New hypotheses on serial offender’s spatial behaviour

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Abstract:

Geographic profiling is a methodology used to delineate a prior search area for a serial offender. Two new hypotheses integrating recent researches on offender’s behaviour are proposed to broaden the applicability of the techniques of geographic profiling to commuters and irregular patterns of crimes. The journeys-to-crime variance and place attractiveness will be successively integrated in GP methods. In order to evaluate the variance of the journeys-to-crime on real road network, a method based on least square adjustment in raster mode is developed. A real case of serial rapes illustrates the effectiveness of those assumptions for a non-uniform pattern of crimes.

Keywords: Geographic Profiling, Crime attractors and generators, distance decay heuristic, Raster analysis

1 Geographic profiling: its origin, methods and limits

In the 1980’s, environmental criminologists stressed the importance of the spatial dimension in crime analysis, and encouraged spatial analysis to become an investigative tool to narrow the offender search area (Brantingham and Brantingham, 1981, LeBeau, 1987). Theories such as routine activity (Cohen and Felson, 1979) and rational choice (Cornish and Clarke, 1986) were used to describe the criminal’s spatial behaviour, which is supposed to be directly influenced by the configuration of its immediate environment. According to the theory of routine activities, an offender is taking advantage of a criminal opportunity during his usual activities such as going to work, visiting relatives, etc. The rational choice postulates that an offender will try to minimise the effort and the risks to commit an offence while maximising the profit.

Subsequently, Rossmo transposed Brantingham’s theories into practice with the creation of the geographic profiling (GP). GP was firstly defined as a methodology of *investigation that uses the locations of a series of connected crimes to determine the criminal’s most probable area of residence* (Rossmo, 2000). It is based on the heuristic that offenders do not travel far to commit their crimes so that the likelihood to commit an offence deceases with the distance to his residence; this is called the “distance decay effect”. This heuristic is supported by both the rational choice and routine activity theories. It requires several crime locations to work effectively, and, therefore, it focuses primarily on crime series. This method is particularly effective at narrowing large pool of suspects (van Koppen et al., 2011) or at constraining an area for DNA investigation. Therefore, GP helps reducing the resources and time spent in investigations.

However, Rossmo’s definition of GP is too restrictive with respect to the evolution of the discipline. Indeed, the methodology can highlight any kind of anchor point of the serial offender such as work place, a relative’s residence, etc. Secondly, several locations can be connected to a single offence: the initial contact scene, the offence and disposal/release sites, etc., rendering GP applicable to that kind of single cases (Knabe-Nicol and Alison, 2011). Within this new canvas, GP can be defined as "*a specialized subset of behavioural analysis directed at examining the geographical and temporal decision-making of an offender, in order to provide an investigative advice*" (Knabe-Nicol and Alison, 2011 p127). This definition emphasizes the relationship between the time and space aspects in any decision process. As the investigator tries to understand this process, GP requires making hypotheses on the offender's behaviour. This hypothesis is often the constraint of proximity between the offence locations and the offender's anchor point. Besides, this definition broadens the scope of GP to any useful information that could help the investigators.

In practise, the 'spatial distribution' and 'spatial interaction' models are the most commonly used to determine a prior offender's search area. While the former model focuses on the geographic arrangement of crimes (central tendency and dispersion), the later analyses the offender's geographic behaviour through its mobility characteristics (Brantingham and Brantingham, 1981, Canter and Larkin, 1993, Rossmo, 2000, Kent and Leitner, 2009). GP-dedicated softwares provide basic spatial statistics such as the centroid, the centre of minimum distances, and the harmonic mean or the deviational ellipse to study the spatial distribution. Amongst spatial interaction models, the journey-to-crime (JTC) estimation techniques are mainly used to estimate the offender's anchor point. The form of the distance decay function does not seem to affect GP effectiveness. However, the function needs to be calibrated with solved cases on the study area.

GP techniques require specific conditions: the offence locations should be uniformly distributed around the anchor point and the offender should not travel too far to commit his crimes. This uniformity hypothesis is usually met in modern cities and grid-like road networks. This partially explains why GP has been successfully applied in Canada and USA but is still conspicuously lacking in European countries, excepting the UK, which are characterized by a small and highly populated territory with a complex road network. Indeed, researches in the Netherlands (van Koppen et al., 2011) and in Belgium. (Trotta, 2011) have shown that the uniform hypothesis is often not met. More concerns about the influence of the geographical features on the journeys-to crime are therefore needed to implement GP techniques in European cities.

New Bayesian approaches (Levine and Lee, 2009, Mohler and Martin, 2011) allow to take into account some of those geographical influences. Unfortunately, these methods mainly rely on Euclidean distances; therefore, they do not consider that the offender's journey can be constrained by some geographic barriers such as the road network and landuse.

Moreover, current GP methodologies are based on the heuristic of the distance decay function. As mentioned above, it requires an offender acting from his anchor point and committing his crimes uniformly around it. This behaviour is what defines a 'marauder' (Canter and Larkin, 1993). On the other side, less commonly, the behaviour of the 'commuter' is characterized by the non-respect of the uniformity and proximity conditions. There are, however, other heuristics that can be tested in order to explain those behaviours (Bennell et al., 2009).
Herewith, I propose two new hypotheses integrating recent researches on offender's behaviour to broaden the applicability of GP techniques to commuters and irregular

patterns of crimes. JTC variance and place attractiveness will be successively integrated in GP methods.

2 New hypotheses for serial offender's spatial behaviour

The first new heuristic is that a serial offender, by his repetitive behaviour, tends to minimize the variance in the distances travelled from his anchor point to the crime sites. This heuristic can be seen as a limit case of the distance decay effect where the buffer area is quite large in comparison with the distance an offender is willing to travel. As a result, the offender always travels just behind the 'too-risky area' and minimizes the variance of his journeys-to-crime. This heuristic presents several advantages. First, it is only based on the offender's own spatial behaviour. There is no distance decay that needs to be calibrated with already solved cases on the same study area. This is in line with recent observations that variance is much higher for inter-offenders JTC than for intra-offender ones (Lundrigan et al., 2010, Townsley and Sidebottom, 2010). Besides, this hypothesis could be specifically applied to commuter's behaviour where the variance between the journeys is small in comparison to the travelled distances (Mohler G and Martin, 2011). This heuristic should not be confused with the centre of minimum distance, which focuses on the place where the mean of the JTCs is the smallest.

Another concept needs to be integrated in GP methodologies: place attractiveness. (Brantingham and Brantingham, 2008) distinguished three kinds of places: crime attractor places, crime generator places and neutral places. Both the crime attractors (places known for their numerous criminal opportunities) and generators (locations with high concentration of both potential offenders and targets) are related with a higher attractiveness. This means that offenders travel longer distances to reach those locations than they do for neutral places. However, the measure of the absolute place attractiveness can be very difficult to estimate. At a small scale, urban hierarchy techniques can help to determine the places concentrating the highest levels of services that potentially attract people from 'remote' places. But at a larger scale, the influencing factors are numerous. The absolute attractiveness can also be approached by the Bayesian techniques with the origin-destination matrix. However, it is easier to estimate the relative attractiveness of places. This measure really makes sense in the context of a crime series as each offence location can be compared to the others.

According to Brantingham (2008), a distance decay effect can only be observed for neutral place. However, this affirmation needs to be nuanced: the slope of the distance decay actually depends on the place attractiveness; the more attractive is a place, the less steep is the slope (Trotta, in prep).

It is then possible to combine the assumptions concerning the distance variance and the place attractiveness. The places presenting the same profile in terms of attractiveness should reflect the same offender's decision process. The offender's anchor point should then be located at the place minimising the variance of offence locations with the same attractiveness profile.

The following sections of this article will successively present how to test the variance heuristic on a real environment when road network is used to estimate the travel distances. Then, a real serial rape series illustrates how place attractiveness can be combined with this new hypothesis.

3 A least square adjustment as a method

While integrating place attractiveness only requires a variation of the slope for the distance decay function, the first heuristic, minimizing the variance of the JTCs needs a new methodology. The problem can be mathematically defined as follow:

The observations correspond to the position of the n crime locations *(x_i)* presenting a similar attractiveness. The objective is to compute the value of the 2 unknowns: the constant travel distance on road network from the anchor point to each crime location (d) and the origin of all these journeys *(x_o).*

The location of the anchor point should then ideally solve the following equation system: for i= 1 to n,

$$x_i = x_o + d$$

However, if an offender is presenting a constant behaviour, small variations in human behaviours always exist. A v_i term is then introduced in the above equation: for i=1 to n,

$$x_i + \nu_i = x_o + d \tag{2}$$

Trotta et al (2011), working on constant departure time instead of constant travel distance, have demonstrated that the solution of such a system can be estimated thanks to a least square adjustment (LSQ).
As distance d is estimated on the road network, the LSQ cannot be computed analytically. However, a raster approach allows computing it numerically by comparing all local solutions. For each pixel j of the study area, the distance to each crime site (x_i) is calculated (d_{ij}). The local solution in pixel j is then given by the mean of the n (d_{ij}). The global solution is finally given, following the least square adjustment, by the local solution j that minimises the following equation.

$$\sum_{i=1}^{n} (\bar{d} - d_{ij})^2 \tag{3}$$

The raster process has the advantage of enabling the calculation on any point of the territory (more exactly on any cell). By contrast, the vector approach is constrained by the network nodes. The raster process can be described as follow. Firstly, a cost surface is created with the mask of the road network. A crossing cost of 1 is assigned to every pixel of the network while an infinite cost is given to pixels outside it. Any GIS software working with raster process (ex: GRASS, ARCGIS) is able to generate the cost distance from one specific location (in this case, a crime location) to any cell of the cost surface (the road network) (ex: the function “CostDistance” in Arcgis). See (Trotta et al., 2011) for the description of the algorithm. The raster calculator computes then for each pixel the mean of the d_{ij} and the local values of equation 3 corresponding to the sum of the squares of the residuals (SSR).

A major question of this methodology is to provide an upper bound above which the hypothesis of constant travel distance cannot be accepted. The variance on the travelled distances (S^2) is given by the ratio SSR/n. As the residuals of the least square adjustment are assumed to follow a normal distribution, the a-priori variance corresponding to the tolerated variation existing in all human behaviours restricted the value for S^2 (Dixon and Frank, 1983).

$$\frac{S^2}{\chi^2_{1-0.5\alpha}/df} < \sigma^2 \tag{4}$$

where σ² is the a-priori variance, S^2 is the variance computed with the ratio SSR/n and the degree of freedom for the χ^2 Test is given by $n-1$. It is then possible to build the following test:

$$S^2 < (\sigma^2 \times \chi^2_{1-0.5\alpha}/df) \tag{5}$$

which means that, for a chosen variance (σ^2), the hypothesis of constant travelled distance is validated for all the pixels with a value inferior *to* $n*\sigma^2 * \chi^2_{1-1/2\alpha}/df$

4 Implementation on a real crime series

This section illustrates how this new method can be implemented on a non-uniform pattern of unsolved crimes attributed to the same unknown offender.

I use data concerning 18 rapes committed by a single offender on a short period of time (between April 2004 and May 2008) obtained via the Federal Police of Belgium. The objective was to delineate a priority area around crime locations for DNA testing as the offender was assumed to be local. The series presents a pattern focusing on two different city centres and the uniform distribution principle required to apply previous methodologies is not respected. Besides, as Belgian police does not have a long tradition in crime mapping, there is no information concerning already solved cases in the area available. The figure 1 presents the distribution of the crime sites with each number corresponding to its position in the chronology of events. All the crimes were located near a major road or near one of the two cities centres, not far from pubs or nightclubs. The first event (in chronological order) presents the particularity to be located in a small village where no attractive location could be identified.

Based on this data, two different profiles of place attractiveness are identified: the attractive city centres and the isolated rural area. The hypothesis of constant travelled time is then tested for all the crimes except the first one. One difficulty is to estimate the a-priori variance chosen to determine the upper-bound under which the hypothesis could be accepted. As the distance between the two sub-patterns is about 10 km, we consider that 10% of this distance can approximated the offender's variability, corresponding to a variance of (1000)², with a resolution in metres. The figure 2 illustrates the area delineated by the computation of SSR/n < σ² * $\chi^2_{1-1/2\alpha/df}$ for with $\alpha = 0.05$.

As the first event is isolated and neutral in term of attractiveness, a linear distance decay function is then applied from this unique crime location. In order to combine both results to create a prioritized search area, each pixel under the upper-bound of the first treatment is multiplied by its distance to the first crime location. (Figure 3)

The actual residence of the offender was finally located very close from the first crime location and inside the area delineated by the minimization of variance. Those results favour the existence of another spatial hypothesis underlying the decision process of serial's offenders (minimisation of the JTCs variance) and the necessity to nuance the classical assumption of distance decay with regard to place attractiveness.

Figure 1: The pattern of crime locations is far to be uniformly distributed.

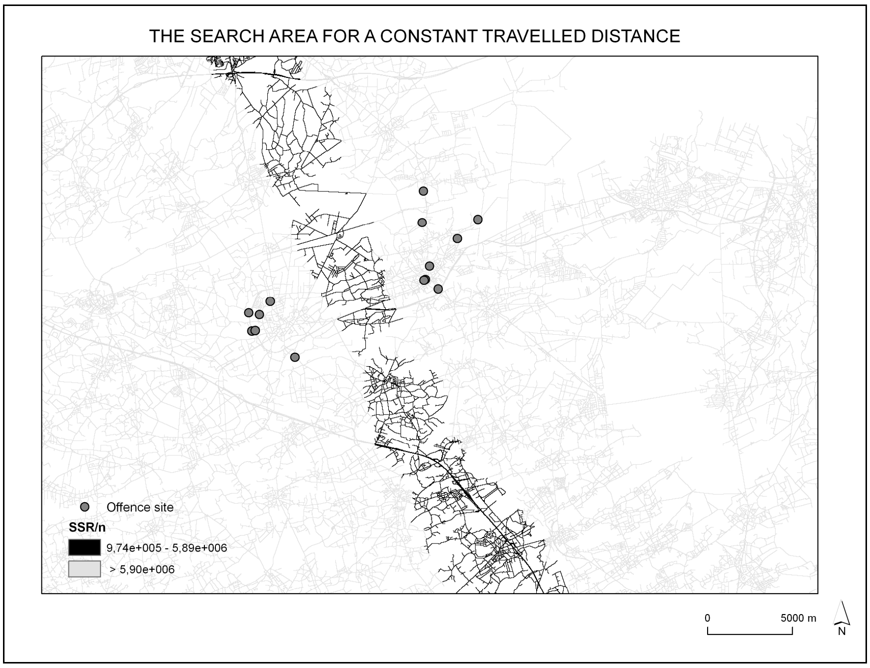

Figure 2: The χ^2 test, considering an a-priori variance of (1000)² delineates a search area between the two sub patterns of offence locations (in black on the map).

5 Conclusion and perspectives

This paper discusses the opportunity to develop new hypotheses to describe the serial offender's journeys-to-crime when the crime pattern is not uniform. Two hypotheses: constant travel distance and a distance-decay effect varying with place attractiveness are proposed to describe the decision process underlying such pattern. An original approach in raster mode, based on least square adjustment, is then proposed to test the hypothesis of constant travelled distance. An unsolved case of serial rapist provided by the Belgian police illustrates how the combination of both assumptions results in a prioritized search area for DNA testing.

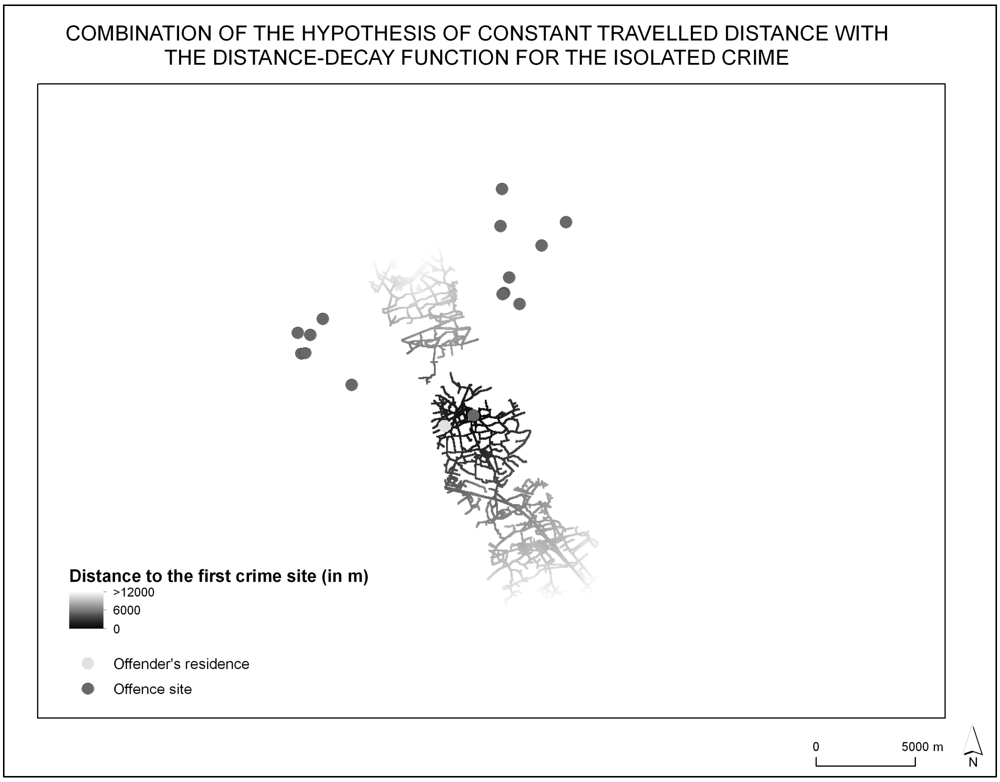

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Figure 3: The distance decay function from the first event prioritizes the results provided by the hypothesis of constant travelled time, the solution of the LSA.

Several improvements could be made on this methodology. Firstly, the relative attractiveness of each crime location could be estimated with a matrix of origin-destinations of solved cases. Secondly, if a lot of researches have focused on the average distance travelled in journey-to-crime, literature concerning the variance is very limited. A better understanding of the variability of human's choices under the same decision process would help to choose the best a priori variance. Finally, human decision processes are also influenced by their perception of space. Time distances could then better describe the offender's journey-to-crimes.

Acknowledgment

The research achieved by M. Trotta is funded under F.R.S.-FNRS fellowships (Belgian National Fund for Scientific Research).

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