Agent-Based and Population-Based Simulation of Displacement of Crime (extended abstract)

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Abstract. Within Criminology, the process of crime displacement is usually explained by referring to the interaction of three types of agents: criminals, passers-by, and guardians. Most existing simulation models of this process are agent-based. However, when the number of agents considered becomes large, population-based simulation has computational advantages over agent-based simulation. This paper presents both an agent-based and a population-based simulation model of crime displacement, and reports a comparative evaluation of the two models. In addition, an approach is put forward to analyse the behaviour of both models by means of formal techniques.

1 INTRODUCTION

Within Criminology one of the main research interests is the emergence of so-called criminal hot spots. These hot spots are places where many crimes occur. After a while the criminal activities shift to another location, for example, because the police has changed its policy and increased the numbers of officers at the hot spot. Another reason may be that the passers by move away, when a certain location gets a bad reputation. Such a shift between locations is called the displacement of crime. The reputation of specific locations in a city is an important factor in the spatio-temporal distribution and dynamics of crime. For example, it may be expected that the amount of assaults that take place at a certain location affect the reputation of this location. Similarly, the reputation of a location affects the attractiveness of that location for certain types of individuals. For instance, a location that is known for its high crime rates will attract police officers, whereas most citizens will be more likely to avoid it. As a result, the amount of criminal activity at such a location will decrease, which will affect its reputation again.

The classical approaches to simulation of processes in which groups of larger number of agents and their interaction are involved are population-based: a number of groups is distinguished (populations) and each of these populations is represented by a numerical variable indicating their number or density (within a given area or location) at a certain time point. The simulation model takes the form of a system of difference or differential equations expressing temporal relationships for the dynamics of these variables. Well-known classical examples of such population-based models are systems of difference or differential equations for predator-prey dynamics (e.g., [8], [12], [13], [9], [4]) and the dynamics of epidemics (e.g., [10], [7], [4] [1], [6]). Such models can be studied by simulation and by using analysis techniques from mathematics and dynamical systems theory.

From the more recently developed agent system area it is often taken as a presupposition that simulations based on individual agents are a more natural or faithful way of modelling, and thus will provide better results (e.g., [5], [11], [2]). Although for larger numbers of agents such agent-based modelling approaches are more expensive computationally than population-based modelling approaches, such a presupposition may provide a justification of preferring their use over population-based modelling approaches, in spite of the computational disadvantages. However, for larger numbers of agents (in the limit), agent-based simulations may equally well approximate population-based simulations. In such cases agent-based simulations just can be replaced by population-based simulations. In this paper, for the application area of crime displacement these considerations are explored in more detail. Comparative simulation experiments have been conducted based on different simulation models, both agent-based (for different numbers of agents), and population-based. The results are analysed and related to the assumptions discussed above.

This paper is organised as follows. First, Section 2 introduces the population based model which has been defined for this domain and briefly presents the outcomes of a mathematical analysis of the model and simulations using the model . Thereafter, Section 3, introduces the agent-based model and briefly describes the simulation results using that model. Finally, Section 4 is a discussion.

2 A POPULATION-BASED MODEL

In the population-based model, the densities of the different agent types (i.e. criminals, passers-by, and guardians) are calculated by means of differential equations. An example of an equation to determine the number of criminals at location L is specified as follows:

$$c(L, t + \Delta t) = c(L, t) + \eta_1 \cdot (\beta(L, c, t) - c(L, t)/ c)\, \Delta t$$

This expresses that the density $c(L, t + \Delta t)$ of criminals at location L on $t + \Delta t$ is equal to the density of criminals at the location at time point t plus a constant η_1 (expressing the rate at which criminals move per time unit) times the movement of criminals from t to $t+\Delta t$ from and to location L multiplied by Δt. Here, the movement of criminals is calculated by determining the relative attractiveness $\beta(L, c, t)$ of the location (compared to the other locations) for criminals. From this, the density of criminals at the location at time point t divided by the total number c of criminals (which is constant) is subtracted, resulting in the change of the number of criminals for this location. For the guardians and the passers-by similar formulae are used. The calculation of the attractiveness of locations has been omitted for the sake of brevity.

A mathematical analysis has been conduced to investigate the behaviour of the model, and it was shown that in all cases attraction to the equilibrium will take place. Hence, given the set of assumptions as described above, the model will eventually stabilise.

Besides the mathematical analysis, simulation runs have been conducted as well and the outcomes confirm the results found in

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the mathematical analysis. The computation time needed to perform the simulations is approximately 1 second.

3 AN AGENT-BASED MODEL

For the agent-based model, the following algorithm is used:

1. initialise all agents on locations
2. for each time step repeat the following
   a. each agent calculates the attractiveness of a location depending on its type (passers-by, criminals, and guardians) for all locations.
   b. η % of the agents of each type is selected at random to decide whether the agent moves to a new location or stay at the old one
   c. the selected agents move to a location with a probability proportional to the attractiveness of the specific location (i.e. a selected agent has a higher probability of moving to a relative attractive location than to a non-attractive one).

Using the agent based model, simulation runs have been performed, and the results are closely correlated to the results using the population based model. The computation time needed to perform the agent based model (for 100 runs) is 16.39 seconds.

4 DISCUSSION

In this paper two models have been introduced to investigate the criminological phenomenon of the displacement of crime. Hereby, a population-based model has been introduced as well as an agent-based model. These models have been presented in a generic format to allow for an investigation of a variety of different functions representing aspects such as the attractiveness of locations. Using mathematical analysis, and confirmed by simulation results, the population-based model was shown to end up in an equilibrium for one variant of the model. The parameter settings for these simulations have been determined in cooperation with criminologists. The simulation results for the agent-based model using the same parameter settings show an identical trend to the population-based model except for some minor deviations that can be attributed to the fact that the agent-based model is discrete, as confirmed by the formal evaluation. The computation time of the populations-based model was shown to be much lower than the computation time of the agent-based model.

The results reported in this paper differ at some points from the results reported in [3]. In the results using an agent-based model reported in that paper, cyclic patterns were observed whereby there is a continuous movement so called hot-spots (i.e. places where a lot of crime takes place). As already stated before, this paper shows that the population of agents at the various locations stabilises over time. The difference can be attributed to the fact that in [3] all agents decide where to move to based upon the attractiveness of locations, whereas in the case of the models presented in this paper only a subset of the agents move. The results can however be reproduced using the model presented in this paper as well by using an $\eta = 1$ and $\Delta t = 1$. Determining what settings are most realistic in real life is future work.

The idea that population-based models approximate agent-based models for larger populations is indeed confirmed by the simulation results reported in this paper. Future work is to introduce a general framework to make a comparison between the models possible.

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