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A Comparison of the Efficacy of Different Decay Functions in Geographical Profiling for a Sample of US Serial Killers

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Abstract

Many studies have shown that distributions of the distances that offenders travel in the commission of their offences are typically characterised by a decay function. However, there are few empirical comparisons of the different mathematical functions which may characterise such distributions. Further, there has been little consideration of what different forms of function may reflect about the underlying factors and psychological processes governing this aspect of the journey to crime. With the increasing use of geographical profiling systems which incorporate decay functions into their calculations, it is particularly of value to explore the most appropriate mathematics for describing the frequencies of crime journeys and to determine the impact of different decay functions on the effectiveness of a geographical profiling system. A two-stage study was therefore carried out using data derived from 96 US serial killers. In the first stage three different decay functions were examined, in terms of the extent to which they fitted a distribution of the distances travelled to offend for the sample; logarithmic, in accordance with Steven's 'Power Law' for distance estimation; negative exponential as an estimate based on the 'friction' generated by journeys; and quadratic, which reflects key principles found from journey to crime research. A 'control' function, simple negative linear, was also tested against the data. It was found the logarithmic function provided the closest approximation to the journey to crime distances of offenders in the present sample ($R^2 = 0.81$*, *$p < 0.001$*), suggesting that distance estimations may be an important part of the explanation for the length of the crime trips that offenders make. In the second stage, all four functions were utilised within a geographical profiling system (Dragnet) and their impact on the search cost for locating an offender established for the whole sample. In general it was found that the search cost function, which relates the proportion of the sample to the search cost, was positively monotonic with a distinct change in gradients around 58% of the sample, indicating that the software was producing useful results in the majority of*

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cases. However, although the logarithmic function produced the best results overall, and the linear function the worst, as hypothesised, no significant differences between the search costs were found when each of the different functions was utilised. The implications for the robustness of the software and the possible influence of the low precision of the raw data are discussed. Copyright © 2006 John Wiley & Sons, Ltd.

INTRODUCTION

Research into the spatial behaviour of offending populations has shown that the distribution of distances travelled by offenders in the commission of their crimes is typically characterised by a 'distance decay' function (Canter, Coffey, Huntley & Missen, 2000; Phillips, 1980; Rengert, Piquero & Jones, 1999; Rhodes & Conly, 1991; Turner, 1969). Essentially, as the distance from an offender's home or base increases, the likelihood and frequency of their offending decreases (Turner, 1969). This decline is non-linear in form, with a negative exponential or power function typically used to reflect the relationship between location and distance (ESRI, 1996).

As early as 1969, Turner hypothesised that a number of different forms of function could characterise distance decay in criminal spatial behaviour. Indeed, Brantingham and Brantingham (1991), Canter *et al.* (2000), Hunter and Shannon (1985), Kent (2003), Levene (2002), Phillips (1980), Rhodes and Conly (1981) and Turner (1969) all propose different decay functions as providing the closest approximations for describing the distances travelled to offend for various criminal populations.

Eldridge and Jones (1991) observe that different functions will have different behavioural implications. For example, a steep function that decayed quickly would suggest that the home might have a very strong influence on the behaviour of those offenders, in that they would appear to be reluctant to travel far from it. Conversely, if the decay function were much shallower, with the distances travelled to offend decaying very slowly, then the implication would be that the offender's home had less of an influence on their activity, and that they instead operated over a much broader area (Canter *et al.*, 2000). Therefore, different functions can each be treated as a set of hypotheses about the factors governing the distances that offenders travel in the commission of their crimes.

To date there have been few empirical comparisons of the various decay functions which may characterise offender travel distances. Further, there has been little consideration of what different functions might reveal about the underlying factors and psychological processes governing the journey to crime.

There are, however, published studies of the efficacy of various functions in terms of their accuracy at reflecting the distributions of other distance-based data. For example, De
1 Vries, Nijkamp and Rietveld (2004) considered home-to-work journeys between municipalities in Denmark in a study on commuting flows, and found exponential and power functions to be ineffective at characterizing the decay in distances travelled, providing poor fits to data on such phenomena despite being those functions most frequently used for such purposes. Conversely, a logarithmic function was found to work better, and they conclude by suggesting that a pragmatic direction for future work would be to utilise functions of this form in representing distance decay (De Vries, Nijkamp & Rietveld, 2004). The value of De Vries *et al.*'s (2004) comparisons indicate a similar likely utility in studying home-to-crime journeys.

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Decay functions play an important role in systems that help investigators to infer the location of an offender's base from the location of linked crimes, known as geographical profiling systems (Canter *et al.*, 2000). The significance of the hypotheses presupposed by different decay functions can therefore be tested by comparing how geographical profiling systems perform when different functions are incorporated into the calculations that they use to model the spatial behaviour of offenders.

Geographical profiling systems are becoming increasingly commonplace within the investigative domain, but they also provide a useful research tool for modelling and characterising the journey to crime. However, with the exception of Canter *et al*. (2000), there has been little consideration of how different functions affect the operation of any system and what might be the most appropriate mathematical algorithm to employ when describing the frequencies of journeys to crime.

A means of assessing the effectiveness of one such geographical profiling system, Dragnet (Canter *et al*., 2000), used in the present study, is to use a specifically defined measure termed the 'Search Cost Function' (Canter & Snook, 1999; Canter *et al.*, 2000). In cases where the location of the offender's home or base is known, the search cost allows the effectiveness of Dragnet in predicting this location to be examined.

The Search Cost is defined as 'the proportion of the total search area that has to be searched in order to find the location of the offender' (Canter & Snook, 1999). The search cost function represents the relationship between the proportion of the total area searched and the proportion of offenders located for each search cost.

Canter and Snook (1999) propose that search cost values can be used to determine whether an offender's spatial behaviour followed a particular function, and that low search costs would suggest that such a function accurately represented the relationship between the offender's home and the location of their offences. It should therefore be that the opposite is also true—that if a function accurately represented the relationship between home and crime location then the search costs produced using that function should be low. Essentially, when utilising the decay function that provides the best fit to any given distribution, a geographical profiling system would be expected to perform more effectively for the offenders whose crime trips generated that distribution than when any other functions are used.

A two-stage analysis process is suggested for determining how effective a decay function is for use in geographical profiling. First, the efficacy of the function, in terms of the extent to which the function fits data on the distances travelled to offend needs to be determined. Second, the efficiency of the function when it is utilised within a geographical profiling system needs to be established, using the 'search cost function' to evaluate how accurately and reliably the system operates when using that function as the basis for its calculations.

Three decay functions were compared: exponential, logarithmic and quadratic. A fourth function was introduced as a 'control'. This was a straight negative linear function, which does not display incremental 'decay' characteristics. The fit of the functions to the raw data was first established in order to determine which best represented the spatial relationship between an offender's home location and their offence sites, using R^2 values as a measure of the strength of this relationship. Subsequently, the effect of the type of function on the operation of a geographical profiling system, Dragnet, was examined. It was predicted that the better the fit of a function to the raw data, the lower the search costs produced by Dragnet.

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STUDY 1

The logarithmic, exponential and quadratic functions

Three different functions were examined, in terms of the extent to which they fitted a distribution of the distances travelled between home and crime location(s) for the offenders in the sample. Each of them illustrates the non-linear decay in the frequency of offending as the distance from an offender's home or base increases, but each presupposes somewhat different explanations and hypotheses as to how and why this decay occurs.

The logarithmic function

The logarithmic function providing a close approximation to a distribution of journey to crime lengths would suggest that the frequency of offending decreases dramatically initially, and then in a more gradual fashion, as the distance from the home or base increases. A best-fit curved line is mathematically calculated that describes the rate of change as the data decreases quickly and subsequently levels out (Kent, 2003).

An explanation for the form of decay which this function proposes can be drawn from the work of Stevens (1961) and his 'Power Law'of magnitude estimations, in relation to how distances from home to potential crime locations are likely to be estimated by the criminal.

There is a considerable literature, most clearly summarised by Stevens' seminal 1961 paper, which indicates that people do not estimate any magnitudes in a linear way. In other words, as magnitudes get larger, a greater increase in magnitude is needed for the same increase in estimation. The relationship between estimated magnitude and actual size has been shown by Stevens to be characterised as a specific logarithmic function for each modality being estimated. Therefore, if it is assumed that offenders are considering how far to travel to commit a crime then they must be making some estimate of the length of the journey. This estimate would be distorted by the logarithmic function proposed by Stevens and it may therefore be hypothesised that the frequency of their journeys to different distances would also obey this logarithmic relationship.

The exponential function

2 In their examination of burglars, robbers and rapists, Rhodes & Conly (1981) found that the distance decay displayed by the offenders in their sample was typically negatively exponential in nature, and that this was the function that best characterised the journey to crime. Capone and Nichols (1976) also find that an exponential function is that which would be expected to fit most closely the distribution of crime trip distances, both those that are meaningful and purposeful and those that are accidental. Further testimony to the power of the exponential function in characterising distance distributions can be found in research into many other aspects of spatial and behavioural phenomena as cited for example by Golledge (1987).

A close approximation of the exponential function for journey to crime data would indicate that the likelihood of offending is highest in the region around the offender's home, and then drops off with distance. This decrease is at a constant rate of decline (Kent, 2003), thus dropping relatively quickly near the place of residence, and then levelling out until it approaches a zero likelihood.

Phillips (1980) argues that the distance decay in offending behaviour results from 'the friction of distance; the cost in money, time or energy of overcoming distance' (p. 136).

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The exponential function is that which most closely reflects this, with the shape and form of the function illustrating the impact of this friction of distance on the likelihood and frequency of offending. This is analogous to impedance, the impediment (opposition) to electrical flow, a combination of resistance and reactance (dictionary definition).

This impedance, or 'friction effect', has been found to relate to a wide variety of phenomena, including property values (Richardson, Gordon, Jun, Heikkila & Dale-Johnson, 1990), migration (Kothari, 2002) and even fishing (Beverton & Holt, 1957). The terms refers to resistance to movement over space (Canter, 2004), in relation to cost in terms of [3] time, money and effort, as proposed by Phillips (1980). The increased costs incurred are what generate this resistance to longer journeys, and the resultant pattern in the distance travelled to offend can be estimated and represented by the form of the exponential function, illustrating this influence of 'friction of distance'.

The quadratic function

The form of the quadratic function is somewhat different to any of the others being examined. It merits consideration as, because of its unique shape, it mirrors two different perspectives on the influences on the distances travelled to offend.

A quadratic function providing a close fit to a distribution of journey to crime distances would suggest that the frequency of offending declines rapidly with distance from the home initially, and then levels out so that the frequency of offending is represented as being substantially less for distances further away from the home. However, after a point the frequency of offending begins to increase again, so that more offences would be expected to occur at locations a notable distance from the home compared with those of medium distance (although the frequency of offending at these distances is much less than those for regions immediately proximate to the home).

The quadratic function therefore incorporates both the process captured by the logarithmic and exponential functions of decrease in crime frequency further from the home location and also the process which has been reported whereby criminals sometimes favour locations further away from home, where the risk of recognition and consequently detection may be reduced (Brantingham & Brantingham, 1991). There is also the possibility that the opportunities for crime closer to home will become exhausted, forcing an offender to travel further afield to find suitable targets for their crimes (Lundrigan & Canter, 2001).

The control, negative linear function

A simple negative decreasing linear function was also tested for fit to the distance distribution. If it were to provide a close approximation, then this would suggest that the probability of offending at a particular location decreased by a constant amount with increasing distance from an individual's home or base location (Levene, 2002).

The linear function has been presented as a valid representation of the relationship between distance from home and frequency of offending (Turner, 1969). However, given that most research proposes that the rate of decrease is likely to change, the linear function can be regarded as a form of experimental 'control' that makes fewer assumptions than the other more complex functions.

Data

The data utilised in the present study was derived from the *HITS* and *Missen Corpus* databases, detailed by Canter *et al.* (2000). These incorporate data drawn from published

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accounts of serial killers operating within the US since 1960. In total, 96 series of offences were used, each representing a single offender, and each consisting of five of the offences committed by that individual.

For each offender, the location at which they had been residing at the time of their offences were determined from at least two independent sources, as were the body disposal locations, which were taken as the crime sites (for a detailed account of the preparation and features of this data set, see Canter *et al*., 2000).

The home and offence locations were converted into geocoded co-ordinates and subsequently transformed into a format that would enable them to be fed into the Dragnet system (see www.i-psy.com for details of the files used by Dragnet, as well as for a comprehensive introduction to the system and how it operates).

Fitting the functions to the data

In order to determine which of the four functions provided the 'best fit' to the raw data a number of steps had to be taken. Initially, the distances travelled between each home and each offence location were calculated and entered into a Microsoft® Excel® database. Once a full set of all of the journey to crime distances had be compiled, the values could then be grouped into distance intervals, using a method detailed by Kent (2003). First, the home to crime distances were sorted into ascending order. Next, a frequency distribution was applied for each of these distances, and grouped into 1 km intervals (Kent, 2003; p. 63). These frequency intervals were then converted into relative frequencies for each distance value. This was done by dividing the frequency values for each interval by the total number of incidences in that interval, and multiplying this figure by 100 in order to obtain the frequency percentage for each distance value.

The distance intervals and the frequencies of offending for each of these intervals are given in Figure 1. The shape of the chart shows clear distance decay in the journeys made to commit offences by the present sample.

Using SPSS® 11.0 and Microsoft® Excel®, a scatterplot was constructed with points marking the frequencies of occurrence for each of the distance intervals. Each of the four functions—linear, exponential, logarithmic and quadratic—was calculated for this scatterplot in order to obtain the 'best fit' for the distribution (Figure 2).

The equations for each of the functions were calculated, and the best-fit formulas for each of the lines were found to be as follows:

Logarithmic

$$y = 5.6735 + (-1.3307)\cdot \text{In}\, x \qquad R^2 = 0.81$$

Negative exponential

$$y = 2.13403\ e^{-(-0.04574)x} \qquad R^2 = 0.45$$

Quadratic

$$y = 0.000981x^2 + (-0.13129)x + 4.14137 \qquad R^2 = 0.75$$

Linear

$$y = -0.03213x + 2.45555 \qquad R^2 = 0.46$$

One advantage of Dragnet is that it allows any function to be called up as a specified .fun file as the basis for its calculations of the probabilities of home locations. It was therefore possible to input each of the four best-fit functions in turn and to calculate the search

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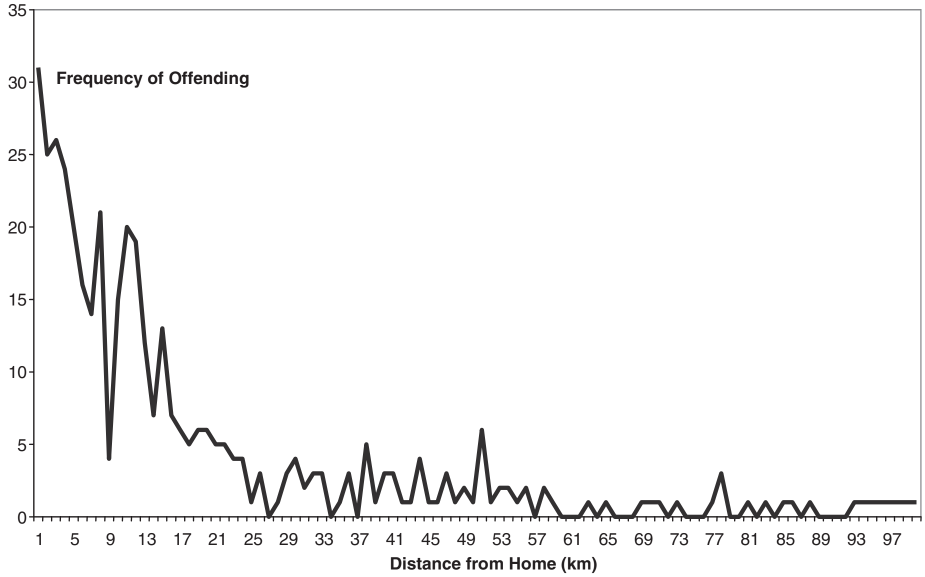

Figure 1. The distribution of the distances travelled to offend by all serial murderers in the sample ($N = 96$).

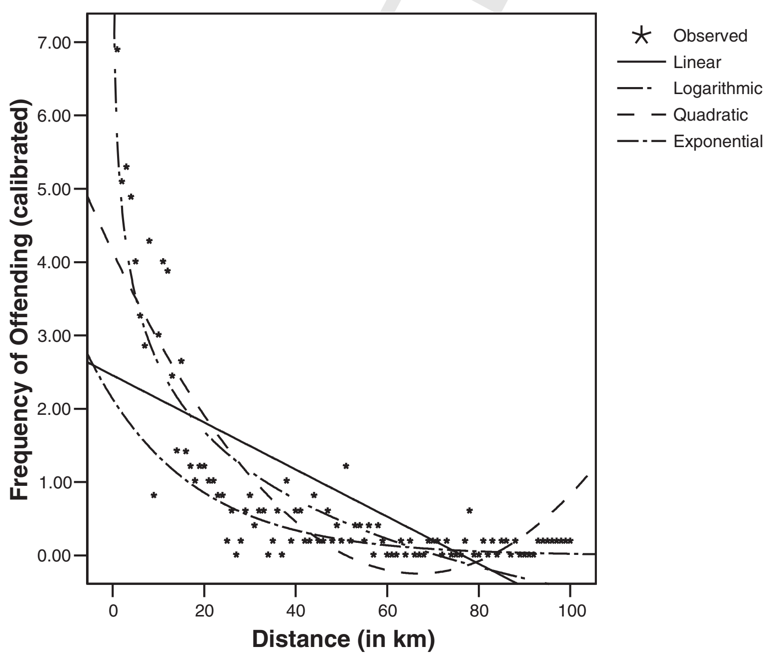

Figure 2. Scatterplot of the frequencies of occurrence for each of the distance intervals, with the calibrated functions 'fitted' to the distribution.

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cost for that function. Dragnet also calculates the search cost for each offender and the version used, DragnetK, enables all of the costs to be processed as a batch file, thus reducing inputting and calculation errors.

The best-fit formulas derived for each of the functions were used to create files for each of the functions that could be entered into Dragnet. The same 20 *x* values were put into each of the formulas, and the *y* values produced were those that were used to characterise each function in its respective Dragnet .fun file.

Findings on the fit of the functions

The co-efficient of determination, R^2, measures the strength of the regression relationship to the frequency data. Consequently, it may be used as a measure of how well a mathematical model fits a given distribution (Kent, 2003), as it evaluates the extent to which the independent variable, *x* (in this case the distance between the offender's home and their offence location) can account for the variation in the dependant variable, *y* (in this instance the frequencies of occurrence of each of the distance intervals).

'As a descriptive measure between 0 and 1, R^2 is interpreted as the percentage of variation in the dependant variable that is explained by the independent variable. Analysis of Variance (the F statistic) is used to evaluate the statistical significance of R^2 (Kent, 2003; p. 68).

The R^2 values for each of the four functions under consideration in the present work are shown in Table 1. For each model the R^2 values were found to be highly significant ($p < 0.01$).

The logarithmic function was found to have the highest R^2 value and thus provided the best fit to the raw data ($R^2 = 0.81$). Consequently, it may be assumed that it was the function that best represented the distribution of the distances travelled from home to crime for offenders in the present sample. The quadratic function was also found to have a relatively high R^2 value ($R^2 = 0.75$), and so proved to fit the data reasonably well, whereas the negative exponential and linear functions both had much smaller R^2 values (0.45 and 0.46 respectively), and so provided the poorest fits of all of the functions. They may therefore be taken to provide the weakest representations of the relationship between the distance from home to crime and the frequency of occurrence. The differences between the three functions and the control linear function, in terms of their fit to the data, were found to be significant ($p < 0.05$).

On the basis of these findings, it was hypothesised that, when used in Dragnet, the logarithmic function would prove to be the most effective, producing the lowest search costs. Conversely, the linear and negative exponential functions were expected to be the least effective functions, and thus to produce the largest search costs.

Table 1. *R* and R^2 values for each of the four functions

Function	*R* value	R^2 value
Logarithmic	0.90100	0.81179
Exponential	0.67211	0.45174
Quadratic	0.86612	0.75016
Linear	0.67997	0.46237

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STUDY 2

The use of decay functions within a geographical profiling system

There are a number of systems that draw upon the principle of distance decay in order to predict where an offender's home or base might be located. One such system is Dragnet, developed at the Centre for Investigative Psychology at the University of Liverpool by Professor David Canter, Malcom Huntley and colleagues (Canter *et al*., 2000).

Dragnet is a 'geographical offender location system', a decision support package designed to identify the area in which a serial offender is most likely to reside. The system operates by adding the estimated probabilities of the location of the home from each crime location (Canter *et al.*, 2000). In common with other systems (e.g. Rossmo, 1995), for 4 operational support it produces a prioritised probability map of the area in which the crimes occurred. The probability distribution for each crime is derived from the particular decay function that is called up by the system. For research purposes the system also provides the actual probability value for each point on the map. If the location of the home is known then the system calculates the probability value of that location and uses that value in calculating the 'search cost' of reaching that location, i.e. the proportion of the map area that has to be 'searched' before that probability value is reached. It is these search costs that form the basis of assessing the effectiveness of any particular decay function.

Research on the efficacy of Dragnet is currently scarce and relatively limited. However, Canter *et al.* (2000) found that the system accurately predicted 51% of all offender residences within the top 5% of the search area, and 87% of the offender residences within the top 25% of the search area. Overall the model was able to reduce the size of the original rectangular search area to just 11% of the total size (Canter *et al.*, 2000).

Canter *et al*. (2000) propose that to enable the development of geographical profiling systems, like Dragnet, it is necessary to 'explore the various feasible mathematical functions that describe the distance decay displayed by offenders in order to determine which functions are most effective' (Canter *et al*., 2000; p. 460). Further, they note that little empirical research has been published that has compared different functions on any measure of effectiveness, or any set of crime data, and that there is therefore a great need for further consideration of such factors (Canter *et al*., 2000).

Canter and Snook (1999) address the significance of the application of different functions in geographical profiling, emphasising the importance of establishing the impact such functions have when they are built into geographical profiling systems. They propose that a key research task would be to delineate what functions may be used and the impacts that they might have on the Search Cost Function (Canter & Snook, 1999).

Results of search cost functions

Regardless which of the three decay functions were used, the search costs produced by Dragnet for this sample were generally very low. Overall, more than 50% of the sample had a search cost of less than 0.1 (i.e. were located within the first 10% of search area as prioritised by the system), and over 80% of the sample produced search costs of 0.5 or less.

The median search costs produced by Dragnet when each of the functions was used within the system, as well as means and standard deviations of these values, are given in Table 2.

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Table 2. Median search costs produced by each of the four functions (means and standard deviations in brackets)

Function	Median
Logarithmic	0.08342 (M = 0.2109, SD = 0.2448)
Exponential	0.08376 (M = 0.2132, SD = 0.2427)
Quadratic	0.08360 (M = 0.2130, SD = 0.2423)
Linear	0.08996 (M = 0.2391, SD = 0.2791)

The logarithmic function, the model which provided the best fit to the raw data (R^2 = 0.81), was found to produce the lowest average search cost (median = 0.083). However, the quadratic and exponential functions both produced median search costs of 0.084 which was only marginally different from the logarithmic search costs. The linear function produced the highest search costs overall, with a median of 0.090.

However, whilst the logarithmic function produced the best results and the straight linear the worst, as predicted, the differences between the various functions, in terms of the search costs that they generated when used within the Dragnet system, were not significant.

The median search cost value is only a gross indicator of the effectiveness of any geographical profiling system. It is very likely that the distribution of the search costs is not symmetrical and from an operational point of view the proportion of low cost searches is possibly a more important indicator. It is there of value to look at the 'search cost function', which relates the proportion of the sample to the search cost, as illustrated in Figure 1. This shows that the search cost function is positively monotonic for all decay functions with a distinct change in gradients around 58% of the sample regardless of the function employed. The curves of each of the search cost functions displays a distinct 'elbow' at the 0.1 value (10% of the total search area needed to be searched in order to locate the offender), with the curves then tapering off at a much slower rate across the higher search
5 cost values.

The point at which this elbow, the distinct change in the gradient of the search cost function, occurs can be viewed as an indication of a point at which some qualitative change occurs in the operation of the system. Where the curve starts to level out or flatten may be an indicator of where offenders were less likely to be committing crimes around their
6 7 home/base as 'marauders' (Canter & Larkin, 1993). In this instance, the fact that this is at the 0.1 search cost value, for 58% of the sample, is testament to the power and effectiveness of the Dragnet system in reducing the search for an offender. The elbow, at such a low search cost value, indicates that the system is highly productive in this respect.

DISCUSSION

Two different issues have been explored in the present paper. One is an attempt to explicate the theoretical basis for the often found decay function in offender journey to crime distances. It was proposed that different explanations of why such a decay function occurs would lead to the function itself taking different forms. Explanations based on cognitive processes within the offender, relating to the offender's possible estimates of how far he is traveling away from home, were postulated as being supported by a strong logarithmic

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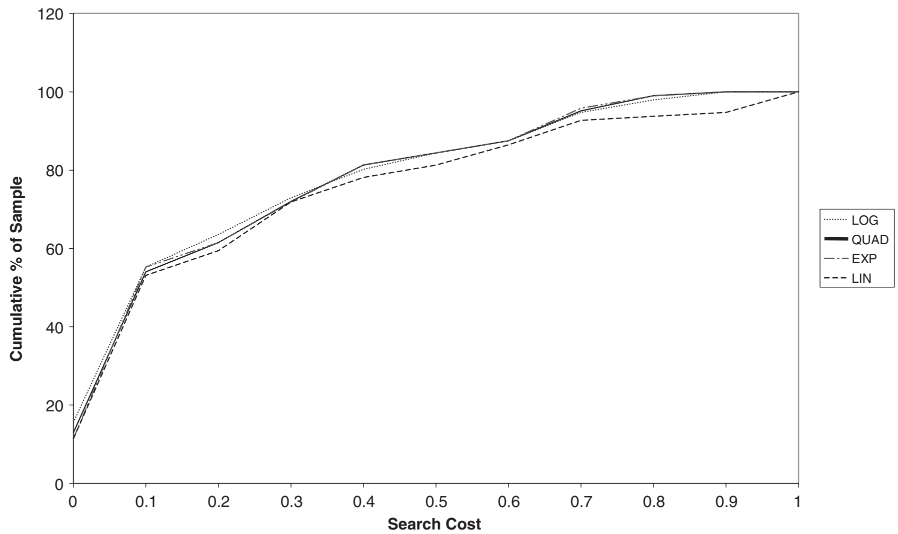

Figure 3. Cumulative search cost percentages produced by each of the functions.

function. The finding that, for this sample of serial killers, that was the function that had the strongest relationship with the raw data does lend support to the role of magnitude estimation in offenders' crime location choice. 8

However, the fact that each of the other functions, including the straight linear function, produced significant R^2 values with the distribution of distances travelled would suggest that a complex set of other processes are also involved, notably some form of 'impedance' generated by the increasing costs of lengthier journeys and even the increased attractiveness of distant locations as supported by the quadratic function. These results support the view that friction of distance, cost in terms of time, money and effort, familiarity 9 with an area, the influence of the home and the risk of detection associated with regions closer to the residential location all play a part in the decision of how far an individual will travel to commit a crime. A three function model that takes account of a) the cognitive processes of the offender, b) the effort involved in the journey to crime, and c) the opportunities and attractiveness of the target may therefore be necessary to fully model offenders' journeys to crime.

However, the dominance of the logarithmic function with the present sample is worth emphasising because it reflects results found for distance decay for other aspects of human behaviour, for example commuting, or shopping trips. De Vries, Nijkamp and Rietveld (2004) found that the logarithmic function was far more effective at characterising dis- 10 tance decay than other functions, such as the exponential. Therefore the parallels between the extreme and bizarre activities of serial killers may be usefully compared with the more mundane actions of commuting to work or shopping, lending support to the view expressed by Lundrigan and Canter (2001) that, although the actions of serial killers are difficult to explain, their choice of site for disposal of the body may have quite direct and everyday 11 causations.

A second aspect of the present paper was to explore the impact of different decay functions on the effectiveness of the geographical profiling system Dragnet. The results show that with the current data set Dragnet is not especially sensitive to the particular decay

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function employed. This is likely to be the case for all other geographical profiling systems that incorporate decay functions. The reasons for this may, in part, be due to limits in the precision of the original data, and to the averaging processes that take place within the software. In the present case only five offences were considered for each offender and this may have curtailed the range of values generated. The normalisation process which adjusts the calculations against the average inter-point distance (Canter *et al*., 2000) may also have reduced the impact of more extreme values which is where the decay functions have their largest differences.

Other factors may also be reducing the impact of the more extreme distances where fewer offences are likely to be occurring. It may therefore be that, were a different sample utilised in which there were bigger variations between the distances travelled by any given offender, the influence of different decay functions might be more marked.

It is plausible that different decay functions would provide the best for different offending subsets (Canter *et al*., 2000; Hunter & Shannon, 1985; Turner, 1969). For example, a large body of research has shown that those committing crimes against property tend to, on average, travel further to commit their offences than those committing crimes against [12] the person (Phillips, 1980; Pyle, 1974; Rhodes & Conly, 1991; White, 1932). The implications this may have on the decay functions for these different crimes have not yet been fully explored. Yet, as Capone and Nichols (1976) pointed out over a quarter of a century ago, it seems logical to assume that different functions might provide the best fits to distance distributions for different crime types, and future research would need to determine whether this is in fact the case.

The operational implications of the present findings are that, at least for a sample such as the present one, the particular function employed will not make a very great difference to the efficacy of the system. This is likely to be true for any geographical profiling system incorporating decay functions. Broadly speaking, such systems when applied to the present type of data can be expected to give impressive results in approximately half of the offence series. Whether that can be improved by more accurate and precise data and with more complex models remains to be established. It may turn out that the value of studies of different ways of modelling the journey to crime may be of more use in enriching our understanding of criminal behaviour than in improving police investigations.

REFERENCES

Brantingham, P. J., & Brantingham, P. (1981). *Environmental criminology.* Prospect Heights, Illinois: Waveland Press Inc.

[13] Beverton, R. J. H., & Holt, S. J. (1957). On the dynamics of exploited fish populations. *Fish. Invest. Lond*. Ser. II, Vol. XIX.

Canter, D., Coffey, T., Huntley, M., & Missen, C. (2000). 'Predicting serial killers' home base using a decision support system. *Journal of Quantitative Criminology*, *16*, 457–478.

Canter, D., & Larkun, P. (1993). The environmental range of serial rapists. *Journal of Environmental Psychology*, *13*, 63–69.

Canter, D., & Snook, B. (1999). *Modelling the home location of serial offenders*. Paper for Expanding the Boundaries: The Third Annual International Crime Mapping Research Conference—Orlando, December, 1999.

Capone, D. L., & Nichols, W. W. (1976). An analysis of offender behaviour. *Proceedings of the American Geographer*, *7*, 45–49.

[14] Cornish, D. B., & Clarke, R. V. (1986). *The reasoning criminal: rational choice perspectives on offending*. New York: Springer-Verlag.

DOI: 10.1002/jip

Eldridge, J. E., & Jones, J. P. (1991). Warped space: a geography of distance decay. *Professional Geographer*, *43*, 500–511. 15

ESRI (1996). *The GIS. Glossary*. Environmental Systems Research Institute, Inc.

Golledge, R. G. (1987). *Analytical behavioural geography*. London: Croom Helm.

Hunter, J. M., & Shannon, G. W. (1985). Jarvis revisited: distance decay and service areas of mid-19th century asylums. *Professional Geographer*, *37*, 296–302.

Kent, J. (2003). Using functional distance measures when calibrating journey to crime distance decay algorithms. MSc thesis: Louisiana State University.

Kothari U. (2002). *Migration and chronic poverty*. Institute for Development, Policy and Management: University of Manchester. Working Paper No. 16.

Levene, N. (2002). *Crimestat II: spatial modeling*. Report for the US Department of Justice, 13 August , 2002.

Lundrigan, S., & Canter, D. (2001). A multivariate analysis of serial murderer's disposal site location choice. *Journal of Environmental Psychology*, *21*, 423–432.

Phillips, P. D. (1980). Characteristics and typology of the journey to crime. In D. E. Georges-Abeyie, & K. D. Harries (Eds.), *Crime: a spatial perspective.* New York: Colombia University Press.

Pyle, G. F. (1974). *The spatial dynamics of crime.* Research Paper No.159. Chicago: Department of Geography, University of Chicago.

Rengert, G., Piquero, A. R., & Jones, P. R. (1999). Distance decay re-examined. *Criminology*, *37*, 427–445.

Richardson, H. W., Gordon, P., Jun, M. J., Heikkila, E., Peiser, R., & Dale-Johnson, D. (1990). Residential property values, the CBD, and multiple nodes: further analysis. *Environment and Planning*, *22(A)*, 829–833.

Rhodes, W. M., & Conly, C. (1981). Crime and mobility: an empirical study. In P. J. Brantingham, & P. Brantingham (Eds.), *Environmental criminology.* Prospect Heights, Illinois: Waveland Press Inc.

Stevens, S. S. (1961). To honor Fechner and repeal his law. *Science*, *133*, 80–86.

Turner, S. (1969). Delinquency and distance. In T. Sellen, & M. E. Wolfgang (Eds.), *Delinquency: selected studies.* New York: Colombia University Press.

Van Koppen, P. J., & De Keiser, J. W. (1997). Desisting distance decay: on the aggregation of individual crime trips. *Criminology*, *35*, 505–513.

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