The Agent-Based Spatial Simulation to the Burglary in Beijing

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Abstract. Since the Agent-based simulation tool was introduced into criminology research, most work concentrated on crime theory validation or hypothesis testing, little was contributed to crime spatial pattern replication. In this paper, using street network and subway network as the landscape and proposing a statistic-based instead of predefined human mobility pattern as the individual's routine activity, the spatial distribution of burglary in Beijing is simulated and valid by the actual pattern. The result indicates that the Agent-based modeling method partly detects the crime hotspots and the spatial pattern of crime, and specifically the crime level on the nodes with different accessibility is proved to be identical to the actual one. The study made in this work demonstrates that Agent-based modeling is a potential tool to predict or explain crime pattern in space, and also some further work which aims to improve its validation is discussed in the end of this paper.

Keywords: Agent, Crime hotspot, spatial pattern, simulation.

1 Introduction

During the past few years, as the development of Complex Adaptive System (CAS) theory, the Agent-based simulation tool was introduced into criminology research. Traditionally, the criminology was viewed as social science and numerous relevant studies were concentrated on social investigation as well as data analysis to valid crime theories. But overall, it is accepted broadly that the crimes being distributed around the corners in cities are generated from the interactions between people and people as well as people and environment, so using traditional methods to study crime meet some difficulties in disclosing the dynamics behind the crime activities. However, CAS does.

The first work about Agent-based simulation about crime was proposed by Brantingham and Brantingham in 2005 [1]. In their work, they suggested a framework how to simulate individual's activities in space using Agent. Following their work, Malleson, borrowing from Brantinghams' ideas, constructed an artificial city environment

B. Murgante et al. (Eds.): ICCSA 2014, Part IV, LNCS 8582, pp. 31–43, 2014.

and simulated how burglary occurs within the backcloth of human routine activity [2]. After that, Groff contributed crime simulation by proposing a work in which the street network in Seattle was used to carry on individuals activities, and her work indicated that people taking the risk of robbery was influenced by the intervals people spending outside of their house [3][4][5]. Further, Malleson advanced Agent-based simulation of crime by integrating population into the model [6].

Since much work has been done on crime simulation with Agent-based model, some disadvantages still exist. One of the highlighted problems is that the purposes of Agent-based simulation work are testing crime theory or relevant hypotheses, but replicating of crime pattern in space was seldom taken into account. Thus, in this paper, the spatial pattern of burglary in Beijing is replicated using Agent-based modeling method, and its validation is tested with actual data.

2 Landscape Definition

The environment in which offenders, victims and passers-by lives include various elements, such as road, street, square, home, entertainment sites, school, office, factory, government, et al. However, in backcloth of individual movement all these can be simplified into two types of structure: node and path [7]. The nodes are where people spend their time living, working, entertaining, and path connects the nodes so that people could reach any place they want. Currently, as modern traffic becomes more and more convenient, many people prefer to take public traffic to shorten the distance of traveling, thus, the landscape where individuals perform routine activities could be represented by integration of street network and traffic network (see Figure 1).

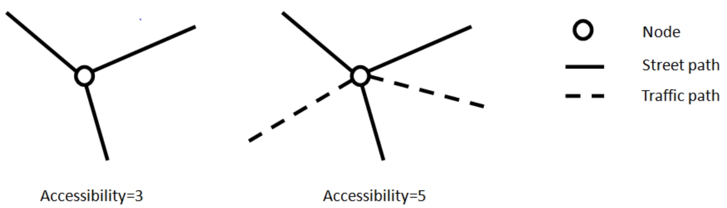


Fig. 1. Topology structure of landscape

In Figure 2 the street network and subway network in Beijing is demonstrated. The subway network is selected as the traffic network because it is the busiest line across the city, each day millions of people take the line to travel. The topology of street network and subway network are analyzed using software package ArcEngine, which is a development tool in ArcGIS. The outcomes show that the streets are intersected into 13008 nodes and 20975 paths, namely each node has 3.22 connections on average. While the subway lines are composed of 119 nodes and 131 edges, each node has 1.1 connections on average.

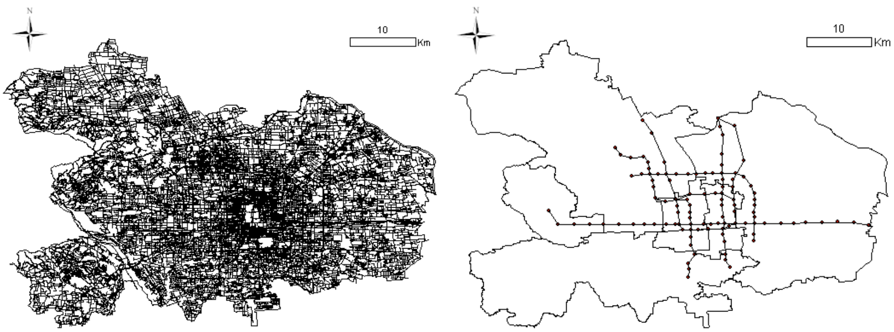


Fig. 2. Street network and subway network in Beijing

3 Mobility Behavior Definition

The individual's mobility pattern was well described by crime pattern theory [8]. Brantingham and Brantingham thought people performed their routine activities in the places around the nodes and paths where they feel safe and comfortable, and they called places awareness space. Thus, people's routine activities are described as the movements in the awareness spaces.

In previous work about crime simulation, the individual's movement in space was predefined [4][5][6], which means the agent moves along the fixed routes following the shortest path between any pair of nodes. Additionally other researchers let agents move totally randomly in space. Actually, both treatments neglect the aspects that people's movement is the integration of deterministic and stochastic. People indeed travel between their homes, schools, companies, entertainment sites in lowest cost, but meanwhile they also occasionally walk aside to take a drink on the way home or work, or go to see a friend on holiday. So another way of simulating agent movement behavior is proposed. Based on Gonzalez's work in which he detected the mobile phone's signal and discovered that people's staying time obeys heavy-tail distribution [9], a statistic-based mobility behavior rule is suggested by Ni [10]. However, his model failed to consider people have to travel via different networks. So after making corrections to the model, a new mobility behavior definition is described below:

1) *Initialization*: each individual agent *h* is initially located at node *i*, which can be thought of as their home location.
2) *Traveling*: At each time step, individuals leave the node they are currently located on with a probability of p_{move} and choose either to move along the paths (street or subway network) with probability p_{move}. At each time step, a uniform random number generator is used to determine which choice is made. For example, in the case of deciding which network (street or subway) to move along, if the random number generated (μ) is less than p_{select}, individual *h* will walk on the street network; otherwise individual *h* will move using the subway. If the agent decides to move, it randomly selects one of the nodes directly connected to their

current location from the relevant network and moves to one of the adjacent nodes; otherwise, the agent remains at its current location.

3) *Waiting*: when agent h moves to a node j, it is assigned a waiting time interval t_w drawn from a heavy-tail distribution $p(t_w) \sim t_w^{-(1+\lambda)}$, where $\lambda > 0$ and $1 \leq t_w \leq T_w$. The agent will wait for t_w time steps at node j before it moves again.
4) *Returning*: after waiting t_w time steps at node j, agent h returns back to node i (i.e. the home node) with probability p_{back}, and then proceeds from step 2); otherwise, the agent will travel to another node k randomly selected from the neighboring nodes of node j, then followed by step 3).

After introducing the mobility rule, the individual's movement behavior is dominated by statistical parameter p_{back}, p_{move}, p_{select}, t_w and λ instead of unchanged routes.

4 Agent Rules

According to routine activity theory [11], three types of agent are defined in the model: police, offender, and civilian. For the civilian agent, their homes are the potential targets of offenders and they perform their routine activities by using the mobility behavior model. But for the other two agents, the police is the crime reduction and prevention force while the offender is the crime opportunity searching agent.

Police

The task of police in the model is to detecting offender and preventing burglary occurring. So police includes basically three functions, where are learning, decision-making and mobility.

Learning. The police in the model need to learn how many crimes have occurred on the node where he is staying and directed neighbored ones so that he can decide where to move. So the police learning function is to compute the count of burglary occurred on the nodes in past intervals.

Decision-making. As the main task of police is to prevent or stop the burglary occurring, the decision-making process is to select the targeted node which owns the most frequent burglary. So in this step the police will reorder the computed burglary table and choose the highest crime-level-node as the target.

Mobility. When the targeted node on which most burglaries occurs is selected, police will directly move to that node. Otherwise if the node meeting the condition does not exist, police will randomly select a neighboring node and move.

It could be inferred that the three functions have to be iterated consecutively in each time step, thus the police will keep moving in space all the time.

Offender

The offender's functions are relatively complicated compared to police because in addition to the basic routine activities like civilian he has several stages to change from a civilian into formal criminal. The first is motivation emergence. Many previous studies support the view that economy's rise or reduction will lead to the change of crime rate [12][13]. The reason for this phenomenon is that the unemployment produced from economy's fluctuations has deeply impact on crime rate, which means the people with lower incomes would choose to commit property offence to maintain their lives. Thus the personal owning property level directly decides whether the offender would be risked to commit crime. The second stage is decision-making process. The rational choice theory indicated that offender have to balance his risk and income from committing crimes [14]15]. The potential risk comes from the being discovered by passers-by or witnesses, being arrested by police or stopped by guardians. While their incomes are consist of not only being the money or property from offence, but also the satisfactory and accomplishment feelings. In following parts two functions are described.

Motivation emergence. A variable named *personal property* was defined to describe offender's identity. When offender's personal property is zero, its offending motivation emerges and the agent becomes a potential offender who is ready to commit crime [4]. Once he has changed from civilian into a potential offender he will keep searching for suitable targets for maintaining his lives all the time. If the offender's personal property is non-zero, the agent will keep maintaining in civilian identity and perform the routine activities, but at meantime he has to consume 1 unit of property each day.

Decision-making. When the agent is motivated to become a potential offender, he would become into the predatory criminals who keeping searching for suitable targets [16]. During this process one factor that influences it's succeeding or failing to finish the illegal activities is the guardians. The guardians could be the police or passers-by, they play the roles of preventing or stopping burglary on one site, however, their roles are different. The ones who located in their awareness space are called formal guardians because they would stop the property crimes occurring in strong wills. As a contrary, the ones located in their non-awareness space are called informal guardians who would prevent property crimes occurring in lower will. An investigation made by Reynald indicated that 23% of passers-by would intervene when they witness abnormal actions [17]. Therefore, in this work 20% is measured as the guardianship to the civilian who locate in their non-awareness spaces, but to the ones who locate in, their crime prevention level is defined as 100%. In this sense, on one node 5 guardians will totally stop offender from committing crimes. However, it doesn't mean offender have no chance in this case, the offender still could succeed in committing crime when guardians number is lower than 5, but some risks have to be paid by them. Thus, another variable – *offending risk* – is defined to describe if offender could make a successful offence on the node. The variable is generated from a random number generator, if the number is lower than the existed guardianship the offender would drop off the offending action, but if the generated number is higher than the guardianship the offender would commit crimes in risks.

In Figure 3 the motivation and decision-making processes of offender is demonstrated. It could be referred from the flow chart that offender has to experience several stages and make multi- decisions to commit a successful crime, but before he makes it he would keep iterating this process until he does an offence and gets benefits from it.

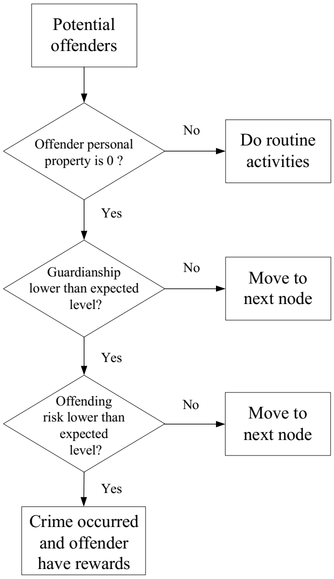


Fig. 3. Motivation and decision-making process of the offender agent

5 Initial Conditions and Parameter

Before simulation is started one work has to be made is to populate the civilians, police and offender agents on the nodes. Based on the principle that each node has to be covered by at least one civilian agent, the number of civilian agents deployed on the node is determined according to the following rules: if the population density on node A is four times to the one on node B, there will be one civilian agent placed on node B while four on node A. The police agents are initially placed randomly on the nodes and their proportion to the civilian is kept in lower level, namely 1%. The number of offender agent is also controlled at 1% of the total civilian agent because the population living in lower standard in Beijing is estimated to be 1.1%. As there is no data available about where these people live, they are initially distributed in space in proportion to the street node density by output areas (There are eight output areas in Beijing, see Appendix A).

Another condition has to be predefined is the time step. It is assumed that each individual agent takes 4 minutes on average to finish the distance between any pair of node however connected, so each day is consist of 360 time steps.

In Table 1 the parameters and other initial conditions are listed. The parameters are referenced from Beijing Annual Statistic Book (2007), which includes both demographic and traveling pattern data.

Table 1. Parameters to the simulation work

Parameter	Rationale
$N_{civilian}$=17716	Total number of civilian agents
$N_{offender}$=177	Total number of potential offenders
N_{police}=177	Total number of police agent
p_{jump}=1.0	The probability of civilian and offender agent leaving their home node
p_{select}=0.17	The probability of civilian and offender agent traveling in tube network
p_{back}=0.5	The probability of civilian and offender agent returning to their home node
T_{max}=360	Time step in each day
λ=0.6	The parameter describing how people spend their time across a day
personal property=(1,5)	The variable determine the identity of offender agent, generated from a uniform random number generator
offending risk=(0,1)	The variable of offender agent risked to offence, generated from a uniform random number generator
$E_{guardianship}$=0.2	The guardianship non-owner of the node prefer to intervene property crime
iterations=20	The times of the simulation running to smooth randomness

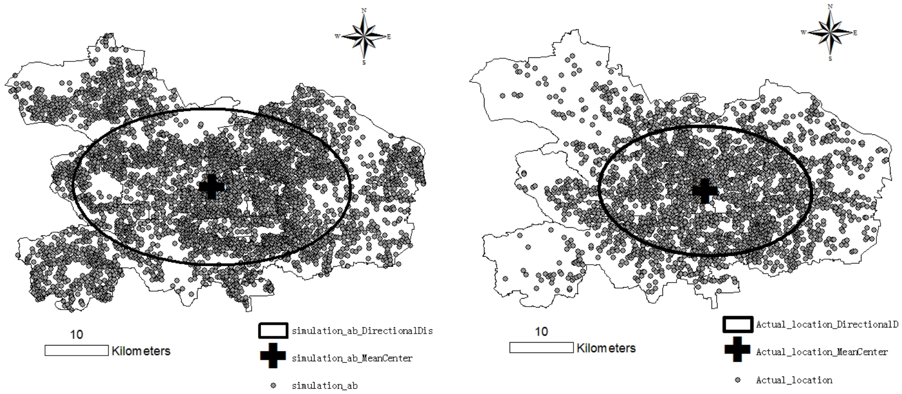
6 Result

The model is configured and simulated using a personal computer. It takes 10 hours to run for 20 times to smooth the randomness and the final result is the mean level of all variables. The result is compared to the actual data for validation from perspective of visualization and crime level on nodes in different accessibility.

Firstly, the simulated crime points and actual data are displayed in Figure 4, and the mean center as well as standard deviational ellipse are used to describe the central as well as directional tendency of a point pattern. Results indicate that the distance between the actual and simulation distribution mean center is 3,550.34 meters, but is remarkably small when considering that these eight output areas in Beijing are 1,368.35 km^2 in size. The resulting standard deviational ellipses indicate that the real residential burglary pattern is a little different from the simulated pattern. From the picture it could be seen that the pattern generated from simulation distribution is more dispersed than the actual distribution of residential burglary events but their orientations are similar.

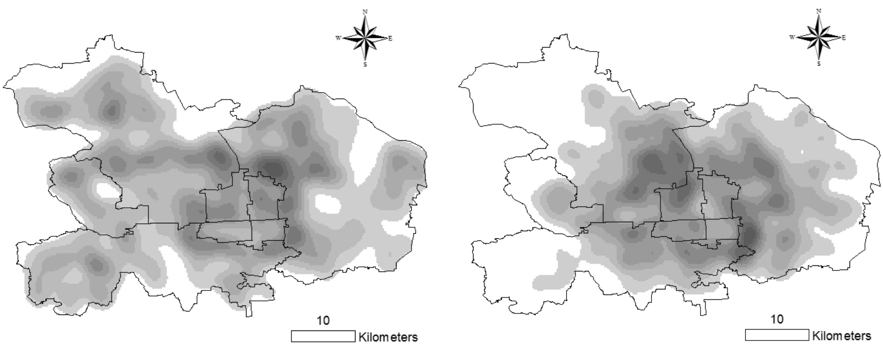
The hotspots of both crime patterns are studied with kernel density estimation method (KDE). The cell sizes of the two analyses are treated equally but the searching radius are varied so that crime hotspots in different levels could be identified and comparable. It could be inferred from the Figure 5 and 6 that simulated crime patterns demonstrate a similar spatial distribution with actual data. The hotspots identified in both analyses mainly concentrate in the zones around the center areas, but in simulated pattern the hotspots on the edge areas are not valid by the actual result.

In further, the count of burglary on each node is computed and treated as the attributes of the polygon where the node sitting in. After that the local Moran's I which is a useful statistic tool in Local Indicator of Spatial Analysis is used to identify the hotspots that are in significant statistic level [18]. The street blocks where crimes are located in are treated as the basic unit to make the statistic, and the result is demonstrated in Figure 7. It could be seen from the graph that some significant hotspots are detected by the model in the zones around the center areas, but it could also be found that some hotspots are failed to be simulated by the model. For example, the hotspots simulated by the model concentrated on North-West, South-West and North-East corner of Beijing are proved to be invalid by the actual pattern.



(a) (b)

Fig. 4. Crime distribution in space, (a) simulated pattern, (b) actual pattern



(a) (b)

Fig. 5. Crime distribution identified by KDE in space, (a) simulated pattern, (b) actual pattern, searching radius is 3.0Km, cell size is 250 meters

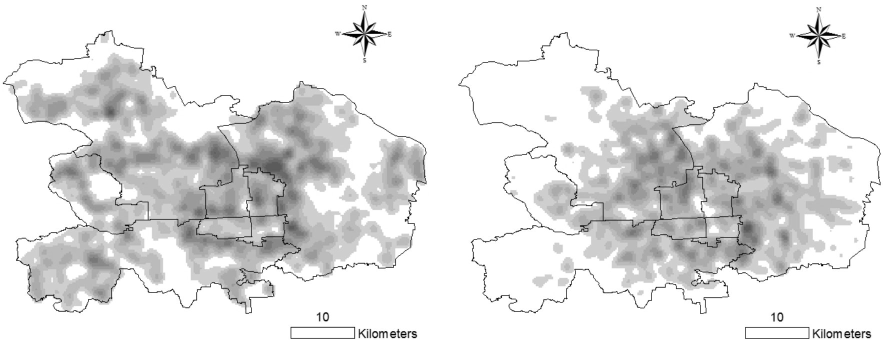


Fig. 6. Crime distribution identified by KDE in space, (a) simulated pattern, (b) actual pattern, searching radius is 1.5Km, cell size is 250 meters

(a) (b)

Fig. 7. Crime distribution identified by Local Moran's I in space, (a) simulated pattern, (b) actual pattern

From descriptive analysis in visualization it can be seen that the Agent-based modeling study partly identifies the hotspots and also some clues are inferred from the result. First, the original location of offender might have impact on crime distribution in space. As indicated by theory of journey to crime (JTC) that offenders are often searching for crime opportunity in least effort principle [19], therefore the initial locations of criminals would decide where crimes occur and concentrated. So, the locating initial position of offender agent by output area might cause the improper distribution of hotspots. Second, the unreported offence is probably another reason to cause the difference between simulated and actual crime pattern. Based on previous research made by Zhang who reported that it was estimated that only 77% residential burglary were recorded by the police [20], so in this work it is believed that more than 20% unrecorded offence is not known and brings negative influence to outcomes.

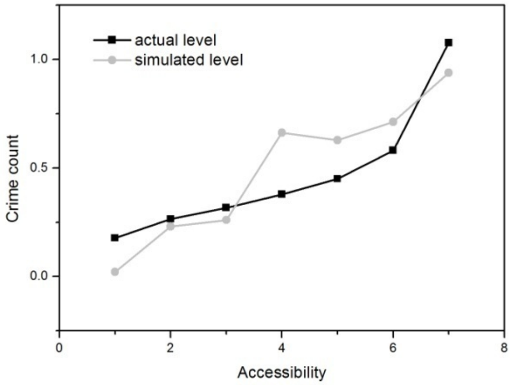


Fig. 8. Simulated crime count against actual count by node accessibility

Finally, the influence of node accessibility to the crime count is tested. As described by previous literatures, the accessibility to the node dominates how the place being reached by civilian, offender and police, then the crime pattern is influenced [21][22][23]. So the simulated crime count against actual crime count by varied accessibility is displayed in Figure 8. It could be inferred that both simulated and actual crime pattern demonstrate higher crime count concentrated on the node with higher accessibility, or in another words, the higher crime risk occurs on the places that are more easily accessed. This is identical to the previous work made by Newman and Johnson who stated that the crime risk is lowest on cul-de-sac because strangers often go unchallenged for ambiguity in these places [24][25]. To date though how crime distributed by street segment accessibility is still a controversy, the simulation shapes similar distribution with actual one proves the model works well in replicating crime risks in the places by different connection in Beijing.

7 Conclusion

This paper sought to replicate crime distribution pattern in Beijing with Agent-based modeling method. In order to accomplish this target the street network and subway network are treated as the landscape, a statistic-based human mobility behavior rule is proposed as agent routine activities and motivation driving decision-making process to the offender agent is constructed. In study, the spatial distribution of burglary is simulated and compared with the actual crime pattern to valid the model. The visualization descriptive analysis results demonstrate though the hotspots on the edge areas are failed to be detected the locations in center area of Beijing are identified by the model. Finally, the influence of the node accessibility to the crime level is tested, and the findings indicate that the model well replicate the crime level by different connected node.

The simulation result in this paper is proved to be a potential tool to replicate and study crime distribution in space, but more future work have to be made in order to achieve a better effect of crime pattern replication. The first thing is to include offender home locations into the model. As JTC theory has indicated that offenders usually search for targets and commit crimes with least effort, thus the fine-scale information on offenders should be collected and added into the initial condition of simulation. The second issue is that more data about land use and environment should be included. The lands with different functions are often having different attractions to the offenders and civilians. The important sites as shopping center, bar and station usually play the roles of crime generators or crime attractors in shaping crime distribution [26]. Therefore introducing more basic infrastructure data would improve the validation of Agent-based model. Another important problem have to be emphasized is the crime data collection. As more than 20% crime data is in short the replication effect of the model is difficult to be proved, so more accurate crime information will benefit to the model validation.

Acknowledgement. This work was sponsored by National Science Foundation (71203229), and Professor Du Shihong was greatly appreciated for his suggestions in improving this paper.

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Appendix A: Map of Output Areas in Beijing

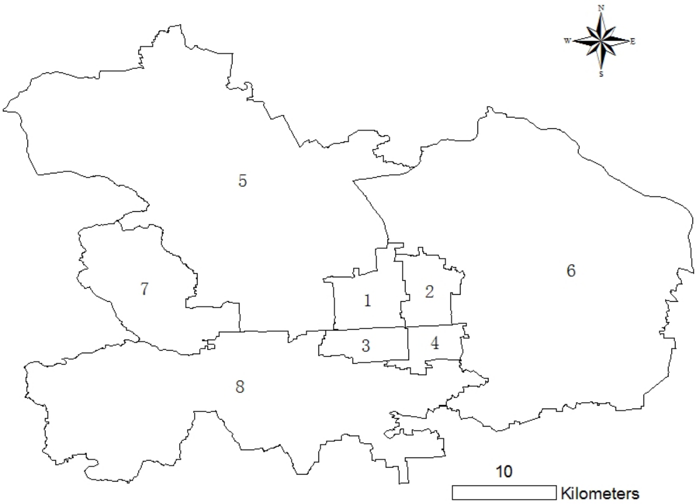

Fig. A.1. Beijing's output areas