DECAY FUNCTIONS AND OFFENDER SPATIAL PROCESSES:

GEOGRAPHICAL OFFENDER PROFILING VOLUME CRIME

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Abstract

Although it is now well established across diverse samples that the frequency of offending ‘decays’ as distance from the home/base increases, it remains unclear what form of decay function best characterises this relationship. Yet different forms of decay function, reflecting as they do different patterns and rates of decreasing overall offending likelihood as distance from the home/base increases, do imply rather different underlying psychological processes. As such, considerations of the particular function characterising distance decay may throw light on the appropriateness of theoretical explanations of offender spatial behaviour.

The present study therefore examined the fit of logarithmic, negative exponential and quadratic decay functions to the distribution of the distances travelled to offend by a sample of 70 prolific burglars from the U.K. It is argued these functions are consistent with the operation of perceptual processes of magnitude estimation, friction or effort effects, and the influences of cost-benefits assessments respectively. The results suggest a closest fit to the logarithmic function, consistent with Stevens’ perceptual processes of distortion in magnitude estimation, as the dominant factor in offending distance decay patterns, while not ruling out additional processes relating to the increased effort required in travelling greater distances to offend.

As Geographical Profiling systems are built upon the distance decay function, the impact of utilising the different forms of function on the accuracy of geographic profiles was also assessed utilising the ‘search cost’ calculation. The results showed little impact of applying different decay functions. Thus, while the decay function does have important theoretical implications for understanding offender spatial behaviour, it is noted that the particular variant used does not significantly impact on the effectiveness of Geographical Profiling systems as they currently exist.

Introduction

Distributions of the distances travelled to offend by criminal samples have been consistently shown within the criminological literature to be characterized by distance decay, that is, as the distance from an offender's home or base increases the likelihood of offending decreases (Turner, 1969; Phillips, 1980; Rhodes & Conley, 1991; Rengert, Piquero & Jones, 1999, Canter and Hammond, 2006; Rattner & Portnov, 2007; Emeno, 2008; Block & Bernasco, 2009). However, the relationship between distance travelled to offend and frequency of offences is non-linear and it remains unclear which of a variety of decay functions it follows. As well as being integral to Geographical Offender Profiling systems such as Riegel and Dragnet, the distance decay function is the starting point or 'prior' within Bayesian approaches to modelling crime locations (Block and Bernasco, 2009; Levine, 2009; O'Leary, 2009). Yet, different functions describe different patterns of reduction or decay in likelihood of offending as distance from home increases. As Canter and Hammond (2006) note, different functions imply different underlying processes determining offenders' crime location choices or 'journeys to crime'

There are a number of different forms of decay function that could characterize this relationship (Turner, 1969; Canter, Coffey, Huntley & Missen, 2000). For example, Canter et al. (2000) note that if the function which provided the closest approximation to the distance distribution of a sample had a very steep slope and decayed rapidly within a short distance from the home, then that would suggest that the home were exerting a strong influence on the geographical activity of those offenders. In contrast, if a function with a much shallower gradient that decayed slowly proved the best means of characterising a journey-to-crime distribution this would imply that the home had less significance for those offenders and less of an impact on the spatial distribution of their crimes (Canter et al., 2000).

In one of the few published comparisons of the ability of different functions to characterize distance-based data, De Vries, Nijkamp & Rietveld (2009) report the logarithmic function as much more effective in characterizing the journeys made from home to work and commuting flows between municipalities in Denmark than exponential or power functions.

The functions most commonly used in characterising crime-based data have been negative exponential or power functions (ESRI 1996). However, a number of studies have suggested different functions provide the closest approximation to journey to crime data for various offending samples (Turner, 1969; Phillips, 1980; Hunter & Shannon, 1985; Brantingham & Brantingham, 1991; Canter et al., 2000; Levine, 2002; Kent, 2005). Most recently, Canter and Hammond (2006) showed that a logarithmic function provided the closest approximation to the distances travelled by their sample of 96 serial murderers.

Canter and Hammond argue that their results point to an important role for cognitive distortions in distance estimation in shaping offenders' spatial behaviour. Relating their findings to Stevens' (1961) more general findings on magnitude estimation in human sensory perception, Canter and Hammond’s argument is that frequency of offending falls off rapidly because longer distances are over-estimated. As such, their findings suggest that it is the perception of a distance rather than simply the relative effort or cost involved in travelling that distance that determines crime location choices. By specifying the mathematical function underlying the well-established distance decay pattern then, Canter and Hammond provide some initial empirical support for the processes underlying offenders’ spatial behaviour.

The Canter and Hammond approach to exploring the possible psychological and behavioural processes shaping offenders’ crime location choices opens up a range of possibilities for consideration. One possibility is that different underlying processes are implicated in relation to different forms of criminal behaviour. Relatedly, certain processes may also be more salient in relation to the particular distance ranges typical of certain types of criminal activity. As such, the present study extends Canter and Hammond’s study of serial murderers to examine the fit of data on distances travelled by property offenders, specifically burglars.

Distances travelled by burglars may provide particularly productive data for considerations of the processes underlying spatial choices. The extensive availability of potential burglary targets in typical urban areas is important in facilitating the exploration of the psychological, rather than situational, processes involved in crime location choices. The ready supply of targets means that offenders do not have to travel to very particular locations to find appropriate opportunities to offend. Similarly, it means that the simple distances studied are unlikely to be confused by the directional influence of physical geographical features that Elridge and Jones (1991) draw attention to. In cities, burglary targets are generally available in many directions.

One challenge to the approach comes from the recognition that individual level journey to crime probability distributions cannot be inferred from aggregate data (van Koppen and Keijser 1997; Smith, Bond and Townsley 2008). These authors have drawn attention to the important point that, as with all psychological phenomena, individual level patterns do not mirror aggregate patterns. Certainly the aggregate analyses do not compare differences in a specific individual’s likelihood of offending at different distances. Rather, aggregate analyses are based on comparisons of different individuals rather than the same individual on different occasions. In general, unless there are specific variations among the individuals comprising the sample group, that are meaningful to the processes being studied, aggregate results will provide a valid representation of the psychological processes in question. It is left to subsequent studies to extend the present research on burglars as a group. Such studies would need to propose what the meaningful variations may be between individuals that would imply differences in magnitude estimation distortions as well as the other potential processes studied. The hypothesised different forms of ‘offence travel narratives’ that extends the original Commuter-Marauder typology (Canter and Youngs 2009), would be an interesting place to start in delineating these groups for study.

Effectiveness of Geographical Offender Profiling systems by Search Cost

Decay functions are utilized by geographical profiling systems in order to prioritise areas according to their likelihood of containing an offender's home or base. Such systems are being used more and more for investigative purposes, yet there is presently little research considering how different functions affect the efficiency with which these systems operate (Canter et al., 2000; Santilla, Zappala, Laukkanen & Picozzi, 2003; Canter and Hammond, 2006; Emeno, 2008).

Dragnet (Canter et al. 2000), one such system, produces a prioritised map of the area over which a series of crimes occurred, deriving a prediction of where an offender's home or base is most likely to be located. This map is produced by combining the estimated probabilities of the location of the offender's home from each of the crime locations in a series. The size of the prioritized area searched to locate the base (the 'Search Cost' – Canter et al., 2000) is a measure of the effectiveness of a geographical profiling system. A 'Search Cost Function' (Canter and Hammond, 2006) can subsequently be produced illustrating the relationship between the proportion of the total area searched and the proportion of offenders located at every search cost.

To date, there have been limited empirical considerations of the effectiveness of any geographical profiling system. As Canter (2005) notes, 'No detailed studies of representative samples have shown that geographical profiling models are very accurate in more than a small percentage of cases' (Canter, 2005; p 4). The few published accounts of the efficacy of geographical profiling systems (Canter & Snook, 1999; Canter et al. 2000; Snook, Zito, Bennell and Taylor, 2005; Paulsen, 2006a; 2006b) have principally comprised samples that are biased towards a particular region, small and/or which incorporate only serious offences.

In the limited published research specifically considering the effectiveness of the Dragnet geographical profiling system (Canter and Snook, 1999; Canter et al., 2000), Dragnet has been found to be reasonably effective in reducing the area needing to be searched in order to locate an offender; Canter et al. (2000) find that 51% of the offenders in their sample were located within the first 10% of the total search area, and 81% within the first 25 %. Canter and Snook (1999) find that for their sample of serial killers around 30% of the total area needed to be searched in order to locate 65% of the offenders.

However, the question remains as to how accurate Dragnet, or indeed any geographical profiling system, is in prioritizing the search for an offender when volume crimes are considered. Such findings would have numerous implications, most notably for the potential of such methods for operational purposes.

Search Cost and Decay Functions

The search cost function will be influenced by the precision and accuracy of the decay function. Low search costs imply that a function accurately represents the relationship between an offender's home or base and their offence locations, and the influences shaping this affiliation (Canter & Snook, 1999).

Therefore, the reverse should apply; if a function accurately reflects the shape of a journey-to-crime distribution for a sample, then that function would be expected to produce low search costs when employed within a geographical profiling system. The system would be expected to perform more effectively when utilizing the function that provided the best fit to the distribution of distances travelled to offend for that particular sample of offenders.

Within Dragnet different functions can be incorporated into the analyses that the system runs in order to prioritise a search area. Using Search Costs and the Search Cost Function, it is therefore possible to determine the impact of different functions on the system effectiveness. This provides an indication of the validity of the decay function.

Data

The data utilized in the present study were comprised of a sample of 70 prolific burglars, who between them had committed a total of 920 offences (Mean = 13.14 offences per individual). Only residential burglaries were included, and these had all been committed within London, U.K., over a three year period (1998-2001).

Only those cases with known home and offence locations and for which there was enough information to enable them to be geocoded were utilized. Any items for which information was incorrect, unidentifiable or missing were excluded from the data.

Analysis

A two-stage study was conducted in order to examine the impact of decay functions when used for geographical profiling and the implications of their utilization for the validity of the assumptions that the different functions presuppose. Initially, each of the functions was fitted to the distribution of the distances travelled to offend by the sample, and their accuracy in characterizing the shape of the decay in offending with increased distance from the home established. Subsequently, each of the functions was utilized within the analyses performed by Dragnet, and their influence on the effectiveness of the system in terms of the search costs determined.

Study 1

The Functions

Three different functions were compared for their fit to the distribution of the distances travelled from home to crime by the offenders in the present sample. All of these reflect the negative non-linear relationship between the frequency of offending and decreased distance from the home. However, each postulates somewhat different hypotheses and assumptions about the factors that may influence the distances travelled to offend and would be consistent with a different behavioural explanation for the decay in offending distance distributions.

The Logarithmic Function

The logarithmic function decreases dramatically initially from the highest frequency starting point. The decline becomes markedly more gradual at around 5-10 km from home and continues to slowly level out (Kent, 2003). As a representation of the distribution of distances travelled by offenders to commit their crimes, the logarithmic function would be consistent with small increases in the distance travelled producing a rapid reduction in the likelihood of offending while at the further from home locations the offence occurrences are more spread out across the distance intervals.

This distribution would be consistent with S.S. Stevens' (1961) 'Power Law' of magnitude estimation. Stevens' Law postulates that magnitudes are not estimated in a linear fashion. Rather, as magnitude increases, proportionally larger increases are required for the difference in magnitude to be perceived. The relationship between the estimated and actual magnitudes is shown by Stevens to be characterized as a specific logarithmic function for each modality being estimated.

This pattern would suggest a significant role for perceptual processes in offender spatial behaviour such that the distortions in distance estimation influence the frequency of observed journeys-to-crime.

The Negative Exponential Function

In the context of journey to crime data, the exponential function would also suggest the likelihood and frequency of offending to be highest around an offender's home, declining at a decreasing rate with increased distance from this residential location. This pattern is less marked than the Logarithmic pattern in the initial focus around the home and decline at the very short journey to crime distances.

Such a pattern in journey to crime data may be analogous to impedance. Canter and Hammond (2006) cite a definition of impedance as 'the impediment or opposition to electrical flow, which is a combination of resistance and reactance'. This 'friction' effect, when applied to distance, illustrates resistance to movement over space (Canter, 2004), and has been shown to reflect distributions of a similar nature for a wide variety of other behavioural phenomena (Golledge, 1987). Along similar lines, Phillips (1980) proposes that the decay in offending with increased distance from the home results from the 'friction of distance; the cost in money, time or energy of overcoming distance' (Phillips, 1980; p136).

Thus it might be argued that an increase in effort - irrespective of potential reward - is what generates this resistance to increased journey lengths, which is represented by an exponential function, its shape resulting from friction effects, and reflecting the decrease in the likelihood and frequency of offending with increased distance from the home or base. This suggests the operation of processes on offender spatial behaviour that are associated primarily with the effort of travelling to offend.

The Quadratic Function

The shape of the quadratic function is again consistent with the higher frequency of offending close to home with a sharp decline as distance travelled increases from this. However, it indicates that after a certain point (here approximately 15 km), the frequency of offending will begin to increase with increased journey length, with a larger number of offences being committed notable distances from the offender's residence. It is consistent then with the operation of processes on offender spatial behaviour that make longer distances more favourable. This may be a preference shown by particular subgroups of offenders or by all offenders in some of their offences. Such a pattern may be produced where specific and/or high value rewards are only obtainable at particular locations. It may also be produced where an offender feels closer to home opportunities are exhausted or are more risky. In general terms then it does suggest the operation on offender spatial behaviour of some form of cost-benefit or risk-rewards type analysis as advanced within Rational Choice perspectives (e.g. Cornish and Clarke, 1986) but with a particular emphasis, unlike the negative exponential function, on the potential rewards rather than the costs.

The Control: A Straight Negative Linear Function

A negative linear function which assumes a constant decay in distance travelled was also tested for fit to the distance distribution in the present sample. This function has been advanced as an accurate representation of the relationship between distance travelled to offend from home and frequency of offending within a sample (e.g. Turner 1969).

Examining the Fit of the Functions to the Distance Data

To determine which of the four functions provided the best fit to journey to crime data of the offenders in the present study, each was mathematically calibrated to the distribution of the distances travelled to offend, using the following methodology;

Firstly, the distances between each home and each crime location were determined. Once a complete set of distance data had been complied, the distance values for each were grouped into distance intervals (see Kent, 2003), and which were then used to calculate the frequencies with which crime trips were made to each of the different distances from the home.

A chart of the frequencies of offending associated with each of the distance intervals is provided below. It clearly shows the reduction or decay in the frequency of offending with increased distance from the home or base (Figure 1.).

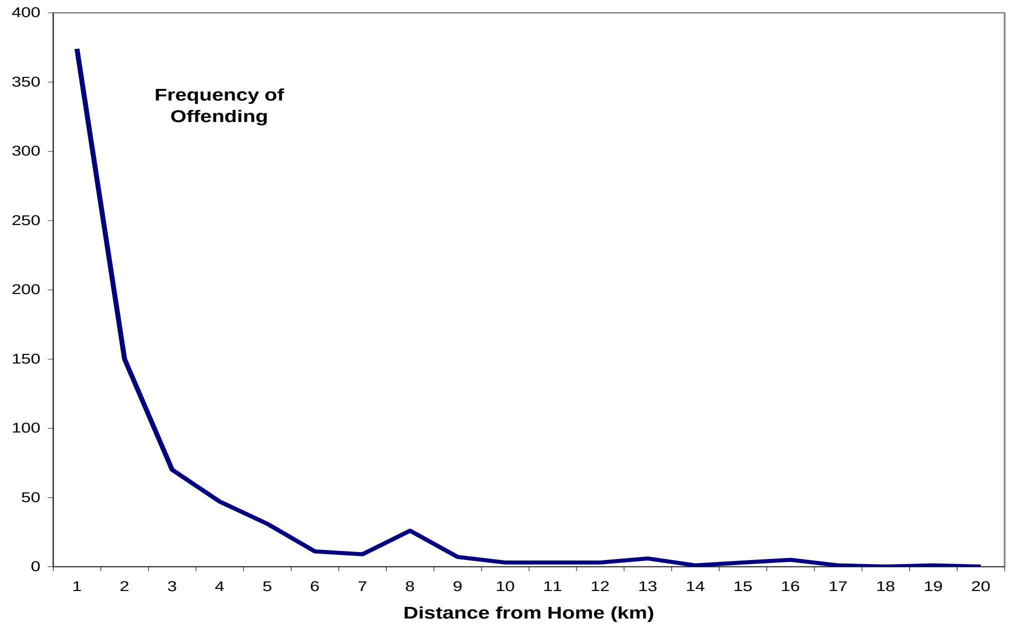

Figure 1**: Distribution of the Distances Travelled to Offend by a Sample of Prolific Burglars (N=70)**

A scatterplot of the frequencies of occurrence for each of the distance intervals was then constructed, and the best fit forms of each of the functions were calculated (Figure 2.).

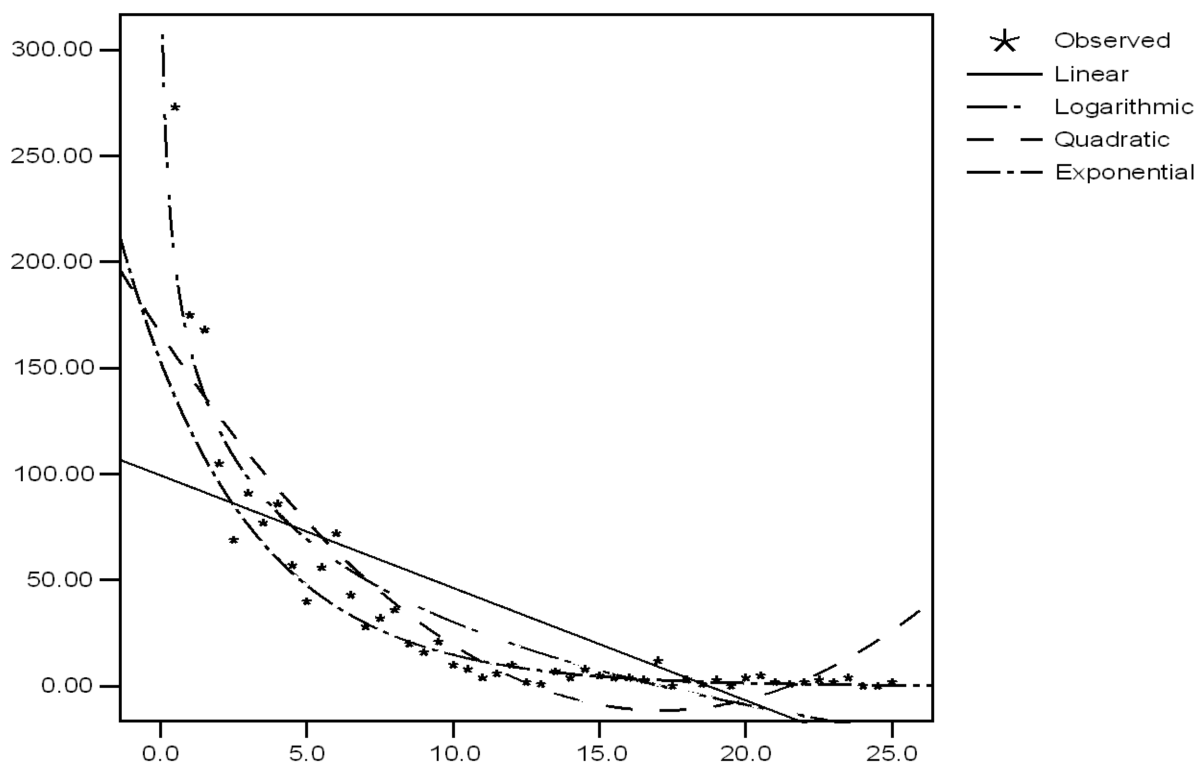

Figure 2**: The Four Functions Calibrated Against Distribution of Distances Travelled to Offend**

The best fit forms of each of the functions were represented by the following formulae:

LOGARITHMIC

$$y = 159.742667 + (-56.244165). \ln x \qquad R^2 = 0.87$$

NEGATIVE EXPONENTIAL

$$y = 153.066774\, e^{-(-0.234174)\, x} \qquad R^2 = 0.74$$

QUADRATIC

$$y = 0.606007x^2 + (-20.756908)\, x + 166.2944 \qquad R^2 = 0.80$$

LINEAR

$$y = -5.303741\, x + 99.330694 \qquad R^2 = 0.52$$

The co-efficient of determination, R^2, measures the strength of the regression relationship to the frequency data, and can therefore be used as a measure of how well a mathematical model, in this case each of the functions, fits a particular distribution (Kent, 2003). The R^2 value determines the extent to which the independent variable, x, (in this case the distance travelled between home and crime) can account for the variation in the dependant variable, y (for the present study the frequencies of occurrence for each of the different distance intervals) (Kent, 2003; p68). The R^2 values found for the best-fit forms of each of the functions under consideration in the present research are given above, alongside the formula for each.

There were notable variations between the R^2 values produced by each of the functions; the values ranged from only 0.52 for the linear function, which had been hypothesised to provide the poorest fit to the data and was used as an experimental control in the present research, to 0.87 for the logarithmic function, which provided the best fit of all of the functions to the distribution of the distances travelled in the commission of crime for offenders in the present sample. However, both the quadratic and negative exponential functions were also found to provide good approximations to the journey to crime data, producing R^2 values of 0.80 and 0.74 respectively. The differences between the three key functions and the linear control in terms of the fit of the functions to the data were found to be significant ($p<0.05$).

The finding that the logarithmic function provided the closest fit to the distribution of the distances travelled to offend by the individuals in the present sample would suggest that magnitude estimation, and the perception of the individual of the distances that he or she is travelling from home to commit their offences, plays a key role in the selection of offence locations and the journeys made to them.

However, it does also appear that there may be some merit to the hypotheses about the influences on spatial behaviour that underlie both the quadratic and negative exponential functions, with the reasonable approximations to the distance distribution provided by each suggesting that, to some extent, friction of distance and resistance to movement over space, as well as the assessment and avoidance of risk, form some part of the explanation for the length of the trips that offenders make from their homes to their crime locations.

Under the assumption that the better the fit a function provides to the raw data the more effectively a geographical profiling system will perform when utilising that function (in this instance, the lower the search costs produced by Dragnet will be), as suggested previously, it was hypothesised that the logarithmic function would generate the lowest search costs, followed by the quadratic and negative exponential functions, and that the linear control would produce, on average, the highest search costs overall.

<u>Study 2</u>

The Impact of Different Decay Functions on the Effectiveness of a Geographical Profiling System (Dragnet)

Regardless of which of the decay functions, including the control negative linear function, was employed within Dragnet the search costs produced by the system for this sample of prolific burglars were remarkably low. More than 70% of the sample produced search costs of 0.1 or less (i.e. were located within the first 10% of the prioritised search area that Dragnet produced) and almost the entire sample produced search costs of 0.5 or less.

The median search costs produced by Dragnet when each of the different functions was utilised within the system, as well as the mean search costs and standard deviations, are given in Table 1.

Function	**Median**
Logarithmic	**0.011542** (M = 0.10463, S.D. = 0.1898222)
Exponential	**0.021429** (M = 0.10864, S.D. = 0.1881695)
Quadratic	**0.021542** (M = 0.10871, S.D. = 0.1880882)
Linear	**0.024737** (M = 0.11564, S.D. = 0.1956546)

Table 1: **Median Search Costs Produced by Each of the Three Functions and the Control Linear Function (Means and Standard Deviations in Brackets)**

The logarithmic function, which had provided the closes approximation to the raw data (R^2 = 0.87), produced the lowest average search cost (Median = 0.011). However, both the exponential and quadratic functions produced median search costs of 0.021, not much higher than the search costs found for the logarithmic function. The linear function produced the highest search costs overall (Median = 0.024).

However, whilst the logarithmic function produced the best results and the control negative linear function the worst, as hypothesised, the differences between the four functions under consideration, in terms of the search costs produced by Dragnet when each of the functions was utilised within the system, were not significant.

The 'Search Cost Function'

Average search cost values merely provide gross indicators of the effectiveness of a geographical profiling system. The distribution of the search costs is unlikely to be symmetrical. From an operational stand-point the proportions of both low and high search costs when the parameters are altered provide a more useful indicator of system effectiveness. The present study varies the form of decay functions to examine the impact on search cost.

The utilisation of 'search cost functions', relating the proportion of the sample to the search costs produced, is therefore of value. Figure 3 shows the search cost functions for each of the three functions as well as for the negative linear control function.

Each search cost function is positively monotonic in shape for the four functions under consideration, with a distinct change in gradients at around 75% of the sample regardless of the nature and form of the function employed. The curves of each also display a distinct 'elbow' at the 0.1 search cost value (10% of the total search area needed to be searched in order to locate the offender), with the curves subsequently evening out and tapering off at a much slower rate across the higher search cost values.

The point at which this elbow occurs, illustrating a distinct change in the gradient of the search cost function, can be viewed as illustrating a qualitative change in the operation of the system occurs. The fact that this is at the 0.1 search cost value for almost 80% of the sample is consequently testament to the power and effectiveness of the Dragnet system at prioritising and reducing the search for an offender, indicating the system to be highly productive in this respect.

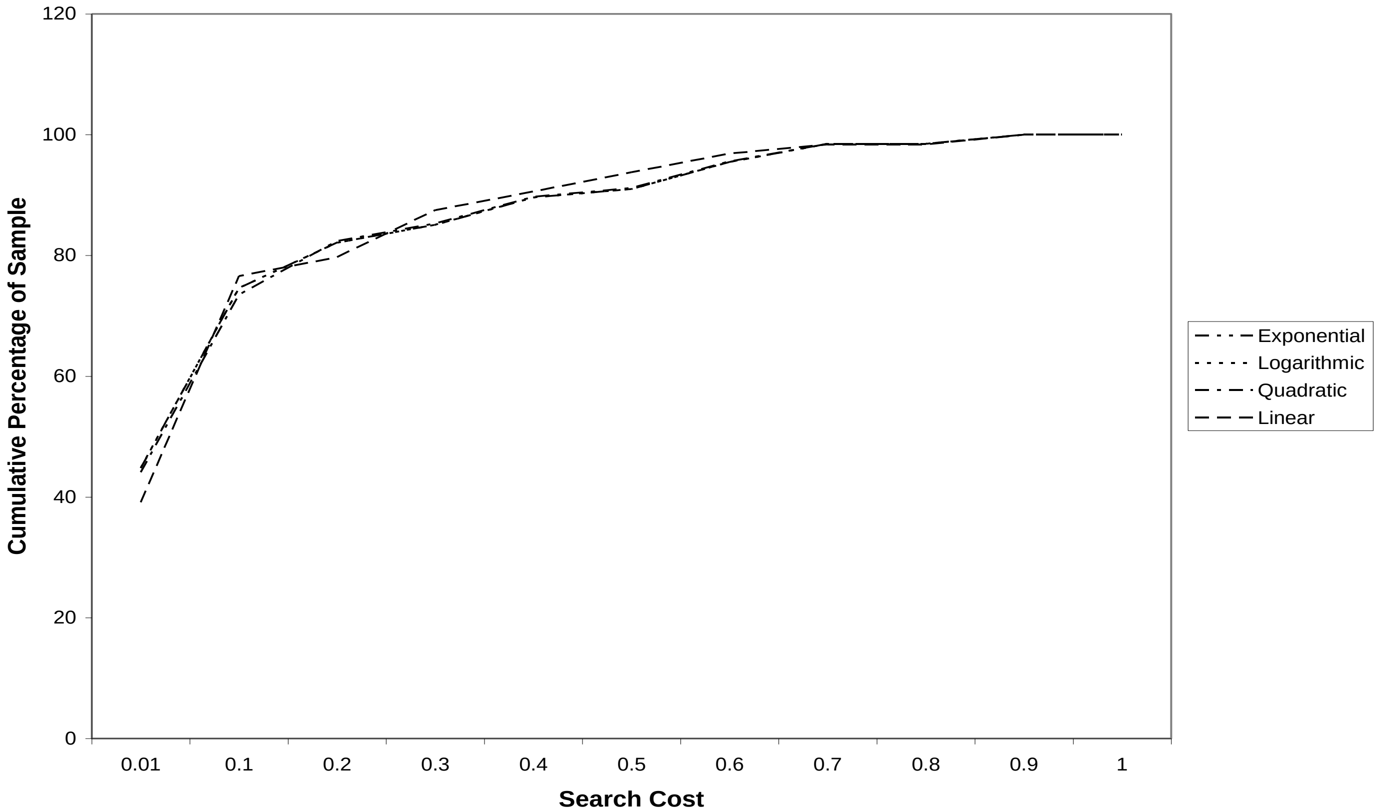

Figure 3: **The 'Search Cost Function' (Cumulative Search Cost Percentages) For Each of the Functions**

Discussion

The present paper has attempted to explicate the 'decay' function found in distributions of the distances that offenders travel to commit their crimes and in so doing inform understanding of the processes underlying offender spatial behaviour. It was proposed that the decay function itself could take different forms, each form consistent with a slightly different pattern of decay in the frequency of travel distances across the sample. The closest data fit was found for the logarithmic function, showing a very high initial frequency of offending at distances very close to the home followed by a sharp decline that becomes markedly more gradual at around 5-10 km from home and then continues to slowly level out.

It is argued that this pattern of decay, which is consistent with small increases in the distance travelled producing a rapid reduction in the likelihood of offending while at the further from home locations, equivalent reductions require larger distance differentials, may reflect the general perceptual distortions in magnitude estimation outlined by Stevens (1961). In his Power Law, Stevens argues that magnitudes are not estimated in a linear fashion; rather, as the size of a magnitude increases, proportionally larger increases are required for the difference in magnitude to be perceived. Stevens provides evidence of logarithmic functions for the relationship between estimated and actual magnitudes across a variety of phenomena. The present finding that distances travelled to offend also follow this pattern does suggest that perceptual processes influence offender spatial behaviour. It suggests that decisions about how far to travel to offend are, at least in part, made at the general perceptual level.

In terms of existing theoretical frameworks for explaining criminal spatial behaviour, the relevance of perceptual processes to the widely reported distance decay, would be consistent with an environmental psychological perspective and broad cognitive representations such as notions of domocentricity shaping distances travelled to offend rather than more concrete concerns with actual effort, routes or familiarity.

However, although the overall pattern of decay across the full range of distances showed the closest fit to the logarithmic function, it should be noted that at the shorter distances only, both the negative exponential and the quadratic functions, suggesting processes of friction/effort and cost-benefit analyses could also be argued to be relevant the general pattern of rapid decline for this subset of closer to home spatial decisions. It is also the case that while within the current sample little evidence was found for the quadratic form, this pattern may be appropriate different types of offences (e.g. thefts of specialised goods) or even types of offenders. Thus while emphasising the significance of perceptual processes in offender spatial behaviour the present findings should not be taken as necessarily indicating a lack of support for other frameworks in addition.

It may then be that a three or more function model is necessary to comprehensively detail this aspect of the spatial behaviour of offenders, taking account of the cognitive processes of the offender, the effort involved in the journey to crime and the opportunity and appeal of potential targets.

The present paper also explored a second aspect of the use of different functions to characterise the decay observed in the distances that offenders travel to commit their crimes, considering the impact that the different forms of function had on the effectiveness of a geographical profiling system, Dragnet. The fact that, regardless of the decay function employed in the calculations used by the system to prioritise the search for an offender, the search costs for the prolific burglars in the current sample were typically very low would suggest that Dragnet is not especially sensitive to the particular decay function employed. This is likely to be the same for any such geographical profiling system. Potential reasons for this observation could relate to the nature of the data employed, and limits in its accuracy and precision, as well as to averaging processes and normalisation procedures employed by the system. However, the fact remains that, for the sample in the present study at least, and likely for many other samples, different decay functions do not appear to impact greatly upon the efficacy of geographical profiling systems.

As previously mentioned, there has, to date, been little consideration of the applicability of methods and systems of geographical profiling to volume crime within the criminological literature; rather past analyses have been conducted on limited crime types, usually samples of serial murderers (for example; Canter et al. 2000; Rossmo, 2000). Therefore, the finding that, for the sample in the present study, Dragnet proved remarkably effective at reducing the search for prolific burglary offenders regardless of the decay function employed within the system, is particularly worthy of note.

In operational terms, the applicability of a geographical profiling system and the reliability with which it prioritises the search for an offender when applied to volume crime as demonstrated in the present study has numerous implications for the use of such systems within the investigative domain. Moreover, it raises the potential for further empirical consideration and consequently for the refinement of such methods in order to enhance their applicability to a wider range of criminal populations and crime types.

Research should also seek to delineate further shapes or forms of function that may beneficially be employed to reflect the underlying psychological factors and decision processes governing the selection of crime locations and the distances travelled to offend, and the impact that these functions have, if any, on the operation of geographical profiling systems. It has been shown that all three of the experimental functions under consideration provided a close approximation to the distribution of the distances travelled to offend that the estimation of distances, the ‘friction’ of distance and resistance to movement over space and the assessment and calculation of risk all play notable roles in determining the length of the journeys made to offend. However, the parameters affecting the influence of such processes, as well as other factors potentially impacting upon the distances travelled to offend and variations across a greater variety of crime types, remain to be determined.

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