APPLYING GEOGRAPHICAL ANALYSIS TO SERIAL CRIME INVESTIGATIONS TO PREDICT THE LOCATION OF FUTURE TARGETS AND DETERMINE OFFENDER RESIDENCE.

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Applying geographical analysis to serial crime investigations to predict the location of future targets and determine offender residence.

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Abstract

This paper presents two case studies to illustrate how geographical analysis of serial crime conducted within a geographic information system can assist crime investigation. Techniques are illustrated for determining the possible residence of offenders and for predicting the location of future crimes based on the geographical pattern of the existing crimes. It is found that such methods are relatively easy to implement within GIS given appropriate data but rely on many assumptions regarding offenders' behaviour. While some success has been achieved in applying the techniques it is concluded that the methods are essentially theory-less and lack evaluation. Future research into the evaluation of such methods and in the geographic behaviour of serial offenders is required in order to apply such methods to investigations with confidence in their reliability.

Introduction

This paper presents two case studies that illustrate how geographical analysis conducted within a geographic information system (GIS) can aid in the investigation of serial crime. The two case studies come from the United States. The first involves the unsolved Green River serial homicides that occurred in Seattle, Washington State in the early 1980's. The second case is an unsolved series of armed robberies from Phoenix, Arizona that occurred in late 1999. In the first case, geographic methods are applied to determine the likely residence of the offender during the period of the crimes. For the armed robbery series, the analysis predicted the likely locations for future robberies based on the evolving pattern of the offenders' crimes. This paper describes the techniques used and discusses the problems that arise both in developing methods and in applying the results to the investigation of the crimes.

Case 1. The Green River Serial Homicides

Introduction

The Green River serial homicide case comprises at least 49 female victims, mostly young prostitutes and runaways, who were abducted along the main transport route between downtown Seattle and the Seattle-Tacoma international airport between 1982 and 1984 (Smith and Guillen, 1991). The red light area around the airport, known as "The Strip", was in the early 1980's a densely populated area of transients, travellers and local workers. Hotels and motels serviced the thousands of travellers coming into the US by the Pacific Northwest and travelling between Vancouver, Seattle, Oregon and California. At its height, The Strip attracted hundreds of young prostitutes who worked the area or other red light areas in Seattle year round (Smith and Guillen, 1991).

The bodies of the first victims were discovered in the Green River to the east of The Strip in August 1982. More victims were discovered buried in wooded areas on the urban fringe of Seattle, in

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nearby rural areas and several were found outside Portland in Oregon (Smith and Guillen, 1991). When police presence on The Strip increased and prostitution moved to other areas out of police scrutiny so did the abductions. The apparent determination of the offender suggested to many that the killer was toying with authorities in the pattern of his abductions and body dump sites (Smith and Guillen, 1991). Of the 49 official victims of the Green River killer, remains of seven of the victims have never been found and there are four sets of unidentified remains (Sanders, 1999). The crimes appeared to cease in late 1984 and while the investigation continues the case remains unsolved.

Determining the offender's residence with travel distance modelling

Numerous authors have suggested that an analysis of the distribution of serial crimes might provide a means of determining the offender's residence (see Egger, 1998 and Rossmo, 1995 for summaries). The objective of the analysis was to develop a simple method to determine the likely residence of the offender at the time of the homicides based upon the geographical distribution of the crime scenes and existing empirical data on offender geographic behaviour. The approach was to develop scenarios that could be tested against investigators' theories and be used to look for consensus as to the offender's likely residence.

The basic methodology employed was to identify the likely average distance travelled by the offender from his residence to the crime sites under a variety of different scenarios and use this to work back to the offender's residence. This approach is based upon the work of Rossmo (1995, 1997) though the methodology is less sophisticated than his approach. The distances used are based upon the empirical research of Le Beau, 1987a, 1992, Dietze et al., 1990, Godwin and Canter, 1997 and Warren et al., 1998, though adapted for each scenario. These authors specifically considered the distances travelled or mode of travel by offenders involved in sexual assaults and homicides.

The methodology was implemented as follows. Firstly, the street grid for the region was polygonised using the GIS. That is, the street vectors were transformed into individual polygons for each block. This allowed data to be associated with the blocks themselves rather than with the street vectors alone. Next, each crime site was buffered a distance and in a specific shape depending upon the scenario being modelled. The shape of the buffer was most often a circle, given that the empirical data usually considered straight line distances between offender residence and crimes. However, elliptical buffers were used in some scenarios, oriented according to the direction of major travel routes. The buffers were then intersected with the street polygons and a score was added to each street block according to how many buffers intersected it. The greater the score, the more likely that the offender lived within the street block. The analysis was restricted to the greater Seattle region, approximately equivalent to King County (about 2,400 square miles).

Scenarios

In order to identify the likely residence of the offender five scenarios were designed. The scenarios are summarised in Table 1. Street blocks having the highest 1% of scores for each scenario were considered to be the high probability areas for the offender's residence. The results are also summarised in Map 1.

In the first, "vanilla" scenario, each abduction and disposal site was buffered five miles and ten miles respectively. A circular buffer was used in all cases and no other assumptions were applied to the data. The buffered circles represent the minimum area within which the offender must have lived in order to travel up to the mean distance between the residence and crime for the crime site at

hand. For this scenario, the highest 1% of scores are found fanning out from the south end of The Strip. The area covered at this probability is approximately 16 square miles.

The second scenario was a consideration of case linkage. This scenario replicated the vanilla scenario but excluded six victims on the basis that their inclusion in the official victim list was in some doubt (Smith and Guillen, 1991). In this case the high probability area is about 20 square miles centred on the southern end of the Strip.

Dietze et al (1990) found that serial murderers often spent a great deal of time driving around as a form of recreation and prelude to criminal activity. The third scenario was based on an individual who spent excessive amounts of time driving and was therefore prepared to travel long distances to crime sites. To model this, elliptical buffers were created for the abduction sites with the longest axis aligned to the direction of the major travel routes. Away from major travel routes, circular buffers were applied (Table 1). As it is suggested that the offender would be less inclined to be driving around with a body in his vehicle, smaller circular buffers were applied to the disposal sites. The distances used here are admittedly subjective and are intended to be at the maximum end of average distances from the literature (particularly Le Beau, 1987a, Godwin and Canter, 1997 and Warren et al 1998) and to reflect travel times within King County. The resulting high priority area is 24 square miles centred on Riverton Heights (Map 1).

The next scenario was based upon the idea that the offender was more familiar with certain body disposal sites. When the temporal patterns of disposal site use was investigated it was found that there were two predominant patterns. The first were sites used for one disposal and then later returned to for multiple disposals over a short period of time and never used again. The second group was used regularly throughout the series. The later sites are considered to be areas of greater comfort to the offender and likely to be closer to the offender's home. It was assumed that the former sites were not as well known. To implement this scenario, different weights and distances were applied to each of the disposal sites (Table 1). Abduction sites were also weighted according to their closest disposal sites as a measure of familiarity. This scenario results in a circular high probability area centred on The Strip of around 30 square miles.

The final scenario considered was time restriction. In this scenario it is assumed that the offender, like any other person, has only a certain amount of discretionary time available, and this will restrict his mobility (Le Beau, 1992). This scenario also draws on the ideas developed in Brantingham and Brantingham (1981). As disposal sites are most likely pre-determined, or at least the offender would tend to exercise more control over their selection it is more likely that abduction sites will be influenced by available time. The model uses "doughnut" buffers around each abduction site. The "hole" represents the area where it is assumed that the offender will not act because it is too close to his residence. The "dough" is the distance within which the offender is prepared to travel and act. The distances selected are in accord with those from the literature, though subjectively scaled to take into account the distances between the abduction and disposal sites and local driving times (Table 1). It was assumed that while the offender would spend more time on abductions than on disposals it was likely that he had spent discretionary time searching for them. So, for disposal sites the "excessive driving" scenario was replicated. The high priority area determined is an area of about 20 square miles centred on Riverton Heights.

As there was no way to judge what might be the most plausible scenario, the idea was that if results tended to consistently identify the same areas then this area would be considered a good priority for investigation. For the most part this was the case. These scenarios tend to place the offender's residence near The Strip, towards the northern end when time and distance are taken into account and towards the southern end when scenarios are less restrictive (Map 1).

Table 1. Summary of scenarios used to identify the Green River killer's residence.

Scenario name	Assumptions	Abduction Sites	Disposal Sites	Result (Top 1% by score)
Vanilla	No explicit assumptions used.	5 mile (circular)	10 mile (circular)	16mi^2 from south end of Strip.
Case linkage	Six victims excluded as possible victims of other offenders.	5 mile (circular)	10 mile (circular)	20mi^2 centred on south end of Strip
Excessive driving	The offender spends a great deal of time driving around.	Near Strip: ellipse 24 by 4 miles aligned to highway N-S or E-W; otherwise 15 miles (circular).	20 mile (circular)	24mi^2 centred on Riverton Heights.
Familiarity	Pattern of use suggests that more regularly used sites are closer to residence.	Weighted from 0.5 to 2 depending upon regularity of use. Distances between 3 and 15 miles (circular).	Weighted from 0.5 to 2 depending upon regularity of use. Distances between 10 and 20 miles (circular).	30mi^2 centred on The Strip.
Time restriction	The offender is restricted to a certain amount of time to carry out crimes.	Based upon the distance to abduction site and expected maximum distances from literature.	As with excessive driving scenario.	20mi^2 centred on Riverton Heights.

Initial problems

Once an area is identified as having a high likelihood of including the offender's residence, what do investigators do with this information? Rossmo (1995, 1997) details how areas identified in such a manner can be further investigated. However, these suggestions are mostly directed at contemporary investigations and might be difficult or irrelevant for an unsolved case almost twenty years old. There were a further number of problems that rendered the analysis less useful than the theory might suggest:

- The areas predicted though relatively small in comparison to the size of the region are still large for an investigation. These areas range from 16 to 30 square miles and include thousands of people, many of whom were travellers and itinerants.

- It was clear that the offender was commuting to The Strip to carry out his crimes. He may have been commuting from nearby or from a great distance. Except by relying on statistical data on other crimes there was no real way of assessing this.

- The methodology was quite complex and included so many assumptions that it simply did not inspire enough confidence to contemplate the enormous task of interrogating existing case data.

Overall the analysis was found to lack any way of being investigatively relevant. A particular problem was that in identifying The Strip as a likely residence this might have in fact simply identified the area of victim activity. With this in mind, a further analysis was conducted using a method based on the offenders likely travel routes and a more detailed consideration of the information content of crime site locations.

Determining the offender's residence with route analysis

One of the fundamental problems with the previous analysis was that it assumed that the offender determined the crime sites. However, given that the victims were prostitutes working common areas, abduction sites were more likely due to this than the offender's choice. It is further likely that some of the disposal sites were in fact victim directed (Jensen, 1999, pers. comm.). The methodology could thus be improved by discriminating between offender directed and victim directed sites.

The first step of the analysis was to classify the disposal sites on the basis of the degree to which they might reflect the offender's choice. Sites could be classified into three groups. Firstly, victim directed sites are those where it is likely that the offender was directed to the site by the victim as part of the "date". Sites that had a historical record for being used as body disposal sites or were otherwise unlikely to require local knowledge were referred to as "group" sites. Finally, sites that were probably only known to a restricted population, including the offender, with local knowledge were referred to as "individual" sites. It is assumed that abduction sites are for the most part determined by the victims and, on their own, do not add any information to determining the offender's residence.

Map 1 shows the main disposal sites. Rural disposals in North Bend, Enumclaw and Maple Valley are group sites, having either historically been used as body dump sites or are obvious routes out of the urban areas. Victims discovered near The Strip may well have directed the offender to isolated spots where they would regularly conclude their "dates". It follows that while the offender would have had knowledge of The Strip, these disposal sites are better classified as victim directed. Green River, Star Lake and Auburn are isolated areas that are too far from The Strip for "dates" and suggest some local knowledge and are classified as individual.

In analysing this pattern, the first consideration was that of the routes between abduction sites and disposal sites. Map 2 shows the approximate route frequency between abduction and disposal sites. The routes for the journeys were subjectively determined by following main roads. It shows that routes along Pacific Highway South and particularly routes through and feeding off The Strip contain the bulk of the offender's travels. If the offender was attempting to minimise travel distance between abductions and disposal sites, then he would need to have been residing somewhere along Pacific Highway South between Riverton Heights and Federal Way (see also Map 1).

It is possible to invert this process and start with possible locations for the offender and calculate how many miles would be accumulated for each location given the pattern of crime sites. Assuming

that the offender is attempting to keep his effort to a minimum and so minimise travel distance, the location with the lowest aggregate distance is more likely to include the offender's residence.

Table 2 shows the accumulated distance for return trips from all of the body disposal sites to five places along Pacific Highway South. Kent stands out as the most likely location of the offender. Auburn is the second most likely candidate from this list. Routes to Kent were found to be slightly more complicated than for Auburn but routes to both result in quite economic and simple patterns. For Kent there are basically two axes to the routes. Going north-south from The Strip along Pacific Highway South and east west from North Bend along Interstate 90 and from Enumclaw along State Highway 164 (Map 1). For Auburn the pattern includes routes to Kent and further distance is travelled on Pacific Highway South. It should be emphasised that the selection of routes were based on those that appear to be the most likely but they may not accurately reflect the actual travels of the offender.

Table 2. Accumulated return trip miles from all body disposal sites to five locations in King County.

Location	**Accumulated Return Trip Miles (n=42)**
Central Seattle	1,414
Rainier Valley	1,296
The Strip	1,059
Kent	970
Auburn	1,031

Based upon this analysis it is likely that the offender was residing in Kent or Auburn. He probably had strong local knowledge of the Green River, Star Lake and Auburn areas. While not particularly useful alone, the fact that the offender must have had some significant connection with all of these dispersed areas might be applied in prioritising suspects. That the offender has some degree of knowledge of The Strip is somewhat a given but this is not considered particularly useful for identifying suspects.

Application and problems

This analysis resulted in two possible avenues for investigation. One was simply to prioritise the investigation of suspects who lived in Kent or Auburn, or suspects who had connections to these towns and the other local areas suggested. The second possibility was to use the analysis to identify routes where the offender may have been witnessed or received a traffic citation or simply be known to frequent.

However, in application there was no easy way to apply these ideas to the historical data. While the more general results are less restrictive and easier to test, the resources simply do not exist to apply this kind of analysis to the data. Part of the problem is in the nature of the data itself. Abduction sites, which make up half of the data, appear more related to the victims' behaviour and say little about the offender's activities. Overall, the fundamental problem concluded from this case study is that while the data and technology exists to model offender behaviour there is an absence of research into individual offender geographic behaviour that can guide its application.

Case 2. The "Supersonic" Armed Robberies

Introduction

This series of armed robberies occurred in Phoenix, Arizona between 13 September and 5 December 1999 and included 35 robberies of fast food restaurants, hotels and retail businesses. The offenders were named the "Supersonics" by the Phoenix Police Department Robbery Detail as the first two robberies were of Sonic Drive-In restaurants. After the 35th robbery, the offenders appear to have desisted from their activity and at present the case remains unsolved. The MO was for the offenders to target businesses where they could easily gain entry, pull on a ski mask or bandanna, confront employees with a weapon, order them to the ground, empty the cash from a safe or cash register into a bag and flee on foot most likely to a vehicle waiting nearby. While it appears that the offenders occasionally worked alone or in pairs, the MO, weapons and witness descriptions tend to suggest a group of at least three offenders.

The objective of the analysis was to use the geographic distribution of the crimes to predict the location of the next crime in an area that was small enough to be suitable for the Robbery Detail to conduct stakeouts and surveillance. After working with a popular crime analysis manual (Gottleib, Arenberg and Singh, 1994) it was found that the prescribed method produced target areas so large that they were not operationally useful. However, the approach was attractive as it required only basic information and relied on simple statistical analysis. To identify areas that were more useful for the Robbery Detail, it was decided to use a similar approach combined with other measurable aspects of the spatial distribution of the crimes. As this was a "live" case, new crimes and information were integrated into the analysis as it came to hand.

Predicting future target areas

The first analysis was conducted in November 1999 after 22 armed robberies had occurred. Three geographic factors were considered in order to identify a likely area for the next crime:

- As the previous crimes averaged 0.97 miles (sd = 0.68) from the freeway, it seemed reasonable to suggest that the next crime would occur within 1.5 miles of the freeway. The freeway was buffered within the GIS by 1.5 miles.

- The distance between the crimes were calculated to be a mean of 4.64 miles (sd = 2.48), so the next crime was likely to be within 2.5 to 7.5 miles of the last. By weighting the distances between the later crimes the last crime site was buffered a reduced range of 2.5 to 5 miles.

- Considering the crime locations in sequence there appeared to be a back and forth motion of crimes across the city. An analysis of the directionality between sequential crimes suggested that the next crime was likely to occur to the west between 5 and 30 degrees of the last crime.

Target areas based upon these three predictors were calculated within the GIS and the area where all three intersected was considered to be the high likelihood target area for the next crime. Map 3 shows an example of analysis produced by this method.

As it turned out the 23rd crime occurred the day after the analysis was completed. The prediction identified the correct direction but the distance was not predicted well. The analysis was repeated with more attention paid to the relationship between the time and distance between crimes. It was found that when a crime occurred near the boundary of the city, the next crime tended to be in the

opposite direction and at least seven miles away. There was also a weak positive relationship between time and distance between crimes. The longer the time between crimes the further the distance the next crime occurred from the last.

As each further crime occurred the analysis was repeated. The method was also adapted in an attempt to provide more restricted areas suitable for surveillance and stakeouts. Improvements included: interpolating the predicted target areas onto the Phoenix half-mile grid squares to make the areas easier to identify and communicate, and; analysing only the first crime of each day. It was thought that these were the best planned and would be more indicative of the offender's spatial behaviour. Crimes that seemed to occur in a "spree" of two or three following this first crime were considered more opportunistic and likely to detract from the analysis.

Problems and further improvements

With 28 crimes in the series the predictions tended to provide large areas that included the target crime but were too large to be useful given the limited resources the police had at their disposal. At this stage, a more detailed look was taken at the directionality and distances between crimes. No significant trends could be found in the sequential distance between crimes so an attempt was made to better quantify the relationship between crimes in terms of directionality.

The methodology began by calculating the geographic centre of the existing crimes. The geographic centre is a derived point that identifies the position at which the distance to each crime is minimised. (See Le Beau (1987b) for applications of the geographic centre to crime analysis.) Once constructed, the angle of each crime from the north point of the geographic centre was calculated. From this it was possible to calculate the change in direction for the sequential crimes. It was found that the offenders were tending to pattern their crimes by switching direction away from the last crime. It appears that the offenders were trying to create a random pattern to avoid detection but unwittingly created a uniform pattern based upon their choice of locations. This relationship was quantified and a simple linear regression used to predict what the next direction would be.

By 22 November the series had reached 32 crimes. The analysis was once again applied to the data. While the area identified was reduced from previous versions and prioritised into sub-segments, the problem remained that the areas predicted were still too large to be used as more than a general guide to resource deployment.

A major improvement to the methodology was to include individual targets. By this stage of the series, hotels and auto parts retailers had become the targets of choice. A geocoded data set became available that allowed hotels and retail outlets to be plotted and compared to the predicted target areas. Ideally those businesses falling within the target areas could be prioritised as more likely targets. However, in some cases the distribution of the likely businesses appeared to contradict the area predicted. For example, few target hotels appeared in the target zone identified by the geographic analysis. In this case, more reliance was placed upon the location of individual targets. From this analysis it was possible to identify a prioritised list of individual commercial targets, which was of more use operationally. Maps were also provided to give an indication of target areas. Map 4 demonstrates a map created using this methodology. However, by the time this method had been refined … the crimes ceased!

It is apparent from the above discussion that the target areas identified were often too large to be used as more than a general guide by the Robbery Detail. However, by including the individual targets, it was possible to restrict the possible target areas to smaller, more useful areas, and a few prioritised targets. However, such an approach has the danger of being overly restrictive and it is

not the purpose of the analysis to restrict police operations but to suggest priorities. This problem was somewhat dealt with by involving investigators in the analysis and presenting the results in an objective manner, such that investigators could make their own judgements about the results.

To be more confident in using this kind of analysis a stronger theoretical background to the methods is required. What has been applied here is to simply exploit the spatial relationships in the information available without considering what the connection is to the actual behaviour of the offenders. For example, what is the reason behind a particular trend observed in the distance between crimes? Why would such a trend be expected between crimes that occur on different days and possibly involve different individuals? While some consideration was given to identifying the reason behind the pattern of directionality and while it seems reasonable to expect offender's to look for freeway access, such reasoning has tended to follow the analysis rather than substantiate it. Without a theoretical background the analysis rests only on untested statistical relationships that do not provide an answer to the basic question: why this pattern?

Discussion

While it is relatively easy to implement the kind of analysis described on the Green River homicide series and the Supersonic armed robberies within GIS, it is apparent that there are some problems in applying the results.

For the Green River investigation the value in determining areas where the offender was likely to live was limited by the size of the resulting areas. How useful is a 20 square mile target area to the investigation of a case almost 20 years old, even though it has reduced the search area from 2,400 square miles? Given the amount of resource that would be required to check the areas identified against collected suspect data, it is not difficult to understand that the analysis was not specific enough to proceed. A similar problem exists for the route analysis that identified highways and towns that might be checked for suspects. Can resources be applied to manually check the collected suspect, citation, witness statements and so on when the analysis relies on a number of untestable assumptions?

The analysis of the Supersonic armed robberies also raises some issues. The areas predicted for the next crimes, while generally accurate, were only useful as a general guide to operations. By mapping individual targets it was possible to restrict predictions of future crimes to smaller areas and just a few targets. This approach appears to be very useful but has the danger of being overly restrictive in terms of what possible targets and target areas are prioritised.

The fundamental problem concluded from these two case studies is that while the data and technology exist to model offender behaviour there is an absence of evaluation of the techniques and of research into individual offender geographic behaviour that can guide their application. In the Green River series attempts were made to model possible offender behaviour using a scenario approach but without a means to assess the likelihood of a particular scenario, the results were not particularly useful. For the Supsersonics the method was even more removed from theory and simply used spatial relationships with little consideration of their connection to the actual behaviour of the offenders. Without such consideration the analysis wavers between being inappropriately and perhaps dangerously restrictive to being so inclusive that it offers little to investigators. Importantly, the involvement of investigators in the analysis process will assist in getting the balance right.

It is also apparent that the cases analysed include a lot more crimes than would be involved in most investigations. The Green River series with 49 victims includes almost 100 crime sites and the Supersonics reached 35 known crimes in their three month series. However, it is of obvious benefit

for methods to be applied when there are only a handful of cases in the series without having to wait until the crimes have reached a dozen, three dozen or 50! This is a further priority for research.

Conclusion

This paper has presented two case studies to illustrate how geographical analysis of serial crime conducted within a GIS can assist crime investigation. For the Green River serial homicides it was possible to determine a restricted area where the offender was likely to have lived during the time of the murders. Unfortunately, the areas identified were too large to have been of much use to investigators. Further, because of the number of assumptions applied the method does not inspire enough confidence to dedicate resources to comparing its results to the enormous amount of suspect data collected on the case. A second analysis of this case using route analysis, identified routes, places and towns that could be checked for suspect and witness records. This approach appears to have some merit though it requires further research and evaluation. The Supersonic armed robbery investigation was aided by predictions of the next crime sites as the series progressed. While the target areas predicted tended to be large, the mapping of individual commercial targets appears to offer a significant improvement to the method. However, as they stand, these methods lack a theoretical basis that would allow the results to be judged and applied in investigations. Limitations such as these can be offset to some degree by the involvement of investigators in the analysis. The priority for future research into this area should therefore be in the evaluation of current methods of geographic analysis of crime series and in the development of a greater understanding of the geographic behaviour of serial offenders.

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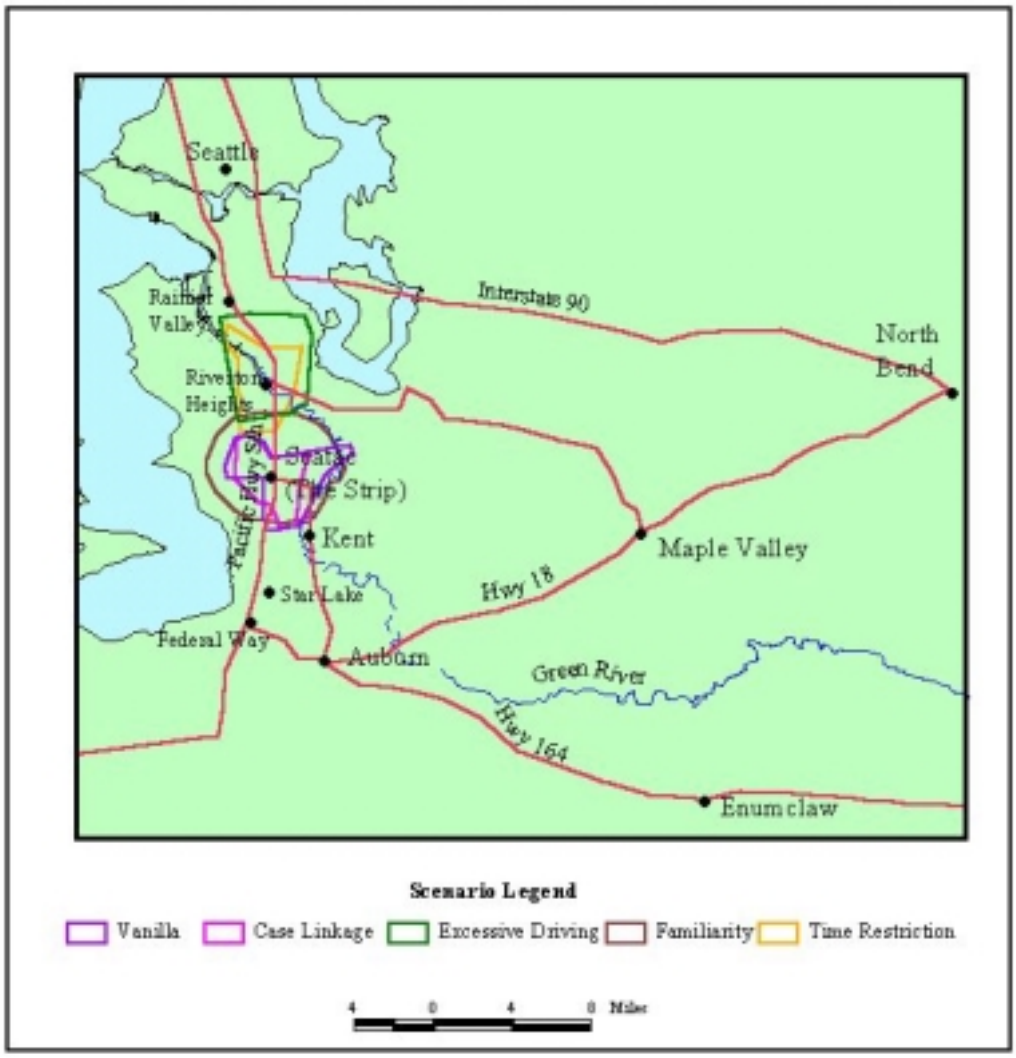
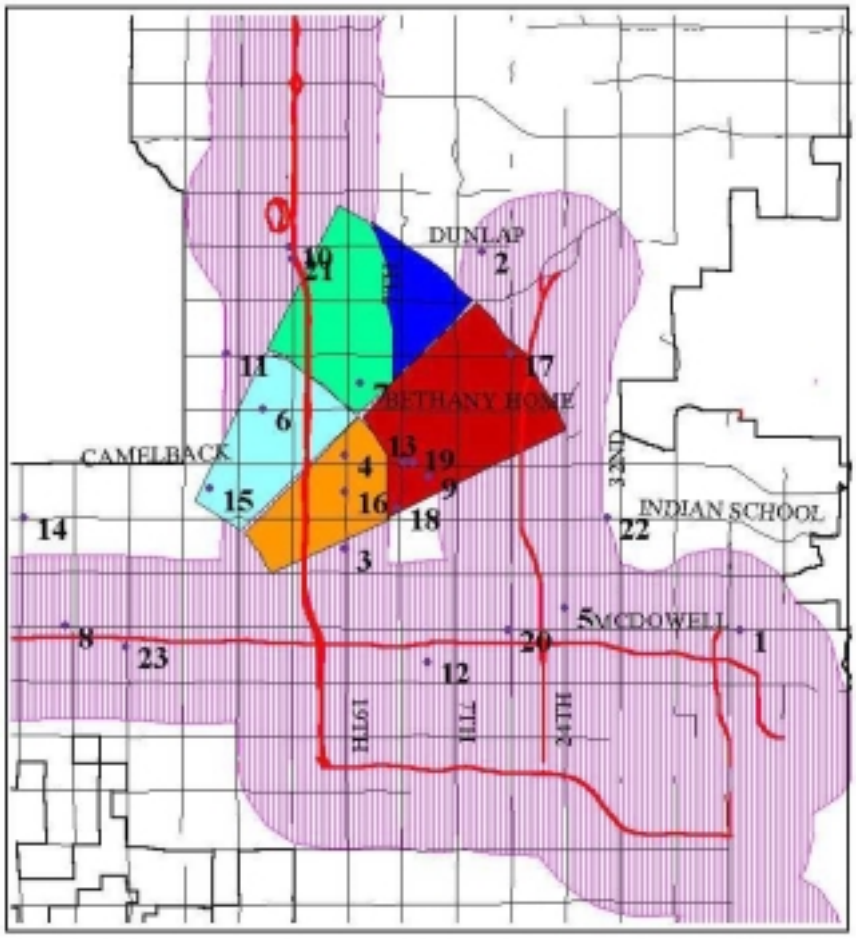
Map 1 King County, Washington State with sites related to Green River homicides



Map 2 Approximate route frequency between abduction and disposal sites

Map 3 Robbery area prediction for
Supersonics, Phoenix, Arizona



Map 4 Crime prediction based on directionality target distribution (demonstration)