Exploring the Emergence of Organized Crime in Rio de Janeiro:

An Agent-Based Modeling Approach

Bianica Pint, Andrew Crooks, Armando Geller
Department of Computational Social Science, George Mason University
Fairfax, VA 22030, USA
bpint@gmu.edu, acrooks2@gmu.edu, ageller1@gmu.edu

***Abstract*—This paper focuses on the emergence of criminal activity due to the unmet human needs of those living in Rio's favelas. An agent-based model is developed to explore how human needs, environmental factors, and individual attributes impact state-level behaviors. The emergence of organized crime is observed as "common" criminals turn into gang members. The prevention of conflict requires policies that anticipate responses and avoid conflict. By "re-creating" the current environment, we have the ability to potentially predict the onset of violence where it does not yet exist or understand the source of conflict in those areas already in the midst of violence.**

Keywords-agent-based modeling, PECS framework, Human Needs Theory, organized crime.

I. INTRODUCTION

Almost one million people live in the nearly 700 squatter settlements, known as "favelas," that exist in Rio de Janeiro, Brazil today. Although only one to three percent of those living in the favela are involved in criminality, all favela residents suffer the daily violence, prejudices, and marginalization that come with the activity [1]. In 2000, over 10,000 youths between the ages of 15 and 24 were killed in Brazil by firearms. In 2008, not including Iraq or Afghanistan, only four other countries registered more homicides for people in this age group: El Salvador, Colombia, Venezuela, and Guatemala [2].

According to human needs theorist John Burton [3], when a state fails to provide its residents with the necessary levels of security, recognition, and identity, conflict emerges as humans pursue some means for which to satisfy these needs, whether it be through ethnic wars, street gangs, or domestic violence. Difficulty associated with quantifying such human factors has led to some resistance in including them in social analysis. However, the PECS model for simulating human behavior provides us with the framework while agent-based modeling provides us with the tool for which to implement Human Needs Theory in the context of the conflict that exists today in Rio. Such conflict arises from years of repression, collective action, resource availability and an ideal geography [4].

An agent-based model is developed that explores how unmet human needs combined with environmental and other factors impact individual, neighborhood, and state-level behaviors. It utilizes empirical data in its attempt to re-create the current environment in an area of Rio. Population dynamics are observed as residents search for employment, go to school, or join criminal activity, leading to the emergence of organized crime.

II. MODEL FRAMEWORK

A. Background - Human Needs Theory

Human Needs Theory tells us that people require a set of needs to survive, which go beyond food, water, and shelter. These basic, non-negotiable needs are security, identity, and recognition [3]. When a state fails to provide these basic needs to its residents, conflict emerges as humans drive to satisfy their unmet needs [5].

Structure, predictability, and stability are met by ensuring that the proper mechanisms are in place for maintaining order, resolving conflict, and providing general protection over individuals. At the state-level, security of its citizens can be met through an effective police force. If residents do not feel protected, they may create neighborhood watch groups or hire private security. Recognition, at the state-level, deals with concern over the general well-being of residents. This is accomplished by providing basic services such as utilities, education, and healthcare. If unmet, neighborhood associations or non-profit organizations may help fill the void. At the individual-level, recognition may be met by receiving good grades as a student, a raise or promotion as an employee, or gratitude from a spouse as a homemaker. Identity concerns the need to feel that you play an important role in society. At the state-level, humans may feel a sense of self as rightful citizens of a state, and as such, being granted certain rights. At the neighborhood and individual-level, individuals may feel "pride" in the neighborhood which they reside or in the organization for which they work or attend school.

Under certain conditions, criminal organizations may, instead of the state or civic associations, fill the void. Today, gangs in many of Rio's favelas provide economic aid, maintain order, and resolve conflicts in an effort to maintain the community's support [6]. The state's inability to provide favela residents with basic human needs left a void which criminals filled, in turn providing them with legitimacy to continue their operations, political leadership due to their unique position between politicians and residents, and an extraordinary amount of wealth as residents and police allow criminals to continue their operations. These criminal organizations also provide many, mostly young men with a

feeling of self-worth, a feeling that they are part of something bigger than themselves.

B. PECS Framework

The PECS framework, which is a model for simulating human behavior, states that behavior can be modeled by factoring an individual's Physical conditions, Emotional state, Cognitive capabilities, and Social status [7]. PECS groups all behavior into one of two groups: reactive and deliberative. While reactive behavior is as an unconscious or internal response to the environment (a person sells drugs because it is the only means for which to provide an income to feed their family), deliberative behavior involves the conscious pursuit of a goal (a person chooses to sell drugs for the purposes of gaining power even though other opportunities exist for which to earn adequate income). Modeling deliberative behavior involves the development of an internal set of goals and sub-goals. Behavior is driven by the importance of the goal, distance to completion of the goal, and other influences. Reactive behavior is described as an automatic reaction, which are mostly instinctive without need for deliberation. This automatic reaction may be driven by a set of needs, including "basic needs required to preserve life [7]." These needs, combined with environmental and other factors, will drive a person to pursue a certain goal. The function which determines the goal is the Intensity Function (T) and is defined in (1), where N is the set of needs driving the behavior, E is the set of environmental influences and X is the set of other influences, such as age and gender, potentially affecting the behavior. An individual will then take the steps (or actions) necessary to accomplish the goal. This particular type of reactive behavior is called drive controlled behavior and is the mechanism which will direct the behavior of agents in the model [6]. Figure 1 illustrates the high-level process.

$$T = \phi(N, E, \Xi) . \quad (1)$$

As Human Needs Theory is grounded on the idea of the human drive to satisfy a set of basic needs, the drive controlled behavior within the PECS framework is an ideal model. Humans require that this set of basic needs be fulfilled, and when left unmet, will pursue any means possible for which to satisfy these needs.

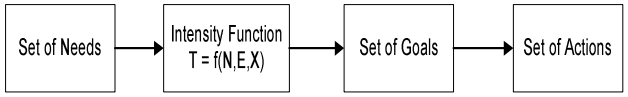


Figure 1. Process diagram for drive controlled behavior, adapted from Schmidt [8].

Previously, the PECS framework was successfully implemented in Malleson, Heppenstell, and See's agent-based model of residential burglary. Their model simulates the occurrence of crime in a hypothetical city and successfully tests the impact of various crime theories [9]. Other agent-based models developed to explore criminal phenomena include Berger, Borenstein, and Neto's model, which studies criminal behavior by utilizing car theft data from a city in Brazil [10], and Markowsky's Crime and Mortality Simulation (CASIM), which models agent decisions through the use of a career maximization function [11]. All these models tackle difficult problems in understanding and analyzing criminal behavior, however, none study crime at the organizational level.

III. Model Development

A. State Variables and Scales

The model is implemented in AnyLogic University 6.4.1 [12]. It contains five hierarchical levels: resident (individual), household, employer, neighborhood, and state. Of these, two are modeled as agents. The first are residents, which are characterized based on their age, gender, death age, education level, individual need level, family, and neighborhood in which they reside. Individuals are connected to other residents within a specified distance to create a "family," which defines a household unit. Household income is the sum of each resident's income within a family.

The other type of agent is the employer. Employers are characterized by the salary range they provide their employees, the minimum hiring qualifications, their maximum staff size, their overall employer wealth, their type (e.g. construction, domestic services, manufacturing), and the neighborhood in which they reside. Employer type is further categorized based on whether it is formal or informal. For purposes of the model, criminal organizations are informal while all other employers are considered formal.

The modeling world consists of two neighborhoods: a high-income neighborhood (Ipanema) and a low-income neighborhood (Cantagalo). This area was chosen because of data availability and geography. Cantagalo is the only favela which sits adjacent to one of Rio's most prominent neighborhoods, Ipanema, while to the north, is a lake and to the south is the Atlantic Ocean. The neighborhoods are represented as polygons with a continuous surface. Neighborhoods are characterized by their need level, terrain, and the age, gender and education level distribution of its residents.

Within the model, state consists of the entire modeling world. Basic services, rights, and security provided by the "state" in the model are meant to replicate what the city of Rio of Janeiro would provide to the neighborhoods of Ipanema and Cantagalo. The level of basic human needs provided by the state varies across the two neighborhoods.

B. Resident Behavior

While Human Needs Theory provides the model's theoretical foundation, the PECS component related to reactive drive-controlled behavior directs the behavior of resident agents in the model. Figure 2 illustrates the framework used in the model.

1) Set of Needs: The main input which drives agents' behavior in the model are Burton's basic human needs [3]. The model further breaks-out basic needs at the state,

neighborhood, and individual-level. A resident's total level of security, recognition, and identity are comprised of state-level, neighborhood-level, and individual-level components. State level needs range from zero to one and are held constant throughout the simulation run. Neighborhood and individual- level needs, on the other hand, initiate at zero and update annually based on changes in the environment or individual attributes.

State-level needs are set at values to best represent the situation of each neighborhood. There is much literature on the denial of basic services, basic rights, and protection of those residents of Rio's many favelas [4], [6], [13], [14]. Therefore, the level for which the state provides these needs is minimal. In Rio's high income neighborhoods, on the other hand, residents receive basic rights and services. A corrupt police force and many residents' decision to opt for individual security, however, places the level of security Ipanema receives from the state below what is required to satisfy that need.

The source of changes in neighborhood-level needs is the presence of gangs or recruits. Gangs will fill the role of the state by providing residents protection, basic services, and basic rights. On the other hand, if only recruits exist in a neighborhood and there is no formal organized "network," security decreases as crime increases. There is no impact to neighborhood-level recognition or identity when recruits are present, as recruits would not "take away" current services or rights nor would they provide such services or rights. Note that we are making the simplifying assumption that other organizations, such as neighborhood associations or non-governmental associations, would not help fill the void. There is the underlying assumption that collective action, such as that which formed the Red Command from Rio's prisons [4], has ensued and the right resources are available.

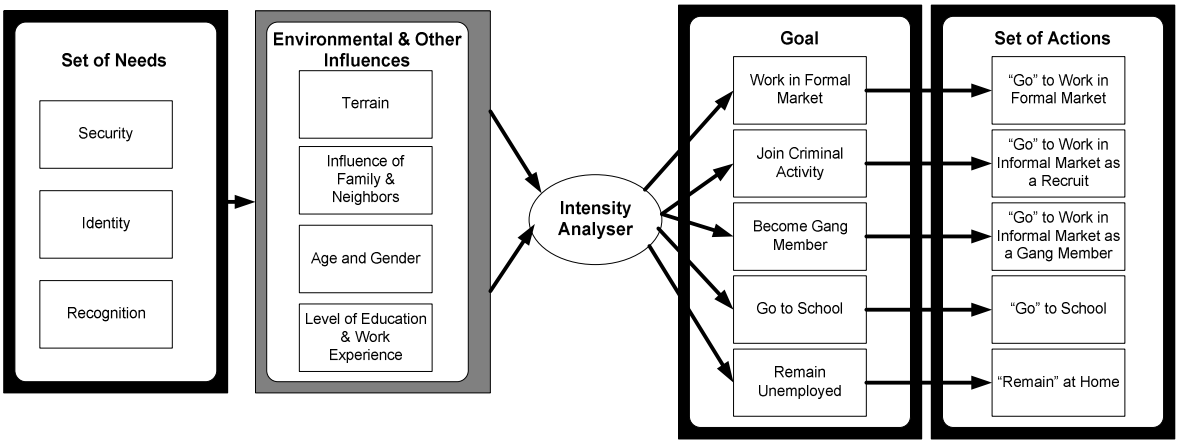


Figure 2. Resident needs, environment factors, and individual attributes and how their intensities drive resident's behavior, adapted from Schmidt [8].

Changes in individual-level needs are a function of income, employment, and education. For those residents not involved in criminal activity, security level increases with household income. We assume that with increased income and unsatisfied security by the state or neighborhood, a household may choose to purchase a gun, to add a security system or fence around their home, or to hire a guard to watch the house. The higher the household's income, the more security a family can "purchase." For recruits and gang members, on the other hand, changes in security-level are on an individual basis. This is because it is said that many of those who join the drug trade do so because they have been estranged from their families and often see the idea of having a gun as a source of protection. Since recruits are often those performing "front-line" criminal operations, they are also the ones in most danger of being imprisoned or killed [14]. Because of this, their individual security-level will peak only at 0.5, while gang members who can remain "hidden" will have security levels which start at 0.5 and can reach 1.0. Individual-level recognition is based on a resident's sense of "appreciation" or "value" in his or her role in society. For a resident employed in the formal market, recognition will increase with increases in his or her salary; simulating a raise or promotion. Students, on the other hand, gain recognition with increased years of education. A recognition level of one is attained if a student completes 16 years of education (12 years of grade school plus 4 years of college). Because recruits join the drug trade with the hope of having more powerful roles within a gang [14], there recognition will only peak at 0.5. Gang members recognition levels will begin at 0.5 and can reach 1.0. Recruits and gang member's recognition will increase with increased salary. Individual-level identity is based on a resident's feeling of belonging to a group. In this model, residents either feel as if they belong to a group or do not, thus individual-level identity is either zero or one. If a resident is unemployed, he or she will have an individual identity-level of zero, otherwise, he or she will have an identity-level of one.

2) Environmental and Other Influences: In addition to human needs, environmental factors and other influences will help drive agents' behavior. Environmental factors include the neighborhood's terrain and other factors include influence of family and neighbors and individual traits such as age, gender, and education.

Neighborhood terrain is a value ranging from zero to one (zero indicates a very flat terrain and one means a very steep terrain). The Ipanema's terrain is randomly generated from a

range between 0.0 and 0.2 and Cantagalo's is between 0.5 and 1.0. Residents are influenced by their family and other residents in their neighborhood. Residents with family members who are recruits or gang members are more likely to join criminal activity. Age and gender can also affect a resident's propensity to join criminal activity, with young males being the most susceptible. Education level can impact a resident's ability to find employment and the salary range for which they are eligible to receive.

3) Intensity Analyzer and Goals: The intensity analyzer evaluates the resident's current level of needs, the environment, and other influences to determine what goal the resident should pursue. The intensity analyzer was implemented in the model via a set of submodels, which are described here. The output of the submodels drives the resident's goal and consequently, their actions, in the model. Note that "goals" in this framework are not necessarily the "desire" of an individual but an automatic reaction to the needs and influences facing the individual.

a) Evaluate Propensity to go to School: All residents 22 years of age or younger are evaluated for their propensity to attend school. The number of years a resident is likely to attend school is predetermined at initialization of the model. Residents between ages 18 and 22 that are attending school are said to be earning college degrees. After 22, residents must leave school and search for employment.

b) Search for Employment: In order to become an "employee," a resident must first search for employment. A resident will search for employment if his/her predetermined education level has been met or the resident is more than 22 years old. A resident randomly selects an employer in the formal market which is hiring (an employer is hiring if its staff size has not reached capacity) and the resident's education level is evaluated against the employer's required education. If the resident does not meet the qualifications, the resident selects another hiring employer and performs the same evaluation. A resident continues searching for employment until he/she finds an employer which will hire him/her or the resident's search capacity has been reached. If a resident reaches its search capacity, the resident either remains unemployed or becomes a recruit. A resident's decision to become a recruit is based on its propensity to join criminal activity.

c) Evaluate Propensity to Join Criminal Activity: A resident's propensity to join criminal activity is based on his/her age, gender, and influence from family. Propensity ranges from zero to one. For example, a male between the ages of 15 and 25 with family members who are gang members will have the highest propensity to join criminal activity [4], [14]. This propensity is evaluated against its current need level. If gang members are currently present and the resident's propensity is greater than its current need level, the resident will become a recruit. If no gang members are present, the resident must be at least 18 years old to become a recruit. Otherwise, the resident will remain unemployed.

d) Evaluate Ability to Become a Gang Member: All recruits are evaluated for their ability to become gang members. This ability is dependent on time spent as a recruit and the neighborhood's terrain [4]. The resident must be a recruit for at least one year and the terrain must be "steep" (range between 0.5 and 1.0), although a small chance (5%) exists that a recruit can become a gang member in a neighborhood with flat terrain.

4) Set of Actions: Actions are implicit in the model in that agents do not "physically" go to work or go to school. However, resident's employed do earn an income, get raises, and can be "laid off," students add to their level of education as they remain in school, and recruits and gang members see increased income as they remain in their roles. Once the intensity analyzer has determined the goal for which an agent will pursue, the agent's state in the model will change to reflect the corresponding action. Residents can enter one of five states: unemployed, student, employee, recruit, or gang member. Each resident state represents the goal, and thus action, for which a resident pursues. The process diagram for residents is illustrated in the appendix.

Time in the model is continuous with events occurring on a monthly and annual basis. On a monthly basis a resident's household income is evaluated. Those events occurring annually include, residents ageing, dying, evaluation of needs and thus their goals.

C. Employer Behavior

Once a year, employers will "remove" an employee with the lowest salary and will replace them with a new employee. If all employers have reached their hiring capacity, the removal of an employee provides other residents with the opportunity to gain employment. It also provides a feedback loop for those employees which are removed. Once removed from an employer, that resident becomes unemployed. If they cannot find employment, their propensity to join criminal activity is evaluated.

D. Model Initialization

At initialization, the population size, the number of employers, and the type of neighborhood (low-income or high-income) are defined. Each neighborhood is represented by a polygon drawn onto an image of the model area. Residents and employers are randomly placed within the neighborhood for which they reside. Residents then "connect" to all agents nearby (within a specified distance) to form a "family." At model instantiation, all residents are unemployed and have no income. Their search energies are set to ten, meaning that individuals will search up to 10 employers for a job before "giving up." Hiring companies in a neighborhood are simply those employers who have not reached their maximum staff size of 10. State-level needs are set to the default for the two neighborhoods. Neighborhood and individual-level need values are set to zero.

Census data from Brazil's Institute of Geography and Statistics (IBGE) provided population data at each neighborhood by age, gender, and education level. It also provided city-level mortality data by gender, while the Children and Youth in Organized Armed Violence (COAV) provided additional statistics on mortality rates for gang members. According to 2009 data from the IBGE, there are seven types of employers in the formal market. Employer type determines the salary range for which an employer can provide its employees and the minimum qualification (in terms of years of education) required for employment. Informal employers (i.e. the drug trade) require no qualifications. Age, education level, mortality rate, and employer type are distributed according to probability density functions (PDF) developed from the empirical data described.

IV. Results and Findings

Three sets of experiments were performed: (1) a control experiment, (2) an experiment which adjusts the state-level needs of Ipanema to match that of Cantagalo, and (3) an experiment which adjusts the state-level needs of Cantagalo to match that of Ipanema. Table 1 details the initial parameters used in the three experiments. Each experiment was run 10 times and each run was set for 100 years. Should any major changes in population dynamics occur, the time frame and number of runs is extensive enough to allow for the occurrence of any anomalies. For purposes of validation, spatial population dynamics were observed with changes in state-level settings. Also, individual residents and employers were observed to ensure they were "behaving" as expected (e.g. aging, dying).

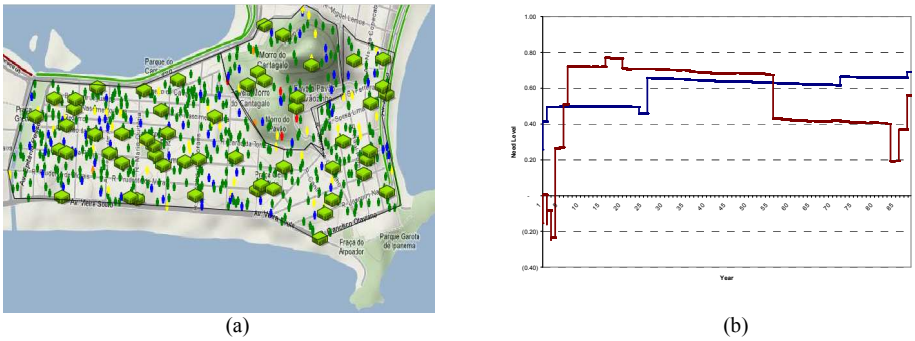
A. Control Experiment

The control experiment is set as to best represent the actual neighborhoods being modeled. All parameters and variables are initiated as discussed in the previous section. Image 1 shows a typical run of the model, where blue residents are unemployed, green residents are employed, yellow residents are students, orange residents are recruits, and red residents are gang members. The green buildings are employers. As expected, most of the recruits and gang members reside in Cantagalo, where state-level needs are most deficient.

As seen in Figure 3, residents in Cantagalo begin to fill the void left by the state, we find that the average total need level of residents in Cantagalo (brown line) eventually surpasses that of a resident in Ipanema (blue line). Initially, the average need level of a resident in Cantagalo is near zero. However, as those residents who cannot find employment or attend school begin turning to the drug trade, we find that need dips below zero. Remember that the presence of recruits in a neighborhood reduces the neighborhood-level security, thus reducing the total need level of a resident. As recruits organize, gang presence increases resident's security, recognition, and identity levels. It is interesting to note the steady increase in need level of the average resident in Ipanema while the average resident in Cantagalo will experience more fluctuations, possibly due to gangs dying off and new gangs later forming.

TABLE I. Specifications for the Three Experiments

	Security		Identity		Recognition	
Experiment	Ipanema	Cantagalo	Ipanema	Cantagalo	Ipanema	Cantagalo
1 Control	0.5	0.01	1	0.01	1	0.01
2 Adjust Ipanema state-level needs	0.01	0.01	0.01	0.01	0.01	0.01
3 Adjust Cantagalo state-level needs	0.5	0.5	1	1	1	1



(a) (b)

Figure 3. Run results of control experiment: (a) typical run result and (b) average total need level over 10 runs.

B. Experiment 2: Adjust Ipanema's State-level Needs

In this experiment, Ipanema's state-level needs are set to equal Cantagalo's from the Control Experiment. Image 2 shows a typical run. When compared to the image from the Control Experiment, we find that there are more gang members in Ipanema and Cantagalo. The increase in gang activity in Cantagalo due to the change made to Ipanema's state-level needs was not expected. However, immediate neighbors are not restricted to those residents in the same neighborhood. For instance, Cantagalo residents living nearest to Ipanema may have "friends" living in Ipanema. Thus, an increase in gang activity in Ipanema could "spill over" to Cantagalo.

Comparing Ipanema's need levels for the Control Experiment against this experiment, we find that by year 30,

the average need level is greater in this experiment (even though state-level needs begins lower). In the Control Experiment, Ipanema's state-level security is 0.5 and with little to no gang activity, neighborhood security will not change. In this experiment, however, as gang activity begins to emerge, gangs will fill the void left by the state. Thus, total need levels for residents in Ipanema will increase.

C. *Experiment 3: Adjust Cantagalo's State-level Needs*

Setting Cantagalo's state-level needs to match Ipanema's from the Control Experiment, we're simulating an environment where the state is providing the entire area with basic services, basic rights, and a certain amount of protection. Here we find that no recruits or gang members emerge in any of the 10 runs across the 100 years. Image 3 illustrates a typical run using these settings. Also, note that Ipanema's state-level needs are the same as the in the Control Experiment. But unlike the Control Experiment, no criminal activity emerges. This is because we will not see a "spill over" effect. Therefore, any gang activity present in Ipanama in the Control Experiment was most likely due to spill over from Cantagalo. We find that instead of joining criminal activities, more residents remain unemployed, remain in school, or find employment. The average need level for resident's in both communities remains fairly constant throughout the run and both neighborhoods show similar need levels for their residents.

D. *Comparison of Runs*

Table 2 provides the distribution of residents across the three experiments. Gang presence is greatest in Experiment 2, where Ipanema's state-level needs were reduced to match that of Cantagalo, and is non-existent in Experiment 3, where Cantagalo's state-level needs were increased to match that of Ipanema. With no criminal activity in either neighborhood, more residents go to school, become employed, or remain unemployed. In Experiment 3, the proportion of employed in Cantagalo is actually higher than that in Ipanema. This is because residents in Ipanema are more likely to pursue higher education.

TABLE II. DISTRIBUTION OF POPULATION BY RESIDENT STATE ACROSS THE THREE EXPERIMENTS

	Control Experiment		Experiment 1		Experiment 2	
Resident State	Cantagalo	Ipanema	Cantagalo	Ipanema	Cantagalo	Ipanema
unemployed	6.9%	7.1%	7.0%	7.2%	9.4%	8.4%
student	9.4%	12.4%	8.3%	10.8%	10.4%	14.5%
recruit	0.2%	0.0%	0.4%	0.5%	0.0%	0.0%
gangMember	5.5%	0.3%	10.6%	8.1%	0.0%	0.0%
employee	77.9%	80.2%	73.7%	73.5%	80.4%	77.5%
TOTAL	100%	100%	100%	100%	100%	100%

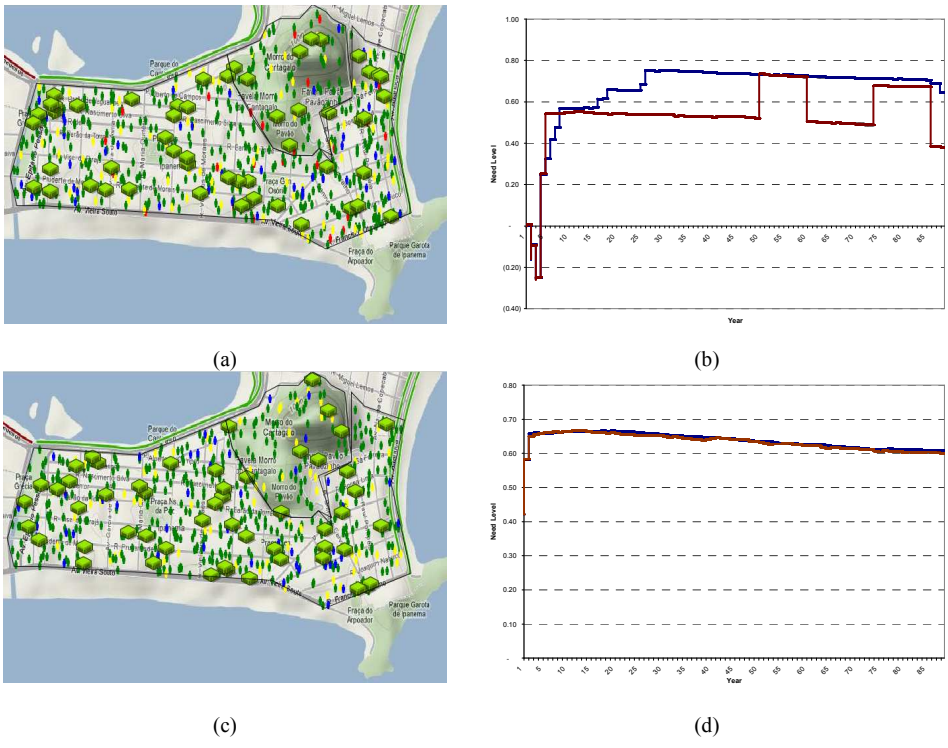


Figure 4. Run results for Experiments 2 and 3: (a) typical run result of Experiment 2, (b) average total need level of Experiment 2 over 10 runs, (c) typical run result of Experiment 3, (d) aedrage total need level of Experiment 3.

V. Conclusion

The ABM presented provides an initial attempt at modeling the emergence of organized crime using empirical data from two neighborhoods in Rio de Janeiro. With additional data collection, research, and extensions to the current model, this type of model could provide policy makers with a tool to implement and drive policy.

Modeling an individual's choice to join criminal activity is not simple. The reason a person turns to crime can include such factors as influence from family and neighbors, the environment in which they live, and their individual traits. This model, through the use of the PECS framework and Human Needs Theory, provides an initial attempt at encompassing those factors which appear to be most relevant based on the literature.

According to John Burton, "conflict resolution means getting to the roots of problems and resolving them in ways that further the longer-term goals of all concerned [15]." Prevention requires policies that anticipate responses and avoid conflict. The PECS framework combined with agent-based modeling provide powerful tools for which we can potentially anticipate the onset of conflict, and thereby, prevent it. By "re-creating" the current environment of a neighborhood, we have the ability to potentially predict the onset of violence where it does not yet exist or understand the source of conflict for those areas already in the midst of conflict. This would give policy makers the ability to implement policy that would focus on those causal mechanisms underlying the conflict.

The model assumes that in the absence of basic needs at the state-level, criminals are the only organization that may fill the void at the neighborhood-level. In reality, however, neighborhood associations, non-governmental organizations, or other non-profits may also play a role. In many of Rio's favelas today, neighborhood associations work with the local gangs to establish basic services and maintain order and security of its residents. While politicians work with neighborhood associations (knowing their relationship to powerful local gangs) seeking votes in exchange for a service. Local police will also take bribes from gangs and in exchange will allow traffickers to do their "job" [4]. Without these networks, gangs would not have the support, strength, and legitimacy that they have today [4]. Adding this type of underlying network to the model is an important next step.

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Appendix: Resident's Process Overview

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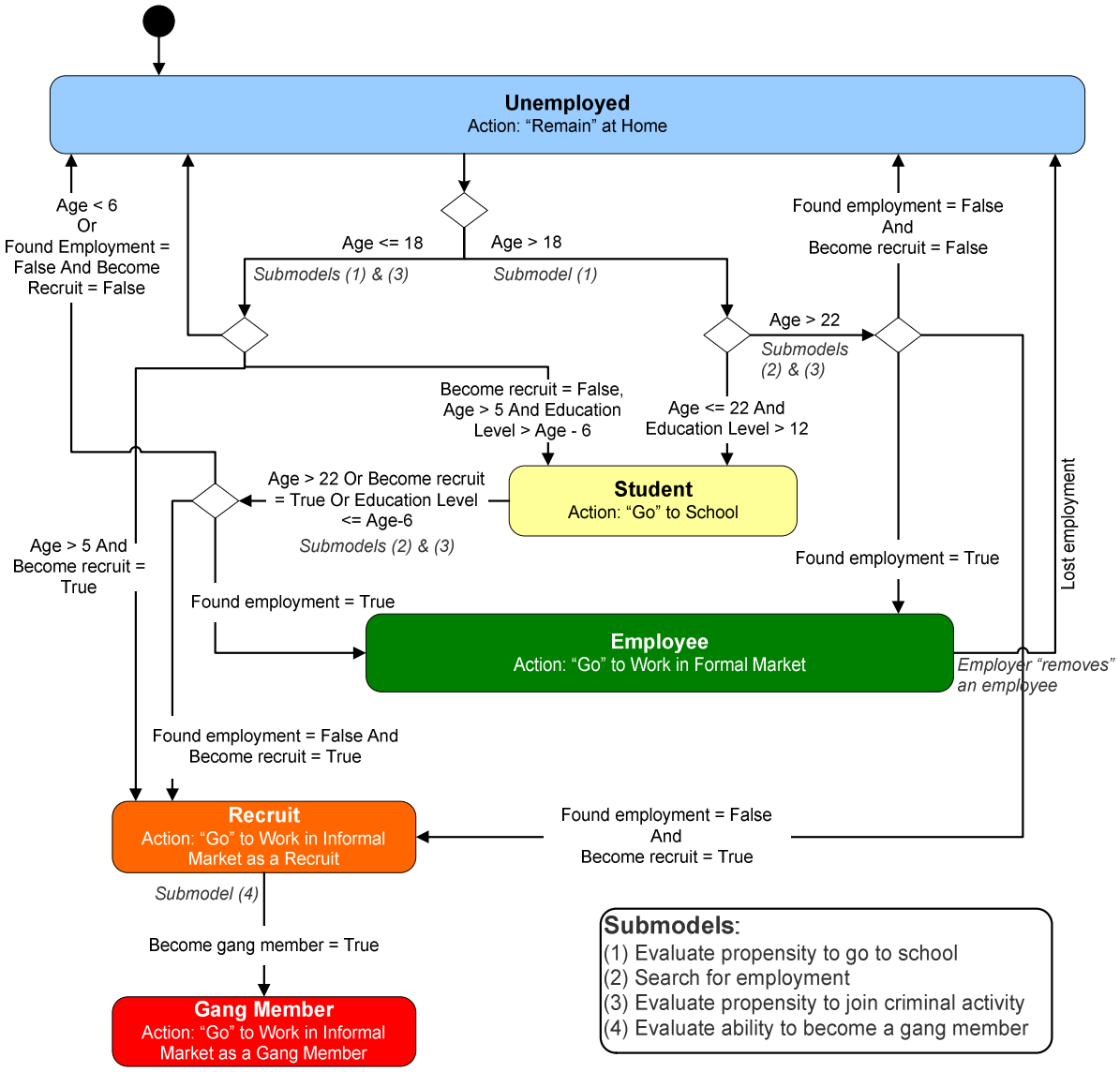

Figure 5. Resident's process overview.