AGENT-BASED MODEL OF CRIMINAL GANG FORMATION

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ABSTRACT

Criminal gangs are of major concern at both the local and international levels. Understanding how gangs form and how they impact society is of interest to criminology. This paper presents an Agent-based Model (ABM) to help in developing a theory on how gangs impact society as a whole. The agents live in a social space and are able climb the social hierarchy and gain resources through service. Criminals steal resources from the weak. The results produced two extreme outputs; either all became alternating criminals or all formed a utopia of non-criminals. The extreme results are also seen in the distribution of agents which were either completely spread or all centralized. In either case, all agents prospered at the same rate which we believe is a consequence of any agent to join the criminal gang in the model.

Keywords: agent-based modeling and simulation, criminology, group formation, team assembly, gang formation.

1 INTRODUCTION

Criminals have an impact on society as a whole. A single criminal acting alone will have a limited impact but a gang of criminals can have a more significant impact, from international human smuggler gangs to business extortion. It is difficult to pinpoint the exact impact that criminal gangs have on our complex society, but better understanding how these gangs form is a significant first step. Agent-based modeling and simulation (ABMS) has been advocated as a tool for helping the researcher form theories (Poile and Safayeni 2016). In this paper we develop a conceptual model for existing criminology literature and use it to develop an ABMS to explore the impact and formation of criminal gangs.

The next section discusses the literature background to the gang formation problem. This is followed by a discussion on model conception then model itself. Results and conclusions are given last.

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2 BACKGROUND

Since the emergence of the study of crime, criminologists have been particularly focused on street crime. Often, the study of street crime has naturally rolled into a study of street gangs. Many criminologists who study street gangs in America have structured their study largely around the continued understanding of gang formation, and the role that the formation and structure of the gangs plays in the subsequent violence and criminal activity. This study utilizes agent based modeling to attempt to shed more light on the understanding of group formation, specifically criminal gang formation.

The science of criminology has traditionally rested on a foundation of statistics analysis and qualitative observations. The emergence of the field of modeling and simulation however has presented criminologists and other social scientists with the opportunity to expand our methods of analysis. This new marriage of the fields of criminology and modeling and simulation have produced some very interesting and very relevant studies that have furthered our understanding of many crime topics (see for example: Malleson, Heppenstall, and See (2010), Groff (2007), Epstein (2002), Lim, Metzler, and Bar-Yam (2007)).

These ABM-criminology studies have started to demonstrate a number of themes and approaches as well. Generally speaking, the current applications of agent-based modeling to crime take the form of actual crime based simulations, that is, an agent is on a grid that is supposed to represent that agent's neighborhood or reality. Agents encounter other agents and either engage in crime or don't as they go about some preset motion though the grid. A second theme of the agent-based modeling and crime literature is more of an abstract representation of larger society and the occurrences of crime on a larger scale within that simulated society. These two approaches to modeling crime issues are simulating different models of crime at different levels of resolution. For the purpose of this project, the abstractness of the latter type is more appropriate for modeling street gang formation in that it is not the individual instances of violence that are of interest, but how the larger theme of violence, other criminal acts, and other relevant group processes enact to result in the formation of groups of street gangs.

2.1 The Criminology of Street Gangs

In an early gang study, Thrasher (1927) observed the formation of groups engaging in collective criminal behavior in urban Chicago. According to the word, "group" is essential to, and included in, any sociological or criminological definition of gangs. Therefore, understanding how these groups form, and what holds them together, and utilizing ABM to do so, becomes an integral part of furthering the understanding of street gangs as a whole and represents a relevant contribution to the gang literature.

The most central theme unifying members of a street gang is violence; either actual violence, or the perceived threat thereof (see for example: Klein (1971), Suttles (1972), Katz and Quade (1989), Sullivan (1989), Loftin (1986)). It is the threat of violence, or the "dread" (Katz and Quade 1989) that then becomes the all-encompassing theme of gang life. Much of street gang behavior revolves around either thwarting an attack from a rival gang, or utilizing violence on others in order to achieve a criminal goal of some sort. Suttles (1972) suggests that it is in fact the level of perceived violence within a neighborhood that is directly responsible for the formation and growth of a street gang. It would appear then that, "victimization at the hands of other gang members, community residents, or family members drove [individuals] to join a local gang in hopes that this group would reduce the probability of victimization" (Melde, Taylor, and Esbensen 2009, 566).

Melde, Taylor, and Esbensen (2009) suggest that as violence (or threat of) was necessary in order for the groups of street gangs to form, a continuation of the previewed violence or threat thereof needs to occur in order for the gang to continue in existence and for other gangs to also form. A splintering off from the original criminal group and the formation of new criminal groups is directly attributable to the perceived level of violence. The group then serves as both protection, social power (social capital) and strength for the individual. As the perceived level of violence, the perceived need for social power, and the perceived competition over available goods and services (both legitimate and not) rises, the gang grows or new gangs form leading to an increased contagion effect.

Loftin (1986) describes the term, "contagion" as the resulting retaliatory violence occurring in response to an initial act of violence perpetrated by one gang against another. As the instances of violence increase, perception of the violence in a given territory increases and gang formation and growth increases. In this effect, as the gangs become a stable presence, normative behaviors such as language, rituals and cultural indicators also emerge to support this pervasive violence and contagion violence theme. Further, Sanchez-Jankowski (1991) suggests that the groups themselves are highly organized around this violence theme and have well established rules, social hierarchy roles, crime related goals, and the means and methods of teaching crime behaviors and tactics to other members.

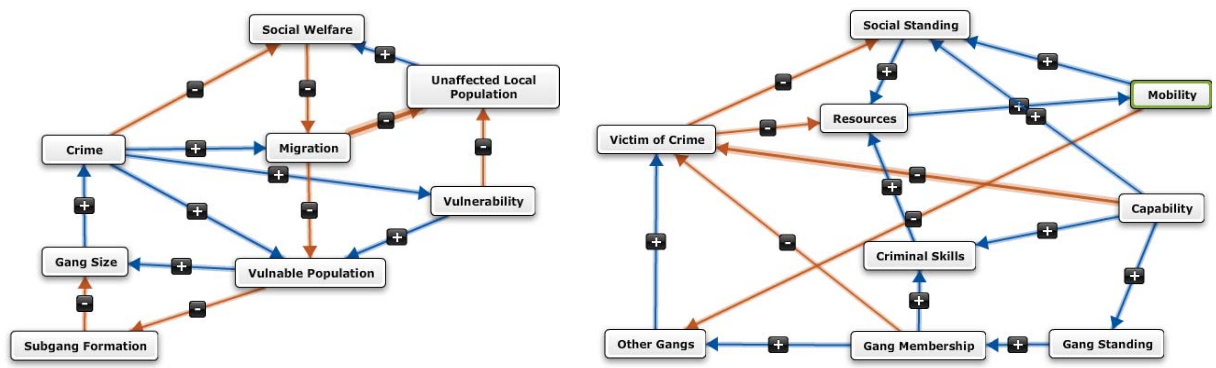
It is in the structure of the gangs, or the basic group processes, that the mutually beneficial relationship of the gang to the individual is revealed. Maxson and Esbensen (2012) state the it is a combination of a normative orientation towards criminal behavior and the prospective of status attainment within the group that explain the question of why an individual would join a gang. While violence may be the overwhelming theme of gang life and therefore gang group formation, it is the idea that the individual will be able to further their criminal behaviors, be protected from other violence, and gain access to contested resources that most contributes to gang group formation.

3 MODEL CONCEPTION

For the current study, conceptual models were constructed to gain some insight into the problem of understanding how gang formation impacts society. Cognitive mapping was used to construct these conceptual models, which is shown in Figure 1. Cognitive Mapping is a process of connecting concepts by how they influence each other (either negatively or positively). It was developed as part of the SODA problem structuring method (Eden 2001).

The intent of this research was to construct a simulation to gain some emergent insight into the problem of understanding how gang formation impacts society. Emergent behavior is one expected outcome of an agent-based model (Gilbert 2007) so this seemed an appropriate modeling paradigm to use. Emergent behavior, in our context, is when the actions of the agents collectively combined to form some, usually unexpected, outcome at the societal level. The tragedy of the commons is an example of emergent behavior (Hardin 1968). To observe emergent behavior, the analyst must have some concept of the individual agents and society as a whole, in the context of the problem.

We decided to construct two different cognitive maps of the problem space. The first was from the societal perspective, at the macro-level, and the second was from the agents' perspective, at the micro-level. The reason for doing this was ensure that we had a basic understanding of the system at both perspectives so we were able to understand how they might be linked if any emergent behavior was found from the results. As Epstein (2007) points out, the language used to describe the micro and macro perspectives might be quite different and making it not obvious how they relate; as such, we try and keep the language as similar as possible in our two conceptual diagrams.



(a) (b)

Figure 1: Cognitive maps of the impacts of criminal gang formation at the (a) macro level and (b) micro or agent level

4 MODEL

Using these conceptual models, shown in Figure 1, as a baseline, the model was constructed. The model is based on a simple representation of a service-based society, where agents generate resources from interactions with each other. For example, a cleaner might provide services to a lawyer and that lawyer might provide legal services for the cleaner. The amount of resources the agent generates for themselves is proportional to the resources of the agent that they interact with. Thus the total resources in the system are always increasing. Criminals are not offering a services and actually take resources from their victims. Agents will migrate to get away from criminals and/or go to richer areas. Their ability to migrate will depend on the resources they have available.

4.1 Environment, Movement, and Resource Collection

A 2-D gird projection is used to represent the agent's environment. Conceptually, this environment is a combination of both physical space and social space. Thus a rich agent is able to buy a house in a upper-class neighborhood as well as gain access to exclusive country clubs. A poorer agent might live in the same area but does not accesses to these exclusive areas.

The agents are assumed to always be navigating towards areas which contain lots of richer agents and also contain low crime rates. This is done by looking at a random grid square, within their possible movement radius (minimum one), and moving towards it if average agent resources minus the criminal activity is greater than the agent's current area. Criminal activity is determined by number of gang members is an area. The formula for a ranking of grid spaces is:

$$A_{ij} = 0.001 v_{ij} P_{ij}(noncriminals) - 0.1\frac{P_{ij}(capable\ criminals)}{P_{ij}(noncriminals)}$$

The attractiveness of location (i,j) is A_{ij}. This is determined by two factors: resources available and the chance of crime. The resources available is equal to average value of the non-criminal population, v_{ij}, multipled by the number of non-criminals there, $P_{ij}(noncriminals)$. We multiple this number by the growth rate, 0.001, since the agents will get 0.001 v_{ij} each time-step (based on their current location). The chance of crime is approximately calculated by dividing the number of capable criminals by the potential victims. We multiply this by the *crime amount*, 0.1, which is the amount of resources we assume a criminal takes during a crime. Criminals use the same formula because if prosperous for non-criminals it will be prosperous for criminals.

Movement reflects an agents ability to leave an undesirable area. This is their ability to sell their house in the undesirable area and/or leave employment in it too. Thus the scale for each time-step is several months. It is assumed that an agent with high resources is able to move faster than those with low resources. For example, a person with savings and contacts is likely to be able to save the relocation costs at a faster than someone living paycheck to paycheck. The movement radius of an agent is half its current value. For example, on a 11 x 11 grid an agent of value 20 could reach anywhere in the gird.

4.2 Gangs and Crime

Criminal activity is determined using a concept of conflict from Epstein and Axtell's Growing Artificial Societies (Epstein and Axtell 1996). In the model, the criminal randomly picks a victim and steal some of their resources, assuming there is no more capable non-criminals to defend the victim at that location. If there are more capable non-criminals then the criminal cannot committee a crime. Hence, a capable criminal is one which has a capability greater than all the non-criminals. The capability of an agent is determined randomly using a standard uniform distribution when they are spawned. In later versions of the model, we might allow agents to change their capability based on either their resources (e.g., ability to purchase crime prevent devices) and/or length of time in a gang (e.g., increase in criminal skills).

Unlike non-criminal interactions, the criminals actually take the resources from their victims (so no new resources are generated). The amount stolen is 0.1. If the victim does not have 0.1 resources, then all their resources are stolen.

4.2.1 Gang Formation

In this version of the model, we assume that there are only one gang. We run two versions of the model: one where all the criminals are in a gang and one where there are no gangs. Mechanically, when there are no gangs, criminals are able to victimize other less-capable criminals.

We also assume that the decision to become a gang member or leave a gang is entirely up to the agent. In later iteration of the model, the gang will be involved in this decision. Criminals might stop being gang members if they do not get any more benefit from it (e.g., surrounded by more capable agents). The decision to be become or remain a criminal was determined by the amount of non-criminals around (to influence the agent positively). We assume that the influence factor is equal to the growth factor. Note that only non-criminals get service income each round. The logical formula for becoming a criminal is:

$$0.0001(1-\lambda)P_{ij}(noncriminals) < 0.1\lambda$$

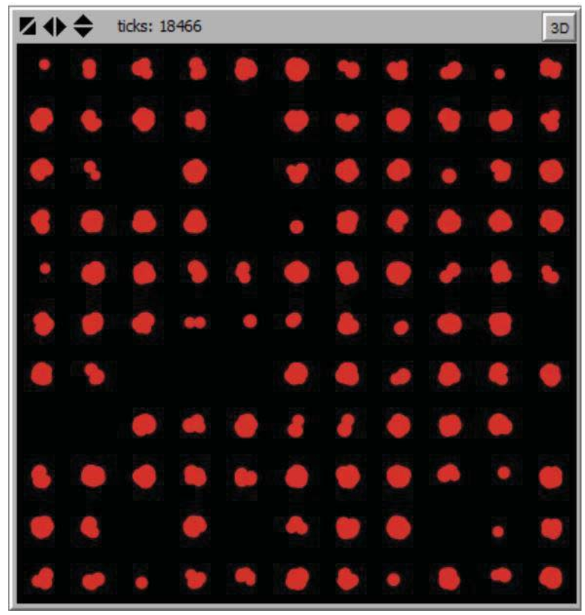
The *decision weighting factor* was λ. If no non-criminals are at the agent's location, we assume that they convert to non-criminals as there are no victims to steal from.

5 RESULTS

The simulation was constructed in the NetLogo software package(Wilensky 1999). The main decision variable used was the decision weighting factor, λ, which we varied from 0 to 1. Since the simulation contains stochastic elements (e.g., movement), each parameter set was repeated 100 times. The simulation has 1000 agents. The simulations were run until at least one agent had a value of 10,000.

Example output from the simulation can be found in Figure 2. All agents are represented as a circle and the size of the circle represents the agents' capability. Grey agents are non-criminals and red agents are criminals. When the agents have no incentive to become a criminal (i.e., a decision weight factor of zero) then the all cluster onto a single grid space as shown in Figure 2 (a). When the agents have a high incentive to become a criminal (i.e., a decision weight factor of one) then they do and they spread out, as seen in Figure 2 (b). Note that when every agent becomes a criminal then the next time-step they would all stop being criminals (as there are no victims). This means that they ae likely to alternate between being a criminal and a non-criminal.

(a)



(b)

Figure 2: Screenshots from our NetLogo model when the decision weighting factor, λ, factor was set to (a) zero and (b) one.

We focus on the simulation results based on the final mean agent value and the time-steps required to reach to finish the simulation.

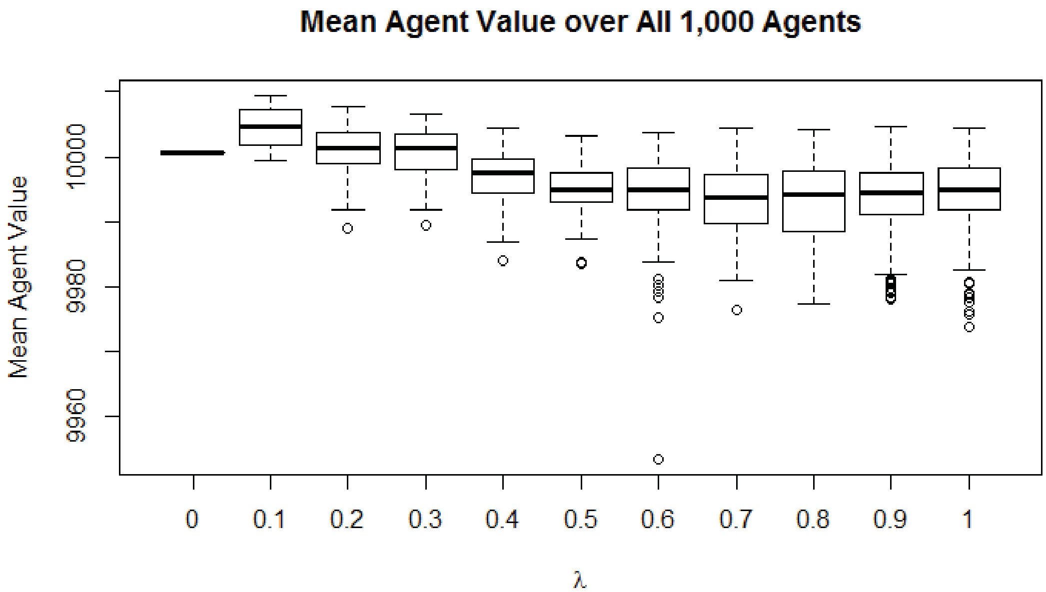


Figure 3: Cutoff boxplot of the mean value of the agents at the end of a run.

The final mean value of the agents was collected and is shown in the cutoff boxplot in Figure 3. What these results show is that all agents have an approximate wealth of 10,000. We know this because the maximum agent value is approximately 10,000 (as this is the stopping condition of the simulation) so the minimum must be pretty close to this value to get a mean around 10,000. This occurs in the non-criminal outcome case because all the agents join together and growth together (note that all agents start with a value of one). It occurs in the criminal outcome case because all the agents become criminals which results in them simultaneously alternating between criminal and non-criminal states. You might expect a larger spread of value (wealth) when criminals are present but because any agent is able to join the gang anytime, they can stop any victimization of themselves by joining. The growth in the agents' value was exponential during the runs.

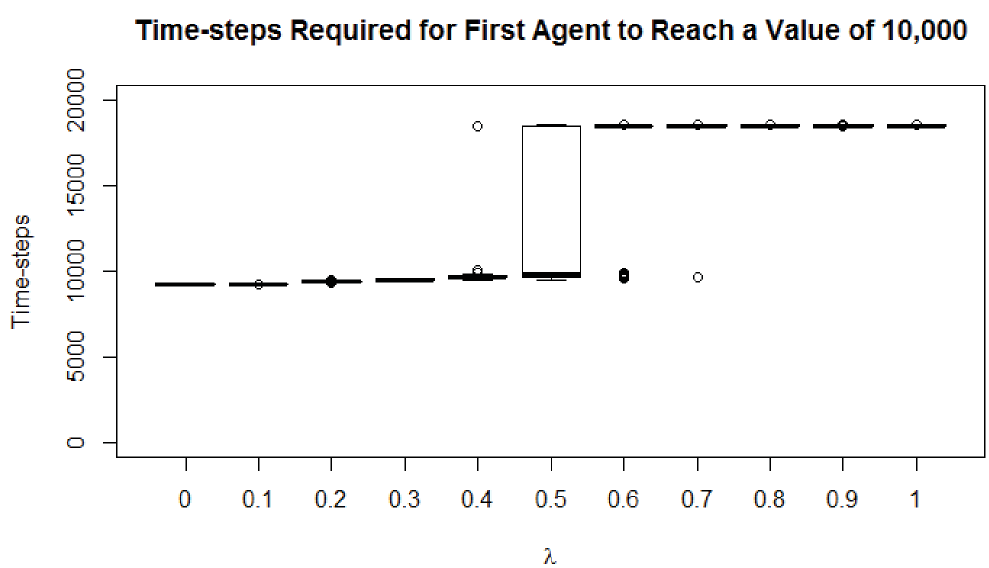


Figure 4: Boxplot graph of time-steps required to reach the simulation terminal state.

Given the two possible outcomes of the simulation (all coming together or alternating criminal), the next question to ask is: when do they happen. Figure 4 gives insight into this, as we would expect the alternating criminal behavior to take at least double as long as the collaborative approach. We expect at least a doubling because the when the agents are all criminals they get no resources that time-step (as there are no victims available). From the figure we see a clear split of the two outcomes. If the decision weighting factor is less than 0.5 then the agents collaborate and if it is greater they become alternating criminals.

Table 1: Pearson's correlation statistics

	Lambda	Time-steps	Mean City Size	Number of Cities	Criminals
Time-steps	0.86	-	-	-	-
Mean City Size	-0.85	-1	-	-	-
Number of Cities	0.85	1	-1	-	-
Criminals	0.84	1	1	1	-
Mean Value	-0.55	-0.52	0.51	-0.51	-0.49

* All significant at 99% level

Other outputs were collected and their correlation statistics are shown in Table **1**. We use the term "cities" to refer to clusters of agents at a grid space. Some of the results are self-explanatory, for example, since there is a fixed number of agents, the number of cities is obviously negatively correlated to the average city size (less cities means larger cities). The correlations of the mean agent value are weak but this is as expected as the mean values are so close to 10,000.

5.1 Impact of No Gang

The original runs did not allow criminals to commit a crime on other criminals. It was assumed that they were all in the same gang and that gang members were immune from victimization. The set of batch runs was completed again but, this time criminals were allowed to commit crimes on other criminals. The results indicated that there were no real impacts on the number of time-steps to completion or the mean agent value. The correlation to the output variables was 0.01.

This lack of impact was due to the limited impact of criminal-on-criminal activity had on either of the two outcomes. If the scenario runs when all the agents acted collaboratively there were very few criminals thus the chance of criminal-on-criminal activity was very small. In the alternating state outputs, the criminal agents would still become non-criminals when there was no non-criminals around as other criminal numbers were not part of this decision. Thus the alternating state still occurred.

If vulnerable criminals numbers had been included in the decision process (to become or stay a criminal) then different results would be expect. This adaption is left to future work along with adapting the decision-making process to include the whole gang and including multiple gangs. These results represent a first step in theory building the impacts of gang formation on society. Since this work is theory building, no validation has yet been conducted on it (Poile and Safayeni 2016).

5.2 Impact of Assumptions

There are several assumptions that are made within the model that might impact the realism of any conclusions. For example, environmental effects on gangs are not considered neither is any government policies. At a deeper level, the education and welfare of individuals will impact their behavior which may be of interested to policy-makers. Our simulation represents a first attempt at modeling strategic gang formation and further research will include improving the realism and validation of the simulation. In this more detailed model, the authors believe useful hypothesis can be tested.

6 CONCLUSIONS

This paper explores the effects of criminal activity on a knowledge-based society through the development of an agent-based model. The results indicate extremes in outcomes, either everyone becomes a criminal or virtually no one does. Obviously this does not reflect reality and the model will need further development to capture the factors that actually matter in gang formation. The main weakness of this version of the model is that everyone is able to join the gang or leave at will. This democracy of criminal activity ensures that all agents progress at the same rate. The next iteration will include the whole gang in the decision process when deciding if an agent can join.

REFERENCES

Eden, Colin. 2001. "SODA - The Principles." In *Rational Analysis for a Problematic World Revisited*, edited by J. Rosenhead and John Mingers, 21-42. Chichester: Wiley.

Epstein, Joshua M. 2002. "Modeling Civil Violence: An Agent-Based Computational Approach." *Proceedings of the National Academy of Sciences of the United States of America* 99 (10):7243-7250.

Epstein, Joshua M. 2007. *Generative Social Science: Studies in Agent-Based Computational Modeling*: Princeton University Press.

Epstein, Joshua M., and Robert L. Axtell. 1996. *Growing Artificial Societies: Social Science from the Bottom Up*. First Edition ed: A Bradford Book.

Gilbert, Nigel. 2007. *Agent-Based Models*. Thousand Oaks, CA: Sage Publications, Inc.

Groff, Elizabeth R. 2007. "'Situating' Simulation to Model Human Spatio-Temporal Interactions: An Example Using Crime Events." *Transactions in GIS* 11 (4):507-530. doi: 10.1111/j.1467-9671.2007.01058.x.

Hardin, Garrett. 1968. "The Tragedy of the Commons." *Science* 13 (3859):1243-1248.

Katz, Jack, and Vicki Quade. 1989. "The Seductions of Crime." *Human Rights* 16 (1):24-51.

Klein, Malcom W. . 1971. *Street Gangs and Street Workers*. Englewood Cliffs, NJ: Prentice-Hall.

Lim, May, Richard Metzler, and Yaneer Bar-Yam. 2007. "Global Pattern Formation and Ethnic/Cultural Violence." *Science* 317 (5844):1540-1544.

Loftin, C. 1986. "Assaultive violence as a contagious social process." *Bulletin of the New York Academy of Medicine* 62 (5):550-555.

Malleson, Nick, Alison Heppenstall, and Linda See. 2010. "Crime reduction through simulation: An agent-based model of burglary." *Computers, Environment and Urban Systems* 34 (3):236-250. doi: http://dx.doi.org/10.1016/j.compenvurbsys.2009.10.005.

Maxson, Cheryl L., and Finn-Aage Esbensen. 2012. "The Intersection of Gang Definition and Group Process: Concluding Observations." In *Youth Gangs in International Perspective*, edited by Finn-Aage Esbensen Cheryl L. Maxson New York, NY: Springer.

Melde, Chris, Terrance J. Taylor, and Finn-Aage Esbensen. 2009. "“I got your back”: An Examination of the Protective Function of Gang Membership in Adolescence." *Criminology* 47 (2):565-594. doi: 10.1111/j.1745-9125.2009.00148.x.

Poile, Christopher, and Frank Safayeni. 2016. "Using Computational Modeling for Building Theory: A Double Edged Sword." *Journal of Artificial Societies and Social Simulation* 19 (3).

Sullivan, Mercer L. . 1989. *Getting Paid: Youth Crime and Work in the Inner City*. Ithaca, NY: Cornell University Press.

Suttles, Galster G. . 1972. *The Social Construction of Communities*. Chicago, IL: University of Chicago Press.

Thrasher, Frederic M. . 1927. *The Gang*. Chicago, IL: University of Chicago Press.

Wilensky, Uri. 1999. "Netlogo." Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL. http://ccl.northwestern.edu/netlogo/.

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