Visualizing the Spatial Movement Patterns of Offenders

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ABSTRACT

Within spatial analysis, the decision-making process of individuals involves six interconnected and fundamental elements: current location, destination, distances, and directions, time budgets and type of activity, all of which influence the movement of people in their environment. In this paper we develop a visualization technique allowing for the display of the aggregate travel paths of offenders in order to identify patterns with it. We show that the patterns in the movement for offenders follows that of the major travel routes within the area and is centered in locations of the city-hubs. Results also indicate that significant movement of offenders occur between cities, not just within cities. Consequently, it is shown that urban form and understanding place play a strong role in criminal patterns and offender movement through the city landscape.

Categories and Subject Descriptors
I.6.6 [Simulation and Modeling]: Simulation Output Analysis – Simulation Output Analysis

General Terms
Algorithms, Experimentation, Security, Human Factors

Keywords
Line density, offender movement, visualization, flow volume

1. INTRODUCTION

Each person will routinely travel along paths between only a handful of locations, such as their home, work, and nearby shopping. With each and every trip, they will familiarize their knowledge further about the path, and everything along that path. Since people are familiar with the paths they travel frequently, they are more comfortable in them, as opposed to moving into unfamiliar areas. These familiar areas become the person’s Activity Space. Offenders, just like people, have their own Activity Spaces they build up from their regular non-offending portions of their lives, as well as through their offending activities. According to Crime Pattern Theory [1], offenders prefer opportunities that are within the area they are familiar with and will use those locations to commit crimes, rather than exploring new areas with which they are not familiar with. This is intuitively correct. If the offender leaves their Awareness Space in search of criminal opportunities, they will have to enter unfamiliar territory and hunt for an opportunity; this exercise is unnecessary if the offender is already aware of a similar opportunity within an area they are familiar with. Thus, the areas where the offender will commit crimes will be sub-regions of the Activity Space.

The purpose of the research presented in this paper is to further explore the properties of offender movement in order to identify patterns that can be acted upon. More specifically, the model in this paper, called the Offender Path Density Estimator (OPaDE), contributes to the understanding of the Activity Space by 1) introducing a model through which individual offender travel patterns can be aggregated, 2) analyzing the aggregated travel patterns of offenders to find correlations between them and the underlying city topology, and 3) applying the model to real crime data to illustrate the efficacy and practical value of the model.

2. RELATED WORK

Several methods have been proposed to determine the locations within a city that act as frequent Awareness Nodes to many offenders. One of these methods [2] used straight distance measures to calculate the nodes in the Activity Space for frequent offenders based on the direction of travel between their home locations to their event locations for which they have been apprehended. The model, when applied to 57,962 offenders in the city near Vancouver, Canada. The locations of the nodes which were detected by this approach were highly correlated to the major hubs within the city.

Another method is similar in concept to [2] but uses a probabilistic model involving the road-network. This model [3] assumed that the crime event location was situated where it was due to some directional preference of the offender, that for some reason the offender wanted to travel in that direction, but then stopped to commit a crime along the way. The model involved the extension of the offender’s path along the road-network in the direction of offender movement (from home to crime location), but, since the path along the road-network does not coincide with the direction of travel from home to crime location, thus a Monte-Carlo-style simulation was employed to assign probabilities to various paths leading away from the crime location. Results indicated that, similar to [2], most paths led to the major hubs within the city, such as shopping malls.

Aggregate travel patterns have also been analyzed by applying colours in order to visually identify which directions offenders are traveling to [4]. Although this reveals travel patterns in various parts of the region, offenders moving towards city-centers for example, or in some cases offenders traveling towards another city to commit crimes, it does not visually indicate the entire travel path of the offender. Do the paths extend all the way into the city-center, or into another city? Are there regions where a lot of offenders have paths while other areas do not? Is there a pattern

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3. METHODS

Although the aggregate movement of offenders within, and in between, cities has been explored [2, 3], to the best knowledge of the authors no work exists which is able to visualize the aggregate set of paths that offenders take from their home location to their crime locations. Visualizing these paths would allow for the analysis of patterns to determine which areas of the city (or cities) offenders move between. The closest visualization technique coloured the starting node of the offender with some colour representing the direction of movement away from home [4]. There was no way to analyze the destination, or path to the destination, using this model. The end goal is to generate a map of paths for all offenders in the area in order to see the travel patterns of the offenders within and in-between the cities.

A technique called Line Density [5], developed by ESRI ArcGIS Desktop and included in Version 10 of their line of GIS software, proposes a solution by setting up a grid of fixed size, and calculating the amount of another feature (in this instance a line) that falls within the grid. Xuejiao et al. [6] use a kernel density estimation function to measure road density in Pearl River Delta in southern China. After calculating the road density, the relationship between the road density and landscape fragmentation was quantified. The results show that the area with higher road density is dominated by a larger portion of build-up landscape. Offender Path Density Estimator (OPaDE), the model presented in this paper makes use of this technique in order to find regions of high offender travel. The first step is to construct the Paths (Chapter 3.1), after which a Line Density Map is created (Chapter 3.2) and the analysis can be performed (Chapter 3.3).

3.1 Generating Journey to Crime Paths

Although people do not move in a straight line from one point to another as they are constrained by the topology of their environment, many studies still ignore that topology. The method in this paper is focused on aggregate patterns on a city-wide scale, where the exact topology of the landscape, and the specific details of the road-network built into it, start to become irrelevant and movement mimics that of a straight line. Thus, for the purposes of this study it will be assumed that the path of movement between two locations is that of a straight line (Figure 1).

First, the coordinate of home location \( h \) with x-y coordinate \((H_{xh}, H_{yh})\) and crime location \( c \) at x-y coordinate \((C_{xc}, C_{yc})\) were derived from each offender’s home address and crime address by calculating the x-y coordinates of both locations from the road-network, a process called geocoding. After the starting point, i.e. home location \( h \) at \((H_{xh}, H_{yh})\), and destination point, i.e. crime location \( c \) at \((C_{xc}, C_{yc})\), were identified, a straight line path from home \( h \) to crime location \( c \), denoted as \( L_{hc} \), was generated for each pair of starting points and destination points. Each line path was constructed using ESRI ArcGIS’s “XY to Line” tool from Data Management tool set.

3.2 Generating Line Density Map

Line Density Model (LDM) calculates the density of lines by summing up the value of the weighted line segments which fall on a specified neighborhood. LDM is a grid based model and the line density calculation is processed based on each grid cell. The grid plane, usually, is a rectangle covering the study area and the grid plane is split up into an \( m \) by \( n \) grid cell matrix, with \( (i,j) \) representing a specific cell. The output density result loses the local variation details as the grid cell size is increased. In this study, we used 100m x 100m grids by some experiments.

For the grid cell \((i, j)\), a circle whose search radius is \( r \) and its centre is \((i, j)\) is drawn. Once the circle is drawn, the length \( (L_m) \) of each line segment falling on the circle is multiplied by its weight value \( (W_m) \) (Figure 2). The weight value could be used if each line segment has different weights. To calculate line density \( D(i, j) \), the multiplied values \((L_m * W_m)\) are summed up and divided by the area of the circle [7]:

\[
D(i, j) = \sum_{m=1}^{n} (L_m * W_m) + \pi r^2
\]

**Search radius \( r \):** All the line segments falling on the circle with the radius from the center \((i, j)\) contribute to the density for the grid cell \((i, j)\). If a large search radius is used, you can see the general trend of the density map, but the model will lose detail. In this study, we specified the search radius as 250m. There is no rule to set the search radius to any specific value, and \( r \) was set to 250 meters in this study after some experiments to produce the best output result which displays both the general and local trends.

**Line weight \( W_m \):** Each line could have a different weight, based on maximum speed limit or number of lanes in roads. In this study the weight simply was set to \( 1 \) for all lines. Line Density function in ESRI ArcGIS Desktop 10 was used to generate the Line Density Model.

4. RESULTS

For the analysis presented in this paper, a collection of databases, called the Crime Data-Warehouse (CDW) was used. The CDW is a research database located at the Institute of Canadian Urban Research Studies (ICURS) at Simon Fraser University. It contains five years of real-world crime data (from mid-2001 to mid-2006) for the Province of British Columbia (BC), Canada, from Canada’s national police, the Royal Canadian Mounted Police (RCMP). For each person involved in each crime, the relevant attributes for this model include the full name (first, last and
middle), home address, and the type of their involvement in the crime. People having the same name were assumed to be the same person. If the location specified in the database was invalid and could not be assigned an x-y coordinate, it was ignored.

Six RCMP jurisdictions were used for studying the Paths of offenders. These jurisdictions included North Vancouver, Burnaby, Coquitlam, Richmond, Surrey, Langley and Chilliwack. This is shown in Figure 3. Regions in light-green were regions where the RCMP did not have jurisdiction and hence those regions could not be included in this study. This yielded 258,333 crimes, where the offenders’ have a valid x-y coordinate for home location and crime locations. Line density in this study was calculated based on those 258,333 crime events.

4.1 Patterns for the Lower Mainland

Significant high line density patterns were found near the regional shopping centers directing from/to those shopping centers. Metrotown (M), Surrey Central Mall (NS), Coquitlam Centre (C), Willowbrook Mall (L), Lansdowne Centre (D) and Semiahmoo Mall (SS) are big shopping centers and line density values are very high around those shopping centers (Figure 4).

Significant high line density patterns were lined up with major traffic transportation routes. Red color patterns, denoting a high density of paths, were found along the BC Translink Sky Train lines (equivalent to an above-ground sub-way system):

- Expo Line runs from Vancouver (V) to North Surrey (NS) passing through Metrotown (M)
- Millennium Line runs from Vancouver (V) to Lougheed Mall (B) and Metrotown (M)

High line densities were found along major roads between cities:

- Lougheed Highway runs from Vancouver (V) to Lougheed Mall (B), Coquitlam Centre (C) and Maple Ridge (MR)
- Fraser Highway runs North Surrey (NS), Langley’s Willowbrook Mall (L) to Abbotsford (A)

The biggest line density cluster was found in Whalley, the north side of Surrey (NS). Whalley has many small retail shops in addition to the Sky Train stations and a big regional shopping centre. This area is also known as one of the biggest crime hot spots in the Lower Mainland, BC. This line density map shows that significant number of crimes in Whalley are accounted by the local offenders as (NS) is surrounded by a lot of high density lines which quickly disappear in most directions away from (NS).

The output map shows that many crimes are coming from the East side of Vancouver (V). Because this study does not include Vancouver crime data, we can assume that Vancouver East is the crime journey starting point and not the journey destination. This is because if it were the destination, then the offender would have been caught in Vancouver by the Vancouver Police Department, and thus not be in the dataset used for this paper. This means that the East side of Vancouver is one of the most significant areas where offenders are coming from to commit crimes in the Lower Mainland BC, especially regional shopping centers.

Last, as we assumed, geographic features such as big rivers and inlets worked as the journey blocker. More line path patterns were found between Coquitlam (C) and Maple Ridge (MR) than Langley (L) and Maple Ridge (MR). Coquitlam (C) and Maple Ridge are connected by a bridge whereas Maple Ridge (MR) and Langley (L) were not connected by road when the crime data was collected.

4.2 Line patterns of regional shopping centers

After a 500 meters buffer circle was drawn from the center of the six major regional shopping centers (Metrotown, Lougheed Town Center, Guildford Mall, Surrey City Centre, Coquitlam Centre, Willowbrook Mall), crimes committed inside the buffer were selected (Figure 5). Once the crimes were selected, six line density maps were generated for each shopping center with the same method conducted in Chapter 3.2.

Line density maps were generated for each regional shopping center with same scale and same symbology so that they can be compared easily. Line density values less than 30 m/Km² were eliminated to display the pattern clearly. The maximum value was found between the East side of Vancouver (V) and Metrotown (Figure 5). The line pattern from the East side of Vancouver was found in the five maps except for the one in Willowbrook Shopping Centre Mall in Langley which is farthest from the Vancouver (Figure 9). In other words, offenders from the East side of Vancouver travel to Burnaby (M), Coquitlam (C) and Surrey (NS), but the journey was limited to Langley (L) for some reason, such as travel distance or by the lack of public transportation (Figure 6 – 11).

Metrotown (Figure 6) is the province’s largest shopping center. The biggest and strongest pattern was found in this map, much more significant than that of the other five malls. Major incoming flows are from the East side of Vancouver (V), Surrey (S) and Coquitlam Centre (C). Especially, offenders’ travelling path from the East side of Vancouver to the Metrotown Centre Mall showed the most intensive pattern.

Many offenders are coming from the local neighborhoods to Coquitlam Centre (Figure 7), except two long paths from the East side of Vancouver (V) and Maple Ridge (MR). According to the results, most of the offenders at Surrey Central City (Figure 8) and Guildford Town Centre (Figure 11) are local, with a significant volume of offenders having a path from Vancouver East side (V) to this mall. Willowbrook Mall is the only mall (Figure 9) where a significant number of paths from Vancouver (V) were not found. Most of the incoming paths are from local offenders including Whalley in Surrey (S). Similar to the previous shopping centers, Lougheed Town Centre (Figure 10) also seems to attract local offenders, with the exception of the significant number of people having a path from the East side of Vancouver (V).

5. CONCLUSIONS

The incentive behind this line of research is to better understand the Activity Space of offenders, with the eventual goal of identifying the motivations behind an offender's target selection from a spatial perspective. With the method presented in this paper, called OPaDE, the specific goal was to visualize and analyze the aggregate patterns of offenders. Since there was a clear lack of literature in this type of visualization, and no technique existed within the field of criminology to permit the type of modeling required by OPaDE, the Line Density method was borrowed from geography allowing for the visualizations.

Thus OPaDE was applied to 258,333 crime events in the Greater Vancouver Regional District, and the results mapped and analyzed. This study gives a unique picture of inter-metropolitan flows of offenders and clearly indicates why looking at movements of offenders only in a single jurisdiction gives a distorted picture of the situation. The results clearly indicate that a
lot of movement happens between different cities and these patterns must be taken into account when looking at, or creating, crime statistics. It was further found that a lot of Paths led to Vancouver, surprisingly, especially given that the model was specifically missing data for the City of Vancouver.

Although OPaDE was able to identify the city-hubs within the city, and the major arteries connecting them, the model does have some shortcomings. It currently is limited to direct travel paths for building the line density statistic for each grid, where in reality offenders do not fly as the crow does, but are constrained to the road-network within the city. OPaDE should be enhanced to handle the road-network, at which point the challenge then becomes identifying the exact path along the road-network the offender took from their home location to their crime location.

6. REFERENCES