The Geography of Conflict Diamonds: The Case of Sierra Leone

Overview, Design Concepts, Details, and Human Decision Making (ODD+D)

July 14, 2016

This document provides an overview of model structure and is based on the ODD (Overview, Design Concepts, and Details) protocol initially developed by Grimm et al. (2006) and extended by Müller et al. (2013) to include human decision-making.

1 OVERVIEW

In the early 1990s, Sierra Leone, a small country on the western coast of Africa, entered into nearly 10 years of civil war. Sparked by an abusive government and fueled by an illicit diamond market, the decade-long war killed an estimated 70,000 and displaced another 2.6 million people (UN Development Programme, 2006). It is said that the primary driver of the war was the country's most abundant and valued resource, diamonds (Leoa, 2010). While the resource has resulted in growth in other countries such as Botswana, Sierra Leone has experienced some of the highest levels of poverty in the world and was ravaged in war (Goreux, 2001). Unlike the diamond mines of Botswana, however, the alluvial diamond mines of Sierra Leone cover widespread areas in remote parts of the country where mining areas cannot be easily fenced and security is minimal (Goreux, 2001).

Le Billon (2001) argued that the spatial dispersion of a resource is a major defining feature of a war, impacting the type of conflict that may emerge. An agent-based model (ABM)

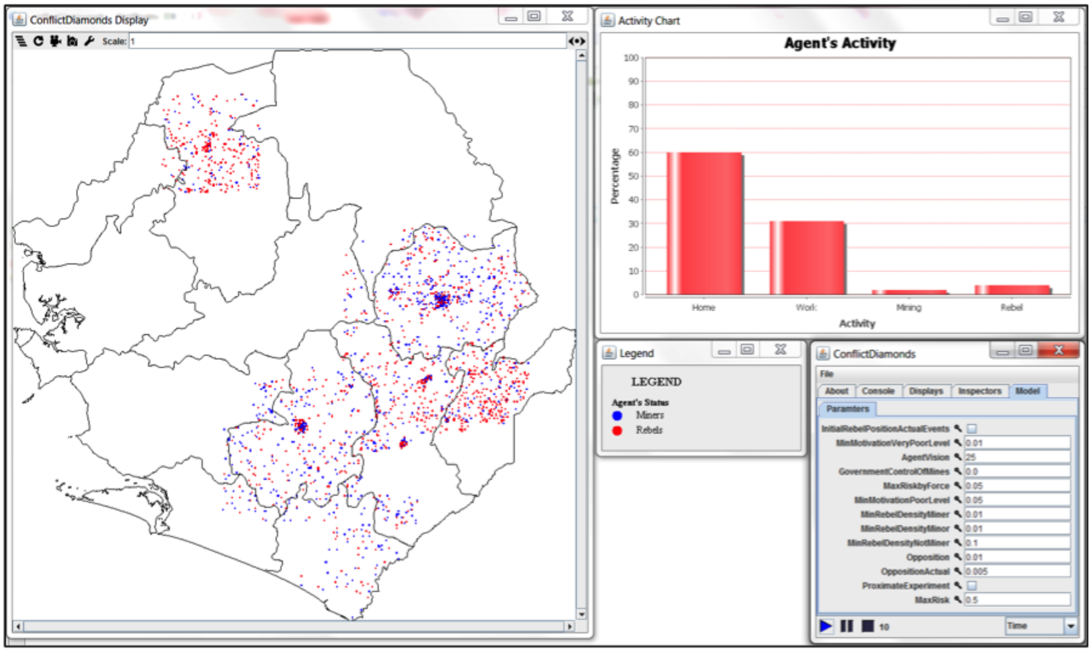

Figure 1: The model's GUI, including the spatial environment display (left), chart of the agents activity (top right), and input parameters and legend for the display (bottom right).

was developed in MASON (Luke, Cioffi-Revilla, Panait, Sullivan, & Balan, 2005) utilizing the GeoMason (Sullivan, Coletti, & Luke, 2010) spatial extension to explore Le Billon (2001) theory. GIS data was utilized to create the modeling landscape, while socioeconomic data of Sierra Leone provided initial agent attributes. Figure 1 displays the graphical user interface (GUI) of the model. For readers wanting to download the source code and data of the model please see `https://www.openabm.org/model/4955/`.

1.1 Purpose

Using Sierra Leone as a test case, the purpose of the model is to explore the role of geography in a resource-driven war. More specifically, the model explores Le Billon's (2001) theory that the spatial dispersion of a resource is a major defining feature of a war, impacting the type of conflict that may emerge. An ABM is integrated with GIS for this purpose. This is an exploratory model and was thus developed for researchers and students interested in agent-based modeling, specifically the role of geography in conflict.

1.2 *Entities, State Variables and Scales*

The model contains the following entities, from highest to lowest hierarchical scale: (1) Environment, (2) Population, (3) Parcel, and (7) Person (individual), which will be discussed in the following sections. Figure 2 provides the high-level Unified Modeling Language (UML) diagram of the model. The modeling world is the country of Sierra Leone and is broken out into the country's fourteen Districts. This is further divided into equal size Parcels, where the agents reside. The agents' (or Person) behavior is determined in the Intensity Analyzer. Depending on the results of the Intensity Analyzer, the Person will either be a Resident or a Rebel. Residents that are employed work for a Diamond Miner or Other Employers, which provides a simple way to track the employed Residents working as laborers in the diamond mines. The model proceeds in one month time steps and is run for ten simulation years (discussed further in Section 1.3).

1.2.1 The Environment, Population, and Parcels

The modeling world, which is the country of Sierra Leone, is subdivided into fourteen areas to represent the fourteen districts of Sierra Leone. In total, this landscape encompasses a 71,740 square kilometer area. Using Landscan data from the Oak Ridge National Laboratory (2007), the landscape was developed as a raster surface with Parcel size of 30 arc-second, or approximately 0.00833 decimal degrees. At the equator, this represents exactly one square kilometer cells (Oak Ridge National Laboratory, 2007). In order to maintain an accurate representation of the population per Parcel, this Parcel size in decimal degrees was preserved. For Sierra Leone, which is located just north of the equator, this means each Parcel size is approximately 0.99 km wide and 1 km high. Thus, space is modeled explicitly and is based on the actual landscape of Sierra Leone. More information about the inputs into the model and the development of the environment can be found in Sections 3.2 and 3.3.

Upon model initialization, the agents (Persons) are added to the Parcels. Determining the agent population per Parcel was completed in two steps. First, the population by district was adjusted

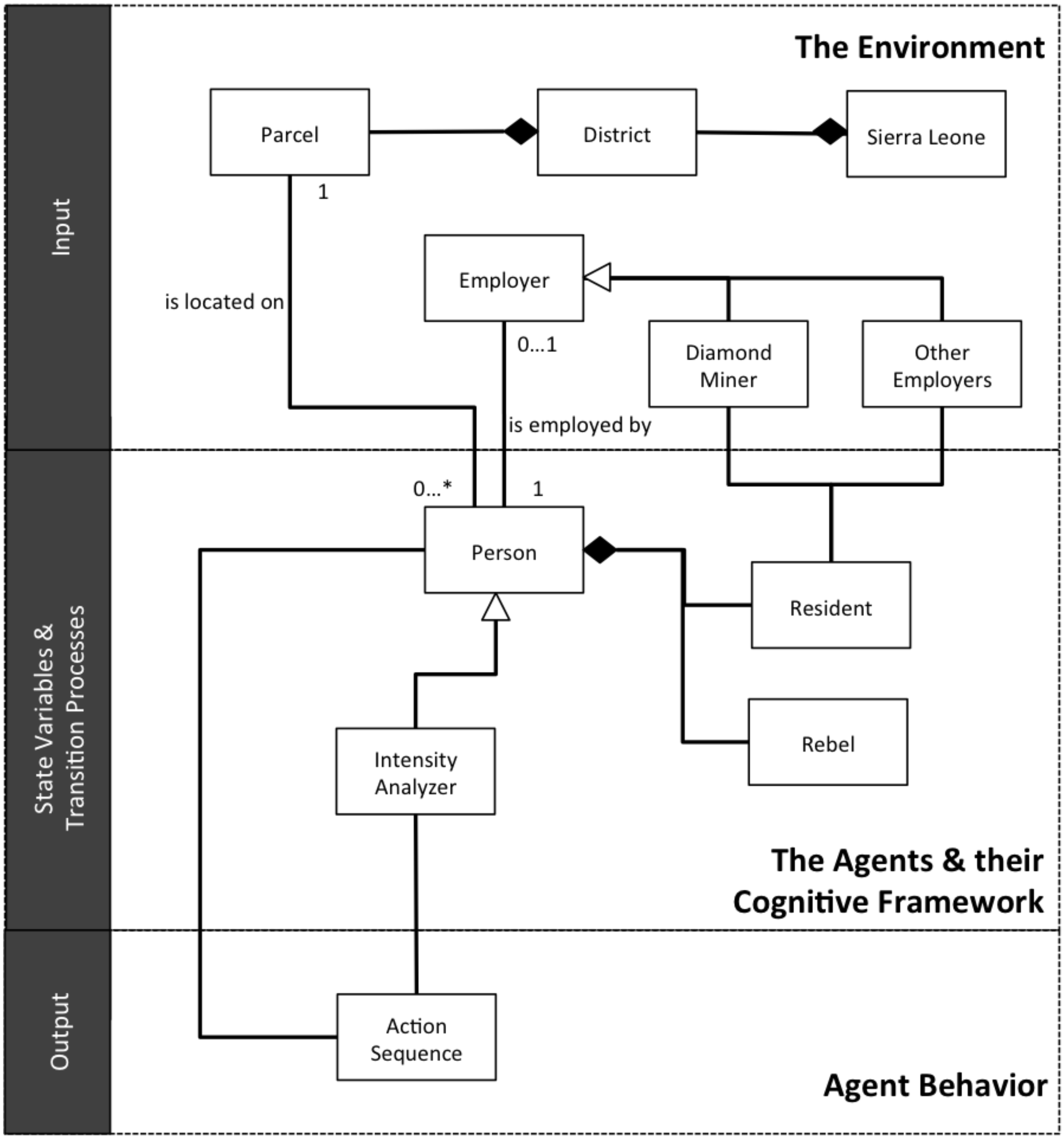

Figure 2: UML diagram of the model.

to more accurately mirror the pre-war population seen in 1985. In Sierra Leone, the last two population and household census were performed in 2004 and 1985. The total population was approximately 4.9 million and 3.5 million, respectively (Statistics Sierra Leone, 2006b). Given the nature of the crisis, there is no census data for the years immediately preceding the conflict, during the conflict, or immediately after. In order to distribute the population across the landscape, LandScan data is used (Oak Ridge National Laboratory, 2007). Table 1 shows how the country's population is distributed across the districts in 1985 (based on Statistics Sierra Leone, 2006b), 2004 (based on Statistics Sierra Leone, 2006b), and 2007 (based on Oak Ridge National Laboratory, 2007). While most districts maintain the same distribution, the Kono district for instance, lost the equivalent of 4% of the country's total population between 1985 and 2007. This can be explained as Kono experienced some of the highest levels of violence during the war, and this is illustrative of the displacement of residents from the area. To adjust for these types of shifts in the population between 1985 (the population prior to the conflict) and 2007 (the population data available by approximately one square kilometer cells), the population within each impacted cell was adjusted accordingly. For instance, the population of any cell within the Kono district was decreased by 4% of the country's total population. This provided a simple mechanism for backcasting the population to levels close to pre-war Sierra Leone.

Table 1: The population distribution of Sierra Leone across the 14 districts (Oak Ridge National Laboratory, 2007; Statistics Sierra Leone, 2006b).

District	1985 Population Distribution (Census)	2004 Distribution (Census)	2007 Population Distribution (Landscan)	1985 to 2007 Population Distribution Change by District
Kailahun	7%	7%	7%	0%
Kenema	10%	10%	10%	0%
Kono	11%	7%	7%	-4%
Bombali	9%	8%	9%	0%
Kambia	5%	6%	6%	+4%
Koinadugu	5%	5%	5%	0%
Port Loko	9%	9%	10%	+1%
Tonkollili	7%	7%	7%	0%
Bo	8%	10%	10%	+2%
Bonthe	3%	3%	3%	0%
Moyamba	7%	5%	5%	-2%
Pujehan	3%	5%	4%	+1%
Western Rural	2%	3%	3%	+1%
Western Urban	13%	16%	15%	+2%
Total	100%	100%	100%	
Total Population (in millions)	3.5	4.9	6.1	

Second, the population distribution of the entire country was reclassified to equal one percent of the total population. Based on the 2004 Population and Housing Census, the total population of Sierra Leone was approximately 4.9 million. However, due to computational constraints of modeling this number of agents, once the population by cell using 2007 Landscan data has been backcasted, the population within each Parcel is then reclassified to one percent of the total population.[1]

Population attributes include age, labor attributes, and income levels. Age is based on the age distribution of the residents within each district (using Thomas, MacCormack, & Bangura, 2006). The active labor force is the percentage of the population between the ages of 15 and 64 that are economically active, which includes those that are employed and unemployed (Braima, Amara, Kargbo, & Moserey, 2006). In addition, residents are eligible to work in the illicit mining industry if they are between the ages of 7 and 64 (the age of 7 was selected because this is the youngest age minors are known to have been involved in the conflict) (Twum-Danso, 2003; UN CyberSchoolBus, 2014). Finally, residents can have one of three income levels: food poor, total poor, and not poor. Food poor and total poor is defined as a household whose monthly income is less than 31,420.42 Liberian Dollars (US$7.30) and 64,223.17 Liberian Dollars (US$14.91), respectively (Statistics Sierra Leone, 2006a). Households that are not poor make a monthly income that is more than 64,223.17 Liberian Dollars (US$14.91) (Statistics Sierra Leone, 2006a). In the model this is simplified to three income levels: food poor residents have an income level of zero, total poor residents have an income level of one, and all other agents (who are not poor) have an income level of two. Table 2 provides the district-level distribution of the labor attributes and income levels used in the model.

Table 3 summarizes the environment and population parameters used in the model. These input parameters create the environment and are used to distribute attributes to the agents.

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1 As LandScan data is in approximately one square km cells, certain populations near the border may not be exact (some of the population from neighboring countries may be included). Thus, LandScan population for the country is overestimated.

Table 2: Sierra Leone labor and poverty data by district (Statistics Sierra Leone, 2006a).

District	Labor Market			Income		
	Percent Employed	Percent in Active Labor Market	Percent Eligible to Mine	Percent Food Poor	Percent Total Poor	Percent Not Poor
Kailahun	27	33	80	45	47	8
Kenema	36	38	80	38	50	12
Kono	39	41	80	22	42	36
Bombali	35	37	79	63	26	11
Kambia	30	36	79	9	62	29
Koinadugu	34	38	79	29	46	23
Port Loko	35	38	79	20	62	18
Tonkollili	29	35	79	32	52	16
Bo	38	36	78	25	39	36
Bonthe	38	36	78	35	50	15
Moyamba	38	39	78	16	52	32
Pujehan	31	35	78	14	45	41
Western Rural	46	41	84	2	13	85
Western Urban	39	35	84	15	30	55

1.2.2 Agents

Agents in the model represent the individual residents of Sierra Leone. They are characterized by unique attributes such as age, labor status, income level, and household employment status. Table 4 lists all agent parameters and provides a brief description of each. Note that households are not explicitly modeled here. The idea of a household is used only to ensure that agents can be assigned an income even if unemployed (e.g., Residents that are Inactive).

1.3 Process Overview

The model proceeds in one-month increments. A monthly time step was selected for several reasons. First, while the decision to join the rebellion may occur in a short time period (hours or even minutes), there is a lag of weeks or even months between the time someone makes that decision (or is forced to make that decision) and the time they are actually ready for combat (BBC, 2014; Beah, 2007). During this period, child soldiers in particular were often forced to watch violent movies, play video games, take drugs, and receive weapons and combat training (BBC, 2014; Beah, 2007; Betancourt, Borisova, & Gilman, 2010). Thus, a month includes the time

Table 3: Environment and population parameters used in the simulation.

Parameter	Description	Reference
Initial number of agents	The population is distributed to equal 1% of the total population prior to civil war.	Oak Ridge National Laboratory (2007); Statistics Sierra Leone (2006b)
Initial opposition group	This is the percentage of the population that strongly opposes the government and has formed the initial opposition group.	Leoa (2010)
Age distribution	Agents are assigned into one or more of the following age-related categories: young child (0-6), minor (7-17), adult (18-64), active labor force (15-64).	Thomas et al. (2006)
Income level distribution	Agents are assigned one of three income levels: 0 = food/core poor (less than 31,420.42 Le / US$7.30); 1 = total poor (less than 64,223 Le / US$14.91); 2 = not poor (greater than 64,223 Le / US$14.91).	Statistics Sierra Leone (2006b)
Labor distribution	Agents are assigned one or more of the following attributes: active labor force (between ages of 15-65 and employable); employed (part of the active labor force); inactive (not part of active labor force); eligible to work in mines (between the ages of 7-65).	Braima et al. (2006)
Vision	The distance, in terms of number parcels out, that the agent can "see."	n/a
Likelihood to mine	If an agent is poor (income is zero or one), this is the likelihood that an agent must meet to be willing to mine.	Adapted from opportunity-based theories (see Section 2.1.1)
Rebel threshold	Minimum density of rebels in neighborhood required for an agent to become a rebel (voluntarily or involuntarily). Threshold values can vary depending on whether the agent is an adult not working in the mining industry, and adult working as a miner, or a minor (between the ages of 7 and 17).	Adapted from opportunity-based theories (see Section 2.1.1)
Distance to diamond mines	Parcels are assigned a distance to diamond mines, valued between zero and one. A value of zero signifies the presence of diamond mines on the parcel. Parcels assigned a value of one are the furthest from any diamond mines.	Hijmans (2009); Gilmore et al. (2005)
Remoteness	Parcels are assigned a distance to roads or cities, valued from zero to one. A value of zero signifies the presence of a road or city on the parcel. A value of one is assigned to the most remove parcels, which are furthest from any roads or cities.	Adapted from Commonwealth Department of Health and Aged Care (2001); Remote Footprints (2014) OpenStreetMap (2010)
Government control over mines	This is the level of control the government has over the mining areas.	Adapted from Le Billon (2008)
Maximum parcel risk	Maximum risk associated with a parcel (a function of remoteness and government control) required for opportunity to exist to mine or rebel.	n/a

Table 4: Environment and population parameters used in the simulation.

Parameter	Description
Age	The Person's age as determined by the Age distribution.
Labor status	The Person's labor status can be employed in the formal sector, working in diamond mines, unemployed, or inactive. At initialization, this is drawn from the Labor distribution.
Income level	The Person's level of income drawn from the Income distribution. This can be 0 (food poor), 1 (total poor), or 3 (not poor).
Household employment status	If at least one agent in the household is employed, than this set to true. Otherwise, it's false.

to join the rebellion and then to prepare for combat. Second, the war lasted years and from a modeling perspective, we are interested in capturing the dynamics of the conflict over years, not days or hours. Third, we need to consider the balance between spatial and temporal computational resources. The modeling world is the entire country of Sierra Leone and simulates the dynamics of a war as it spreads across a country. Given the initial lag between the time an individual joins the movement and the time they are "combat" ready; the span of the war over years; and the computational resources need to model at this level spatially, one month increments was ideal.

Figure 3 illustrates the model's key processes, which are discussed in more detail in the sections that follow. The model's initialization process is discussed in Section 3.2; the agents' behavior, which is determined via the Intensity Analyzer, is discussed in Section 3.4; and the model's outputs are reviewed in Section 4.

2 DESIGN CONCEPTS

2.1 Theoretical and Empirical Background

The behavior of agents in the model draws from several theories of conflict. In this section, we review the relevant theories of conflict (Section 2.1.1) and Le Billon's theory around the spatial dispersion of a resource and its implications on conflict (Section 2.1.2)

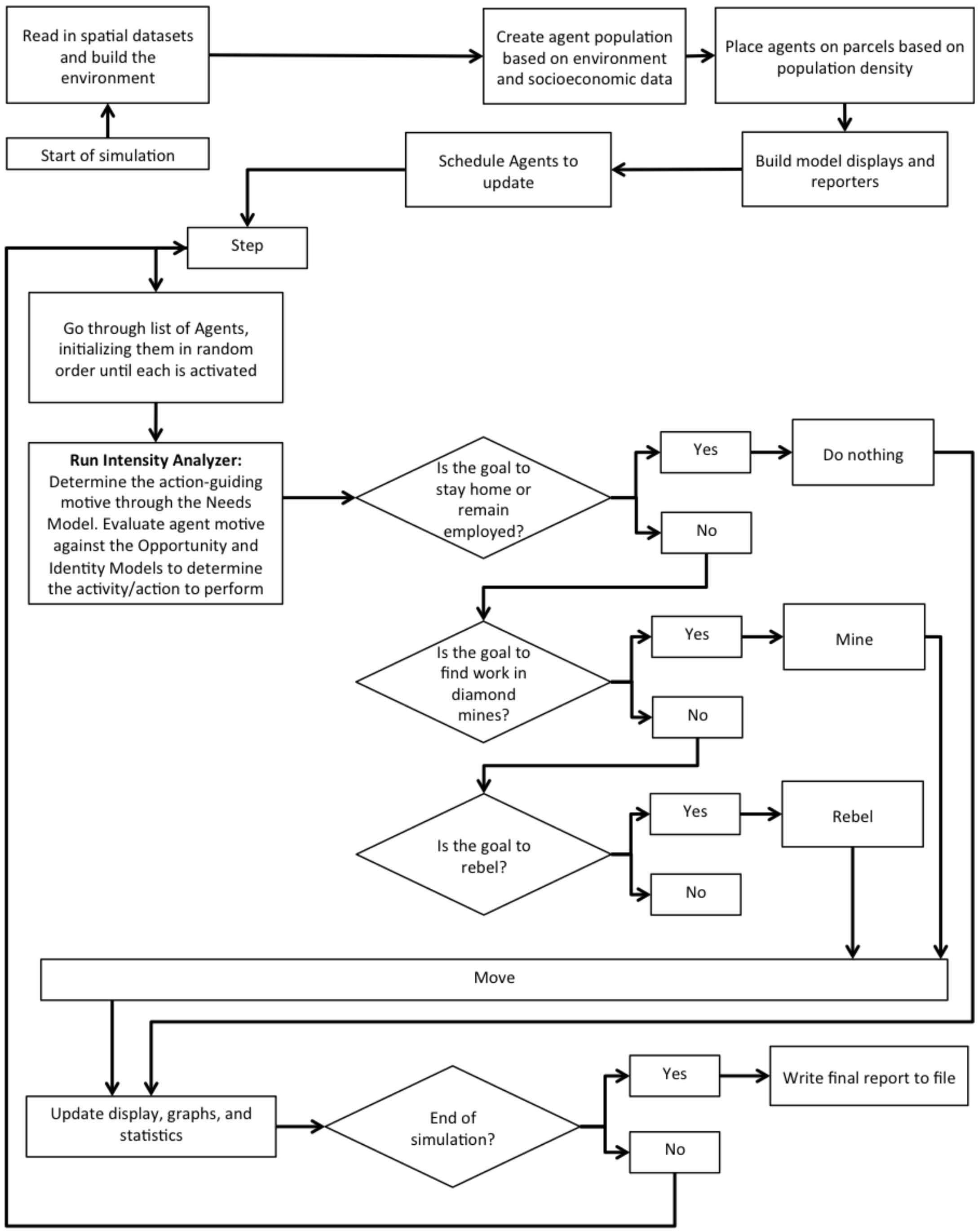


Figure 3: Flow diagram of the key processes in the model.

2.1.1 Theories of conflict

Empirical work has stressed the importance of opportunity, in addition to motivation and group identity, as preconditions for conflict. For instance, Fearon and Laitin (2003) proposed that conditions that favor insurgency, such as weak governments and opportunity, along with motivation are much stronger indicators of war than religious or ethnic grievances for example. Collier, Hoeffler, and Rohner (2009) also cited opportunity in the form of financial and military feasibility as the core driver of rebellion. On the other hand, Lujala and Gleditsch (2005) added identity, along with opportunity and motivation, as a necessary precondition for conflict in what they call a "three-factor model of rebellion" largely inspired by Gurr (1970). Additionally, Ellingsen (2000) used the same three preconditions, labeling them frustration, opportunity, and identity. Others have focused on the financing of war through "lootable" resources (e.g., Collier et al., 2009; Lujala & Gleditsch, 2005). Among some of the first to suggest that the abundance of natural resources may increase the chance for war were Collier and Hoeffler (2004) and Collier et al. (2009). Lujala and Gleditsch (2005) related the looting of abundant natural resources to an economic opportunity for rebels. Le Billon (2001), while agreeing that lootable resources are a factor in conflict, argued further that the spatial dispersion of a resource is a major defining feature of a war, impacting the type of rebellion and length of the war. The model here draws from the opportunity-based theories of conflict and to account for motivation and group identity, it turns to humanistic needs theory and identity theory to help drive behavior.

The conflict in Sierra Leone is said to have been driven by the opportunity to exploit the diamond industry. Opportunity can come in the form of financing, the availability of recruits, and the ability to garner these resources with relative ease, which can be due to factors such as geography, economics, and availability. The more geographically concentrated rebels and potential recruits are to each other, the easier it is to overcome problems in collective action and to mobilize (Lujala & Gleditsch, 2005; Toft, 2002; Weidmann, 2009). It can also be economic as there is an associated cost for each recruit. For example, the lower the recruits' foregone income, the more likely they are to join the rebellion (Collier, 2000; Collier & Hoeffler, 2004; Collier et al., 2009; Fearon & Laitin, 2003).

Empirical work has also suggested that motivation, which hones in on the deprivation of needs, is an important precondition for conflict. One of the earliest theorists on the subject, Maslow

(1954) developed a hierarchy of needs. These needs were grouped into five categories: psychological, safety, belongingness/love, esteem, and self-actualization. While individuals may wish to seek multiple motivations at the same time, the different levels of motivation provide an order by which the needs are met. While Sites (1973) and Burton (1979) identify the set of basic human needs whose absence can lead to the emergence of conflict, Maslow's (1954) hierarchy of needs provides an all inclusive set of needs, which at varying motivational levels help drive the actions of individual behavior, in situations of conflict or peace.

Finally, identity theory focuses on the concept of identities as roles (McCall & Simmons, 1978). It is the way a person is or wishes to be known by others (Stein, 2001) and how that translates to "being and acting" in that role (McCall & Simmons, 1978). Social identity theory, on the other hand, involves the concept of social groups, where a group is a "collection of individuals" who identify with the same social category (Tajfel & Turner, 1979) and is derived from an individual's membership in such a group (Hogg & Abrams, 1988). Such identification with a social group can lead to the differentiation between "we" and "they" when faced with an opposing group (Stein, 2001), and to intragroup cohesiveness and cooperation when intergroup conflict exists (Tajfel & Turner, 1979), which can allow for group mobilization for purposes of social movements. Individuals have an array of identities (Oyserman, Elmore, & Smith, 2010) and by combining role-based and group-based identities into one theory, Stets and Burke (2000) integrate collective identity with the individual, heterogeneous identities of group members, allowing for the dynamic modeling of individual and group identities under one theory of identity.

2.1.2 The spatial dispersion of a resource

Le Billon (2001) argued that the spatial dispersion of a resource is a major defining feature of a war, impacting the type of conflict that may emerge. According to Le Billon (2001), conflict characteristics are affected by two geographic factors: (1) the geographic location of natural resources as they relate to the country's center (proximate versus distant) and (2) the concentration of resources (point versus diffuse). The first factor refers to the geographic distance and accessibility of a resource, which can impact a government's ability to regulate access to a resource (e.g., alluvial diamond mining). The more distant a resource from a country's center of control (i.e., the more remote the area) the easier for rebel forces to capture the area and take control of resource production and revenue streams (e.g., coca production, forests in remote areas, alluvial diamond mining). For example, proximate resources are easier to control and are less likely to be captured (e.g., coffee, oil near center of control). The second factor relates to the geographic concentration of a resource. Diffuse resources are widespread over large geographic areas, making the resource more difficult to secure (e.g., alluvial diamonds). They are typically acquired by productive industries (e.g., agriculture, fisheries, forestry, and alluvial diamonds). Point resources, however, are concentrated in small geographic areas and typically require mechanized extraction (e.g., kimberlite diamonds) Due to the degree of mechanization and technology requirements, point resources are easier to secure and less likely to be exploited by rebel forces (Le Billon, 2001). Assuming an environment that is ripe for conflict, the geographic features of a resource can influence the type of conflict. This relationship is illustrated in Table 5.

Table 5: The relationship between the resource dispersion and conflict type (Le Billon, 2001).

Concentration / **Relation to center**	**Diffuse** Widely spread with minimal control	**Point** Concentrated in small areas
Distant Located in remote territories	Warlordism	Secession
Proximate Close to center of power	Rioting / mass rebellion	State control or coup

When distant resources are diffuse, an environment of warlordism is likely to emerge (e.g., alluvial diamonds in Sierra Leone). These types of resources give rebel leaders the opportunity to exploit the resource with relative ease, and through violence, they create areas of de facto sovereignty. While rebel groups may wish to overthrow the existing regime (via a coup), the availability of distant, diffuse resources provide rebels with continued funding to sustain the insurgency in case of failure. Secession attempts, on the other hand, are influenced by the presence of distant, point resources. Given the increased difficulty in accessing these resources, rebel forces will seek complete sovereignty over the area. Using the existence of these resources as justification from secession from the state, rebels seek mobilization by stressing grievances and the opportunity for future revenues. When diffuse, proximate resources are associated with large numbers of producers, rioting or mass rebellion near the country's center of power is more likely to occur. For instance, poor labor conditions, and the exclusion and displacement of laborers by large corporations may lead to mobilization. Given the challenges associated with controlling the large number of workers over a widespread area, coercive techniques (e.g., warlordism) are exchanged for a more participatory form of conflict (e.g., mass rebellion). Finally, attempts at state control or coups are most likely when point resources are proximate (Le Billon, 2001, 2005). These types of resources are very difficult for rebel groups to access. Given the lack of other revenue streams to finance an insurgency, the best strategy is to overthrow the current regime and seek complete sovereignty over the state (Le Billon, 2001, 2005). The more diffuse and the more remote (or more distant an area is from a country's center of control), the costlier it is for the government to control, and therefore, the easier it may be for rebel forces to exploit (Le Billon, 2001, 2005; Lujala & Gleditsch, 2005). On the other hand, point resources that are closer to roads and population centers, are easier for the government to control, and therefore, riskier to exploit.

2.2 Individual Decision-making

Decision-making processes are modeled at the agent level. Agents make decisions around whether to mine or rebel, which are based on factors such as the agents' income, their distance to the mining activity, the remoteness of the diamond mining areas, and the density of rebels in within their "vision." The agents' decision-making process is discussed in detail in Section 3.4.

2.3 Learning

Learning is currently not a part of the model.

2.4 Individual Sensing

With respect to sensing, agents know there household income and their employment status. Agents will seek to make sufficient income by changing their labor status. Agents are also aware of those within its vision that are mining or rebelling. Agents are heterogeneous in terms of their demographic data, including age, income, and labor status (as discussed in Section 1.2.2).

2.5 Individual Prediction

Prediction is currently not implemented in the model as the purpose is to explore the impact that the spatial characteristics of a resource may have on conflict.

2.6 Interaction

Interactions occur indirectly in the model. For instance, agents' will search their for other agents within their "vision" to determine whether they might rebel (see Section 3.4.2).

2.7 Collectives

The collective modeled are the Rebels. Agents that rebel will move to the areas with diamond mines (see Section 3.4.4).

2.8 Heterogeneity

Residents are heterogeneous in terms of their demographic data, including age, income, and employment status (see Section 1.2.2).

2.9 Stochasticity

Stochasticity is seen in several processes. These include the agent's likelihood to mine if the agent is poor (i.e., food poor or total poor). In addition, the assignment of certain attributes of the agents are assigned based on distributions drawn from empirical data such as age, income, and labor status (see Table 3).

2.10 Observation

Within the model at the global level, we monitor the following statistics: the number of agents that have rebelled, the number of agents that are miners, and the individual demographics of the agents. Statistics are collected by time step and by district so that changes in behavior or trends can be easily assessed. This is discussed further in Section 4. With respect to emergence, the outbreak, intensity, and spatial characteristics of the conflict is an emergent phenomenon.

3 DETAILS

3.1 Implementation Details

The model was developed in MASON (a multi-agent toolkit) (Luke et al., 2005) utilizing the GeoMason (Sullivan et al., 2010) spatial extension. The source code can be found at `https://www.openabm.org/model/4955/`.

3.2 Initialization

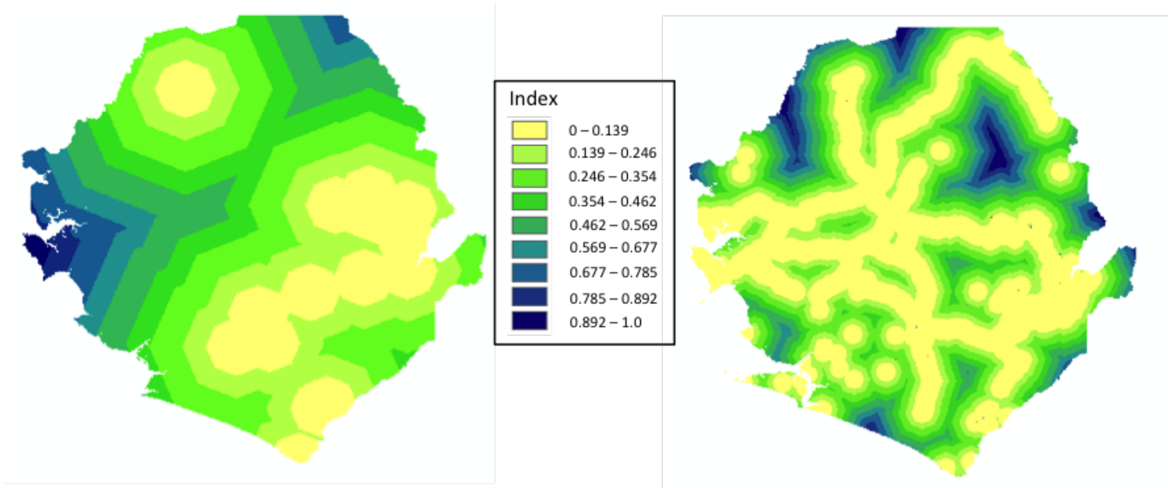
Upon model initialization, the environment is created and Parcels are added. Agents are created and placed on Parcels according to the population distribution of each Parcel (as discussed in Section 1.2.1). Agents are heterogeneous and their age, income, and labor status attributes are distributed at initialization based on a set of empirical distributions (see Table 3).

3.2.1 Creating the Environment

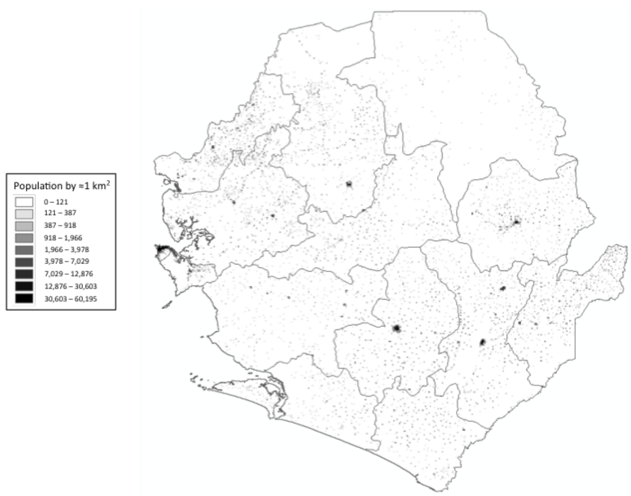
The environment consists of a population raster, which determines the number of agents per Parcel to be placed on the environment, the diamond mines, and cost surfaces that provide agents a route to the diamond mines. Landscan data (Oak Ridge National Laboratory, 2007) provided the main input to the population raster. However, to better reflect pre-war population distributions, the population per Parcel was backcasted using Housing and Census data (Statistics Sierra Leone, 2006b) and then reclassified for computational purposes. This process was discussed in detail in Section 1.2.1. Using geographic coordinates of diamond mines, cities, and roads, cost surfaces are created. The cost surface of the diamond mines provides a “cost” distance of traveling to the mines, which ranges from zero to one (the area where the mines are located have a cost distance of zero and the areas furthest from the mines have a cost distance of one). This also provides a path for the agents to move on the landscape. For example, if it is determined that an agent will work in the mines, that agent will move in the direction with the lowest cost distance until it reaches the diamond mines. This method was selected for a couple reasons: using the road network for agent movement would have been computationally intensive, and the geocoded road data includes only major highways, while locals would require use of smaller roads to reach the mining locations. The cost surface of the cities and highways is used to generate a “remoteness” value (consistent with Commonwealth Department of Health and Aged Care, 2001; Remote Footprints, 2014). Remoteness ranges from zero to one, where zero means the area is in or near a city and/or road, while one denotes the most remote areas of the country. Remoteness helps provide each cell with a “risk” level. The more remote the area, the less risky it is to mine since the ability for the government to control the area decreases as remoteness increases (consistent with Goreux, 2001; Le Billon, 2001, 2005)). Figure 4 shows the cost surfaces and the population raster surface, which were created using ArcGIS 10.0.

3.2.2 Assigning Agent Attributes

The agent population is created based on the environment (e.g., the population raster) and socioeconomic data (discussed further in Section 3.3). At model instantiation, the agents’ age, labor status, income level, and household employment status are defined. Agents are first assigned an age based on the age distribution of the residents within each district (based on Thomas et al., 2006).



(a)



(b)

Figure 4: Raster cost surfaces. a: Raster cost surface of the diamond mines (left) and raster cost surface of the cities and highway network (right). b: Population raster surface.

Agents between the ages of 7 and 17 are called "minors" in the model. These represent residents eligible to be recruited as child soldiers in the conflict (Twum-Danso, 2003; UN CyberSchoolBus, 2014). Next, based on age and district-level labor data, agents are evaluated for whether they will be part of the active labor force. In addition, it is determined whether they are eligible to work in the illicit mining industry. Finally, agents' are assigned an income level. There are three income levels in the model (see Table 3) to represent whether a Resident is food poor (income level is equal to zero), total poor (income level is equal to one), or not poor (income level is equal to two). If an agent is unemployed or inactive (e.g., a child or homemaker), their income is assumed to be generated by the head of household. Thus, an agent does not require employment to have an income. There are two types of employers modeled (Diamond Miners and Other Employers). This provides a simple way to track agents that are employed in the diamond mines and all other employed agents. For simplification purposes, at instantiation all residents who are employed work for Other Employers (see Figure 2). The household employment status parameter is automatically assumed to be true for Resident's that are employed at model instantiation. On the other hand, the probability that an unemployed or inactive Resident is assigned to an employed household is determined based on the percentage of the active labor force that is employed and the assumption that each household has an average of two household members in the active labor market (based on Statistics Sierra Leone, 2006a).

3.3 Input Data

Each run of the simulation begins by reading in the spatial dataset and building the environment. Data used to create the geographic landscape came from the following: the Global Administrative Areas (GADM) database (Hijmans, 2009), which provided the political boundaries of the country and its districts; the Peace Research Institute Oslo (PRIO) Center for the Study of Civil War (Gilmore et al., 2005), which provided the geographic coordinates associated with the diamond mining areas in the country; OpenStreetMap (2010), which provided geographic coordinates of roads and cities; and the Oak Ridge National Laboratory (2007), which provided the

LandScan population data.

Socioeconomic data at the district-level came from the Republic of Sierra Leone 2004 Population and Housing Census (Braima et al., 2006; Thomas et al., 2006) and Statistics Sierra Leone's Annual Statistical Digest (Statistics Sierra Leone, 2006a). This data provided information on age distribution, poverty levels, and employment statistics.

3.4 Sub-models

Three sub-models were created in order to capture the simple behaviors that theory suggests leads to the emergence of conflict (as discussed in Section 2.1), specifically the Needs Model (Section 3.4.1), the Opportunity Model (Section 3.4.2), and the Identity Model (Section 3.4.3). Figure 5 illustrates at a high-level how the PECS (Physical conditions, Emotional state, Cognitive capabilities, and Social status) framework is implemented in the model through the three sub-models: the Needs Model (using green arrows), the Opportunity Model (using blue arrows), and the Identity Model (using red arrows).

PECS provides a framework for which to drive agent behavior. A PECS agent is made-up of three main categories - inputs, state variables, and outputs. The inputs pass in and filter the information received from the environment; the state variables process the information and develop an action plan; and outputs determine behavior and execute the actions (Schmidt, 2002). The PECS agent can have up to four types of state variables (i.e., Physis, Emotion, Cognition, and Social status). However, given the scale and purpose to model the spatial dynamics of a state-level war, individual agent activities are kept simple. In the model, focus is placed on the Physis, Cognition, and Social Status state variables. While Cognition is used to process information about the environment and to draw up an action plan, more intricate components of Cognition, such as the self model, protocol model, and reflection are not included. While agents may join or remain in conflict due to an emotional state such as aggression or fear, these factors are not explicitly modeled. Thus, the Emotion state variables is not used.

Sensor (the environment) and Perceptions feed directly into Physis and Cognition. The Resi-

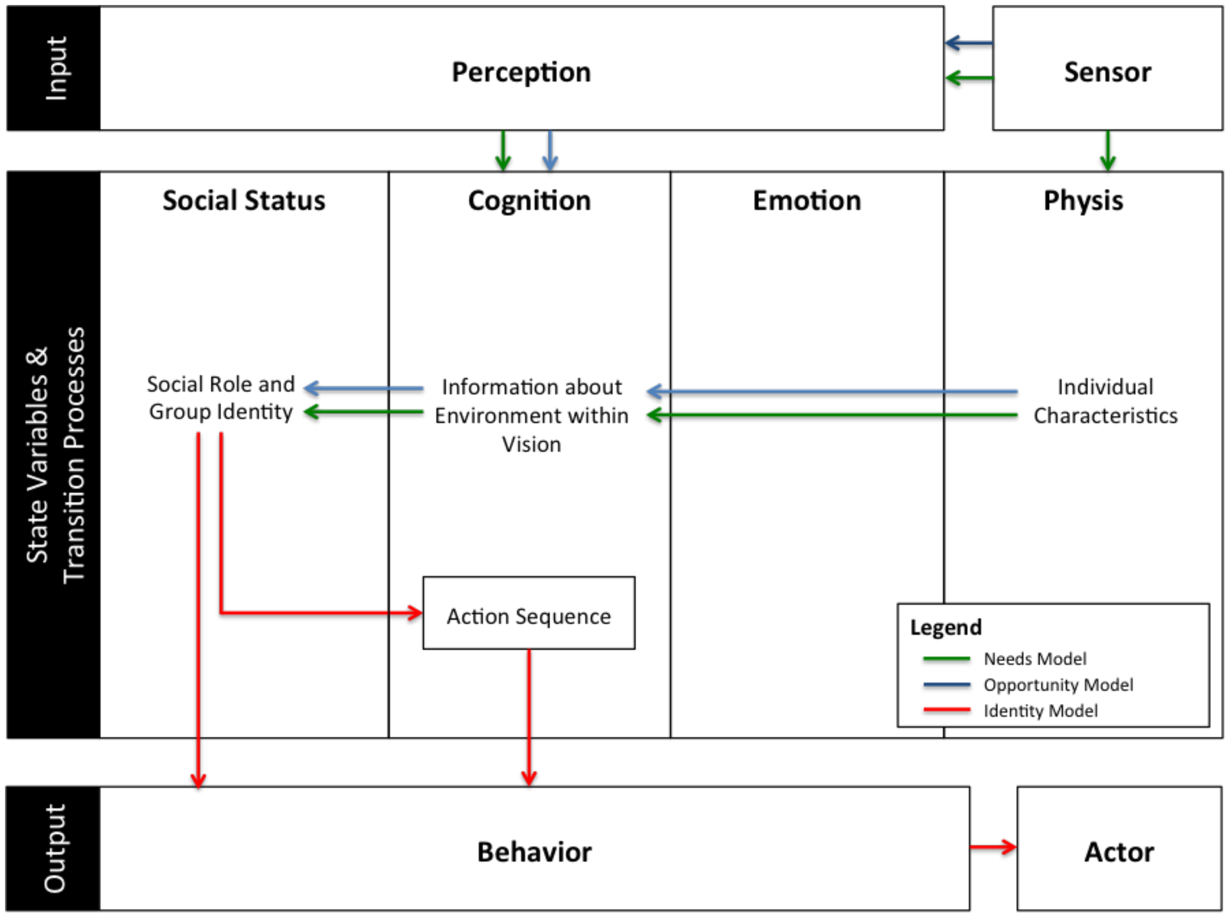


Figure 5: A high-level representation of agent behavior incorporated into the PECS framework (adaped from Schmidt, 2000).

dent then processes any Information about the Environment within Vision, which can include environmental factors and other influences. Using the Needs Model, this information along with the Resident's Individual Characteristics determines a Resident's need. In addition, the Opportunity Model draws from the Resident's Individual Characteristics and the Information about the Environment within Vision in Cognition to determine whether the opportunity to rebel or to become a miner exists. Using results from the Needs Model and the Opportunity Model, the agents Social Role and Group Identity are defined in the Identity Model. This identity directly impacts the action the agent will take, which is generated by Behavior and then executed by Actor. Figure 6 provides details on the specific motives (also known as drives, needs, or desires) and the set of potential actions available to the Resident. The process described in Figure 5, between receiving information from Perception and generating the Action Sequence, are implemented via the Intensity Analyzer, which is responsible for determining the action-guiding motive from the set of possible motives available to the Resident.

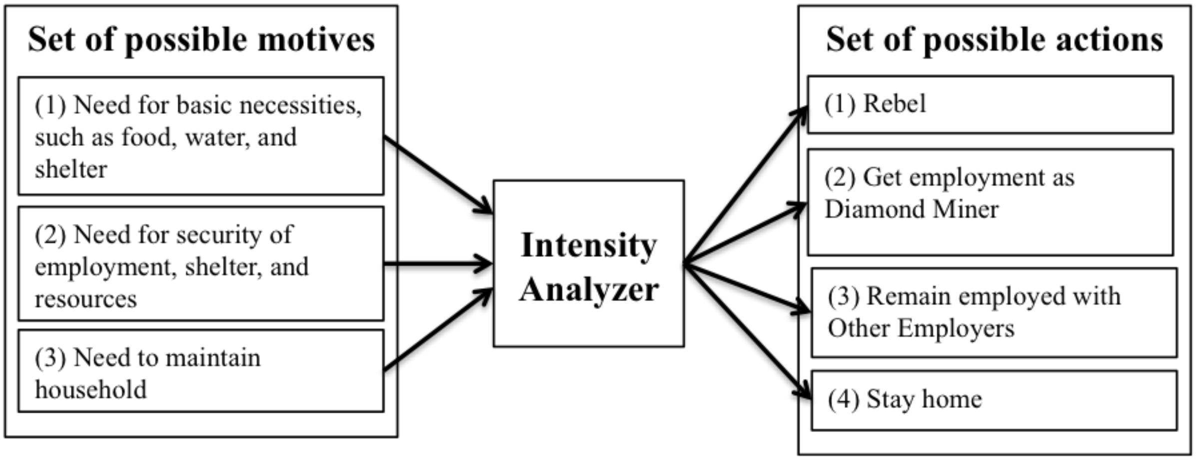


Figure 6: Motives and determining the action-guiding motive via the Intensity Analyzer (adapted from Schmidt Schmidt (2002)).

3.4.1 The Needs Model

Humanistic needs theory (e.g., Burton, 1979; Maslow, 1954; Sites, 1973) focuses in on the deprivation of needs as a precondition for conflict (see Section 2.1.1). As illustrated in Figure 6, residents can have three motives: (1) the need for basic necessities such as food, water, and shelter, (2) the need for security of employment, housing, and financials, and (3) the need to maintain the household.[2] These motives represent the two most fundamental levels from Maslow's (1954) hierarchy of needs: physiological and safety. The remaining levels, including love and belonging, esteem, and self-actualization, are beyond the scope of this model.

Physiological needs such as food, water, and shelter must be purchased. In the model, Resident's may meet this need through an income, which may be due to the Resident's gainful em-

[2] While the Needs Model is responsible for determining the agents' motive, and in that sense, could be called the "Motives Model," it was instead named after the humanistic needs theory for which it draws from. This was done to highlight the application of theory in the sub-model.

ployment or may be said to come from a "household" member. If unmet, these Residents are the most vulnerable to joining the illicit diamond mining or becoming part of the violence as they seek to meet these needs. Safety needs, on the other hand, means that the Resident is meeting its most basic of needs but is looking for a certain level of financial and personal security. This is met through an income that is sufficient to provide some level of security in addition to meeting its basic physiological needs. Residents that are food poor (income level is zero) are motivated to, at a minimum, meet their physiological needs, while Residents that are total poor (income level is one) are motivated to meet their physiological in addition to safety needs.

The Resident's labor attribute is also taken into account to determine individual motivation. Regardless of income, for example, an individual who is not part of the active labor force will be motivated to maintain the household and will not seek employment. On the other hand, Residents that are part of the active labor force will seek to either provide its household with basic necessities or security, depending on its current income level.

In addition, some Resident's will be forced to rebel. Income and labor attributes are irrelevant in this case as these Residents, by rebelling, are seeking to survive and as such, to maintain the most basic of needs. Table 6 provides a summary of the income levels and attributes associated with each motive.

Table 6: Motives and the associated income level and labor attribute.

Motive	Associated Income	Associated Attributes
Need to provide basic necessities	Food poor (income = 0) Any income level (if forced to Rebel)	Active labor force (employed or unemployed) Age is 7 or older (if forced to Rebel)
Need to provide security	Total poor (income = 1), Not poor (income = 2)	Active labor force (employed or unemployed)
Need to maintain the household	Any income level	Inactive (not part of active labor force)

While the Needs Model determines the action-guiding motive, the Opportunity Model helps determine the final goal and, subsequently, the final action the agent will take. Given the right influencing factors, for example, agents that are total poor may seek to move up to not poor. While some agents may chose (or be forced) to rebel regardless of income.

3.4.2 The Opportunity Model

Theorists have pointed to opportunity, along with motivation and group identity, as indicators of war (see Section 2.1.1). Pulling from opportunity-based theories–which have stressed such factors as the accessibility to lootable resources (e.g., alluvial diamond mines), the geographic concentration of rebels, and economic factors in the region–agents in the model require opportunity to join the illicit mining industry or to rebel.

The first factor of opportunity in the model is the accessibility to lootable resources. This is driven by three criteria: the presence of diamond mines, the remoteness of the area, and the level of government control (or security) surrounding the resource (consistent with Le Billon, 2001, 2005)). As discussed in Section 2.1.2, resources can range in concentration from diffuse (e.g., the alluvial diamond mines in Sierra Leone) to point (e.g., the kimberlite diamond formation in Botswana). Diffuse resources tend to cover widespread areas of land and are the least secure (Lujala & Gleditsch, 2005). The more diffuse and the more remote (or more distant an area is from a country's center of control), the costlier it is for the government to control, and therefore, the easier it may be for rebel forces to exploit (Le Billon, 2001, 2005; Lujala & Gleditsch, 2005). On the other hand, point resources that are closer to roads and population centers, are easier for the government to control, and therefore, riskier to exploit. This range in resource concentration (from the less secure diffuse resources to the more secure point resources) is simulated via a government control (or security) variable. All the parcels within a Resident's vision are evaluated for these three criteria and a risk-level is derived for each parcel, which is given a value between zero and one. If their exists parcels within an agent's vision whose risk-level is below the agent's threshold for risk, diamond mines are present, and the agent is likely to mine, then the first factor of overall opportunity exists.

The second factor is economic in nature. Opportunity-based theories have stressed economic incentives, including income (or need) as an impetus for conflict (see Section 2.1.1). The presence of residents in need of basic necessities can provide a pool of potential recruits and laborers (consistent with Twum-Danso, 2003; UN CyberSchoolBus, 2014). While miners, who may operate more as criminals, may not share the same ideological views as rebels in a conflict (Collier, 2000), they nonetheless may be willing to take the risk to play a role in illicit activities. Thus, income may provide the opportunity for conflict as well as for the cheap labor needed to help fund the continued insurgency. In Collier's (2000) model, for instance, rebel leaders recruit labor at an income that is consistent with the economy's opportunity cost of labor (Collier, 2000). Although rebel leaders are not modeled here, there is an underlying assumption that residents in the lower income brackets are the most vulnerable to joining the conflict. For laborers, a simple likelihood to mine is applied representing the chance an agent will mine (the lower the income, the higher the likelihood to mine). Because this is a simple model, there is no explicit way to account for those residents that may need the income, but may choose nonetheless to stay away from the illicit mining industry. These may be residents that prefer to keep searching for regular employment. These may also be residents that are employed in low paying jobs (the income levels are broad, thus an income level of zero can still constitute some amount of income). Only those Residents in the lowest income bracket who are also influenced due to the geographic concentration of neighboring Rebels will become Rebels due to economic opportunity.

The third, and final, factor in determining opportunity is the concentration of rebels within an agent's "vision." The more geographically concentrated the rebels, the easier it is to overcome challenges of collective action and to mobilize (Fearon & Laitin, 2003; Lujala & Gleditsch, 2005). The proportion of agents within its vision that are Rebels is calculated to determine the density of Rebels. This density is then compared to a predetermined threshold. If the Rebel density is higher than the agent's threshold, this second factor of opportunity is met. Creation of neighborhoods (i.e., the agents' vision or number of parcels out an agent can "see") allows us to implicitly model these social networks. This provides a good proxy for modeling an agent's likelihood to be influenced to mobilize and join the rebellion. This also relates to Tobler's (1970) first law which states that all things are similar, but closer things tend to be more similar. Thus, the closer (or more concentrated) agents are geographically, the likelier they are to communicate and to be influenced by one another.

In the model, if the first two factors of opportunity are met (e.g., there exists accessibility to diamond resources and the right economic incentives), then there exists the opportunity for an agent to turn to the illicit market as an independent miner. In addition to these two factors, if the third factor is also met (e.g., there exists sufficient influence from nearby rebels), then there exists the opportunity to rebel. In the case of those agents forced to rebel, however, economic factors are not considered (i.e., the agent can have any income level), as these cases were largely children abducted and violently coerced to join the conflict (Gberie, 2005; UN Development Programme, 2006).

3.4.3 The Identity Model

Group identity is said to lead to a differentiation between "we" and "they." A differentiation that can spiral into violence as the actions of one group in response to the other can be perceived to be threatening or aggressive (Stein, 2001). Theorists have placed group identity at the source of conflict (see Section 2.1.1). At model instantiation it is assumed that there exists a predefined group of residents (selected at random) that share a common group identity, creating the initial opposition group. While group identity may be a necessary precursor to conflict (e.g., the initial opposition group), Stets and Burke (2000) argue that there are sufficient similarities between role- and group-based identities to create one Unified theory to account for both. Agents that are not part of the initial opposition can have one of four identities: Domestic, Employee, Miner, or Rebel. The model draws from the Unified theory (Stets & Burke, 2000) as agents decide which identity to pursue (see Section 2.1.1).

An activated identity is one that is currently directing behavior and is a function of (1) commitment, or the embeddedness of an individual in a social structure, (2) the fit of the identity with the situation, and (3) characteristics of the identity (Stets & Burke, 2000). While the Domestic and Employee identities are activated based only on results from the Needs Model, the Miner identity also requires that it "fit" into the situation. Fit, in this case, is measured by opportunity in the form of lootable diamond mines, which was defined in the Opportunity Model. The Rebel identity, on the other hand, requires a level of commitment in addition to fit in the situation. Commitment, or embeddedness, is a function of the number and strength of connections a person has by holding a given identity. However, since social networks are not explicitly modeled, commitment is measured as a function of the density of rebels within an agent's vision (as determined in Opportunity Model). Note that the Rebel identity may be activated not only by choice but by force, this was especially the case for children (Gberie, 2005; Goodwin, 1999; Human Rights Watch, 2000). Table 7 provides a summary of the requirements for activating each identity, illustrating how motive (as determined by the Needs Models) and opportunity (as determined by the Opportunity Model) feeds into the Identity Model. After running the Identity Model, the agent has determined the active identity. The agent will then perform the actions associated with the given identity.

Table 7: Motives and opportunity requirements for each Identity.

Identity	Action-Guiding Motive (Needs Model)	Environmental and Other Influences (Opportunity Model)
Domestic	Need to maintain household	n/a
Employee	Need for basic necessities Need for security	n/a
Miner	Need for basic necessities Need for security	Presence of diamond mines and risk is below set threshold Likelihood to mine is met
Rebel	Need for basic necessities	Presence of diamond mines and risk is below set threshold Density of rebels is above set threshold

3.4.4 The Action Sequence

As shown in Figure 6, an agent can perform one of three activities at each time step: mine, rebel, or do nothing (e.g., remain employed in the formal market or stay home). The active identity, as determined by the Identity Model (see Section 3.4.3), directly effects the action an agent will take. If an agent's identity is Domestic or Employee, the agent, in terms of its action sequence, will do nothing (as agents "going to work" is not explicitly modeled). If the agent's active identity changes from Employee to Miner or Rebel, that agent will leave its current employer. If the agent is now a Miner, that agent will be added to the Diamond Miner employer. In addition, if the agent's income level was zero, it is increased to one. An agent who becomes a Rebel, on the other hand, does not work for any employer, as the resident is either being forced to rebel or is seeking to take control of a mining area for purposes beyond that of the average independent miner.

Agents that are Miners or Rebels will move on the modeling landscape. As a Miner or Rebel the agent needs to be near the diamond mines, but at the same time it is assumed that the agent will want to move to a location that will minimize its potential level of risk as much as possible. Utilizing the cost surfaces developed to create the initial landscape, an agent will move to a cell within its vision that is closer to the diamond mines but more remote than its current location. The agent will continue to move until it cannot find any parcel within its vision that would be better (i.e., closer to the mines and more remote) than its current location.

4 MODEL OUTPUT

The model exports a set of comparative statistics. These include the number of agents by the set of labor attributes, income levels, and identities. Statistics are collected by time step and at the district-level so that changes in the conflict's dynamics can be easily assessed across time and geographic location. In addition, the spatial dynamics of the conflict as it evolves across time are observed trough the interface during model runs.

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