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Improving Geocoding Rates in Preparation for Crime Data Analysis

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Abstract

Problem-oriented policing requires quality analyses of patterns and trends in crime incidences. Included within this is the identification of geographical clusters or hot spots. Crime incident records must first be geocoded, that is, address-matched so as to have X,Y grid co-ordinates attached to each record. The address fields typically have omissions and inaccuracies whilst a good proportion of crimes occur at non-address locations. This results in the geocoding having an unacceptably low hit rate. We present and test an improved approach to geocoding of crime records that raises the hit rate by an additional 65% to an overall rate of 91%. Kernel density surfaces show that these additional geocoded records have distinct spatial patterning which, furthermore, indicate

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that without the improved hit rate, hot spots of crime also tend to be hot spots of missing data.

Keywords: spatial databases and GIS, clustering, data cleaning, geocoding, crime mapping.

1. Introduction

During the 1980s and 1990s policing in North America and Europe progressively shifted its focus from a reactive incident-driven approach to a pro-active problem-solving approach. Problem-orientated policing [1, 2, 3] is an underlying philosophy which suggests that policing is not just about enforcement of the law but should be more about solving underlying problems within the community – not just catching criminals but working in partnership with other agencies towards crime prevention. Underlying most approaches to problem-oriented policing and crime prevention is the understanding that crimes tend to form patterns [4]. These patterns are the discernible manifestation that a repetitive process is at work which, once understood, can be modified or stopped through an appropriate set of interventions that may be legal, social and/or situational. The patterning of crime occurs in one or more key dimensions: spatially, temporally or in the attributes of the modus operandi (MO). The patterns of most interest would either form a clustering or exhibit a degree of regularity. Both have an element of predictability. Geographical Information Systems (GIS) have been used since the early 1990s to assist in identifying geographical clusters of crime, commonly known as hot spots [5, 6, 7].

Crimes are taken as discrete point events recorded as occurring in a specific location, often against a postal address. Additional attributes of the occurrence will

include date and time, details of victim(s), MO and description of offender(s). These will be recorded against specific fields (often as codes) in a database by the reporting officer either from notes made at the scene of a crime by him/herself and colleagues, as reported at a police station or from statements made over the phone. There are also free-text fields used to incorporate longer descriptions of an event. By way of example, the crime recording system for one metropolitan police force in the UK is organized into 78 tables to record over 700 possible variables of a crime using a unique crime number to join the tables. The volume of crime for this same metropolitan area, requires the recording of just over one million crimes each year – an average of 2 every minute. Even with a commitment for due diligence and attention to detail on the behalf of police officers, the volume of crime in relation to the size of the police force means that omissions and inaccuracies are inevitable. Data quality is thus a recurrent issue for crime data analysts [8, 9] and has important repercussions in drawing tactical and operational conclusions from analyses. One difficulty faced by UK police forces is in consistently and accurately locating crimes geographically. Unlike in the US, for example, where street patterns are predominantly rectilinear and their naming may form some numerical or lettered progression, UK urban street patterns tend to be sinuous, dense and complex – accurately recording all elements of an address often necessitates asking a local resident. Address fields in databases are designed around identifying an individual property leaving non-addressed locations (e.g. a recreational park, road junction, bus station) to be recorded/described in free-text fields. When it comes to mapping crimes as point events, it can easily be the case for some crime types (such as street crime) that considerably less than 50% of the records can be cartographically mapped directly from the database records. Such problems for crime mapping, with

obvious consequences for the reliability of any further analysis and decision-making, are by no means confined to the UK [5].

In this paper we present an improved and tested approach to increasing the mapping rate of crime data so as to make crime analyses meaningful. This approach incorporates data cleaning, text mining, specially prepared gazetteers and novel reconfiguration of data sets. We begin by briefly reviewing the key methods for identifying geographical patterns in mapped crime data and hence the significance of data quality. We then discuss the general means by which logged location records of crime incidences are batch converted to map co-ordinates (geocoding) and the problems that arise. We then present details of our improved methodology for geocoding. Finally we provide evidence of the comparative performance of the methodology on 90,904 crime records and discuss the implications of the results.

2. Approaches to hot spot detection in crime data

At the heart of problem-orientated policing is the analysis of crime data within the framework of the problem analysis triangle (PAT) [3, 10] which focuses on the three key facets of any incident: the incident location, the victim and the offender. Not only does incident location furnish important environmental variables that may be conducive to or regularly associated with certain types of crime [11], but the spatial relationships between incidences and the geographical clustering of crime add understanding of overall trends and risks of re-victimization [7, 12]. High crime areas are primarily so because they are areas of high repeat offending and high repeat victimization [13, 14]. Thus existing crime patterns are a usable predictor of future victimization [15]. GIS are extensively used by police forces for analyzing geographical patterns of crime, and their

use in the detection of hot spots has been extensively discussed in the literature [5, 6, 12, 16, 17, 18, 19, 20]. Yet, there is no standard definition of a hot spot. The most commonly understood meaning within police forces focuses on crime counts: an elevated share of crime in a localized area. The process begins with geocoding, that is, by matching the address or some other location identifier of an incident with grid coordinates stored in a geographical base file (GBF). The distribution of crimes can thus be displayed as points against a map backdrop and analyzed alongside their own and other attributes. Early electronic displays of 'pin maps' (such as Figure 1(a)) allowed subjective judgments of pattern and identification of clusters, but lacked consistency from one individual to another. Experiments have shown that considerable variation can arise in the visual perception of clusters in a distribution of point events [21]. Hence the need for more objective approaches.

A widely used approach to more objective identification of clusters is point density estimation with functionality available, for example, in CrimeStat®, Spatial Analyst extension to ArcView® and Hotspot Detective® for MapInfo®. This is an interpolation that transforms the point events into a gridded continuous surface of density estimates (incidences per unit area) which is then colored or gray-scaled so that the peaks in the surface (the hot spots) are easily visualized. The algorithm of choice is kernel density estimation [22, 23, 24] which uses a Gaussian function across a pre-determined bandwidth (radius) to provide a smooth estimate of point density that is quick to calculate (see Figure 1(b)). Although this approach to hot spot detection has been criticized for its subjectivity in parameter estimation [6, 20], it remains a popular, highly visual approach that forms an important 'first sieve' in focusing attention on high crime areas that are then further analyzed in greater detail.

[Figure 1 about here]

It should be clear from the above, that the process of geocoding is a critical step in achieving quality analyses of geographical pattern and trend within the framework of the PAT. The ideal would be for 100% of records to be geocoded, but in practice this is rarely achieved. Few police forces publish their geocoding rates. Quoted figure for the US [25] suggest a range from 41% to 99.7%. Our experience of UK geocoding rates prior to the implementation of the methodology presented here would suggest that high geocoding rates were only achieved after considerable manual plotting of records by analysts.

3. Issues in geocoding

Geocoding is the process of attaching a mappable spatial identifier to database records. A mappable spatial identifier is often in the form of X,Y grid co-ordinates (two fields) but could be a single field containing a numeric or alpha-numeric identifier corresponding to the primary key in a GIS layer. The fields used in a database for geocoding would be those corresponding to either a complete address or the generalized elements of an address (postcode, district). For crime mapping it is desirable to have the highest resolution and therefore the objective of geocoding is to attach the X,Y grid co-ordinates of an individual property on the basis of it's full address. The UK mapping authority, the Ordnance Survey, produces a GBF for this purpose called Address-Point® which includes all 27 million addressable properties in the UK and conforms with the Post Office Address File (PAF) which lists all delivery addresses to British Standard BS7666. These lookup tables are regularly updated.

The immediate problem lies with the accuracy with which addresses are recorded and entered into a crime records system [5, 11, 25, 26]. Entries may not necessarily conform in structure to BS7666, may contain typographical errors, a range of abbreviations, omissions or may even be based on inaccurate or purposely misleading information provided by members of the public. Furthermore, postcodes in the UK are by no means permanent. They are a device of the Royal Mail (post office) and, having no statutory basis in law, can and are changed with little or no consultation in order to optimize mail delivery in response to local changes in the number of delivery points. Residents often continue to use their former postcode long after it has been changed. A further issue is that not all places where crimes happen have a BS7666 address. Examples would be on a railway line, in a public open space or on a bridge. Road junctions provide address ambiguity as there may be up to four corner properties. Non-addressable locations and road junctions are usually recorded in a free-text field with the address fields left blank. Railway stations and other prominent landmarks such as public buildings are often entered by name with no further address elements.

A number of commercial software products, such as Matchcode® and QAS®, have been developed to solve many of the common problems associated with address-cleaning, address-matching and geocoding. These use methods of standardization and parsing [27] to correct common errors and abbreviations so as to achieve a match with the PAF and/or Address-Point® and thus attach the grid co-ordinates to a crime record. In a batch process an unambiguous match to an individual property needs to be achieved if grid co-ordinates from Address-Point® are to be attached. Whilst in interactive mode ambiguities may be resolved by an operator in order to increase the success or hit rate, for a large metropolitan area this might typically entail manually

processing thousands of records a month. There are also the non-addressable crime records which these commercial address-matching products are not designed to solve. In a test reported below, batch processing using commercial software would typically geocode only half the records. Whilst analysts may be satisfied to take whatever is geocoded as a 'representative sample', there have been no reported studies of what is not geocoded so as to establish the extent to which the hit rate might be spatially biased. Clearly a more sophisticated approach is required.

4. An improved approach to geocoding crime data

A new geocoding toolkit has been developed and tested in order to improve the hit rate. The toolkit has been created as VBA macros, prototyped in Microsoft® Excel and ported to Microsoft® Access. Our purpose has not been to replace commercial address-matching software but to enhance the outcome of the geocoding process by building additional steps and tools around commercial software. The general strategy has been to move from the specific to the general, from establishing as accurately as possible the individual address or road junction, to a small area in the vicinity of the address (postcode) to a section road within a more approximate area. This has resulted in a five-stage process as shown in Figure 2.

[Figure 2 about here]

The first stage is a pre-process function to clean common errors arising in the address fields. Whilst some of these may be automatically taken care of by commercial address-matching software (e.g. Rd changed to Road), a catalogue of minor errors (e.g. letter 'O' mistakenly used instead of number '0' in postcode elements reserved for numerals) were mined from the crime records system and incorporated into the cleaning

process. Also, each address field is checked for consistency and if necessary inappropriately placed entries are moved to the correct field, any padding is removed and non-address entries (e.g. 'car park' or name of railway station) moved out of address fields and into new fields for later processing. The effect of this process is to increase the geocoding hit rate by the commercial software by up to 5%. It also prepares some of the data fields for subsequent stages.

In the second stage the data are passed through commercial address-matching software and where an individual property level match is achieved; then grid coordinates are attached by the commercial software from Address-Point®. In the process, all postcodes are cleaned where possible either from the full address or from a partial address (road name and district) where there is no ambiguity as to which postcode is correct. All addresses successfully geocoded at this stage are given the validation code 'L1'.

In the third stage, the process focuses on non-address locations. The majority of these are road junctions and can be found in the free-text field describing the venue of the incident. Other non-address locations would include railway stations, bus stations and prominent landmarks. The junctions are text mined by searching for keywords. These include J/W J,W JCT JTN JCTN WITH and other variants. Two road names then need to be mined out of that free-text field and recorded in separate new fields. In order to achieve this a pattern recognition exercise was run on a street gazetteer in order to determine key association rules and ordering. Thus it is theoretically possible to have Acacia Road, Acacia Hill, Acacia Hill Road and Acacia Hill Road East together with Rd and Rd. abbreviations for Road and/or E and E. abbreviations for East. A hierarchical approach was devised where, using lookup tables of all possible entries (other than the

root name e.g. Acacia) and their possible abbreviations. Cardinal directions (North, South, East, West) are first identified and if found the search continues with the word to the left. Then finalizations (other than cardinals) such as Road, Street, Avenue, Approach, Broadway and Drive are searched. When found there is a search for possible intermediates such as Hill, Dale, Spring and Wood. Finally the root name element is captured. This process results in two new fields giving two road names that form the junction. In order to geocode a junction, a lookup database of all junctions and their grid co-ordinates is required. This did not exist. In order to create one, the Ordnance Survey road center line product OSCAR® was reconfigured using a MapBasic® macro in MapInfo®. The method is given in Figure 3. The OSCAR® product provides two layers: a road sections (links) layer and a nodes layer for junctions. Road names are attached to links, not to nodes. So the reconfiguration process is to intersect nodes with links, extract the names, organise into pairs of roads coming into junctions, attach grid co-ordinates and deduplicate the final table. This was then matched with postcodes and districts and indexed. For the specific metropolitan area for which the toolkit was created, this new junction database contains 107,355 junction records. Gazetteers of other non-address locations were also created to facilitate their geocoding. Non-address locations geocoded in this stage are given the validation code 'L2'.

[Figure 3 about here]

In the fourth stage, all remaining records with a valid unit postcode are geocoded at the postcode level. Postcodes in the UK are defined by delivery points, not by a bounded geographical area. There are on average 15 delivery points per unit postcode but this number is extremely variable across the UK. For the metropolitan area in this project there are 196,512 postcodes having an average area of 8,000 sq. meters

(approximately 2 acres). The Ordnance Survey product Code-Point® provides population-weighted centroid co-ordinates for each unit postcode. This has been produced from Address-Point® records. A simple database join on unit postcode allows geocoding to take place. Records geocoded in this stage are given the validation code 'L3'.

The final stage of the toolkit attempts to geocode all remaining records according to road name. The problem here is that some roads are very long and some road names, such as High Street, are repeated in different districts. The search needs to be limited in some way. At the Call and Dispatch centre (CAD), a 250m grid code, the CADref, is added to an incident record in order to give its approximate location. CADref can be unreliable but if buffered and intersected with named roads a candidate section of road could form the basis for geocoding. Again, OSCAR® was reconfigured using MapBasic® into a file which contained the digitized intermediate points along all links against road name (procedure in Figure 4). These were then matched with CADref so all the digitized points of a road falling within a CADref could be identified. The final index file contains 543,023 records. If a match for road name and buffered CADref (by one half grid cell on all sides) is achieved then a digitized point for the relevant section of road is chosen at random and used to geocode the crime incident. This is the least accurate level of geocoding and records are given the validation code 'L4'. Nevertheless, the geocoded crime incident falls on the road specified in the crime record and in the approximate area of the CADref provided.

[Figure 4 about here]

5. Results

The improved approach embodied within the toolkit was tested by batch processing one month's crime records for a large (157 sq. km; 61 sq. mile) metropolitan area in the UK. This amounted to 90,904 crime records. Table 1 summarizes the hit rate for each level, with an overall hit rate of 91.1%. The commercial address-matching software, even after the enhancements of the pre-processing stage, only achieves a 55.4% hit rate (L1). Between L2 (junctions) and L3 (postcodes) another 20% is added. Surprising is the 16.8% that would then have been left un-geocoded if it were not for the combination of road name and CADref (L4). The improved methodology has taken the geocoding hit rate from a position that is clearly unacceptable [25] to one which can be taken as a sound basis for crime analysis.

[Table 1 about here]

In order to visualize and explore the spatial dimension of Table 1, a series of kernel density surfaces has been produced using a public domain code for MapInfo® [28]. In order to be consistent, Figures 5 through 7 have all been constructed using a 500m bandwidth across a 250m grid surface. However, the gray scale legend is different for Figure 5 as compared with Figures 6 and 7 because of changes in the range of densities present. Figure 5(a) shows the density surface for all the successfully geocoded records (L1 to L4). This is the best picture we are going to achieve from a batch process though some 9% of data is still missing. It shows a concentration of crime (hot spot) over a wide area of the city center and in the inner city residential areas with other more or less well-defined hot spots in a number of suburban districts. Figure 5(b) shows L1 geocoded records. Overall it looks similar to Figure 5(a) but at much lower intensities with the city centre having a spatially more restricted peak. Overall levels of

crime in Figure 5(b) might be concluded as being much less severe in the absence of Figure 5(a) with the suburban hotspots appearing much milder than otherwise would be the case.

[Figure 5 about here]

Figure 6 is Figure 5(a) minus Figure 5(b). Note the difference in scale of the gray shading. The feature that is striking is that overall, the pattern presented is similar to Figure 5(a), suggesting in fact that hot spots of crime are also hot spots of un-geocoded records. This would seem intuitive if one considers that the intensity of law enforcement activity within hot spots and the pressures on the police officers detracts from their ability to carefully and fully record the location of incidences.

[Figure 6 about here]

Figure 7 shows density surfaces for L2, L3 and L4 geocoded records. Overall they show a concentration of poorly addressed records and non-address records that have been resolved around the inner city. On the one hand the older heart of the city have the most complex road patterns. Commercial buildings here have a tendency not to display a number and often company names are recorded instead. This is also the area with the greatest on-street movement of people (day and night) and concentration of parked cars and hence a higher propensity for on-street crime compared with other areas of the city. Figure 7(a) would suggest a distinct spatial bias in L2 (predominantly road junctions) on a north-south axis across the city center, though the reason for this is not clear. L3 geocoded records in Figure 7(b) shows a tendency to pick out some of the suburban hot spots, whilst L4 geocoded records in Figure 7(c) picks out others. This may reflect differing local practices within individual districts in the attention given to recording the location of crime incidences.

[Figure 7 about here]

6. Conclusions

An improved approach to geocoding of crime data in preparation for crime data analysis has been implemented and tested. The performance of commercially available software on their own are not adequate given the particular issues and complexities of crime records systems. By improving the hit rate through additional processing, a further 65% of crime records can be geocoded as point events to obtain an overall geocoding hit rate of 91%. This better assures the quality of analyses that may be carried out on the data. As has been demonstrated, hot spots of crime are also hot spots of un-geocoded records. The various levels of geocoding, resulting from the new toolkit, each shows their own strong spatial patterning. This would suggest that if L1 data were to form the basis of crime data analysis, it would represent a biased sample.

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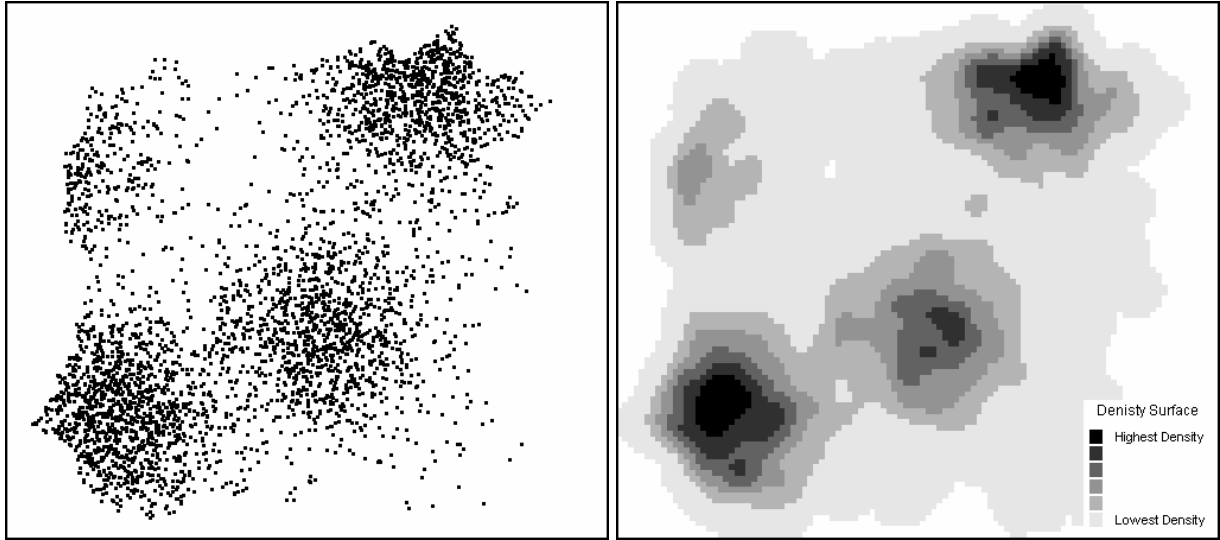
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<i>Level</i>	<i>No. geocoded</i>	<i>%</i>
L1	50,363	55.4
L2	4,164	4.6
L3	13,061	14.4
L4	15,258	16.8
<i>Total</i>	82,846	91.1

Table 1: Geocoding hit rates for each level



(a)

(b)

Figure 1: Hot spot detection: (a) point event data (b) kernel density surface.

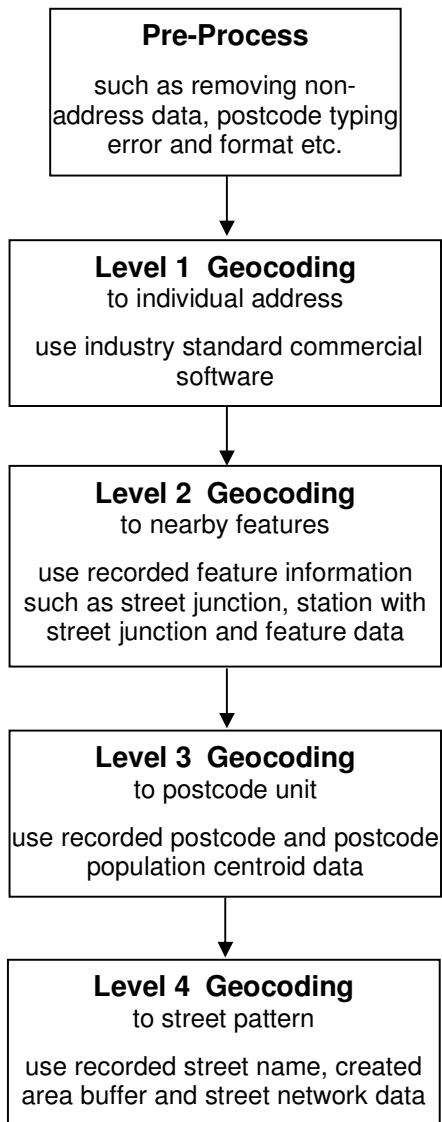


Figure 2: Levels of geocoding in the improved methodology.

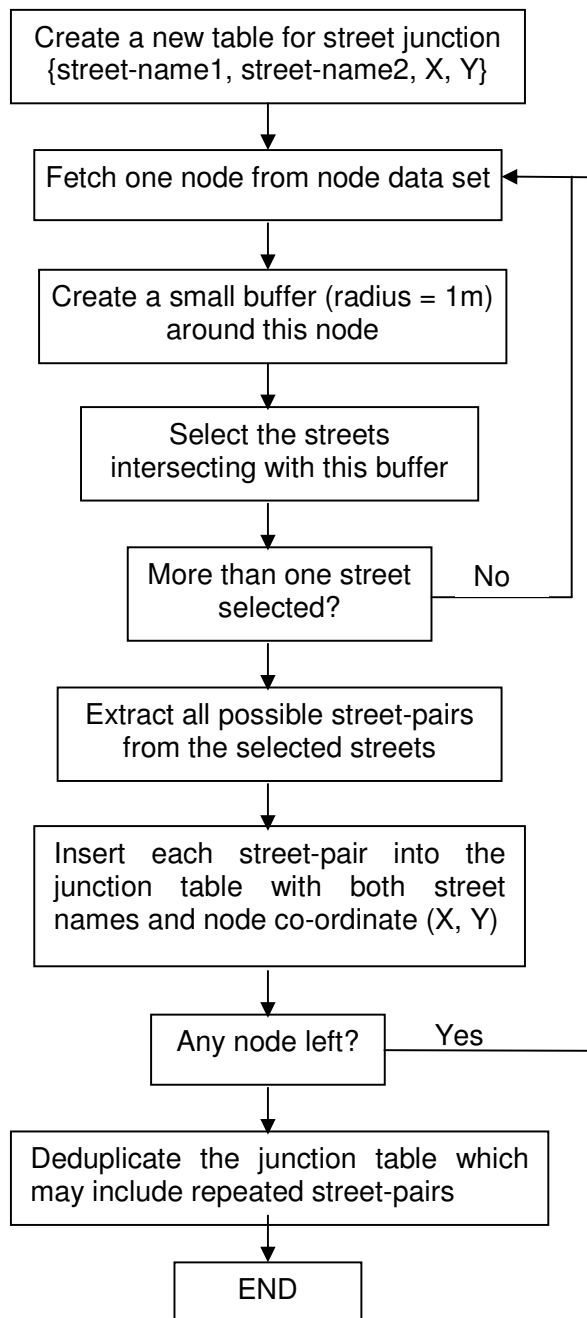


Figure 3: Procedure for creating a junction coding database.

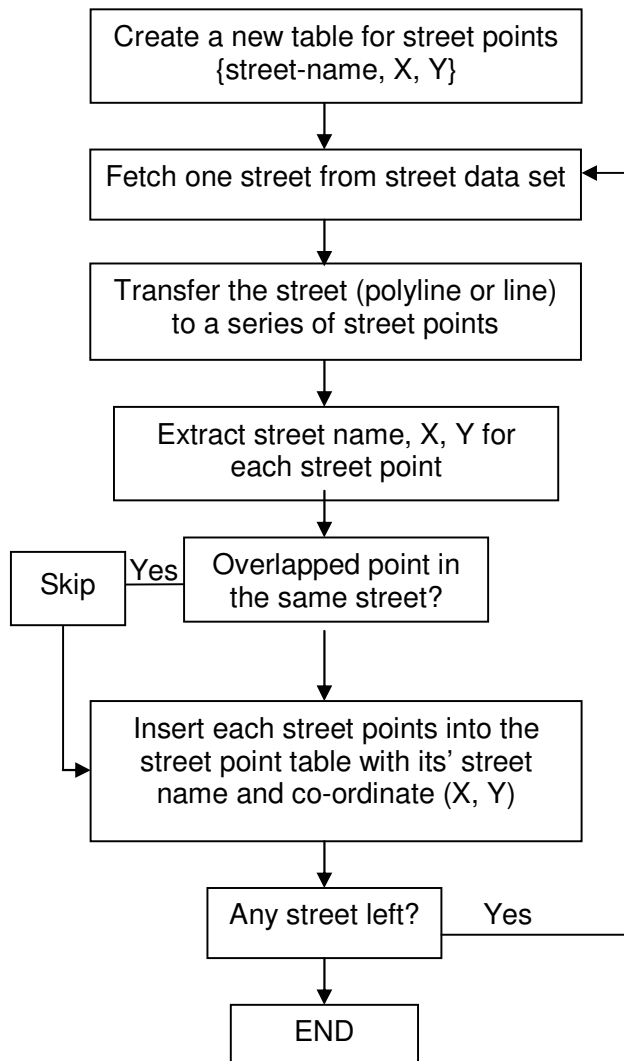


Figure 4: Procedure for creating a point set for geocoding along roads.

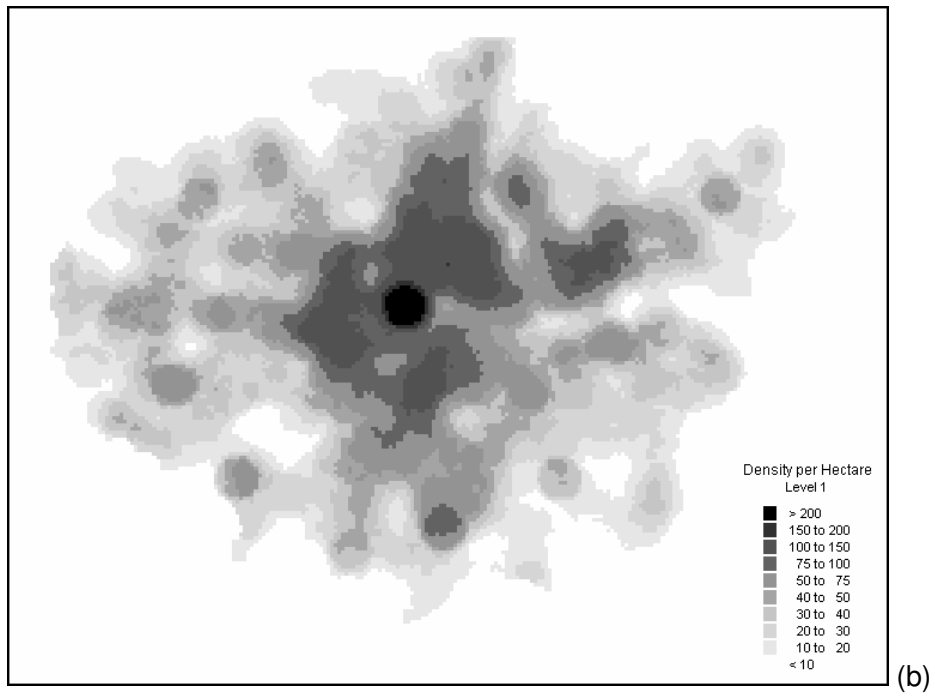
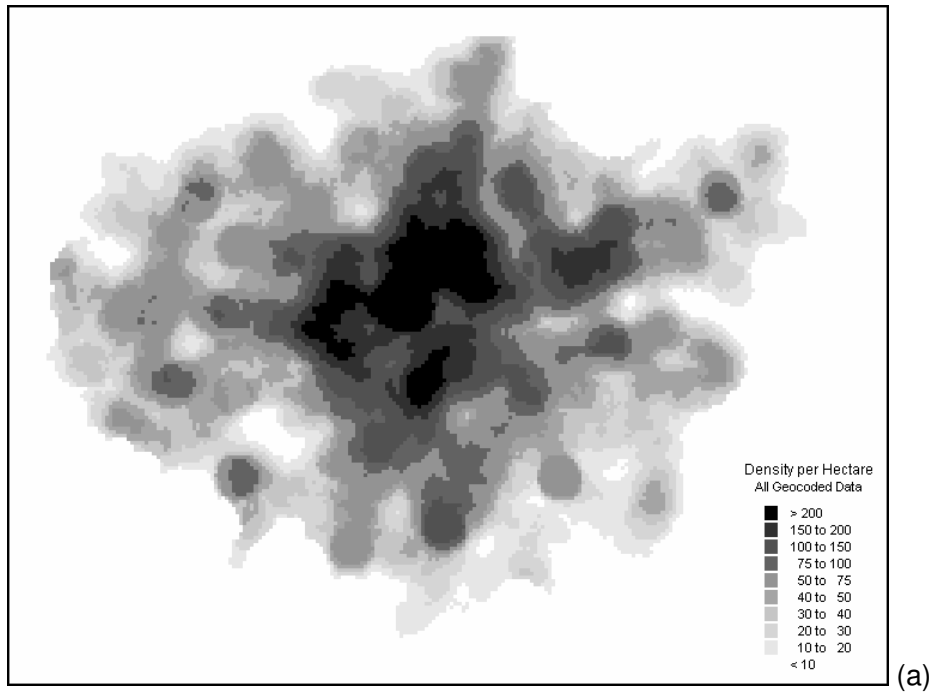


Figure 5: Kernel density surfaces for (a) all geocoded records and (b) L1 geocoded records.

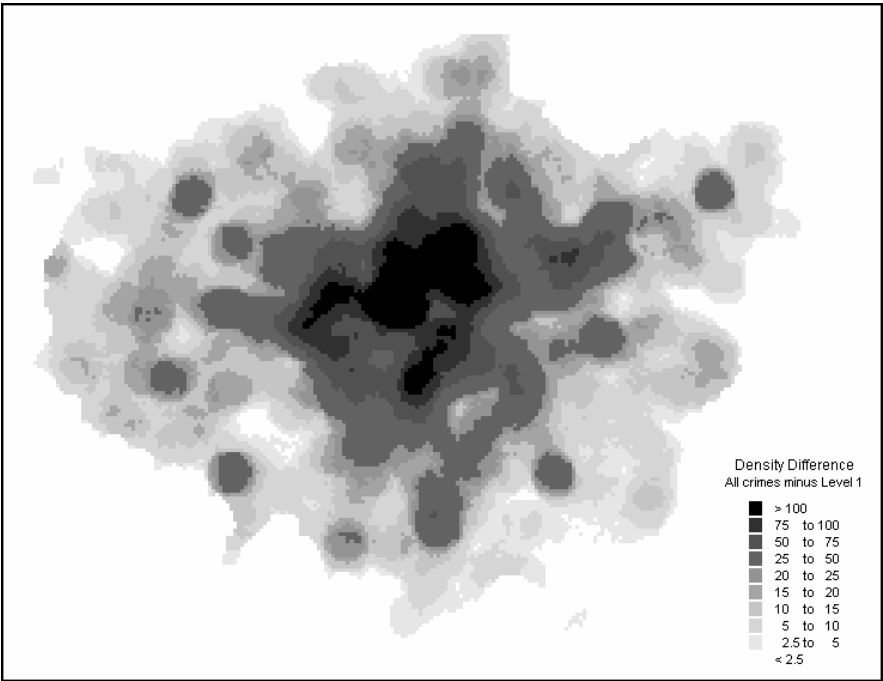


Figure 6: Difference in densities between all geocoded and L1 geocoded records.

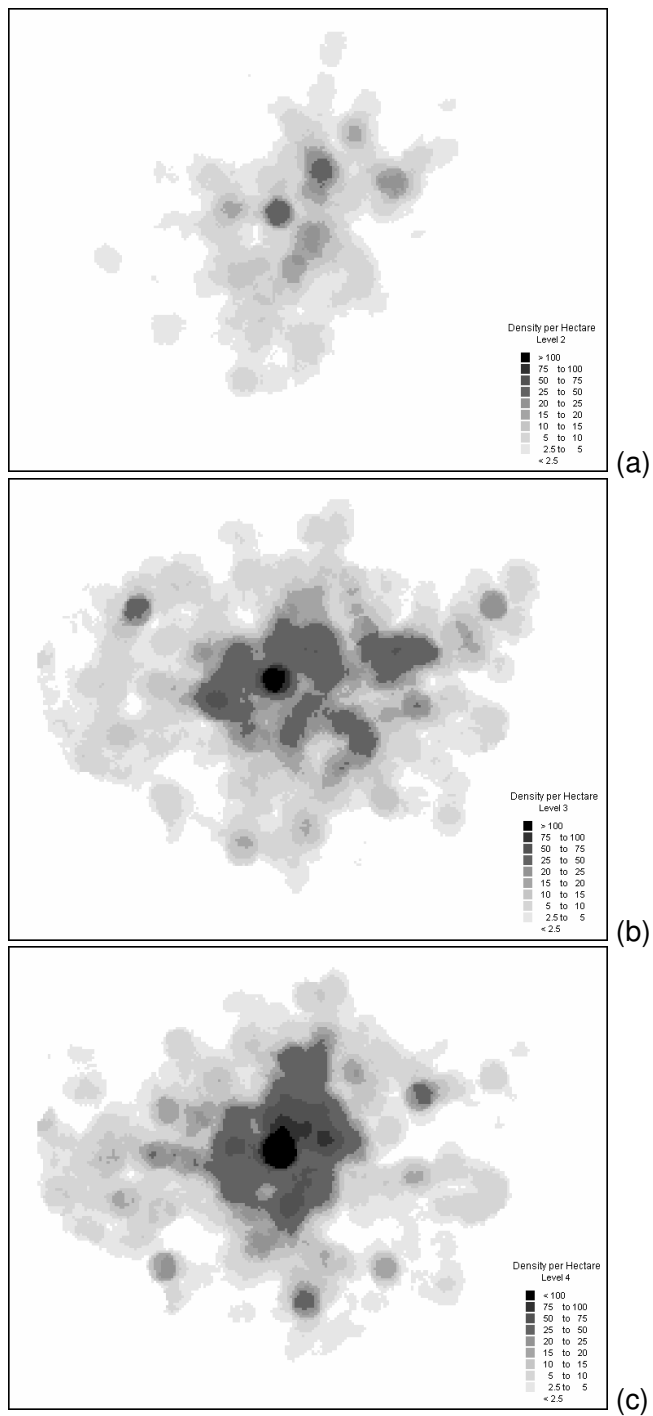


Figure 7: Kernel density surfaces for (a) L2, (b) L3, (c) L4 geocoded records.