# A Comparison of Hotspot Mapping for Crime Prediction

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**Summary:** The thesis explores two novel dimensions in the comparison of hotspot mapping techniques and their ability to predict crime. Firstly, the study examines both the accuracy and precision by which each technique predicts incident clusters. Secondly, the study compares the use of significance statistics against the traditional quantile method for hotspot classification.

The findings:

- Despite widespread recommendation of Kernel Density Estimation, it is not the optimum technique.
- Effective evaluation of hotspot mapping techniques requires separate measures of accuracy and precision.
- Crime prediction by hotspot mapping is dramatically improved when hotspot classification is by statistical significance.

**KEYWORDS:** GIS, Hotspot mapping precision and accuracy measurement, Crime prediction, GI*

## 1. Introduction

Hotspot mapping is routinely applied to crime data by Police Forces in order to assist decision making on where and how to address future crime clusters. However, there are numerous hotspot mapping techniques and limited guidance on how to apply them. In addition, in the absence of an authoritative comparison study, academia and Police do not agree on the best technique to use. Police require an efficient tool for identifying crime clusters by significance. It should describe them with precision and accurately predict their location. As yet, no comparison study has assessed hotspot mapping techniques in this way.

The research aim was to identify the optimum hotspot mapping technique for the prediction of crime clusters. The research consisted of a comparison of 10 techniques and explored two novel dimensions:

- A comparison of techniques by the accuracy and precision with which incident clusters are predicted, and proposed new comparison measures to do so.
- Comparison of the Gi* significance statistic against the traditional quantile method for hotspot classification.

## 2. Background

### 2.1 Situation

Hotspot mapping is a popular method of crime forecasting, however there are a range of hotspot mapping techniques, and significant advantages and disadvantages of each. There have been several hotspot mapping comparison studies, however they have all failed to thoroughly evaluate techniques in order to find the optimum technique/s. Some studies, such as Jefferies (1999) and Chainey et al (2002), focused on each technique's ability to identify and visually display crime data. However, these studies have not quantitatively compared the techniques or identified an optimum technique for determining future crime patterns.

This lack of research into comparing the predictive ability of hotspot mapping led to a paper, Chainey et al (2008), which presented a comparison of four techniques by their prediction success. A dataset was used to form predictive hotspots and compared against a subsequent dataset to measure success. The study proposed a new Prediction Accuracy Index (PAI), see Equation 1, as the comparison measure and found KDE to be the best performing tool. Despite praise for a comparison measure, the study itself attracted significant criticism. This focussed upon the inequality of the technique comparisons because the quantile division of results does not allow the same statistical precision and therefore lacks standardisation between techniques (Pezzuchi 2008). There was also criticism in the choice of techniques with some well performing techniques like Nearest Neighbour Hierarchical (NNH) clustering, absent from the study (Levine 2004). However the most significant criticism was the surprising conclusion of KDE as the optimum technique when as Levine (2008) explained, KDE is a smoothing algorithm that spreads higher values to adjacent cells and therefore creates larger hotspots which, if they do not collect proportionately more predicted crimes, should reduce the PAI score.

$$\frac{\left(\frac{n}{N}\right)\times 100}{\left(\frac{a}{A}\right)\times 100} = \frac{HitRate}{AreaPercentage} = Prediction\ Accuracy\ Index \quad (1)$$

$n$ = number of crimes in predicted crime area
$N$ = number of crimes in study area
$a$ = total area of predicted crime
$A$ = area of the study area

The conclusion drawn from these comparison studies is that the methods are not being effectively compared because the comparison measures are failing to correctly assess the ability of hotspot mapping methods. Together with a lack of statistical robustness in terms of repeat experiments or small datasets, it was evident that a rigorous quantitative comparison was required that addresses the failings of these studies.

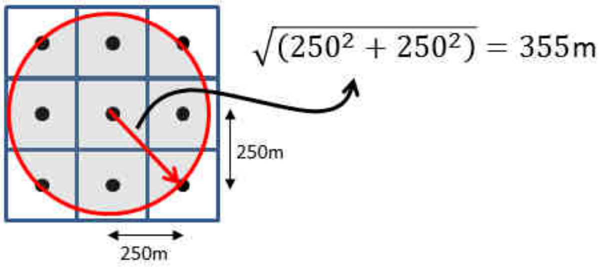
**2.2 Defining the 'Hotspot'**

For hotspot mapping, techniques that produce ellipses or convex hulls define the hotspots directly, but for polygon, grid and continuous surface techniques the critical factor is the threshold for defining a hotspot. Current practice suggests the use of the top class of a quantile classification in order to classify hotspots, such as Chainey et al (2008), which used the top class of a 5 quantile classification. Quantile classification divides data by magnitude to form approximately equal classes, which creates a visually balanced map pattern (Monmonier 1996), however, the quantile method sets arbitrary value ranges and therefore ignores the significance of the spatial distribution. Most importantly, the method prevents a fair comparison of hotspot mapping techniques because the threshold values vary significantly between techniques. It is therefore, a significant flaw in previous comparison studies.

If the conceptual definition of a hotspot is a region containing a significantly high density of points, then the classification of a hotspot should be from the results of clustering analysis and be by a statistical significance threshold. This assessment can be done by applying the Gi* statistic to the results. In order to define the Gi* significance threshold 'z', the tables in Ord and Getis (1995) were used, which gave a 95% significance level of $z \geq 3.8855$ for all datasets over 1000 grid/polygon cell values.

The Gi* test also requires a threshold distance, similar to a search radius, that is defined as, at least the distance between each cell and optimally a radius that covers the centroid of all adjacent cells (Chainey and Ratcliffe 2005). For the techniques under study, the grid cells were 60x90m for KDE, 250m for Grid and the average centroid distance for Geographic Boundaries was 120m. Because a technique comparison was being sought, a consistent search radius was required across all techniques and therefore the value was set using the larger of the cell distances; ie 355m (see Figure 1).

**Figure 1.** Calculation of threshold distance.

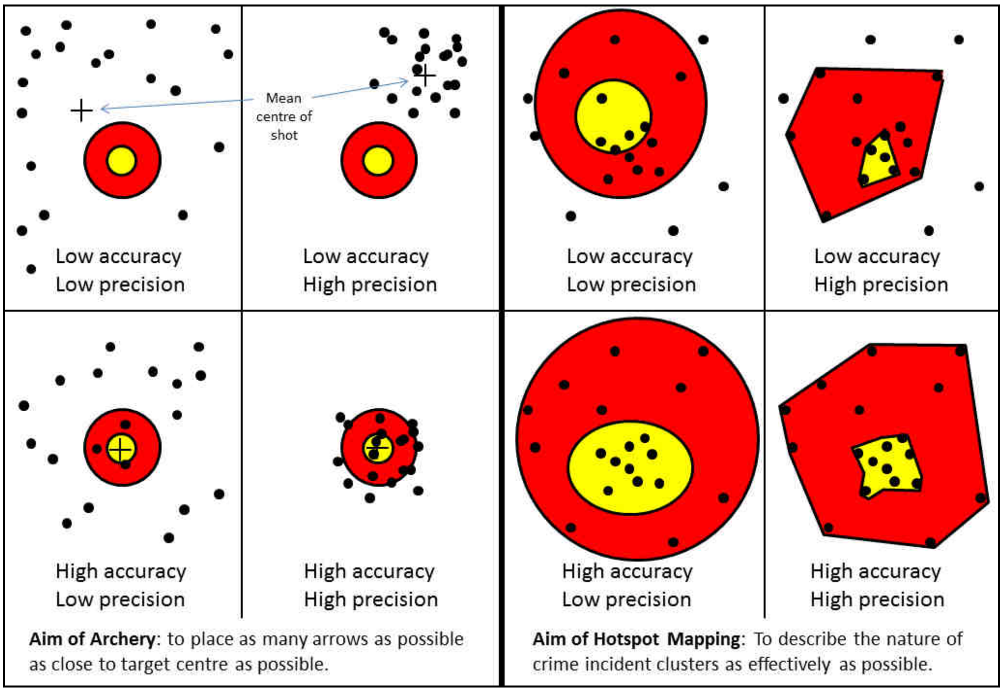



In order to test the hypothesis that using statistical significance improves the predictive ability of hotspot mapping, the experiments using the Geographic Boundary, Grid and KDE techniques used classification of hotspots by both quantile and Gi*.

### 2.3 Measuring Predictive Success

In order to compare hotspot mapping techniques a measure was required to quantitatively assess the performance of each technique for their predictive success. Previously, hotspot predictive ability has only been assessed by some measure of crime count, but this is not sufficient to describe performance, as both accuracy and precision need to be assessed. For hotspot mapping, a trade-off can exist between accuracy and precision and although constrained by the scale of study, the optimum technique will offer positional accuracy in terms of size/shape and precision in terms of areal efficiency, as demonstrated in Figure 2.

**Figure 2.** Predictive hotspot accuracy and precision.



In order to develop measures of predictive accuracy and precision, the hotspot attributes were identified from best practice and are presented as follows:

- The predictive accuracy of a hotspot is a measure of the effectiveness of the hotspot to describe the predicted cluster's size and shape.

- The predictive precision of a hotspot is a measure of the efficiency of the hotspot's point capture.

The PAI developed by Chainey et al (2008) is a suitable test; however as it measures the success of forecasting points in the most efficiently sized area possible it meets the definition of precision rather than accuracy. Therefore the measure was used for the study, but to prevent confusion with Chainey's PAI, the measure was renamed the Forecast Precision Index (FPI).

To measure the effectiveness of predicting the cluster's size and shape, the two areas in terms of point density can be compared. This comparison tests the success of forecasting a hotspot with the same density as for the training data and thereby measures the effectiveness of the description. The accuracy should also be adjusted to compensate for the change in total incident count between training and testing periods. This measure is proposed as the Forecast Accuracy Index (FAI) and both FAI and FPI are presented in Equations 2 and 3.

Forecast Accuracy Index (FAI):

$$\frac{\left(\frac{n^{te}}{n^{tr}}\right)}{\left(\frac{N^{te}}{N^{tr}}\right)} \quad (2)$$

Forecast Precision Index (FPI):

$$\frac{\left(\frac{n^{te}}{N^{te}}\right)}{\left(\frac{a}{A}\right)} \quad (3)$$

$n^{te} =$ count of crimes in testing hotspot area
$n^{tr} =$ count of crimes in training hotspot area
$N^{te} =$ count of crimes in testing dataset
$N^{tr} =$ count of crimes in training dataset

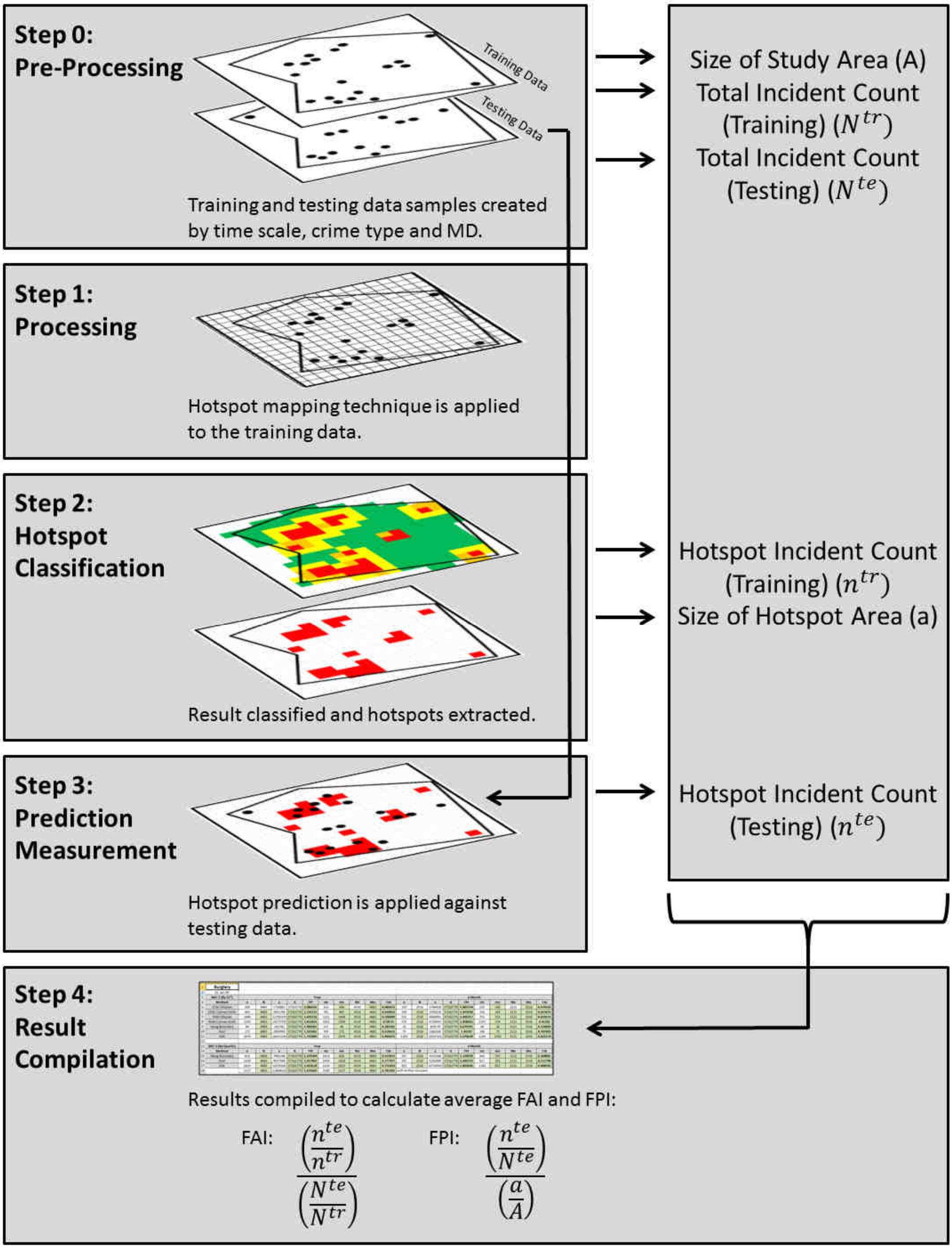
$a =$ total area of forecast hotspots
$A =$ total area of the study area

In operation, the greater the number of test crime incidents in the predicted hotspot areas, and the smaller the hotspot areal size to the whole study area, the higher the FPI value and the better the precision. For the FAI, the smaller the drop between training and testing hotspot densities, adjusted for changes in total incident count between the two, then the closer to 1 and the better the accuracy.

## 3. Methodology

The comparison of hotspot mapping techniques involved 480 experiments using, 4 crime types, 3 temporal scales and 4 data samples. The methodology is presented at Figure 3.

**Figure 3.** Experiment Methodology.



## 4. Results

The analysis of results was by comparison of Precision (FPI), Accuracy (FAI) and Consistency (FPIxFAI) scores as presented in Figures 4, 5 and 6.

**Figure 4.** Technique comparisons in terms of Precision (FPI).

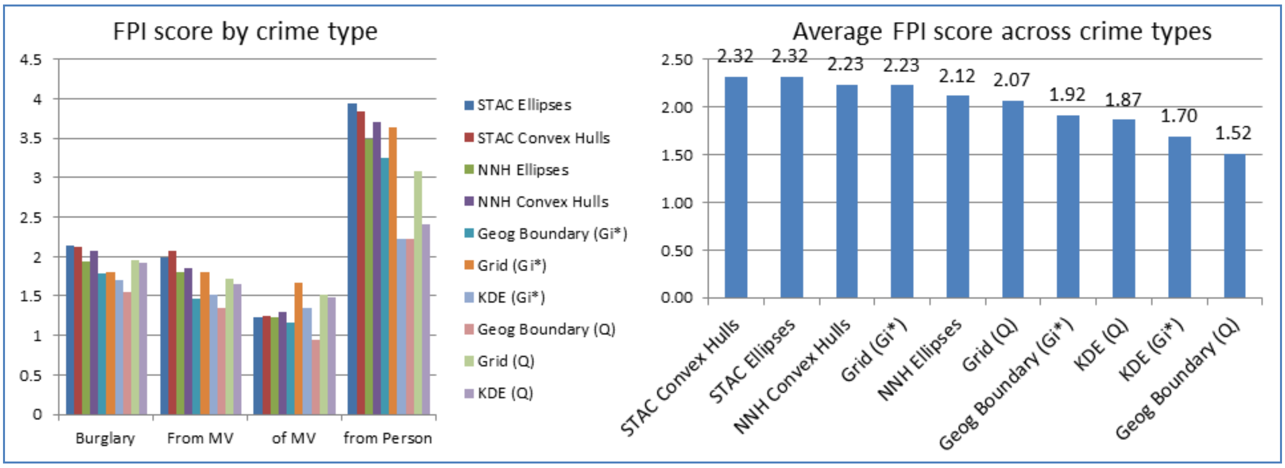



**Figure 5.** Technique comparisons in terms of Accuracy (FAI).

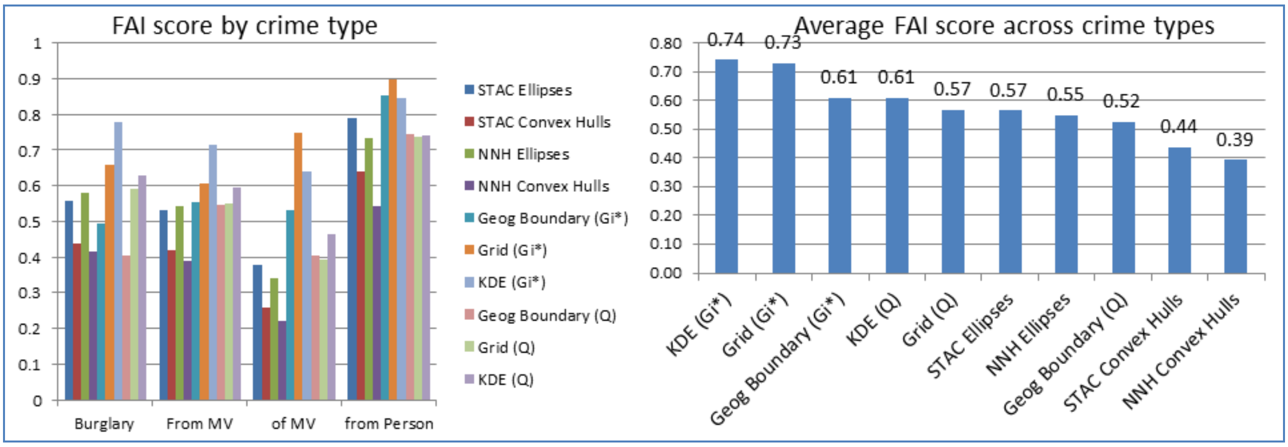
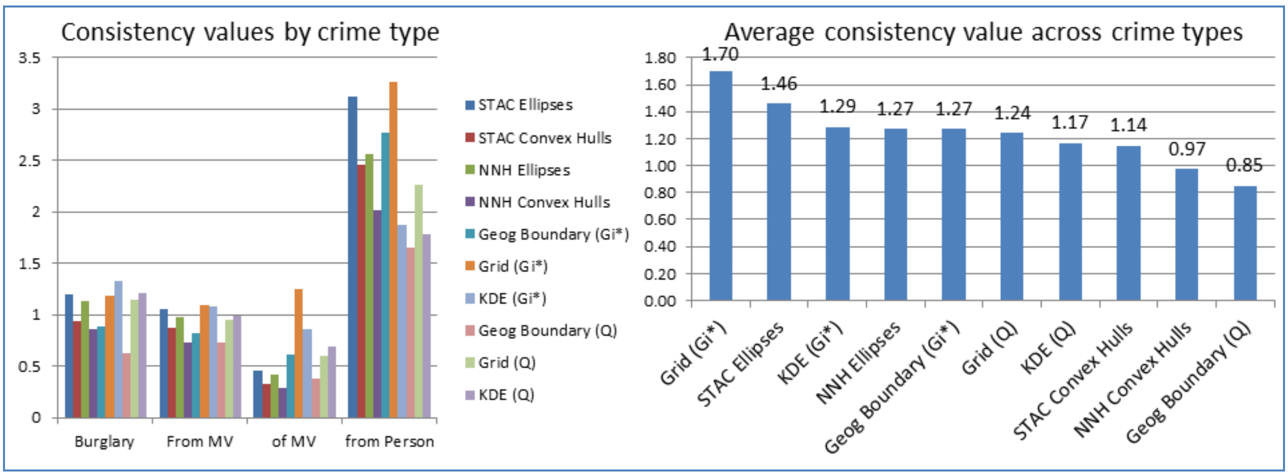



**Figure 6.** Technique comparisons in terms of Consistency (FPI x FAI).



The optimum technique is therefore the combination of Grid Thematic Mapping and Gi* significance, and as it performed 17% better than the next best technique, STAC Ellipses, the superiority of the technique is significant. There are other indicators of the technique's success. If the performance across crime types is studied it can be seen that Grid performed well for precision in both the strongest and the weakest clustered data types; 'Theft from the Person' and 'Theft of MV' respectively. For accuracy, the technique significantly outperformed all other techniques in these two categories. This clearly demonstrates the versatility of the technique.

The success of Grid Thematic Mapping is particularly interesting when linked to the initial observation of the research; that some crime analysis practitioners have moved away from advanced techniques in favour of simpler Grid and Polygon techniques. The preference, of MPS Officers, for simpler techniques, because of an intuitive feel that they achieve better efficiency in resource allocation, can now be supported by statistically robust evidence (MPS 2011).

## 5. Conclusion

The analysis of results led to the identification of an optimum technique, identified strengths and weaknesses of the common hotspot mapping techniques, proved the usefulness of assessing hotspots by separate measures of accuracy and precision, highlighted optimum parameters and methodology, as well as revealing the weaknesses in previous work. The research also provides findings that are directly applicable for practitioners and makes a significant contribution to the field of study; potentially enhancing how hotspot mapping is researched and taught.

The key findings are as follows:

- For the forecasting of crime hotspots, Grid Thematic Mapping combined with defining hotspots by Gi* significance, is the optimum hotspot mapping technique.

- For the evaluation of crime cluster forecasting success, hotspot mapping should be validated by separate measures of accuracy and precision and FPI and FAI are effective measures for this evaluation.

- Defining hotspots by statistical significance using the Gi* measure is significantly superior to arbitrary methods such as quantile divisions.

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As the Senior Instructor within the Royal School of Military Survey, he is responsible for delivery of Geospatial Intelligence soldier (FDSc) and officer (MSc) training. With 10 years of experience in the field, he is at the forefront of military geospatial intelligence expertise. His current focus is developing spatial analysis techniques for military applications.