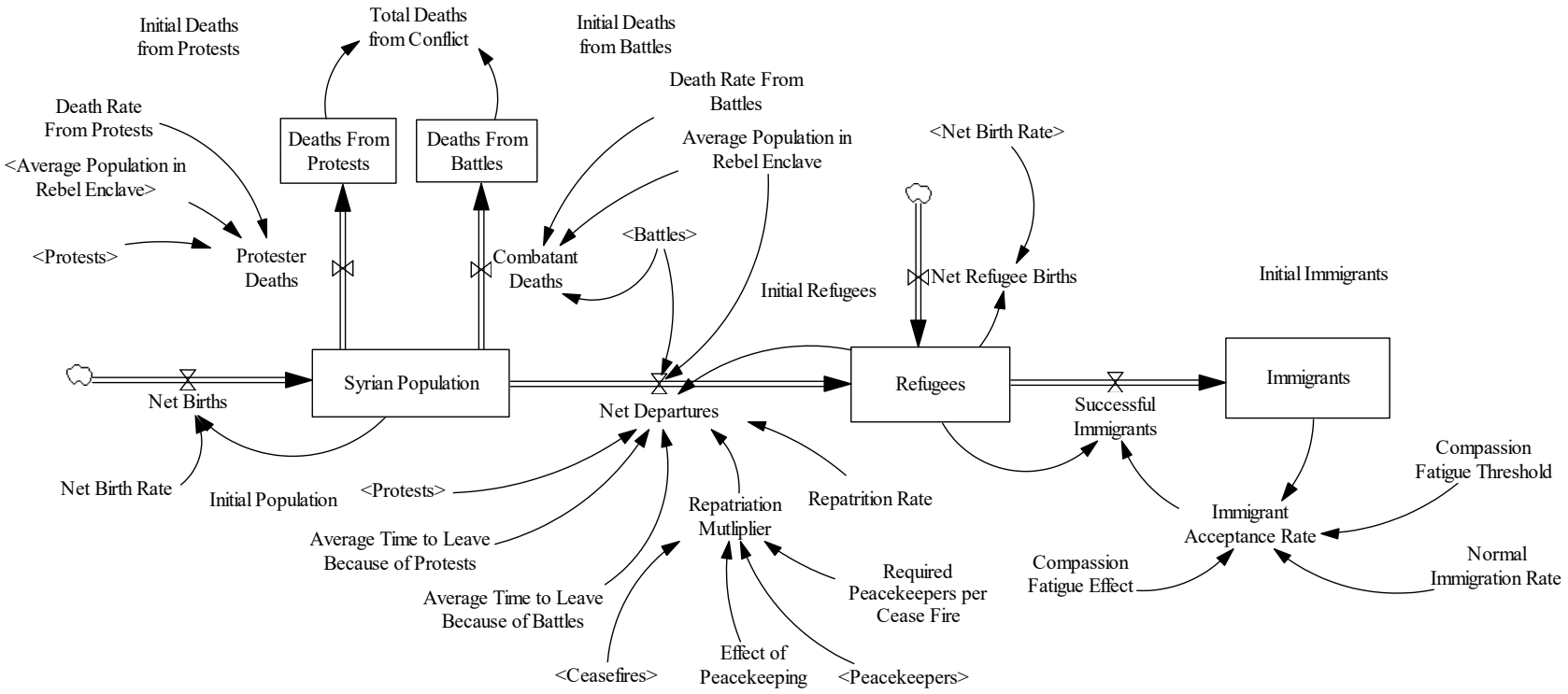

Figure 9: The Refugee Movement Sector in the Syrian Civil War Model

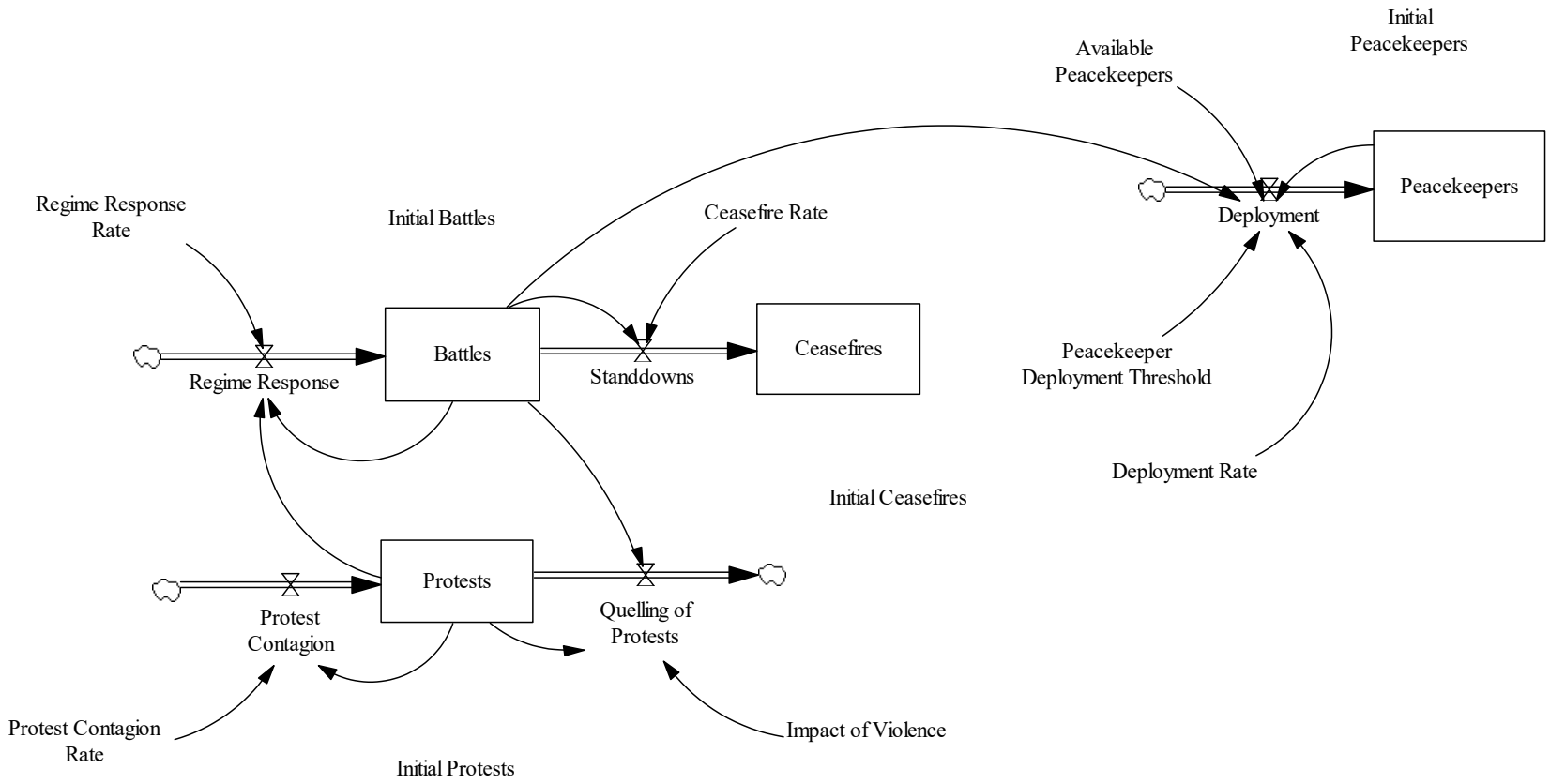

Figure 10: The Violence Sector in the Syrian Civil War Model

generalized it would be better to model the interaction between regime and rebel forces explicitly.

3.3 Summary of the Structural-Confirmation Tests

Overall the co-author with personal experience of the refugee crisis, after examining the models in detail, felt they considered many of the aspects necessary to be realistic models of the refugee crisis based on a country by country analysis. The author who wrote the models felt the recommended changes could be made to the models quite easily. The next section provides a discussion of a new model including the best features of these models while also including the recommendations from their structural-confirmation tests.

4. A New Model

The new model consists of five sectors which are a significant reduction from the humanitarian aid model that consisted of 15 sectors but is a slightly expanded version of the Syrian civil war model that consisted of only two sectors. The refugee movement sector (shown in Figure 11) is a greatly simplified version of the earlier sectors for the refugee movement. It does not explicitly consider all the ways people might die in these countries, but this is implicitly included in the average life expectancies in the crisis country and the neighbouring country. It also does not include the concept of immigration because this is not considered a viable solution to the refugee crisis now that many third countries have almost shut their borders to immigrants. It includes a repatriation flow back into the crisis country once a ceasefire is agreed to.

The safe havens sector (shown in Figure 12) is very similar to the version in the humanitarian aid model (see [20]) except peacekeepers have an influence on the creation of safe havens and on protecting safe havens. Its primary focus is to determine the people outside the safe havens who are considered at risk of violence. The diplomatic effort and peacekeepers sectors (see Figures 13 and 14) are very similar to the versions in the humanitarian aid model (see [20]) except they are based on the number of people at risk of violence and funding is not a limitation.

The primary difference in this model compared to the earlier models is in the violence sector (see Figure 15). This is where the recommendations coming out of the structural-confirmation tests of the previous models were most important. This sector consists of explicit stocks for the regime forces and the rebel forces who are supported by outside countries who contribute to the in-flows of aid to the regime and aid to the rebels. The regime and rebel forces have out-flows based on losses created from battles. The number of battles at any point in time is measured in the violence level that is based on the contact rate between regime units and rebel units. This approach has similarities to the classic models of warfare based on the Lanchester equations [25]. The results of the violence model for the baseline run are shown in Figure 16. This has much the same pattern that was found when data on the Syrian civil war (see Figure 17) was used to validate the earlier model as described in [18].

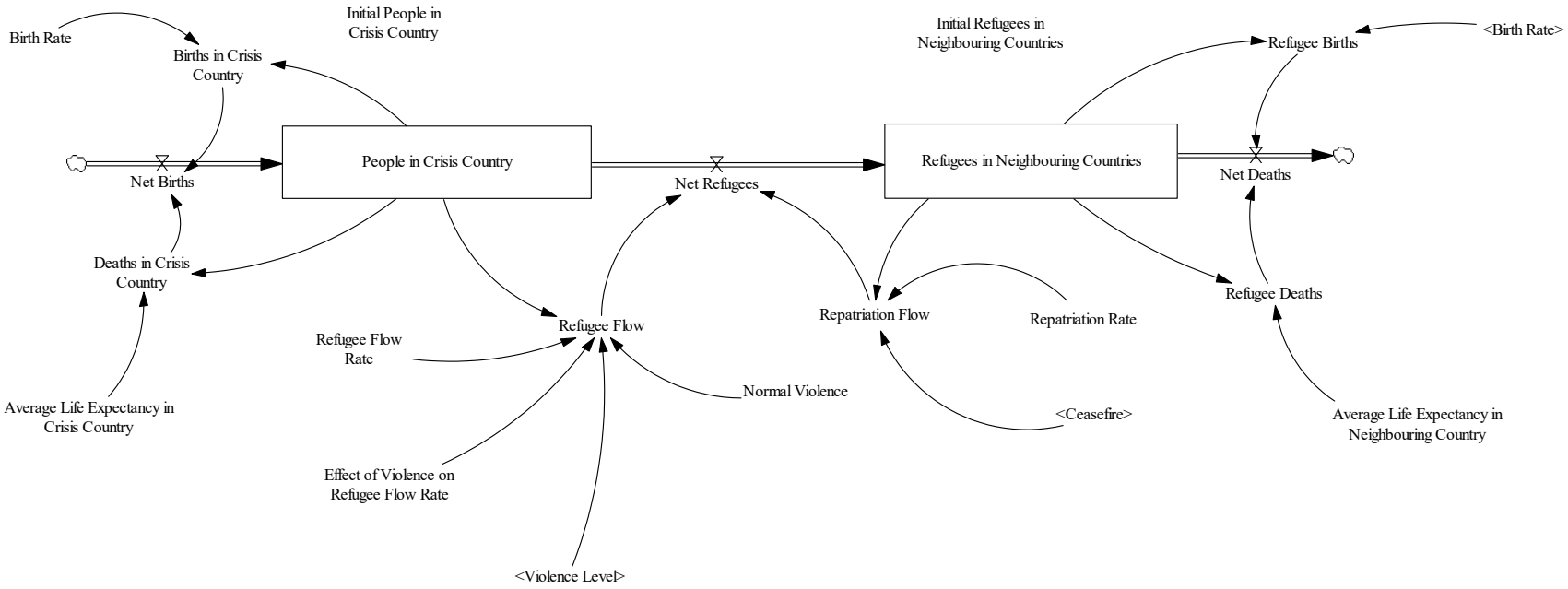

Figure 11: Refugee Movement Sector for a New Model

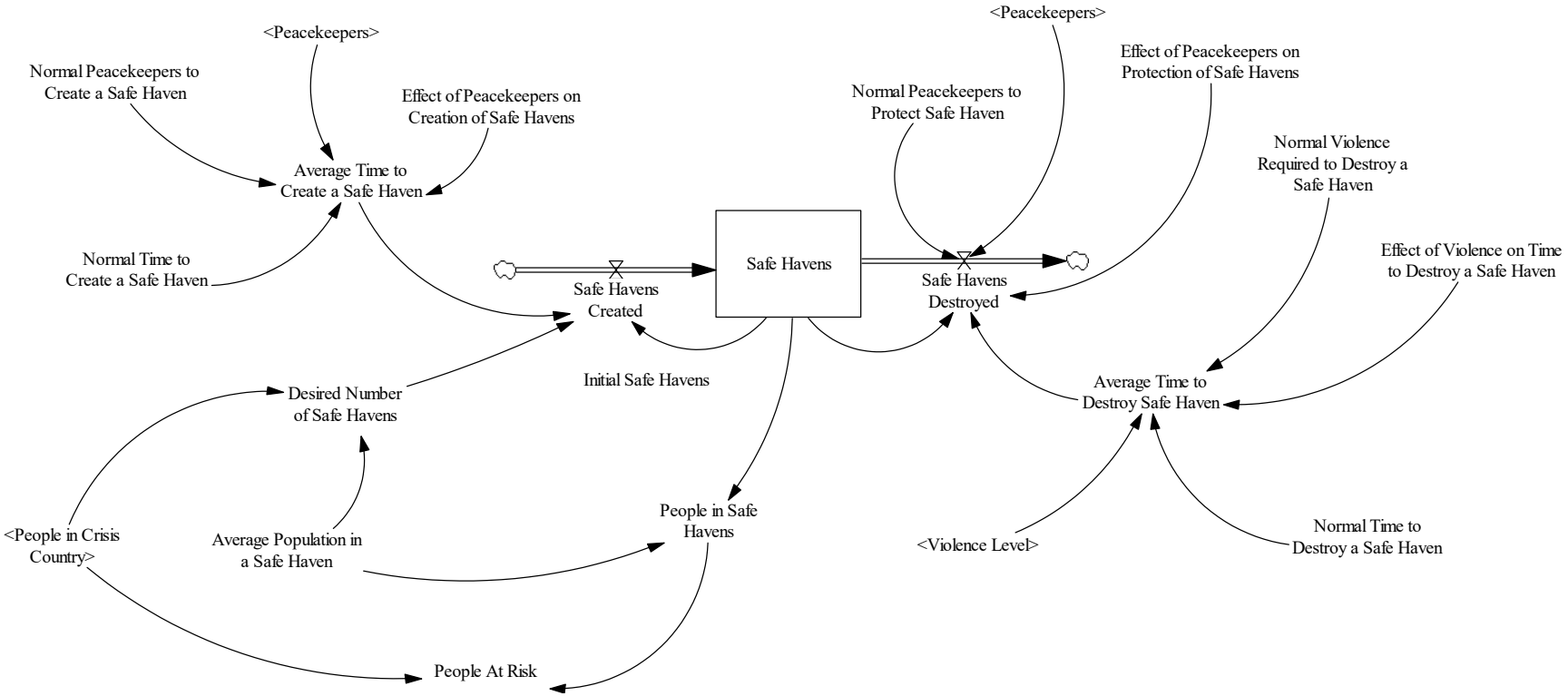

Figure 12: The Safe Havens Sector for the New Model

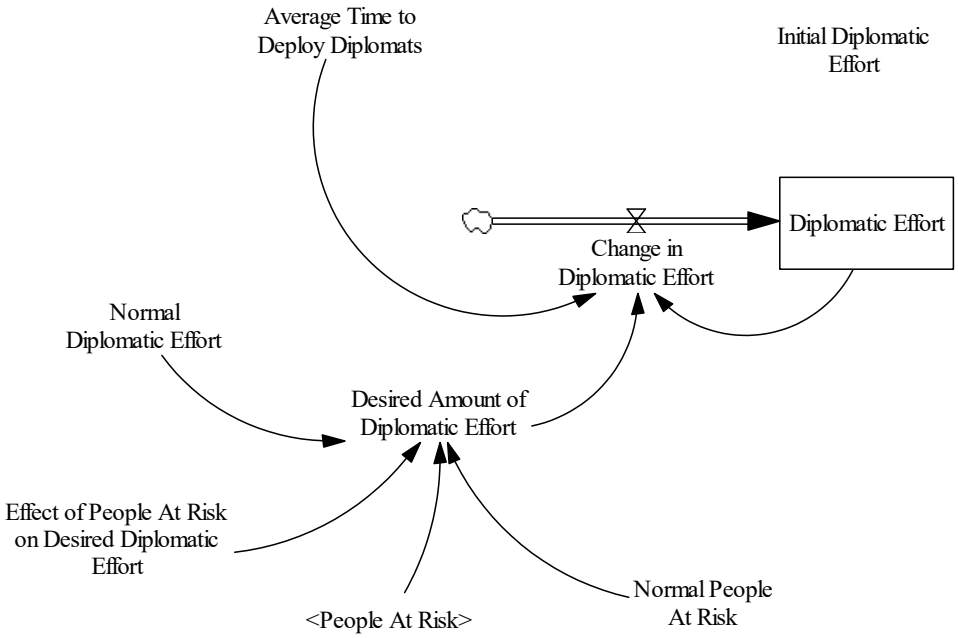

Figure 13: The Diplomatic Effort Sector for the New Model

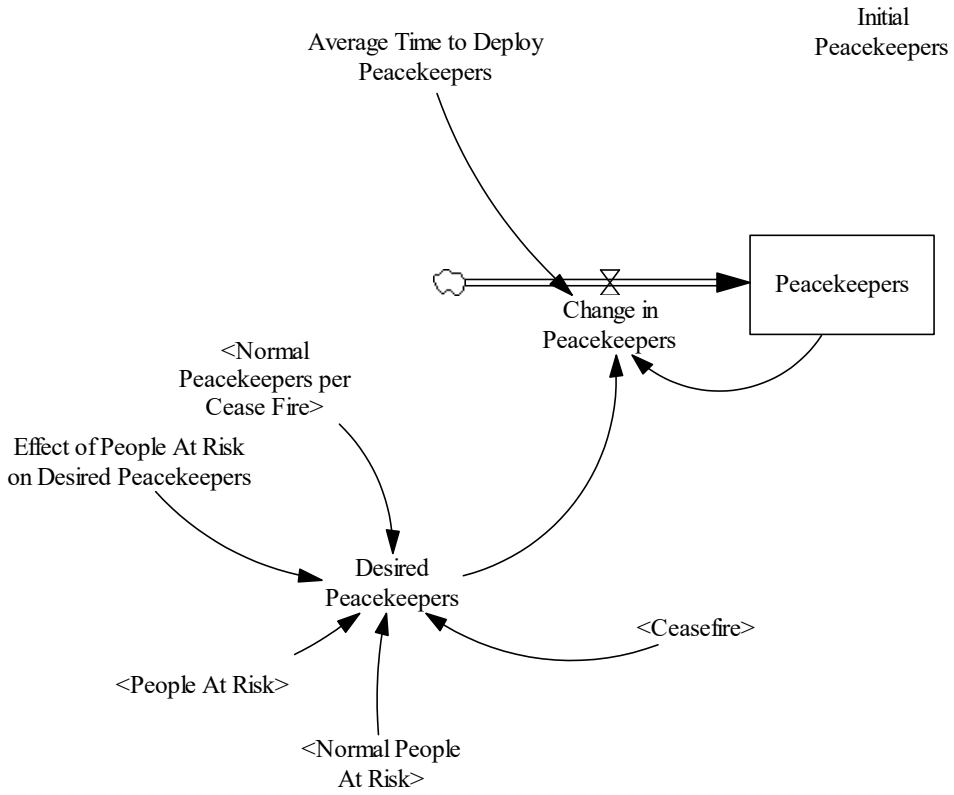

Figure 14: The Peacekeepers Sector for the New Model

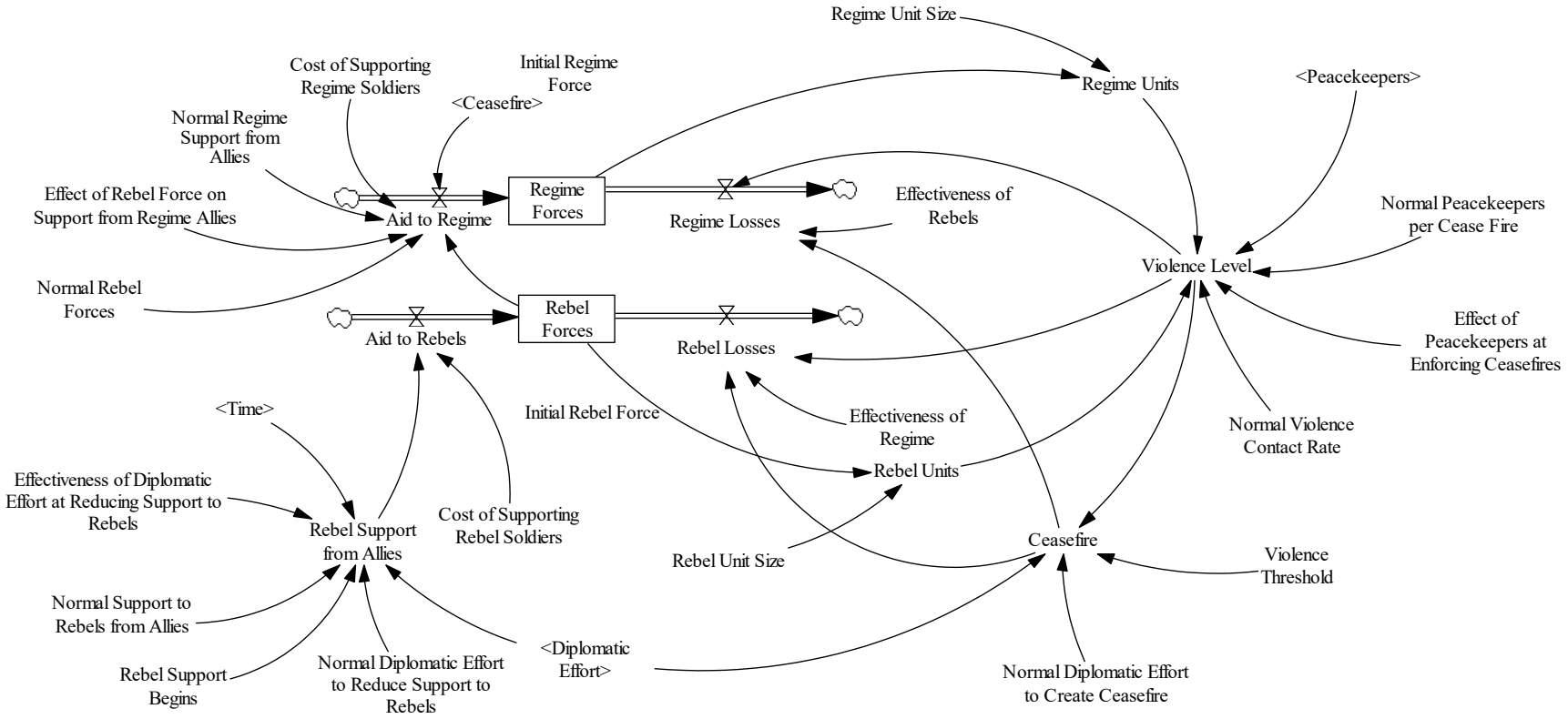

Figure 15: The Violence Sector for the New Model

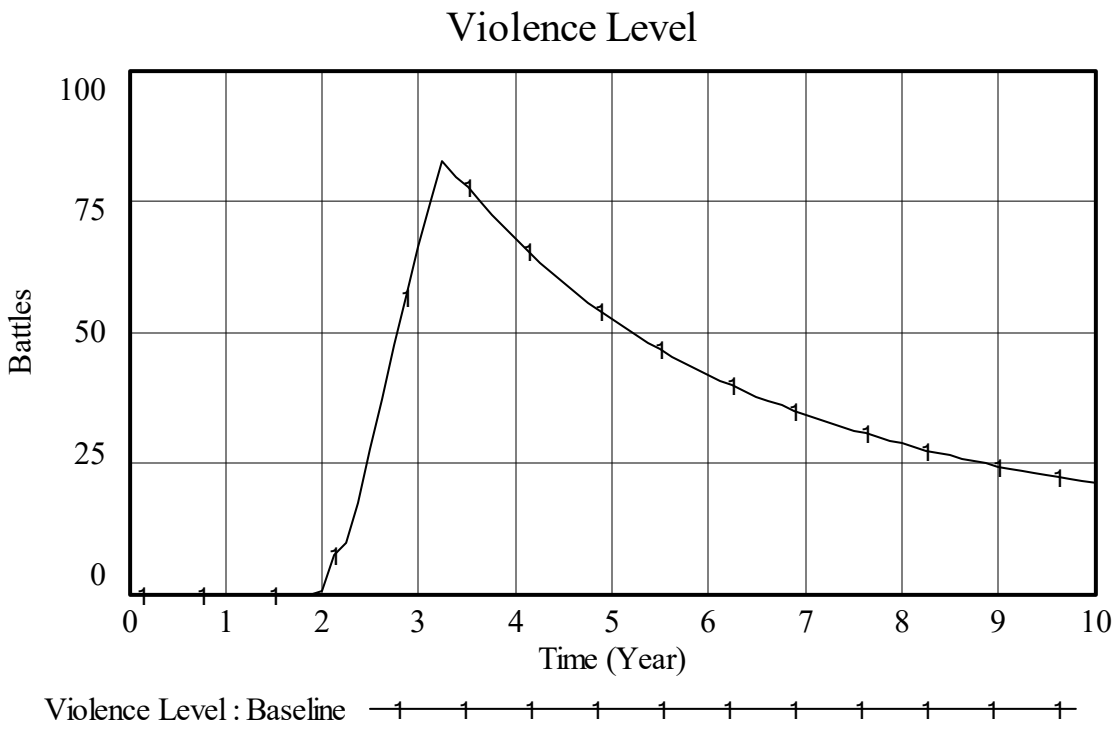

Figure 16: Baseline Results from the Violence Model

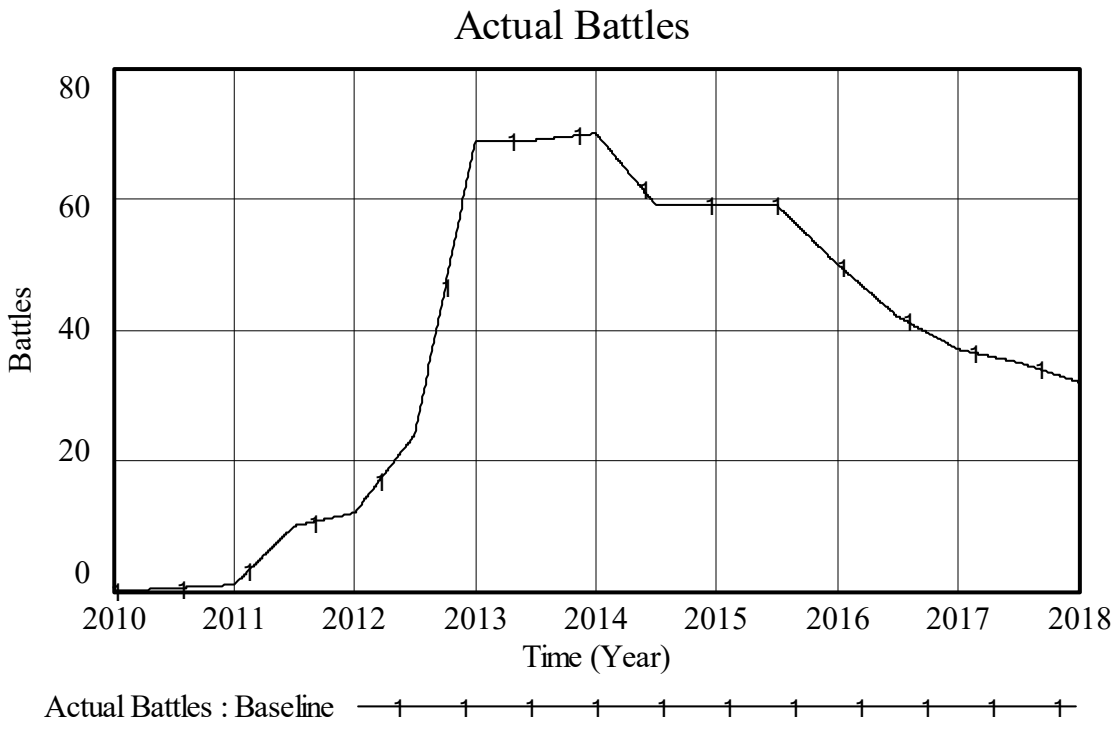

Figure 17: Actual Battles in the Syrian Civil War

As a preliminary validation of the model against real-world data, we initialized the people in the crisis country to the population in Syria before the civil war and calibrated the parameters in the model to produce results similar to those found during the Syrian civil war [26]. The results for the population in the crisis country for the new model baseline run are shown in Figure 18. This has some similarity to the actual refugees resulting from the Syrian civil war (see Figure 19) that was found in [27]. The refugees in the baseline run are shown in Figure 20. This is similar to the Syrian data (see Figure 21). This gives us some confidence the model can be applied to real crisis countries if the parameters of the model are sufficiently calibrated.

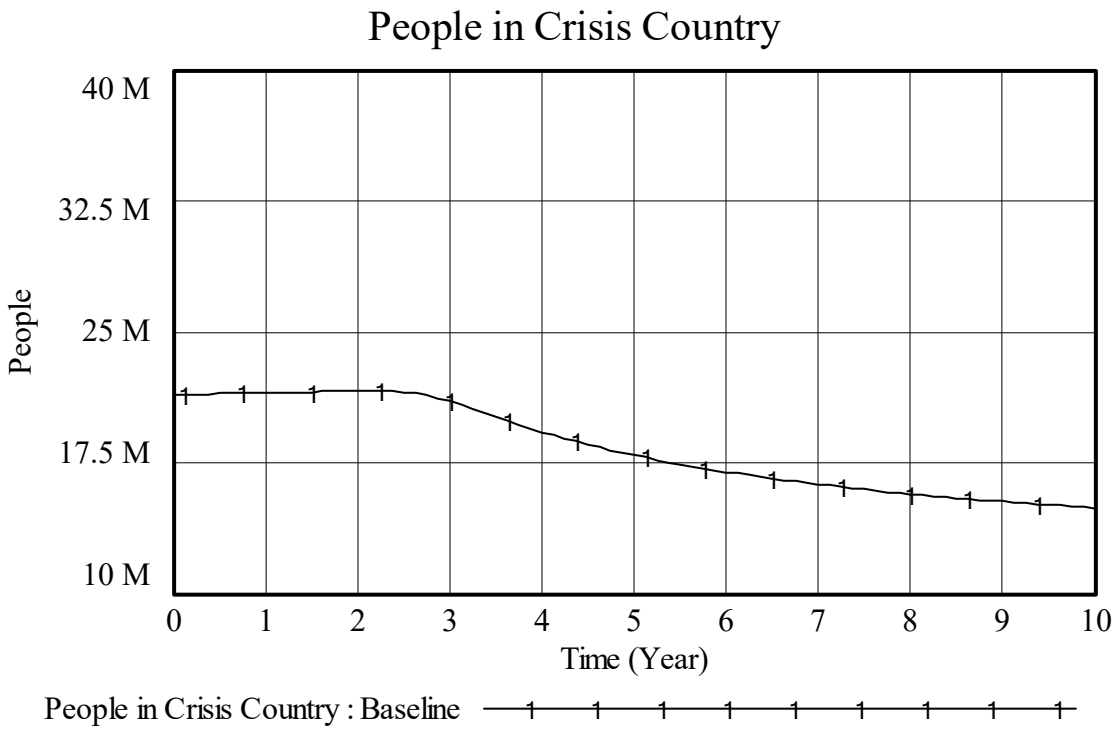

Figure 18: Baseline Results for People in the Crisis Country

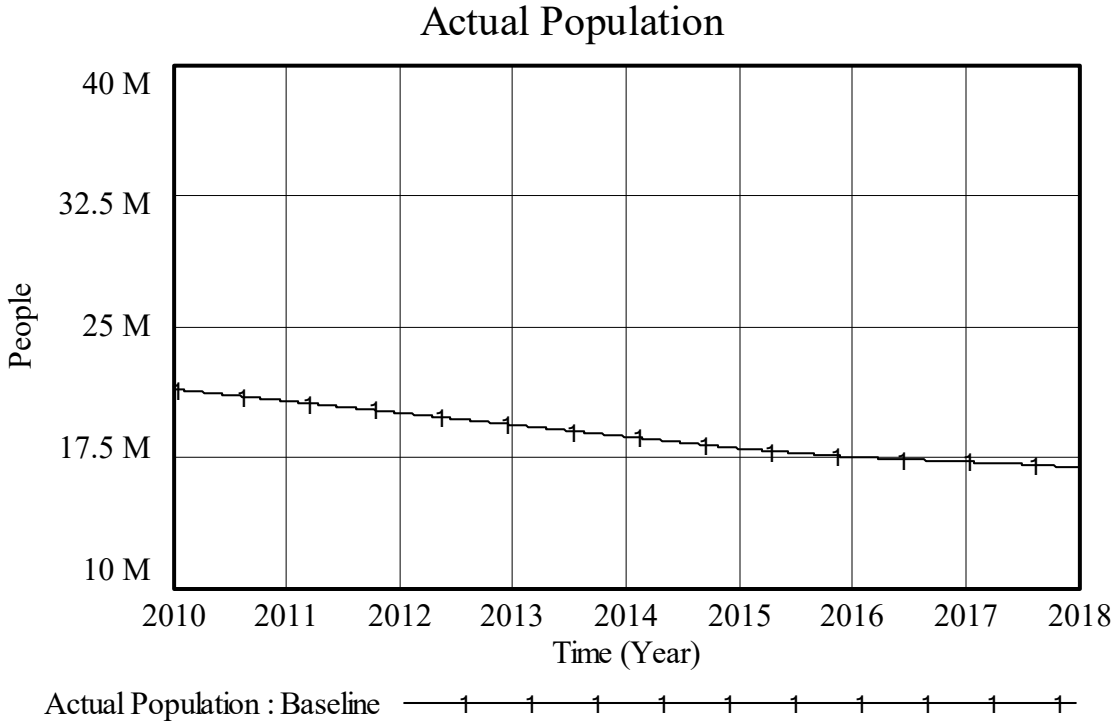

Figure 19: Actual Population in Syria During the Civil War

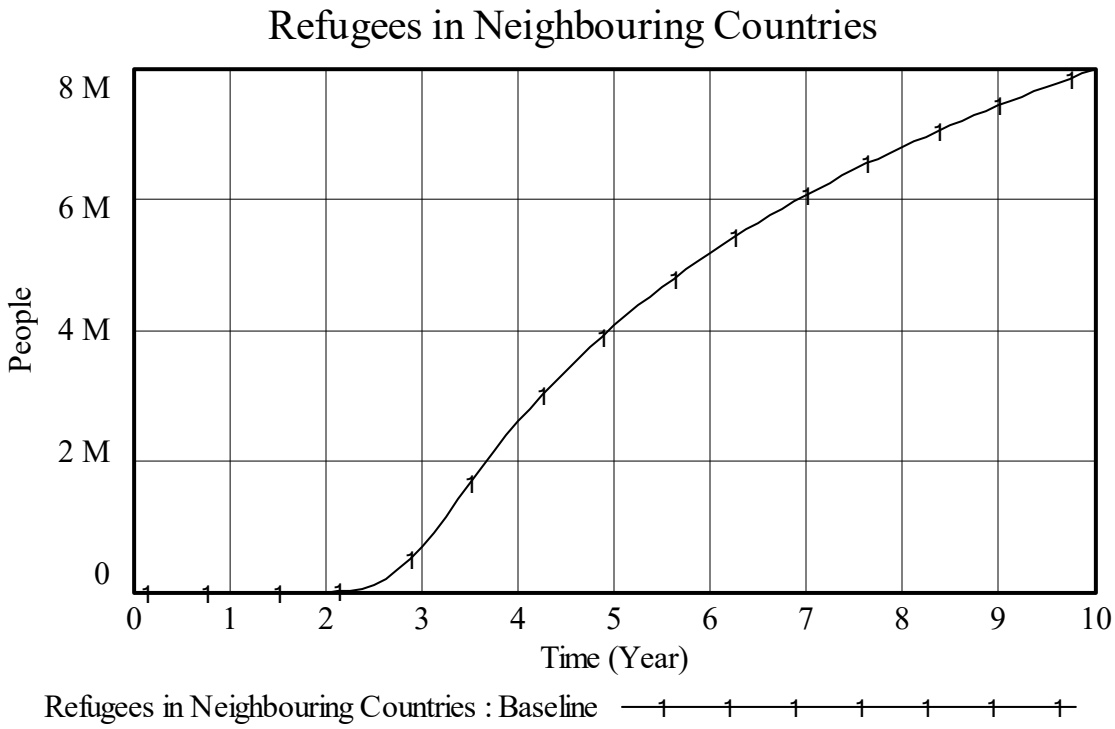

Figure 20: Baseline Results for Refugees in Neighbouring Countries

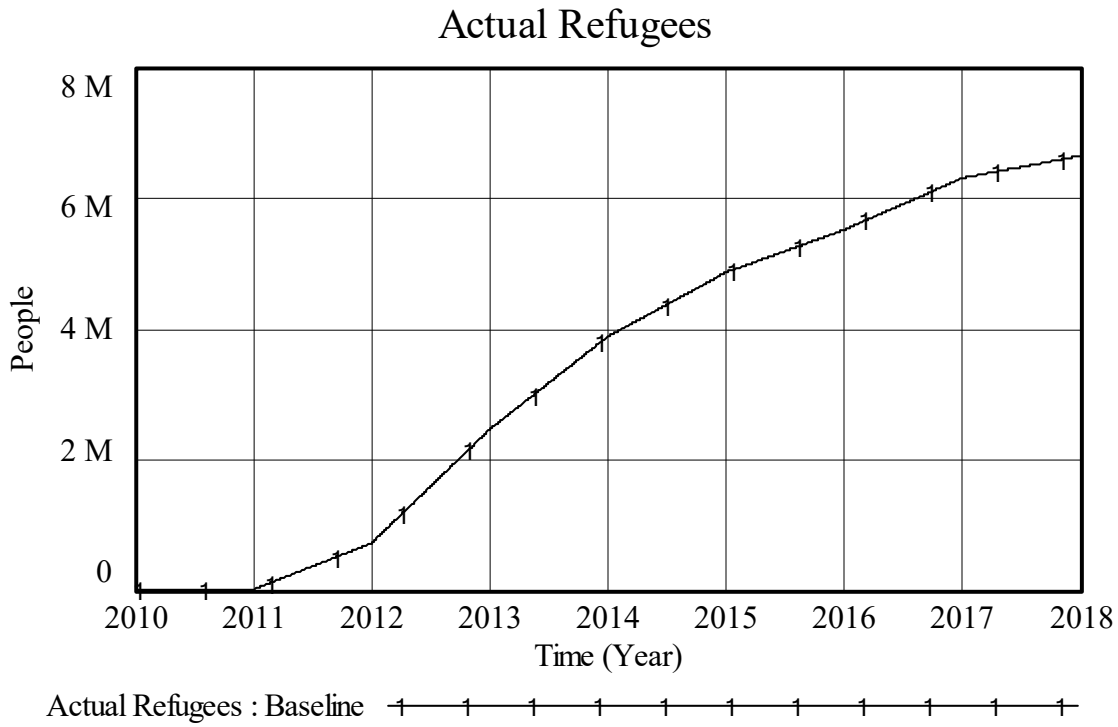

Figure 21: Actual Refugees Caused by the Syrian Civil War

5. Conclusions and Future Work

Structural-confirmation tests of two refugee crisis models were conducted by one of the authors who has personal experience in the real system. This consisted of an examination of the Vensim diagrams for the individual sectors to determine whether the sectors provided a reasonable imitation of the real-world. It was found that there are many good aspects to these models from which useful results can be obtained; as per the famous saying, "All models are wrong, but some are useful" [28]. For example, the models address the need to attack the root cause of the current refugee crisis (i.e. wars). They show the extent of the crisis that war creates on a country by country basis. The humanitarian aid model was focused on the problem of refugees dying in unconventional border crossings which was a serious problem when the model was written in 2015. Since the model was written, this problem has largely been solved [24]. The model has some capability to optimize the allocation of humanitarian aid to reduce the suffering of those affected by the crisis. The model of the Syrian civil war found that immigration would not be able to solve the refugee crisis it created because the accepting countries were showing signs of compassion fatigue. The study then looked at the issues around the repatriation of refugees back to Syria once the civil war was over since an examination of available data seemed to show that the violence has been falling in recent years [18]. The violence sector in the Syrian civil war model was somewhat specific to that particular case and it was suggested that a good model of the refugee crisis needed a more general model of violence. So after the structural-confirmation

tests, a new model was developed which combined many of the good aspects of both models. In particular, the refugee movement sectors developed in both models were able to be greatly simplified. The use of diplomatic effort and peacekeepers to attack the root cause of the crisis (i.e. wars) was adapted from the humanitarian aid model but utilized the need for each based on the number of people at risk of violence. The number of people at risk of violence was based on a safe havens sector that was quite similar to that in the humanitarian aid model. Because the amount of diplomatic effort and the number of peacekeepers deployed was based on the need for them, they were not limited by funding as was assumed in the humanitarian aid model. The timing of the deployment of peacekeepers in the new model was based on the diplomats obtaining a ceasefire between the warring parties. This was similar to the speculated alternative futures in the Syrian civil war model. A new more general model of violence in a crisis country was developed based on the recommendations from the structural-confirmation tests. This explicitly modelled the warring parties and their support from allied nations. The amount of violence projected by the sector was based on the interaction between these warring parties using a technique similar to the famous Lanchester model of warfare [25]. With very little calibration, this model produced reasonable results when compared to the situation in Syria and it was felt the model might have applicability to other crisis countries. To create sufficient confidence in this new model's projections for another crisis country, the parameters of the model would need to be recalibrated based on data from reliable sources.

The primary contribution of this new model is its ability to model the interactions of rebels and the regime in a civil war along with the allies who support them. The model suggests that the introduction of effective diplomacy focused on the support by the allies might cut off the military aid sufficiently to reduce the warring parties capabilities and thereby encourage them to consider negotiating a ceasefire. Then peacekeepers could be deployed to enforce the ceasefire. With the ceasefire is in place, it may be possible for the refugees in neighbouring countries to be repatriated to their country of origin. This is one of the durable solutions to the refugee crisis sought by the United Nations High Commission for Refugees and we believe it is the most feasible solution available.

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