Temporal and Spatial Analysis of Criminal Path of Different Types of Serial Sexual Offenders

Hsu-Hsien Chen(1), Pei-Fen Kuo(2), Sheng-Ang Shen(3)

[1]National Cheng Kung University, graduate student, Taiwan
[2]National Cheng Kung University, assistant professor, Taiwan
[3]Central Police University, professor, Taiwan
Email: chenpi0503@yahoo.com.tw;

Abstract:

Sexual violence is a global problem which causes social panic. This study focuses on analyzing the consistent spatial-temporal characteristics of serial sexual offenders and then further develops the future crime prevention strategies.

This study scans over one thousand court judgments in Taiwan (2009 to 2012) and selects 39 serial sexual offenders who totally committed 114 cases. We collect several criminal characteristics, such as home-to-crime distances, step distance (crime-to-crime distance), offender's age, the relationship between offenders and victims (such as stranger rape, familiar rape and marital rape.), or even the transportation (travel mode) they used.

The methodology of this research includes: 1) testing the temporal and spatial clustering of crime scenes via a revised Knox test, 2) evaluating the goodness-of-fit of offence trajectories with an animal movement model (such as the Levy walk model), and, (3) studying if spatial behaviors differ among various offenders and environmental factors. The results of this study can assist police in future investigations and the prevention of serial sex crimes.

The results show that: (1) the distance between two continuous cases are usually shorter than 1 kilogram, because most crimes happened at offender's home or somewhere the offender familiar with. (2) The criminal moving pattern follows the Levy walk, which is a heavy-tailed distribution. In other words, crimes usually concentrate at specific place. (3) The travel distance is related to their travel mode and their relationship with victims. The results of this study can help the police authority predict the crime pattern and further achieve the purpose of crime prevention.

Keywords: Knox test, levy walk, serial sexual offenders

1. INTRODUCTION

Criminal problem is always an important issue to every country, serious crime causes social panic even effects national economy, so that, exploring crime pattern and developing preventive strategies are primary tasks to every country. In recent years, more and more experts and researchers involved in related works, trying to more understand how those criminals move and are those criminal behaviors have any pattern. Criminologists found that crime is not happened randomly, instead presenting a phenomenon of aggregation at specific places. Which means, criminals are not select those locations randomly, they select them by following some rules, such as external environment or their daily activities, especially serial crimes.

Local crime statistics indicate that most perpetrators of sexual assault have committed prior offenses such as burglary, physical assault, and robbery. They tend to follow specific modus operandi that they learned from their previous criminal experiences. Such practices tend to be low risk, highly efficient, and easy to achieve (Tung, Shen & Hung, 2017). Crabbe (2008) proposed a "behavioral choice preference hypothesis," which argued that there is consistency and stability in criminals' personalities. The modus operandi and other characteristics tend to go unchanged among criminal offenses committed by the same perpetrator, especially the spatial-temporal pattern. Therefore, one research motivation of this study is to examine the spatial-temporal characteristics of serial cases.

In order to examine the spatial-temporal characteristics of serial cases and define the crime pattern of serial sexual offenders, the main objectives of this study include:

1. Test temporal and spatial clustering through the Knox test, and observe the temporal and spatial clustering effects of journeys-to-crimes.
2. Test the compatibility of the step distance variable with Lévy walk, linear, and other advanced animal movement models to determine goodness-of-fit for each.
3. Use statistical tests such as the Chi-square test to evaluate the relationships among offenders using different transportation modes, and the step-distance and offence time for each crime.

2. LITERATURE REVIEW

Times and locations of crimes are often related to the routine activities of perpetrators. For instance, perpetrators may choose potential victims who live nearby to their own homes. Admir (1971) argued that offenders assess situational factors to determine if the time is right to commit their crimes. Situational factors that criminals often take into consideration include the time, season, location,

and a wide variety of crime scenes and others. Crabbe et al., (2008) suggested that personal habits and thoughts change with time and experience, and these changes alter routine activities and one's social network. These conclusions were developed into the developmental path hypothesis, which argues that the crime, the perpetrator's psychological state, situational factors, time, and crime location are all highly related to each other.

Lebeau (1987) reviewed the distances between crime scenes and perpetrators' homes in 89 sexual assault cases in San Diego that were committed between 1971 and 1975. No consistencies were found among the cases, and distances ranged from 0.12 miles to 0.85 miles, with an average of 0.37 miles. However, the distances traveled in sexual assault cases tend to be shorter than those in other crimes. For example, a German study shows that crime scene distances from 156 perpetrators' houses in serial killings varied from 0 to 10 km, with an average of 6.7 km (Snook, Cullen, Mokros, and Harbort, 2005). A later study of four serial rapists (Lebeau, 1992) came to similar conclusions but further explored how the offender's personal characteristics (such as age, race minority, and life style) might affect the spatial temporal pattern of the seral sexual crimes.

A recent local study done by Kao (2014) categorized sexual assault perpetrators into intimate, control, criminal, and chaotic types. He believed that all of offenders were not fixed to a single location, except for control offenders. Control-type perpetrators tend to commit offences in the same location. This is because of their strong need for control. Other types of perpetrators are influenced by various considerations and therefore change the locations of their offences. Intimate perpetrators depend on opportunity as they stalk their victims. Criminal types commit offences when the situation is highly profitable and offers a low level of risk. Lastly, chaotic offenders are limited by their psychological state.

Spatial behavior is less frequent in Lévy walks than in Brownian motion. Lévy walks involve a random choice of continuous trajectory, independent of previous movement. However, the function of movement distance (L) is heavy-tailed. The tail of distribution from its index represents a feature of the Lévy walk, one in which a relatively long distance appears occasionally (Viswanathan, 2010). A Lévy walk usually occurs in an environment in which there are insufficient resources and where a change of direction may yield prey. A simple way of separating a Lévy walk from Brownian motion is to draw a log-log graph to show a straight line; the step-distance between crime locations shows if the offender's movement/path follows a Lévy walk. Brownian motion is more constant. There are many other advanced versions of the Lévy walk, such as

biased and truncated Lévy walks, which are beyond the scope of the discussion here (see Pan et al., 2016 for more details).

In summary, much criminology research has proposed the ideal quality theorem foraging strategy, but relatively few recent studies have provided mathematical models that describe offenders' movement in detail. Several possible distribution hypotheses in the field of ecology have been used for offenders' movements, but the results have been inconsistent. Also, most of distance based on studies have been conducted in Western countries. Consequently, the goal of this study is to apply local serial sex crimes in order to build a prediction model and examine the effects caused by different types of offenders and certain environmental factors in Taiwan.

3. METHODOLOGY

3.1 data collection

This study collected the court's judgment of central Taiwan since 2009 to 2012, including Taichung, Yunlin, Changhua, Miaoli and Nantou. It is an extended study from our previous publication (Kuo et al, 2017). First, we scanned over one thousand court's judgments (PDF files), selected the cases that belong to serial sexual assault, and then inputted useful information in our datasets, such as offender's age, address, and their travel modes. Our key variables are the location where these crimes happened and offender's residential addresses. After that, TGOS, a local geographic information transform platform, was used for geocoding and follow-up research. Our final dataset includes 114 crime cases committed by 39 offenders.

3.2 Knox test

Knox test is commonly used to define the spatial-temporal cluster patterns of data points, because this method is simple and straightforward to interpret. The main idea of Knox test is to separate all data into different spatial and temporal subgroups, and then see if any cell show cluster (observation is large than expected). The column variable is time, and the row variable is distance. The Knox test uses the residual value in each grid to determine if the sample follows the homogeneous assumption distribution in our hypothesis.

Table 1. Knox Test Contingency Table

Time (t = 7 days)	Distance (d = 200m) 0 to d	d to 2d	2d to 3d	3d to 4d	4d or more	Total
0 to t	X_{11}					$X_{1.}$
t to 2t						
2t to 3t			X_{33}			
3t to 4t						
4t or more						
Total	$X_{.1}$					$X_{..}$

D: study unit for step-distance (here 200m)

T: study unit for interval-event time (here 7 days)

X_{11}: frequency corresponding to the first row and first column

$X_{1.}$: sum of all cells in the first row

$X_{.1}$: sum of all cells in the first column

$X_{..}$: sum of all cells

The estimator of the expected value in cell (i, j) used in this study is as follows:

$$\hat{X}_{ij} = \frac{X_{i.} \times X_{j.}}{X_{..}} \quad (1)$$

The expected value (X_{ij}) in each fine grid is the result of multiplying the corresponding column by the corresponding row and then dividing the product by the total number. If no correlation is found between the time and space variables in each fine grid, the observed numbers are near to one another in terms of both space and time. After calculate the expected value (X_{ij}), then further calculate the residual value (r) of each grid by following function:

$$\hat{r}_{ij} = X_{ij} - \frac{\hat{X}_{ij}}{\sqrt{\hat{X}_{ij}(1 - X_{ij}/X_{i.})(1 - X_{ij}/X_{j.})_{..}}} \quad (2)$$

The size of the residual value can be used to define the special characteristics of each fine grid. If the residual value is greater, this indicates that the correlation between space and time variables is higher (Chiu, 2013). The threshold value of the residual value, r, used here is 3 based on our literature review results.

Because when r is greater than or equal to 3, the probability of Type I error is only 1%, suggesting that the test results exhibit space-time clustering (Agresti and Finlay, 1997; Townsley and Chaseling, 2003). However, the statistics describing the residual tend to vary with changes in size to the marginal expected value.

3.3 Levy walk

Formula (3) is the probability function of how a sexual offender commits a crime in location *i* and then moves to location δ to commit the next crime, via a Lévy walk. Because of the rational choice and distance decay theorems, the power term is negative and between -1 and -3. For example, if the offender has a convenient traffic mode such as a car that makes it easy for him to move and travel, the distance penalty is small. If the offender commits the crime on foot because he cannot easily move to another area, the power term variable increases to -3.

$$P(L) = aL^{-\mu} \tag{3}$$

where $1 < \mu \leq 3$ is a constant. When the step-distance is small (i.e., when L is close to 0), the probability is higher, which means the offender tends to commit crimes close to places with which they are familiar. However, the offender may switch to other places that are further away, or even to different cities, when they feel at risk or the original hunting ground has become resource poor. Formula (4) is the probability function when the offender's movement follows a Brownian walk, that is, where λ is inversely proportional to the average step-distance (i.e., a large λ is equal to a small step-distance). This distribution has a thinner tail and limited variance, which means the offender tends to commit crimes randomly and seldom travels far to do so.

$$P(L) = \lambda e^{-\lambda L_j} \tag{4}$$

4. RESULTS

4.1 Knox Test

Table 2 is the result of Knox test, we separated the observed crimes into subgroups. Based on the literature review suggestion, we used five hundred meters as our spatial unit and seven days as our temporal unit. Then, if the crime data were clustered within a cell, the corresponding observed data should be significantly higher than the expected value. If the test criteria is more than 3, than there is a cluster in this cell in 95% confidence intervals. Positive r values mean that there has a cluster, while negative r values mean the crimes are dispersed (Agresti & Finlay,1997; Townsley & Chaseling, 2003). In table 1, only

one cell shows significantly cluster when the distance is less than 500 meters and time is less than 7 days. It means that most of serial sexual assaults concentrated at short distance and short time interval. In the other words, the offenders tend to commit crimes near their residence or some entertainment places, such as bars, parks or streets (Rossmo, 2002; Beauregard et al., 2007).

Table 2. Residual result of Knox test

Distance / Time	<500m	500~1000m	1000~1500m	1500~2000m	>2000m
<7 Days	3.4006	-14.817	-15.369	-15.369	-14.817
7-14 Days	-13.713	-15.369	-15.369	-15.369	-14.817
15-21 Days	-13.713	-14.817	-15.369	-15.369	-15.369
22-28 Days	-14.817	-15.369	-15.369	-15.369	-15.369
29-35 Days	-13.161	-14.265	-14.817	-15.369	-14.817
>35 Days	-8.1923	-14.265	-14.817	-14.817	-14.817

4.2 Levy walk

The formula of Lévy walk movement is relatively complex, because it needs to include point position and direction information. For this reason, most of existing studies first check the probability density function (PDF) of the step distance of the Lévy walk. The movement is identified as a Lévy walk, when the step distance data follows the power low function (for example, $p(\ell) = C\ell^{-2}$). Since a heavy tail is the main characteristic of a Lévy walk, we can use a goodness-of-fit test to check which step distance model fits best.

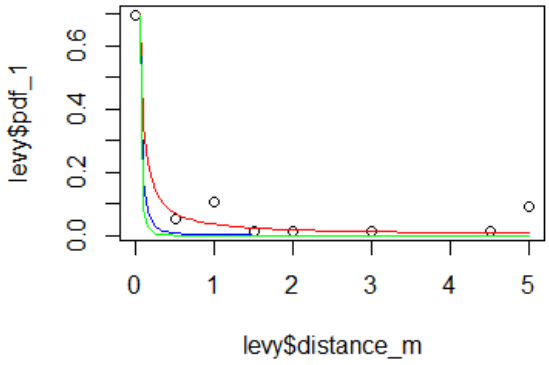

Figure 1. Step distance modeling fitting results

Table 3. Levy walk Modeling fitting results

	P(L)	R-squared
$p(\ell) = C\ell^{-1}$Red Line	0.035016L^-1	0.9715
$p(\ell) = C\ell^{-2}$Blue Line	0.0017451L^-2	0.9505
$P(\ell) = C\ell^{-3}$)Green Line	8.718e-05 L^-3	0.9485

Figure 1 shows the result of step distance modeling fitting. The white circles represent the observed crime data. Three different power levy walk models were used to test and the first model (red line) fit best. In other words, it is possible that these criminals' behavior follow a Levy walk with power term equal to one, which has a characteristic of heavy-tailed distribution.

3. Chi-squared test

Chi-squared test is used to define if two different variables have correlation or not. In this study, we focus on three different variables related to offender's moving distance, such as offender's age, travel mode, and their relationship with victims. .

Table 4 (a). Chi-squared test of distance and relationship

Distance / Relationship	0 km (Home crimes)	0-1 km	>1 km
familiar	45	1	5
stranger	8	11	8
x-squared	34.596		
p-value	3.073e-08		

Table 4 (b). Chi-squared test of distance and transportation

Distance / Transportation	0 km (Home crimes)	0-1 km	>1 km
Walk	52	6	5
Automotive	1	6	4
Mass transit	0	0	1
x-squared	31.277		
p-value	2.68-06		

Table 4 (C). Chi-squared test of distance and age

Distance / Age	0 km (Home crimes)	0-1 km	>1 km
19~23	2	6	5
24~39	15	3	4
>40	36	3	1
x-squared	27.093		
p-value	1.904e-05		

Table 4 (a) shows that if the victim knows offender, then most of crimes happened at offender's home. Otherwise, the travel distance is longer when the offender are stranger. Secondly, the offender's age is positive related to their travel distance. It is inconsistent with existing study, while most western studies show that senior offenders travel farer than junior offender because of mobility. Another interesting finding can be observed at table 4 (C), offenders tend to commit crimes at home or near home if they don't use any travel mode Based on these, these three variables (relationship with victim, offender's age and travel modes) are all related to criminal travel distance, and can be important predict factors for crime pattern.

5. CONCULSIONS AND SUGGESTIONS

The main contributions of this study are twofold. The first one is to define the time-space characteristics of serial sex crimes in Taiwan. The results of Chi-squared test present that offender's age, the relationship with victims and travel modes affect criminal's travel pattern. If the offenders are senior, have better mobility, or are stranger to the victims, they tend to travel far to commit crimes. Most criminals who are familiar with victims tend to commit the crimes at home or near their house. Based on the rational choice theory, criminals usually choose the familiar places to commit crimes in order to reduce their arrest risk. Another interesting finding is that if offender is senior, they also tend to choose fixed places (such as their home) to commit crimes instead of travel around. We need

further analysis for this finding. The second contribution is local crime database was used to proof that the Asia criminal pattern also follow a levy walk, which as same as Pan's research (2016) conducted in western countries. It can help us to build further crime prediction model and design efficient police investigation.

In academic contribution, our result is consistent with LeBeau (1992) finding. We both found that some offenders have similar pattern on space, and they committed the crimes near their residents. In practical applications, this research can help law enforcement to scan their communities, improve policing in high-risk areas, and better monitor parolees with abnormal recidivism trajectories.

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