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Hunting the hunters

Evaluating a new method of Geographic Profiling

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Abstract

Geographic Profiling (GP) may be used when searching for an unknown offender by applying mathematical algorithms to geographical information. This thesis aimed to contribute to improvement of the efficacy of GP's produced by law enforcement by evaluating a the new Spaulding/Morris Centrographic (SMC)-method of GP that claims to counteract two of the main difficulties when constructing a GP in a real world investigation:
1. Being sure that the geographical information really is correctly linked to the same serial offender, and 2. The vastly different effects on travel time and distance diverse urban environments has depending on mode of transport.
The study was unable to replicate previous encouraging results with similar levels of preciseness and accuracy as previous studies. Rather, an experimental analysis of the SMC-method showed that the steps suggested by the authors had a degrading effect on accuracy and preciseness. However as the study is small-n this result is tentative.
The study thus failed to identify a GP-method with higher efficacy than conventional methods, instead putting the usability of the suggested method into question as well as suggesting new avenues of research.

Keywords: rgeoprofile, crimestat, Journey-to-crime, geographic profiling, qgis, geographical profiling, Örebromannen.

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Max Pröckl
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1 Introduction

Geographic Profiling (*GP*) is an investigative method that may be used when searching for an unknown offender (Rossmo, 2000:213). Based in theories and studies of human and criminal spatial behavior, it consists of both a qualitative approach that attempts to profile an offender and of spatial-analysis techniques that uses mathematical algorithms to predict the *anchor-point* of a serial offender (Rossmo, 2000:213-222).

Research intent on improving GP has been conducted since its inception contributing to the underpinning theories and the refinement of conventional methods as well as the development of new GP-methods. By testing a new GP-method and comparing it to the conventional methods of GP, this paper aims to contribute to the development of the GP-methods used in investigating serial offenders.

1.1 Purpose & significance of the study

Improving the efficacy of police work has a double benefit: It enables the state to protect citizens by catching those that break the law, and it minimizes the threat it poses against them through inadequate or excessive policing (Buzan, 2016:53, 55, 60-63). By comparing a proposed *new GP-method* to *conventional GP-methods*, this paper aims to contribute to the work of law enforcement investigations. The rationale of the proposed study thus spans from the micro and meso-levels of crime-deterrence, justice and closure for victims, to the macro-level of national security and foundations of state.

1.2 Scope & limitations

The possible applications of GP are many, at its core, it is a form of spatial analysis that attempts to predict locations from distributions (Levine, 2015:13.1-13.2). As such, it has been applied to fields such as counterterrorism and biology in both an investigative and predictive manner (Kazuki Hirama et al., 2022:135) (Rossmo, 2012:144, 146-148). However, the scope of the proposed study will limit itself to the intelligence analysis conducted in the field of low policing (Brodeur, 2010:130). In practice: The production of a GP that aids law enforcement investigations that aim to find an unknown serial-offender by indicating where the anchor-point should be sought (Rossmo, 2000:213).

GP’s in Sweden has an efficacy of about 70-80% percent (Hildeby in Aftonbladet, 2019a). Several new GP-methods claim to address different factors that have an effect on the success of a GP-profile. One of these methods, the Spaulding/Morris centrographic method (*SMC-method*) will be tested and compared to conventional methods of GP.

1.3 Research question

To successfully achieve the aims of the study, the question “What is the accuracy and preciseness of the SMC-method perform when compared to conventional GP-methods?” is put forward.

2 Background

The the definition of rape and sexual offense used by this thesis is from the Swedish criminal code (6 kap. SFS 1962:700)) and for the definition of serial rapist the thesis uses The Federal Bureau of Investigations (FBI) definition of serial sexual offender as an offender that has committed at least 2 separate offenses (Hazelwood & Burgess, 1987:16).

The significance of the research is now highlighted by describing the extent of the problem of unknown serial sexual offenders (used throughout this thesis synonymously with the term serial rapist) in Sweden.

This is followed by a short historical background and the section ends with an outline of a number of key concepts and their connections to the theoretical underpinnings of modern GP.

2.1 The scope of the problem

The Swedish National Council for Crime Prevention (BRÅ) is responsible for the official Swedish crime statistics (Bilaga 1, SFS 2001:100) but BRÅ has no statistics regarding rape-series with an unknown offender. Furthermore, BRÅ counts reports of assault-type outdoor rapes committed by an attacker unknown to the victim in the same categories as reports other types of rape (Grevholm & Nilsson & Carlstedt, 2005:45-46). The exact scope of the problem is unknown and was subsequently approximated using the information available.

Several thousand rapes are reported every year in Sweden (BRÅ statistikdatabas, 2024). Of these a 2019 study on completed rapes (i.e. not counting attempts) found that 3-4 percent of the reported cases were assault-type outdoor rapes (Holmberg & Lewenhagen, 2019:31). No statistics exists regarding how many of these assault-type outdoor rapes are committed by serial-offenders. However, in 2006 the Swedish criminologist Hans Brun stated that one serial sexual offender was convicted every year and that several suspected series existed (Brun in Cristiansson, 2006:65).

Furthermore, the then head of the police offender-profiling unit stated that serial rapists probably are relatively common in the category of assault-type outdoor rape (Johnsson in Christiansson, 2006:66). In the 2019 study of completed rapes, 4 percent of the investigations of rapes committed by unknown offenders were discontinued because law enforcement were unable to identify a suspect (Holmberg & Lewenhagen, 2019:67-68).

This assessment leads to the overall conclusion that the scope of the problem investigated is significant.

The first first geographic profiler in Swedish law enforcement was trained in 2004 (Hägglund & Grehn, 2005:1). Since then a number of other Swedish analysts have been trained in GP but during 2019 only three persons were working part-time as geographical profilers (Sundberg, Dagens Nyheter, 2019a). This severely limits the number of man-hours available to produce GP which in turn emphasize the importance of accurate and precise GP-methods.

2.2 Key concepts and theoretical underpinnings

Focusing on the current (as opposed to the historical) criminal event and viewing the offender as but one element that in confluence with criminal targets/victims and laws in a specific setting, time and place results in a criminal event occurring (Wortley & Townsley, 2017:1-2). Modern GP is a multidisciplinary approach developed from and continues to be informed by *journey-to-crime research*, *rational choice theory*, *routine activity theory* and *crime pattern theory* (Rossmo & Rombouts in Wortley & Townsley, 2017:163).

The rational choice theory states that criminal behavior and offender decision-making is purposeful and rational and also that criminal events unfold in sequences of stages and decisions (Cornish & Clarke in Wortley & Townsley, 2017:32). It emphasizes that an offender's perception of the environment affects the offender’s decision-making which in turn creates a nonrandom spatial pattern (Cornish & Clarke in Wortley & Townsley, 2017:32-33, 44-47). The nonrandomness of the spatial pattern is one key element in the finding of the home base (*anchor-point*) of an offender through GP.

The *circle theory of environmental range* postulates that the spatial behavior of offenders may be divided into the categories *marauder* and *commuter* (Canter & Larkin in Canter, 2024:240-243). A *marauding* offender commits crimes while marauding around his anchor-point and a *commuting* offender commuting into an area to commit crimes (Canter & Larkin in Canter, 2024:240-243).

When attempting to profile an offender the question of the factors affecting how far an offender is willing to travel to commit a crime is of utmost importance (Rossmo & Rombouts in Wortley & Townsley, 2017:163-164). This is what *journey-to-crime research* is engaged in using both quantitative and qualitative methods to draw conclusions (Townsley in Wortley & Townsley, 2017:146-148) and also create and fine-tune *distance decay functions* that underpin most GP-methods (Rossmo & Rombouts in Wortley & Townsley, 2017:163).

The principle of least effort proposed by Zipf (1965) states that when an individual performs a purposeful action he will search no further than needed to satisfy his goal (Townsley in Wortley & Townsley, 2017:144). This forms the basis of the distance decay function that outlines the lessening (*decaying*) likelihood that an offender commits a crime the further away from his home base he travels (Townsley in Wortley & Townsley, 2017:143) as well as the basis of the *buffer-zone hypothesis* that postulates that a criminal will not commit crimes in the immediate vicinity of his anchor-point (Rossmo & Rombouts in Wortley & Townsley, 2017:164).

Routine activity theory states that in order for a crime to occur, a *suitable target/victim* and *motivated offender* must *intersect in time and space* in the *absence of a capable guardian* (Felson in Wortley & Townsley, 2017:88).

As a rule, this intersection occurs as a result of both the offenders and the victims non-criminal spatial activity (Brantingham & Brantingham & Andresen in Wortley & Townsley, 2017:105). This provides the basis for extrapolating the non-criminal anchor-point of an offender using the criminal spatial behavior (Rossmo & Rombouts in Wortley & Townsley, 2017:164).

Crime pattern theory provided a framework describing the connections between an *activity space* (the physical environment through which a person travels) and *awareness space* (the mental map of the physical environment) (Brantingham & Brantingham & Andresen in Wortley & Townsley, 2017:100-101). Developing the framework created by urban planner Kevin Lynch (1960) Crime pattern theory continues to describe the building blocks that creates this human understanding of the urban environment through activity anchors (*nodes*), the connections between them (*paths*), boundaries of activity (*edges*) and *barriers* to movement (Brantingham & Brantingham & Andresen in Wortley & Townsley, 2017:99-107). These building blocks combine with social and economic factors forming an *urban backcloth* (Brantingham & Brantingham & Andresen in Wortley & Townsley, 2017:106-107), a subset of which is the distribution of opportunities of crime called *target backcloth* (Rossmo & Rombouts in Wortley & Townsley, 2017:168).

2.3 Modern GP takes form

While mapping of crime has been taking place at least since the 1800:s (as reviewed by Wang, 2012:159). The core process of GP is defined not as “putting pins on a map” but as a form of *spatial analysis* that attempts to predict locations from mapped “pins on a map” distributions. By this definition, it traces its roots to the inversion of the logic of *location theory*. *Location theory* is a theory that attempts to find an optimal location for any particular distribution of activities, population or events (Levine, 2015:13.1-13.2). One of the earliest examples of this inverted location theory is when the British physician John Snow successfully found the source of a cholera-outbreak in London in 1854 (Levine, 2015:13.2).

Modern GP, however, is a multidisciplinary approach that has developed from, and continues to be informed by, a number of intertwined theories about human and criminal behavior that share a common interest in the concerned with the criminal event itself as well as the immediate circumstances under which it occurred (Wortley & Townsley, 2017:1).

3 Literature review & earlier research

A systematic literature review was conducted with the aim of evaluating the state of knowledge and practice on the subject of GP (Knopf, 2006:129). Identification of keywords was followed by an iterative process involving citation networking continuing parallel to the study (Knopf, 2006:129-130). The amount of literature reviewed illustrates the size of the field: 116 research articles, 12 books, 1 review article, 7 statistical reports and a number of bachelor and masters theses. The central works relevant to the field were selected (Knopf, 2006:129-130). 1 paper was discarded on the basis it had been retracted (Bernasco & van Dijke, 2021:1).

The following sections will describe areas of disagreement of relevance to the study (Knopf, 2006:129) through its multidisciplinary background, followed by the central human vs. software-debate that initiated the formation of the performance measures used when comparing GP-methods as well as the scope conditions of the theory of GP.

3.1 *Canterist* and *Rossist* GP

GP developed independently in Canada and the United Kingdom during the 1980:s (Canter in Canter & Youngs, 2016:11) (Rossmo, 2000:23). The Canadian criminologist Dr. Kim Rossmo claims that the first GP was used in 1977 during the investigation of "the Hillside Stranglers" (Rossmo in Bruinsma & Weisburd, 2014:1934). However, the British psychology professor dr. David Canter claims the inception of GP took place in the United Kingdom during the 1980 investigation of "the Yorkshire Ripper" (Canter & Youngs, 2016:11-12).

The above disagreement is an expression of the Canterist approach characterized by Canters background in psychology (Canter, 2024:i) and a Rossist approach characterized by Rossmos background in (environmental) criminology (Rossmo, 2000:10). Although the utilitarian orientation of GP integrates both perspectives and methodologies (Canter in Canter & Youngs, 2016:83-90) (Rossmo, 2000:240-242) (Levine, 2015:13.85-13.87, 13.90-13.91) their existance warrants a clarification:

As the geographical profilers working in Swedish law enforcement are trained in the system created by Dr. Rossmo (Sundberg, Dagens Nyheter, 2019a) the thesis leans towards the *Rossist* perspective and uses the *Rossist* terminology throughout.

3.2 GP modernizes & humans vs. software debate

The foundations of the *GP-software* “Rigel” developed by Rossmo were laid in the beginning of the 1990:s, Rossmo (1993:1) and it was introduced in 1997 by the company Environmental Criminology Research Inc. (ECRI) that Rossmo co-founded (Rich & Shively, 2004:14) and David Canter developed “Dragnet” in the middle of the 1990:s (Rich & Shively 2004:1). Levine & Associates began development of the GP-software “Crimestat” during this same period (Levine, 2015:13.12).

These *GP-softwares* were hailed as technological and methodological leaps for the field of GP and several US government agencies began considering acquiring GP-software. However, 2002 and 2004 saw research that questioned if GP’s produced by GP-software were better than a GP produced by a human (Snook & Canter & Bennell, 2002) (Snook, Taylor & Bennell, 2002).

This first comparison between conventional and new GP-methods sparked the human vs software-debate that outlined the scope conditions of the theory of GP and a framework used in the evaluation of GP-methods as well as sparking a rich body of research that inform these processes.

3.2.1 Measures used when evaluating GP-methods

The two studies conducted in 2002 and 2004 compared the performance of the GP-softwares of the time to that of human performance by measuring the straight line distance (*error distance*) between a predicted anchor-point (*point of prediction*) and actual anchor-point, claiming that humans produced as accurate GP-profiles as did the softwares (Snook & Canter & Bennell, 2002:109-111) (Snook & Taylor & Bennell, 2004:111).

In a retort, Rossmo argued that error distance was not suited to measure the performance of a GP because law enforcement rarely search in a straight line from a point of prediction to the anchor-point of an offender, instead he promoted the usage of the *hit-score* as the exclusive measure because it measures how much of the *top profile area* that needs to be searched before finding the anchor-point (Rossmo, 2005:653).

The ongoing debate influenced a panel of 13 experts tasked by the US government with developing performance measures to accurately assess GP-software and they included both error distance and hit-score in the final measures they suggested (Rich & Shively 2004:21) were later picked up by Levine & Block who convincingly argued the importance of measuring both *accuracy* and *preciseness* when evaluating a GP-method using a “bulls-eye” analogy (figure 1).

They asserted that a GP-method may be likened to a dart thrower who is trying to hit the center of the dart-board (analogous to finding the anchor-point of an offender):

Figure A illustrates having neither accuracy nor preciseness, figure B illustrates having a high degree of preciseness but no accuracy, and figure C illustrates having both which is what a GP-method needs to be useful (Levine & Block, 2015:14.20-14.24). Levine & Block defined a number of *distance-based measures* as measures of accuracy and a number of *area based measures* as measures of preciseness and a selection of these measures were used by this thesis (see: table 1) (Levine & Block, 2015:14.20-14.24).

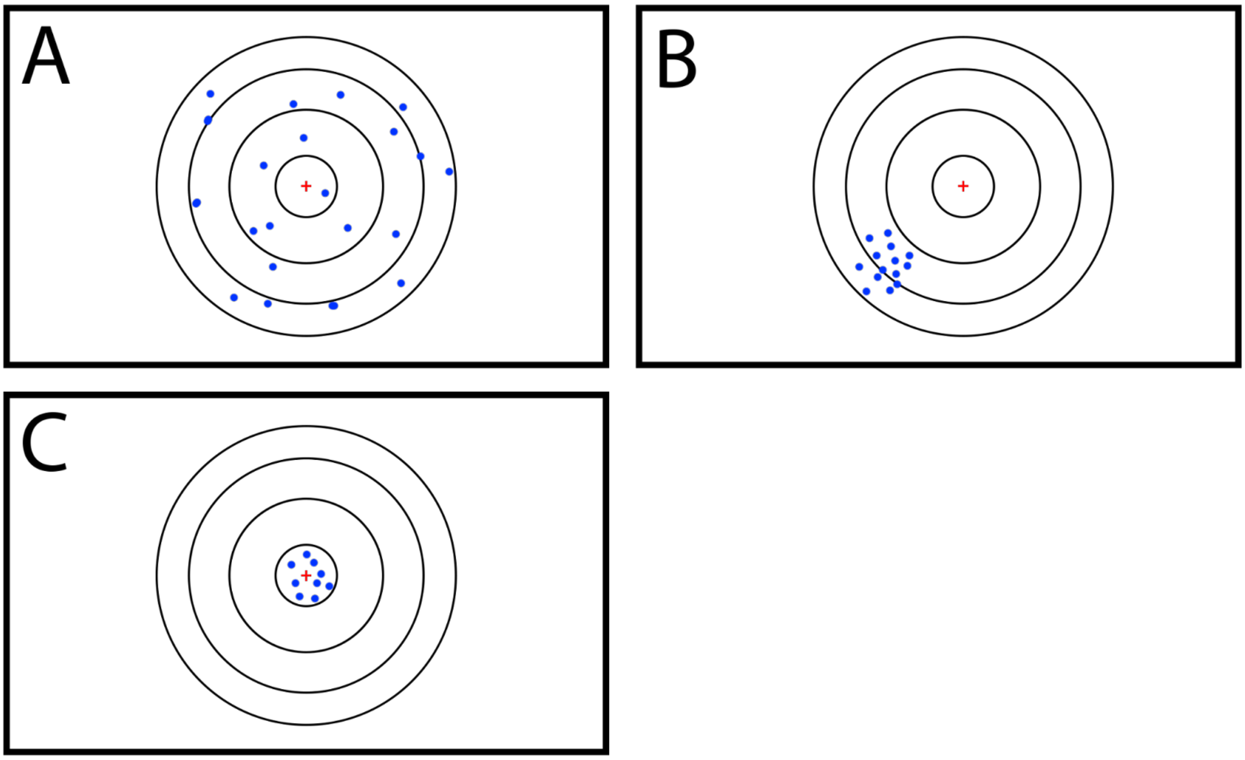


Figure 1, bulls-eye analogy.

Table 1, Performance measures.

Name	Measures	Definition
Error distance	Accuracy	Distance from point of prediction to the actual anchor-point.
Hit score	Precision	The percentage of that need to be searched to locate the cell that contains the anchor-point.
Profile error distance	Accuracy	The distance from the actual anchor-point to the nearest point in the top profile area.
Top profile area ratio	Precision	The ratio of the top profile area to the total search area.
Diagnostic accuracy	Accuracy	The distance between the cell with the highest score and the actual anchor-point.
Profile accuracy	Accuracy	If the offender's anchor-point is within the top profile area or not.

3.3 Scope conditions of GP

The second part of the methodology of evaluating GP-methods is the identification of variables that affect the outcome of the GP, to what degree they do and at what depth of theory these variables lie (George & Bennett, 2005:50-52, 230-234).

The panel of 13 experts suggested that GP-methods should be evaluated under similar conditions as they would be performed during actual criminal investigations and listed a number of criteria (Rich & Shively, 2004:8, 15-17).

Rossmo also takes the view that *scope conditions* should mirror those of real world investigations and this formed much of his criticism of Snook et als. human vs. software-debate research (Rossmo, 2005:651-652).

Snook et al. objected that the suggested variables and at what values they affected outcomes lacked support in research and therefore were unscientific (Snook & Taylor & Bennell, 2005:655) and thus the outlines of the scope conditions began emerging in earnest with additional researchers contributing with differing perspectives (Canter, 2005) as well well as initiating research into their effects on outcomes (Paulsen, 2006:306) (Paulsen, 2007:347).

The scope conditions stemming from the debate are a combination of Rossist and Canterist approaches but they were dubbed *Rossmos criteria* (Rossmo, 2005:651-652) (ECRI, 2012) and they form the starting point for ongoing research and debate.

3.3.1 Marauding pattern

While the 5 performance-measures were more or less universally accepted a few years after their introduction, of the scope conditions that developed from the debate, the field of GP only concur regarding one:

The scope condition that *the offender follows a marauding pattern*. The widespread agreement, supported by research (Paulsen, 2007:347) points to a high-probability relation between the criteria and a successful GP (George & Bennett, 2005:50-52).

3.3.2 Crime linkage

There is also a high level of agreement regarding the scope condition *crime linkage* (or *case linkage*) that is the linking of crimes to the same perpetrator.

This condition is highly influential because it is neccecary for the scope conditions *number of crime-sites* and *series completeness* (see below) that both affect the production of a successful GP (Rossmo & Rombouts in Wortley & Townsley, 2017:166) (George & Bennett, 2005:188).

3.3.3 Unform backcloth

The scope condition of *uniform backcloth* means that for the production of an accurate GP, the accessibility to the area, availability of potential targets and opportunities for committing the crime has to be relatively uniform (ECRI, 2012:14).

However, it has been objected that the claim that an accurate GP needs a uniform backcloth lacks empirical proof (Snook, Taylor & Bennell, 2005:656).

3.3.4 Single and stable anchor-point

The scope condition *single and stable anchor-point*: Profiling an offender that has more than one anchor-point from which they commit their crimes or if they change their anchor-point during the series is said to be tantamount to mixing separate series and will distort and potentially invalidate the GP (ECRI, 2012) (Rossmo, 2005:652).

However, in some cases it may be possible to distinguish that the offender has more than one anchor-point, for example if the series of crimes continues after an offender has moved (ECRI, 2012). Furthermore, research has indicated that it may be possible to compensate for such a move (Bernasco, 2010:404-414).

3.3.5 Series completeness

A GP may be successful even when conducted on an incomplete series of crimes (Paulsen, 2007:348). Rossmo admits that "missing crimes become a problem when they result in a geographic bias", for example when one law enforcement jurisdiction is not reporting a particular type of crime (ECRI, 2012).

Canter highlights that "On a statistical basis there is no need for the crime series to be complete, as long as it is a representative, unbiased sample of the crimes the offender has committed. Any subset of the offender's crime locations should give the same result if the model is appropriate." (Canter, 2005:666).

3.3.6 Number of crime-sites

The scope condition formerly known as "at least five crime-sites" has been repeatedly asserted by Rossmo (2000:236) (2005:651-652). Empirical research has shown both no correlation (Paulsen, 2006:321-327) and positive correlation (Levine, 2015:13.63 & 13.67) between the number of crime-sites and the accuracy of a GP. Later research using simulated data supports the view that at least 7 crime-sites are needed to make accurate predictions and that the accuracy of a GP is not significantly improved after 8 crime-sites (Santosuosso & Papini, 2022:641, 652-653).

However, additional research has also shown that series length correlates with correct identification of a marauding offender as a marauding offender (Hamm, 2022:637-639) and correctly identifying the spatial pattern of an offender governs the methods applied which in turn has a large impact on success (Paulsen, 2007:355.356).

Additionally, the research comparing the accuracy of human GP-profilers before and after training in basic GP-techniques with the accuracy of GP-software had the additional result of showing better predictions for a series of 5 crime-sites than a series of 3 or 7 crime-sites (Bennell, Snook, Taylor, Corey & Keyton, 2007:119, 128-131).

The factor improving human prediction was found to be providing the human GP-profilers with the heuristics of distance decay and circle of environmental range - both closely related to the concept of the marauding offender (Bennell, Snook, Taylor, Corey & Keyton, 2007:119, 128-131).

Finally, real world examples have shown that GP may be successfully performed with just one case (Sundberg, Dagens Nyheter, 2019a). The above research strongly suggests that there is no causal significance between the criteria of “at least five crime-sites" and the construction of an accurate GP (George & Bennett, 2005:230). The criteria “at least five crime-sites” is therefore modified to the condition *number of crime-sites* and expected to improve the accuracy of a GP up until the 8th crime-site after which this effect becomes negligible.

4 Theory

Previous sections presented the framework used to evaluate GP-methods as well as describing the theoretical background of GP. Using two first steps in the *process model of GP*:

Linkage analysis and *examination of offender-victim-environment interaction* as a starting point (Rossmo & Rombouts in Wortley & Townsley, 2017:164-170), this section continues to describe the specifics of the central quantitative concepts in tandem with the functions used in the final steps of completing a GP.

Finally, the central concepts of *buffer-zone*, *weights*, *Bayesian modeling* and *kernel density estimation* are presented last.

4.1 Linkage analysis

The first step in the generation of a GP is to perform a *linkage analysis* with the aim of ensuring that the examined crimes have been committed by the same perpetrator (Rossmo & Rombouts in Wortley & Townsley, 2017:165-166). Crimes may be linked through:

1. Physical evidence, for example fingerprints or DNA. This type of evidence offers the most definitive way of linking crime scenes.
2. Offender description by witnesses or cameras capturing the offender, and
3. Crime-scene behavior, such as proximity in time and space, modus operandi that may include fantasy based paraphilic behaviors not necessary for the crime called "signature" (Rossmo & Rombouts in Wortley & Townsley, 2017:165-166).

4.2 Examination of offender-victim-environment interaction

The second step of the process model is to analyze the data that make up the *offender-victim-environmental interaction* (Rossmo & Rombouts in Wortley & Townsley, 2017:167-168).

By mapping the area where an unknown offender commits his crimes (*the range of operation*), analyzing the police reports, crime scene photographs and if one is available: A behavioral profile, the awareness space of the offender is analyzed (Rossmo & Rombouts in Wortley & Townsley, 2017:167-168).

The effect the elements of an urban city may have on the awareness space are analyzed using the framework outlined by crime pattern theory (Brantingham & Brantingham & Andresen in Wortley & Townsley, 2017:99-107).

The examination of target backcloth is informed by sociodemographic and spatial information as well as crime statistics of the area, maps of transportation networks for example roads, railroads or subway stations (Rossmo & Rombouts, 2017:167-168) (Levine & Lee, 2013:148-149). The results of this analysis will inform the following steps in the construction of a GP (Rossmo & Rombouts, 2017:167-168).

Once determined, the range of operation is used to ascertain if an offender is offending in a commuting or marauding pattern by drawing a circle with a diameter of the distance between the two most distant crime-sites (Canter & Larkin in Canter, 2024:240-243).

If the offender's main anchor-point is inside this circle the offender is considered to have a marauding pattern (Canter & Larkin in Canter, 2024:240-243). Although research into how to create an accurate GP of a commuting offender has shown promise (Glass, Herbig, 2020:359) (Paulsen, 2007:356), establishing the spatial pattern of an offender remains a decisive step in the process of creating a GP.

Research have suggesting additional methods of identifying the spatial pattern of an offender (Paulsen, 2007:351, 355-356), as well as more detailed typologies (Beauregard, Proulx & Rossmo, 2004:590-597) but none have been sufficiently developed.

4.3 Spatial analysis

After completion of the above mentioned steps the core GP-process *spatial analysis* starts by using the range of operation to create a geographically delineated *study area* representing the awareness space of the offender (Brantingham & Brantingham & Andresen in Wortley & Townsley, 2017:100-101).

This is done by first drawing the smallest possible rectangle using the minimum and maximum X/Y-coordinates encompassing all crime-sites, and expanding the area to account for an offender's awareness space reaching some distance outside the original rectangle, and finally dividing it into a grid (*array*) consisting of a number of equally sized *cells*.

The may be done in several ways, Rossmo suggests expanding the rectangle by 1/2 the mean X and Y interpoint distances and dividing the study area into a maximum of 40000 cells (Rossmo, 2000:217-218), Canter proposes expanding the area of the rectangle by 20% and dividing the study area into 13300 cells (Levine, 2015:13:90) and Levine recommends selecting an area and the number of cells “intelligently” (Levine, 2015:13.12-13.13).

4.3.1 Distance Metrics used by functions used by GP-methods

Across the various approaches when performing the spatial analysis there are a number of key differences regarding the results generated as well as type of mathematical *functions* and *distance metrics* used. These will now be described.

Distance metrics are defined as how the distance between points is measured (O'Leary, 2012:10). Some of the more popular measures are straight-line/direct/crow-flight (*Euclidean*) or grid/city block/indirect (*Manhattan*) distance (Block & Block & Levine, 2015:8.11). The Euclidean distance generally underestimates and the Manhattan distance generally overestimates (Spaulding & Morris, 2022:5).

The Manhattan distance measurement is based on the street grid on the island of Manhattan and is only considered appropriate to use when the city of the case at hand has the same type of uniform grid (Levine, 2015:13.13). A more accurate metric is *street-routing* distance measures that follow the streets of the city (Stamato & Park & Eng & Spicer & Tsang & Rossmo, 2021:1).

Stamato et al. argues that that distance measures will always be an approximation and that usage of street-routing distance measure is based on the (incorrect) assumption that the offender always will choose the shortest path between the crime scene and the anchor-point (Stamato & Park & Eng & Spicer & Tsang & Rossmo, 2021:5-6). However, some of these effects may be alleviated by utilizing observations by security cameras or witnesses to map the path of an offender.

4.4 Definition of GP-method and the functions used

This thesis defines a *GP-method* as the combination of one or several *GP-functions* and/or GP-methods. GP-functions are in essence mathematical calculations but may be characterized as quantitative methods used with spatial data. The functions used by conventional GP-methods are divided into the two general categories of *spatial distribution* and *probability distance* (Snook, Zito, Bennell and Taylor, 2005:3) (O'Leary, 2012:10).

4.4.1 Spatial distribution functions

The six basic spatial distribution functions are based on centrographic statistics that are two-dimensional correlates of the four basic statistical moments of single-variable distributions (mean, standard deviation, skewness and kurtosis):

1. Dubbed the "simplest" descriptor of a distribution, *the centroid* is the point where the sum of all differences between the mean X coordinate and all other X coordinates is zero and the sum of all differences between the mean Y coordinate and all other Y coordinates is zero (Levine, 2015:4.1-4.4).
2. When applied to GP of a serial-offender, *the geometric mean* is the same as the centroid, but it leaves out extreme values by converting all X and Y-coordinates into logarithms before calculating the mean (Levine, 2015:4.20-4.23).
3. *The harmonic mean* also discounts extreme values but it does so in a different way than the geometric mean (Levine, 2015:4.23).
4. *The median center* is the point where the separate medians of the X coordinates and the Y coordinates of the crime-sites in a series intersect (Levine, 2015:4.12).
5. *The center of the circle* is calculated as the mid-point of the two furthest crime-sites in a series (Snook, Zito, Bennell, Taylor, 2005:9).
6. *The center of minimum distance* is the point from where the distance to all crime-sites is minimized (Levine, 2015:4.1).

These spatial distribution functions produce points of prediction that may be used to estimate the anchor-point of a suspected serial-offender by indicating a point where the anchor-point may be found or by creating a search area by expanding the point into a shape (circle, ellipse, square etc.) of a certain diameter (LeBeau, 1987:125-126) (O'Leary, 2012:10). In research the points of prediction are utilized to measure error distance.

4.4.2 Probability distance functions

The basis of *probability distance functions* is the distance decay function, which is a mathematical description of the likelihood of crime lessening with distance from an offenders anchor-point, which in turn is based on the principle of least effort (see section 2.3).

Journey-to-crime research has provided ample empirical support of spatial behavior following a distance decay function (Wortley & Townsley, 2017:14) (Levine, 2015:13.7) and a number of different distance decay functions are available, ranging from mathematical functions such as linear or negative exponential to empirically derived (Levine, 2015:13.16-13.28).

Figure 2, illustration of distance decay function.

The probability distance functions work by summing the values produced by a chosen distance decay function of the distances between a general point and elements included in the crime series (O'Leary, 2012:11).

In mathematical terms, one begins by first choosing a distance metric, then selecting a decay function and lastly constructing a "score function" that computes the score by measuring the distance to the crime-site.

Next, the score function is evaluated in the array of cells, producing a scored array of cells (probability surface) where a cell with a higher score is more likely to contain the offender's anchor-point (O'Leary, 2012:11-12). Using this score a top profile area consisting of the cells with the highest score and likelihood of containing the offender's anchor-point is produced (O'Leary, 2012:11-12).

4.4.3 The buffer-zone function

The *buffer-zone* hypothesis is based on the fact that many crimes are not committed close to the anchor-point of an offender (Levine, 2015:13.85, 13.89-13.90). It has been suggested that the reason is because few crime opportunities exist close to anchor-points as well as the perceived level of risk associated with committing crimes close to home (Rossmo, 2000:138).

In practice, the buffer-zone function affects the score by substantially lowering (*truncating*) it at a determined radius around a crime-site and sharply increasing it where the radius of the buffer-zone ends (Paulsen, 2006:330).

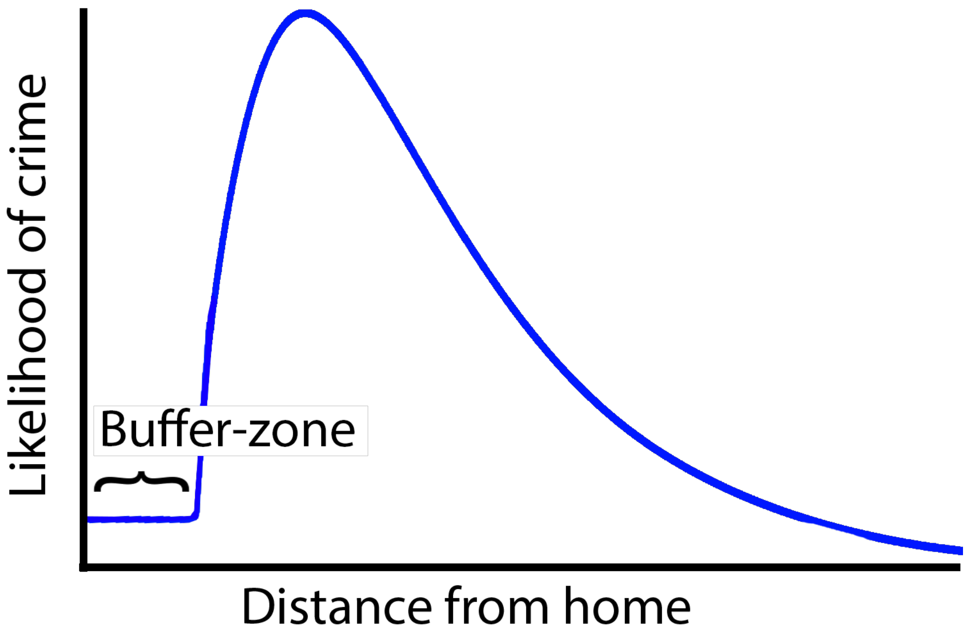


Figure 3, illustration of buffer-zone function.

However, some offenders commit crimes very close to their anchor-points (Levine, 2015:13.88) which demands an accurate size of the buffer-zone radius, otherwise this may result in the GP being unable to accurately profile an offender because the area containing the anchor-point is within the buffer-zone radius.

4.4.4 Weight, Bayesian modeling & kernel density estimation (KDE)

There are other ways than using a buffer-zone to alter the score of cells. *Weights* may be added in any of the above-mentioned calculations by multiplying the X and/or Y coordinates with another variable, "W" and thereby increasing the priority of one crime-site and lowering the priority of another which in turn alters the score of the cells in the study area (Levine, 2015:4.4). *Bayesian modeling* involves calibrating functions and thereby updating scores based on the historical location of anchor-points of other offenders who committed crimes in the same locations and thus demand access to a large amount of data (Rossmo, 2022:772). A kernel density estimation (KDE) method scores by producing densities by using points on a mapthrough measurement of the weighted average of surrounding cells and crime-sites (or other types of points) within a search distance (*bandwidth*) where the weight declines according to a function of distance. (Levine, 2015:2.66, 10.19).

5 Method

This study adopted a mixed methods strategy and used a case study approach to test the claims that the SMC-method produces a more accurate GP than the conventional methods of GP (Spaulding & Morris, 2022b:115). The study used a before-after research design (George & Bennett, 2005:210-211) and divided one single case of serial sexual assault into three separate cases on which a comparable case-study was conducted (Blatter & Haverland, 2012:41-42).

The study maximized between-case comparability by applying different GP-methods to the same cases and using an identical study area (Blatter & Haverland, 2012:41-42). Resulting in comparisons where all independent variables were similar except the one the researcher wishes to examine, in this case the different GP-methods (George & Bennett, 2005:79, 314). The control variables of the study were thoroughly examined through scope conditions and underlying theories of GP (Blatter & Haverland, 2012:40) (George & Bennett, 2005:50-53).

The accuracy and precision of the GP-methods were measured using the quantitative results and the qualitative data converged with these results to provide an in-depth analysis of the results ensuring sufficient causal depth (Denscombe, 2014:146-149). Finally the parts of the proposed SMC-method were separately examined and their effect on the accuracy of the GP-method (George & Bennett, 2005:146-147).

5.1 The Spaulding/Morris centrographic (SMC) method

Since the advent of modern GP a number of new GP-methods have been proposed. Several of these GP-methods were considered before deciding to test the SMC-method. It was selected because it attempts to account for the effect differences in environmental characteristics have on travel times by measuring distance using google maps street routing function and adding weights calculated using the obtained travel times (Spaulding & Morris, 2023a:10-11). Additionally, it attempts to mitigate possible erroneous inclusions of crime-sites by using a leave-n-out process that calculates the weighted centroid for all possible combinations of n crime-sites:

$$\binom{n}{n\text{-}1}\binom{n}{n\text{-}2}\binom{n}{n\text{-}3}$$

The probability surface is created by performing a KDE using all obtained centroids (Spaulding & Morris, 2023a:10-11).

The factors that the SMC-method claims to mitigate both have a strong connection to the conditions under which real world GP's are produced.

Spaulding & Morris developed an open-source software ("rgeoprofile") to simplify research (Spaulding & Morris, 2023a:9, 16 note 2). However, as several other softwares were able to perform the same operations (Levine, 2015:13.85-13.87, 13.90-13.91), the testing of the new GP-method was done using the GP-research software Crimestat 4 and open-source mapping software Qgis.

5.2 Case selection procedure

The case selection was guided by the data requirements determined by the theoretical framework of GP as well as the selected research strategy (George & Bennett, 2005:118). The criteria are as follows:

- The cases should have taken place in Sweden.
- Be cases of serial offenders of sexual assaults against strangers outdoors.
- The offender was not homeless or otherwise obviously not following a marauding spatial pattern.
- Geographical information about the crimes and the offenders anchor-points should be available.
- Geographical information about the crime-sites should be available.
- The cases should consist of at least 5 crime-sites.
- The crime-sites should be clearly established.

To find cases of serial-sexual assaults a systematic search was conducted in media databases as well as legal databases. Online forums were also consulted. Several cases corresponding to the above criteria were found and considered before selecting the case of ÖM.

5.2.1 Case description of ÖM

ÖM was a serial rapist that committed at least 18 assaults, robberies and sexual assaults in the Swedish town of Örebro between the years 2005-2010 when he was arrested. He was sentenced to 12 years in prison for rape and other crimes committed (Örebro tingsrätt B5303-10, 2011:4).

The case of ÖM was selected on the basis that it offered a wide variety of qualitative and quantitative data as well as a discontinuous change in an important variable which combined with the possibility of testing the proposed SMC-method on a case where law enforcement successfully constructed an accurate GP concluded the selection procedure.

5.3 Data collection

The type of data used in this study is both quantitative and qualitative in nature. The main data-source used was the written text and pictures included in ÖMs case-file, other judicial court documents as well as newspapers and magazines and also spatial data which simultaneously were visual and numerical, meaning that the study may be characterized as documentary research (Denscombe, 2014:225-226).

The following data about Örebro was collected from the Swedish Mapping, Cadastral and Land Registration Authority (“Lantmäteriet”) and the Statistics Sweden (SCB):

- All the roads, sidewalks, walking- and bicycle paths in the study area (Lantmäteriet, 2023).
- “Index boxes” are a mesh of equally sized and uniquely designated squares that cover most of Sweden, each square contain statistic information (Lantmäteriet, 2023).
- Land usage information (Lantmäteriet, 2023).

The case-file and other investigative material was procured from the relevant legal government agencies using freedom of information-laws (SFS 1991:1469), (SFS 1949:105)) and is considered authentic (Denscombe, 2014:230). The case file was produced in the context of the law enforcement investigation with the aim of catching and convicting ÖM. The credibility of the claims in the case file have been argued by both the prosecution and the defense and finally determined by the court (Örebro Tingsrätt, B 5303-10, 2011).

The following spatial data was derived from the materials:

Several of ÖM’s anchor-points were found in the case file and two of those were found to be ÖM’s main anchor-points (B5303-10, Aktbilaga 152:1). This information was cross-checked with the Swedish Tax Agency (Skatteverket, 2023). The case file contained both maps and photos of 15 crime-sites. The maps and photos were checked against google maps function “street view” from the dates corresponding to the investigation. This information was combined in a triangulating manner with information available from hearings of witnesses and victims descriptions of crime-sites. The time and dates of the offense were extracted in a similar manner.

A search using the keyword “Örebromannen” (the nickname for ÖM used by media) in the police internal systems was also conducted, resulting in an additional three additional crimes connected to ÖM where the charges had been dropped (A689.083/2023, 2023:1-2). One of the additional crimes (ID: 13) was excluded on the basis that the charges were dropped because law enforcement stated that the event had not taken place (AM-161702-10-156) but the two other crimes were included on the basis that the charges were dropped because of a lack of sufficient evidence for a conviction (AM-161702-10-239) (B5303-10, Dom:75-77) as opposed to if they were dropped because no crime was committed.

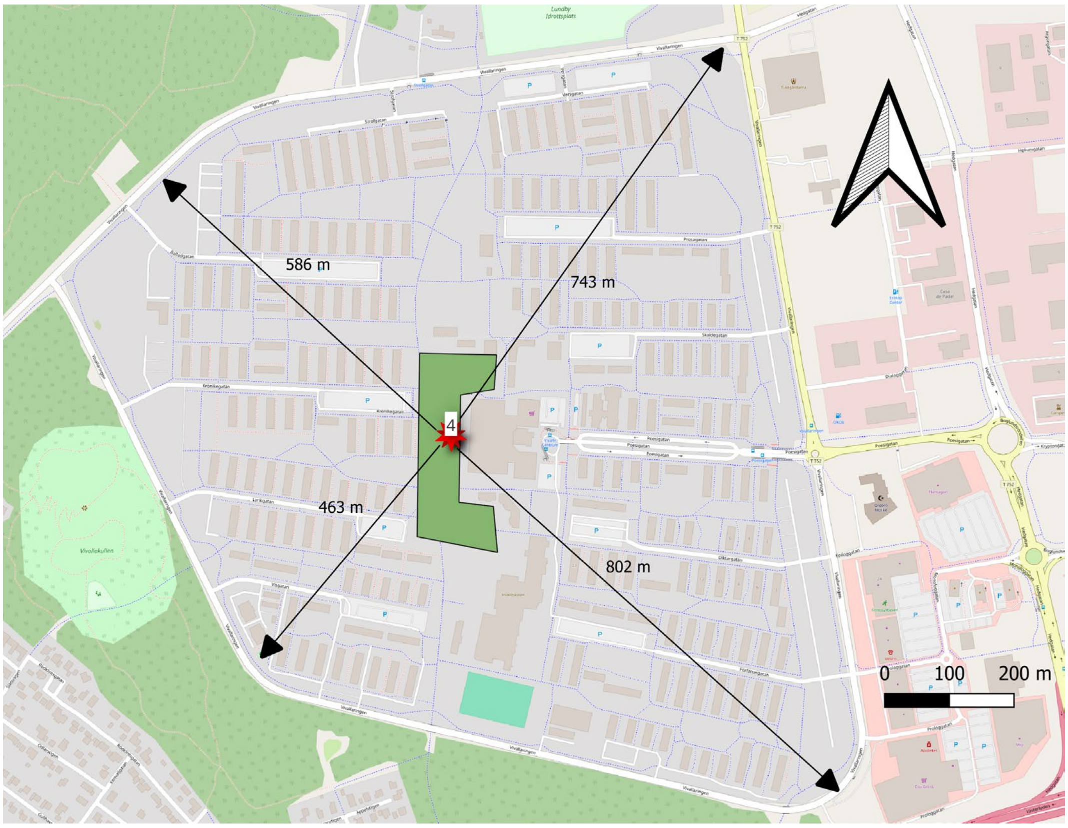
Added to this fact is the public statement of one of the lead investigators that she was convinced that ÖM committed several other assaults that they were unable to prosecute (Innala in NA, 2016).

Finally, both crime-sites are positioned in such a way in relation to the other crime-sites that the wrongful exclusion of them would constitute a strong geographical bias and the inclusion of them constitutes an excellent test of the SMC leave-n-out process and they are therefore included with ID: 4 and ID: 7.

The positions of the crime-sites were cogently established using analysis of the case-file and related materials. However, it was not possible to establish an exact position for crime-site ID: 4. Using the single available spatial information, that the crime-site was “Vivalla centrum” (A689.083/2023, 2023:1-2), a point was placed in the center of Vivalla and used in the analysis.

The location was chosen because firstly, the residential area of Vivalla has an asymmetric/irregular quadrilateral shape with an approximate relationship of the two diagonals of 4:5.

This means that placing the point in the center equalizes the amount of error from any point in Vivalla (distances to corners: NE: 743 m, SE: 802 m, NW: 586 m , SW: 463 m). And secondly, a park area similar to other crime-sites of ÖM is situated in the center of Vivalla (see map 1).



Map 1, Vivalla.

5.4 Data inclusion and exclusion

Law enforcement was unable to produce a DNA-sample of ÖM until an assault in the beginning of 2010 (Innala, in P3 Dokumentär, 2018:31.15). Using a GP produced at an earlier point, ÖM was identified as a suspect and received a summons for dna-testing (B5303-10, Aktbilaga 152:66). As a result of the summons ÖM went into a “frenzy” committing five attacks during a very short time-span (B5303-10, Aktbilaga 152:66).

This “frenzy-series” is excluded on the basis that it does not reflect the normal spatial behavior of ÖM. It also violates the fundamental assumption of GP that an offender returns to his anchor-point after a crime (Stamato & Park & Eng & Spicer & Tsang & Rossmo, 2021:3), for example after an assault by ÖM that was interrupted by a witness on the 10th of October 2010, instead of traveling home, ÖM continued hunting and committed another attack (Springare in P3 Dokumentär, 2018:39.00). The final number of crime-sites used in the study is thereby 12.

6 Operationalization

6.1 Division of data-series

In 2008, ÖM moved residence and thereby shifted his main anchor-point (B5303-10, Aktbilaga 152:1). This within-case sequential development constitutes a discontinuous change in an important variable and allows the division of the data-set into two distinct "before-series" (*BS*) and "after-series" (*AS*) that has the additional advantage of offering excellent ground for between case comparison (George & Bennett, 2005:111, 210-211).

The successful GP of ÖM produced by the Swedish law enforcement is not part of the public domain. However, the likely combination of crime-sites used to produce the GP was deduced by analyzing at what dates that the attacks were connected to the case (Dygnslista 2010-10-26, 2010:3) (Innala, in P3 Dokumentär, 2018:32.49). These crime-sites constitute a third case named the "law enforcement-series" (*LES)*. The anchor-point of the series was determined by the date it was produced by law enforcement and is therefore identical with the anchor-point used in the after-series.

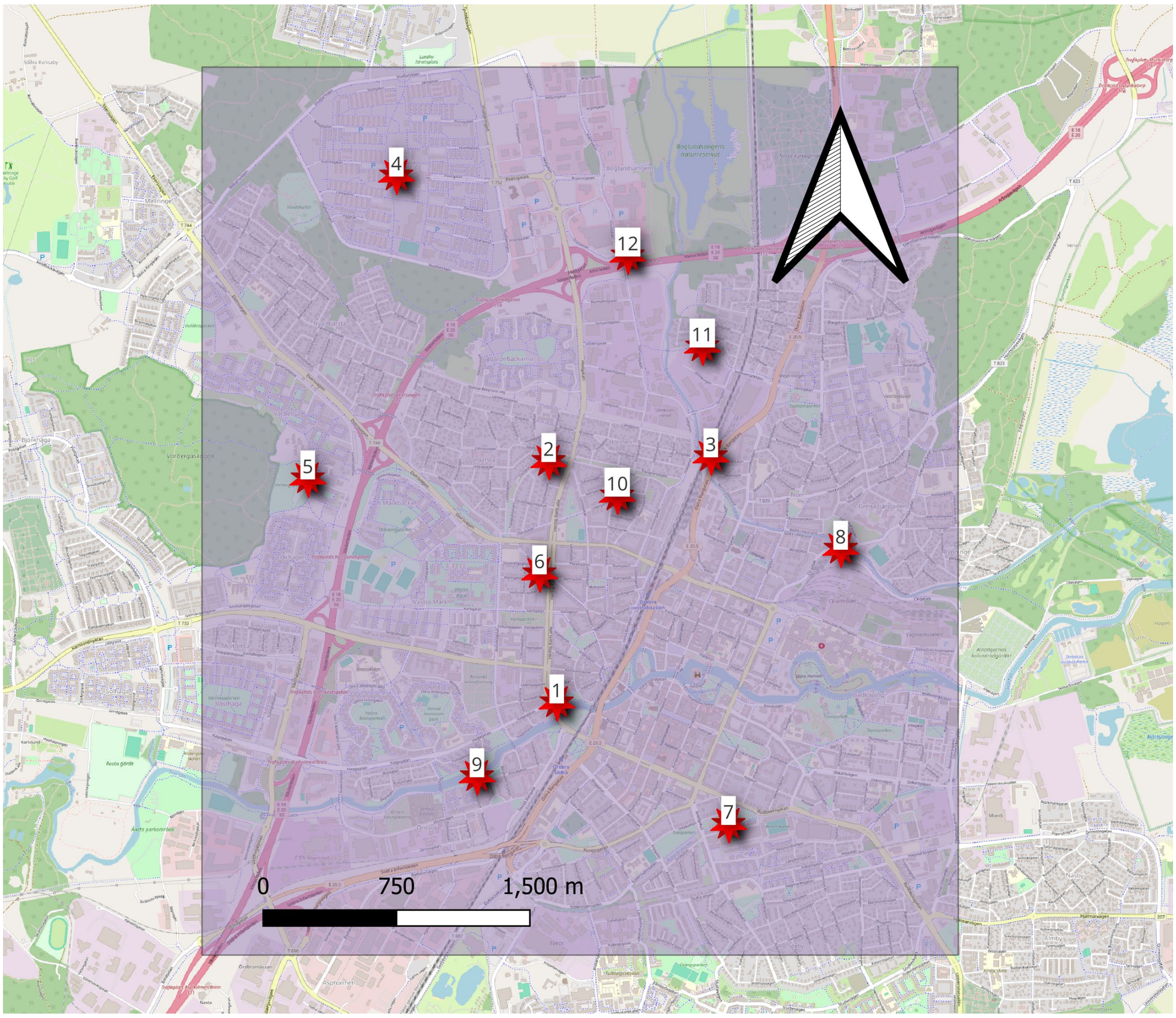
Table 2, Cases and crime-sites.

ID	Before-series (BS)	After-series (AS)	Law enforcement-series (LES)
1	Yes	No	Yes
2	Yes	No	No
3	Yes	No	Yes
4	Yes	No	No
5	Yes	No	Yes
6	No	Yes	Yes
7	No	Yes	Yes
8	No	Yes	Yes
9	No	Yes	Yes
10	No	Yes	Yes
11	No	Yes	Yes
12	No	Yes	No

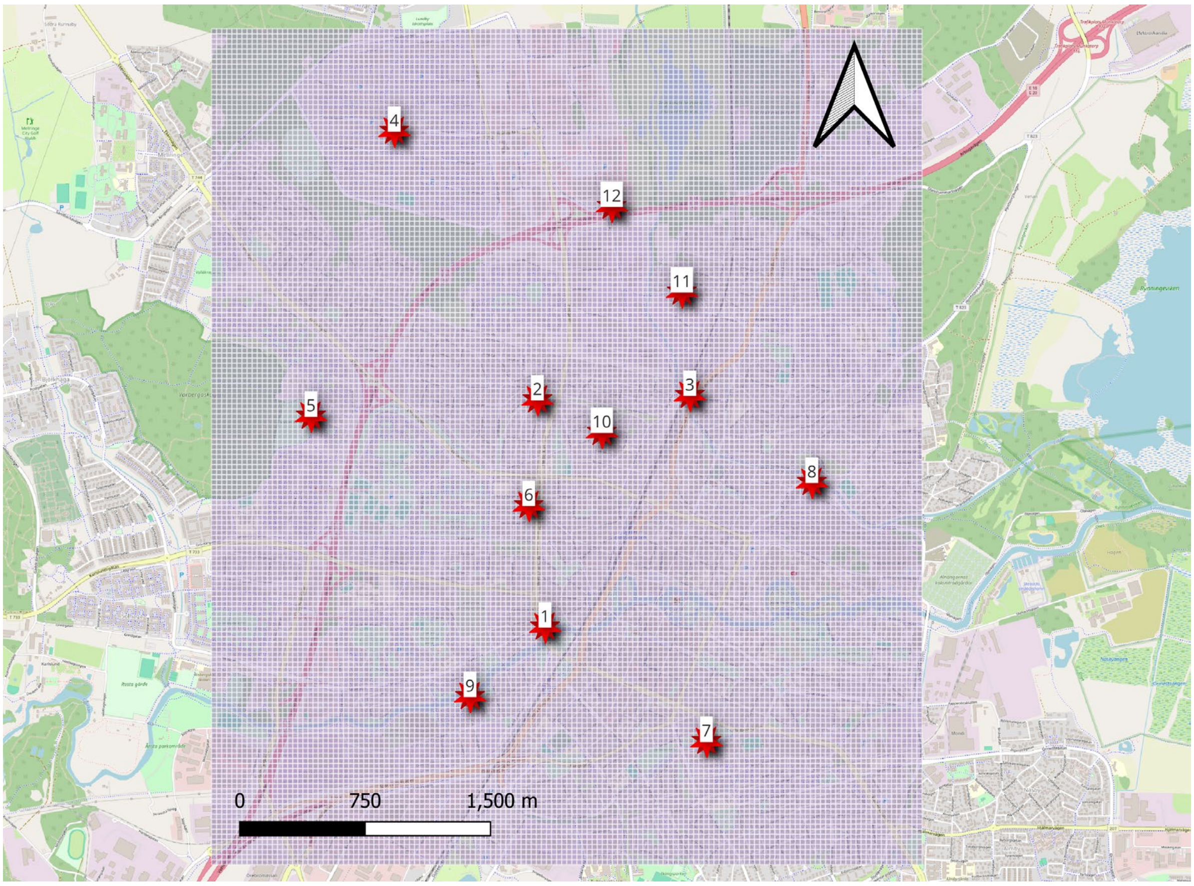
6.2 Study area definition and delineation

The study area was created using a synthesis of the methods suggested by Canter (Levine, 2015:13:90), Rossmo (Rossmo, 2000:217-218), and Levine (2015:13.12) including all of the crime-sites (ID: 1-12) in the creation of a single study area to maximize between-case comparability.

Firstly, the smallest possible square encompassing all crime-sites while still following the 250x250 m statistical index boxes was drawn. The environmental factors of the city of Örebro were then analyzed using the framework outlined by crime pattern theory (Brantingham & Brantingham & Andresen in Wortley & Townsley, 2017:99-107), the large freeway encompassing the north- and westerly edges of central örebro, the large body of water to the east of the city and finally the transition into a more “rural” character of suburb to the south were found to be natural outer limits - resulting in an expansion of 500 meters in all directions thus creating the final study area (see map 2). The study area was divided into a grid consisting of 23100 equally sized squares matching the size of the statistical index boxes (see map 3).



Map 2, the study area and all crime-sites.



Map 3, study area grid and all crime-sites.

6.3 Points of prediction & probability surfaces

First the centroid for the case was produced using the Qgis mean coordinates function. The distance and time between the crime-sites and the centroid was then measured using google maps "directions function" set to "bicycle mode". The distances and times were inverse normalized and then combined to produce a combined weight.

Table 3, Normalized distances and weights for each crime-site in the BS case.

ID	Latitude	Longditude	Distance (m)	Distance weight	Duration (min)	Duration weight	Combined weight
1	15,20166667	59,27258333	1900	2,051	7	0,000	1,026
2	15,20094284	59,28478874	350	10,000	1	10,000	10,000
3	15,21694444	59,28500000	1200	5,641	5	3,333	4,487
4	15,18599411	59,29924426	2300	0,000	7	0,000	0,000
5	15,17716667	59,28394444	1400	4,615	5	3,333	3,974

Table 4, Normalized distances and weights for each crime-site in the AS case.

ID	Latitude	Longditude	Distance (m)	Distance weight	Duration (min)	Duration weight	Combined weight
6	15,20000000	59,27911111	800	8,500	4	7,500	8,000
7	15,21856825	59,26641084	2500	0,000	10	0,000	0,000
8	15,22972222	59,28030556	1400	5,500	6	5,000	5,250
9	15,19377778	59,26886111	1900	3,000	7	3,750	3,375
10	15,20769444	59,28302778	500	10,000	2	10,000	10,000
11	15,21613889	59,29055556	1400	5,500	5	6,250	5,875
12	15,20880556	59,29516667	1800	3,500	6	5,000	4,250

Table 5, Normalized distances and weights for each crime-site in the LES case.

ID	Latitude	Longditude	Distance (m)	Distance weight	Duration (min)	Duration weight	Combined weight
1	15,20166667	59,27258333	850	7,576	3	8,333	7,955
3	15,21694444	59,28500000	1000	6,667	4	6,667	6,667
5	15,17716667	59,28394444	2100	0,000	7	1,667	0,833
6	15,20000000	59,27911111	450	10,000	2	10,000	10,000
7	15,21856825	59,26641084	2100	0,000	8	0,000	0,000
8	15,22972222	59,28030556	1700	2,424	6	3,333	2,879
9	15,19377778	59,26886111	1700	2,424	5	5,000	3,712
10	15,20769444	59,28302778	500	9,697	2	10,000	9,848
11	15,21613889	59,29055556	1800	1,818	7	1,667	1,742

This weight was used to assign the largest influence to the crime-sites closest in both time and distance to the centroid. A new weighted centroid was produced using the weighing option in Qgis mean coordinates function. This weighted centroid was used as the point of prediction of the SMC-method.

As representatives of the conventional GP-methods the spatial distribution and probability distance methods specified in section 4.4. were selected. Crimestat 4 (Levine & Associates) was used to produce the GP's using the unweighted crime-sites. Attempts were made to calibrate the methods but sufficient data about ÖM was not available and therefore the standard settings of Crimestat 4 were used.

To test the effect of the specific parts of the SMC-method on the resulting GP, series omitting the weights and the leave-n-out process were also produced. Descriptions of the specific procedures as well as source code are available from the author at request.

6.4 Scoring

When scoring the output of the spatial distribution methods, the Qgis function “shortest line between features” was used, measuring the distance between the points of prediction and the main anchor-points of ÖM producing the measurement error distance..

When scoring the output of the probability distance methods, the probability surface was divided into three areas. A top profile area, a second to top profile area and a low-probability area. The mean and standard deviation of the scores was used to delineate the areas. The top profile area contained all the parts of the probability surface with scores one standard deviation higher than the median. The second to top profile area contained all the parts of the grid with scores above the median and below one standard deviation from the median. The low-probability area contained all scores below the median.

The top profile area and top profile area ratio was calculated from these areas. If the anchor-point was within the top profile area the measuring variable of profile accuracy was set to “yes”.

The hit-score was calculated by first adding the number of cells with a score higher than that of the cell containing the offender’s residence to half the number of cells with the same score, and then dividing by the total number of cells in the study area (23100) (Rossmo, 2005b:7).

Every measure in table 1 also used by Spaulding & Morris in their evaluation of the SMC-method (Spaulding & Morris, 2023a:13-14) (Spaulding & Morris, 2023b:107-113).

6.5 Issues of validity and reliability

Sweden's confidentiality laws restrict the access to documents pertaining to crimes that an offender has not been convicted of. As such, possible assaults and other information of relevance that law enforcement may have included in their investigation may be missing from the data.

7 Analys

The SMC-method has shown promising results with the method showing similar levels of accuracy and preciseness as conventional GP-methods (Spaulding & Morris, 2022b:107-115). These claims were tested through a thorough examination of the scope conditions which informs and is followed by the quantitative results.

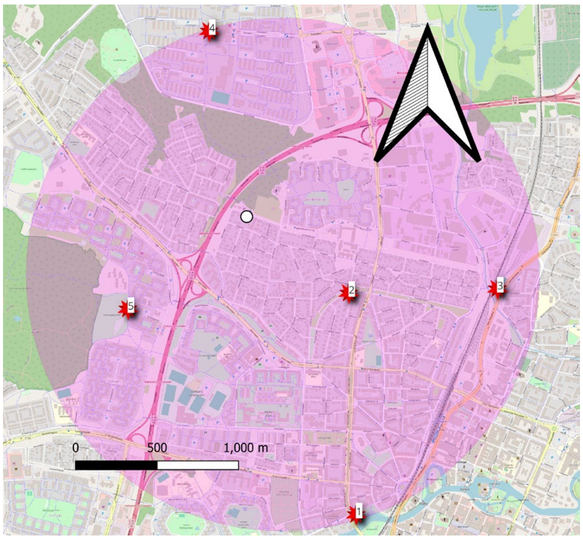
7.1 Scope conditions

7.1.1 Crime-linkage, series completeness & number of crime-sites

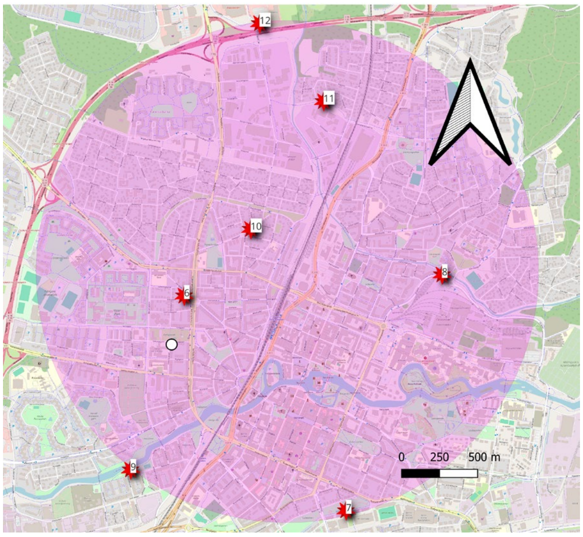
The fulfillment of the scope conditions crime linkage and series completeness have been established in section 4 during the description of the data collection process. While the completeness of the series is not certain, the crimes included in the series are strongly linked through the case-file, police databases, court documents, DNA and ÖM’s admissions of guilt (B5303-10, Aktbilaga 152:60-61).

7.1.2 Marauding pattern

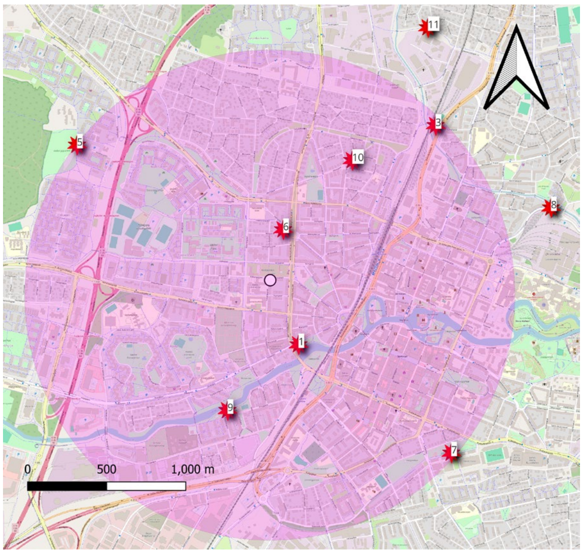
Using the method outlined by the circle theory of environmental range (Canter & Larkin in Canter, 2024:238-246) , in all three cases, ÖM was found to be following a marauding pattern.



Map 4, circle of environmental range, BS. ÖM's anchor-point is the white dot.



Map 5, circle of environmental range, AS. ÖM's anchor-point is the white dot.



Map 6, circle of environmental range, LES. ÖM's anchor-point is the white dot.

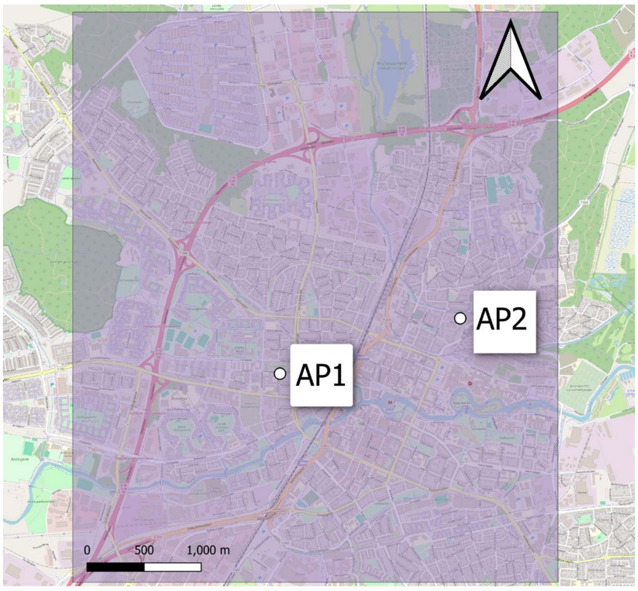
7.1.3 Single and stable anchor-point

The case file provides the resident registration addresses of ÖM during the time of the series, as previously stated, this address changed in 2008 when he moved 1500 meters southeast (B5303-10, Aktbilaga 152:1). ÖM lived mainly at his registered address (B5303-10, Aktbilaga 148:11-12). However, ÖM's mother states that ÖM visited her during some weekends and had his own key to her apartment (B5303-10, Aktbilaga 147:11-12).

Furthermore, ÖM was arrested in the cellar of his mothers apartment building (B5303-10, Aktbilaga 147:14) after fleeing from law enforcement (B5303-10, Aktbilaga 148:106-107) indicating that this was a second anchor-point at the time of his arrest. The question is then for how long this second anchor-point was used by ÖM and to what degree it may affect the scope condition of single and stable anchor-point.

ÖM's father and mother both state that the contact between ÖM and ÖM's mother until the beginning of 2010 was "nonexistent" (B5303-10, Aktbilaga 147:3) (B5303-10, Aktbilaga 147:11-12). However, ÖM clearly states that he has had a key to his mothers apartment (and thereby access to the building) either since late 2007, 2008 or 2006 (B5303-10, Aktbilaga 148:103). ÖM's mother states that she woke up one night to find an unknown man laying down next to her bed and states that she at the time of the police interview thinks that it might have been ÖM (B5303-10, Aktbilaga 147:17-18). Providing a strong indication that ÖM had access to her apartment (and the building) at least since October 2009.

Adopting this later date as a conservative estimate, one finds that during 4 of the 7 attacks included in the after-series and 4 of the 9 attacks included in the LES, ÖM had two anchor-points. Regarding the BS, there is a lack of information in the case-file. However, the small bits of information available suggests that ÖM and his mother had no contact during the BS (B5303-10, Aktbilaga 147:46).



Map 7, study area & ÖM's anchor-points AP1 & AP2.

7.1.4 Uniform target backcloth

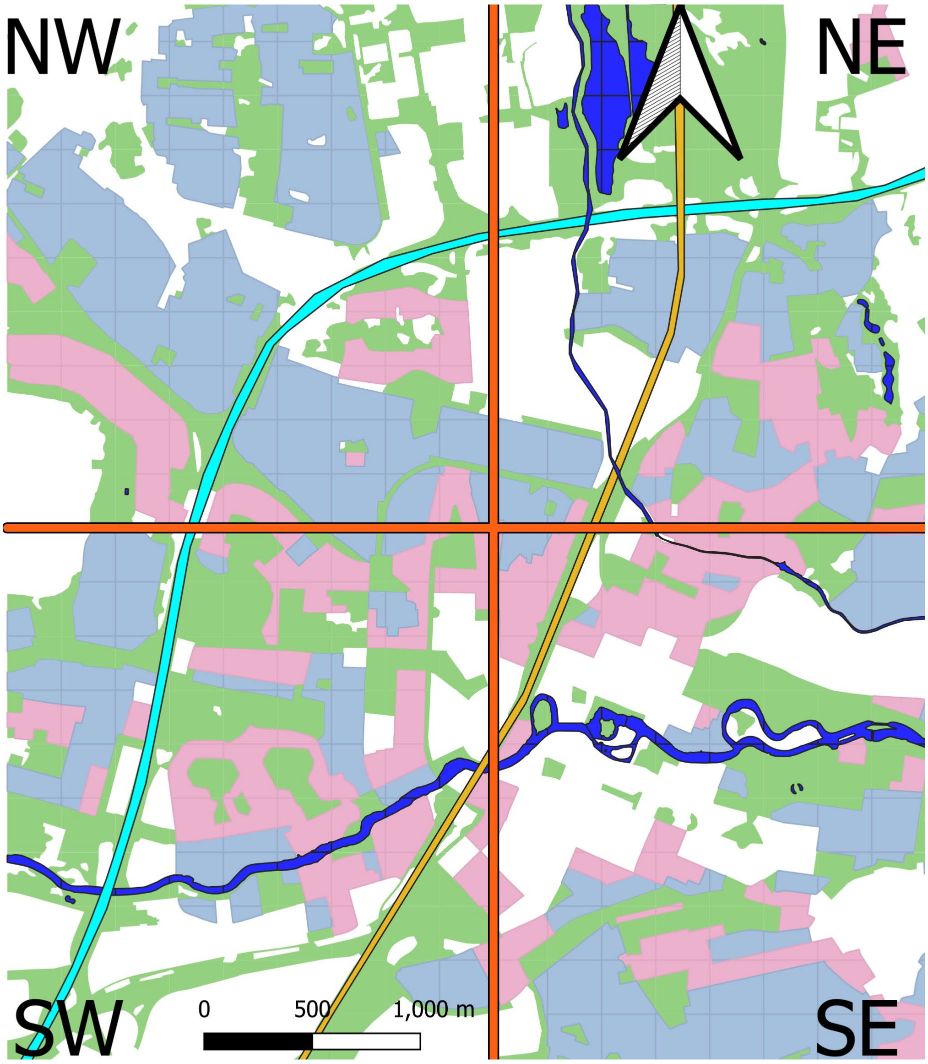
The uniformity of the backcloth was examined by enhancing the framework outlined by Crime pattern theory with rape-specific research conducted in a Swedish setting confirming the importance of environmental factors indicating opportunity, accessibility and anonymity to the selection of a rape (Ceccato & Li & Haining, 2018:210, 213-214, 227-229). Regarding opportunities i.e. availability of potential targets, ÖM did not show a preference of victims that would affect the uniformity of the backcloth, such as only attacking prostitutes stating that who he attacked was “purely random” (B5303-10, Aktbilaga 152:67).

If ÖM had been using the public transport system or a car to travel in the study area, maps of the public transit system or the amount of car roads in the four quadrants would have been relevant measures of this backcloth uniformity. ÖM, however, used a bicycle as his mode of transportation. A bicycle may be used in tandem with walking and therefore in theory will traverse the same type of obstacles as a human being on foot. An overview of the possible obstacles was performed showing that there are four impassable obstacles in the study area, two rivers, one motorway and one railroad. However, they are all crisscrossed by a multitude of bridges and tunnels making the entire study area accessible by bicycle while also providing ample opportunities for escape. The environmental factors affecting the perceived anonymity affecting the opportunities for committing a crime may also be described as the degree of seclusion and hiding spots (Ceccato & Li & Haining, 2018:213-214). They were considered to be closely connected and possible to measure by looking at land usage.

Information from the Swedish Mapping, Cadastral and Land Registration Authority was used (GSD-Fastighetskartan vektor, Lantmäteriet:2023). Out of the 12 attacks committed by ÖM that are included in the series, 10 were committed on land classified as “ÖPMARK[1]”, defined as “Area of other open land, where the height of the vegetation is less than approx. 1.5 m. Meadows and grasslands, plots of land and gardens of an open nature outside built-up areas , undeveloped colony areas, moorland, sandy beach and cobblestone fields” (Lantmäteriet, 2019:76, 78-80). One assault occurred in an area classified as “BEBHÖG”, the definition is: “Dense low-rise buildings, blocks with detached one- and two-family villas, terraced houses, terraced houses or multi-family houses with no more than two floors. Occasional taller buildings may be included. All associated land such as roads, parking lots and land with buildings is included” (Lantmäteriet, 2019:76, 78-80). Finally, one assault occurred in an area classified as “BEBLÅG”, the definition is: “Detached high-rise buildings with multi-family buildings that have three floors or more (about 9 meters to the edge of the roof). Single buildings may occur. All associated land such as roads, parking lots and land with buildings is included.” (Lantmäteriet, 2019:76, 78-80).

[1] The designation by the Swedish Mapping, Cadastral and Land Registration Authority is used in this thesis.

These categories of land usage were selected as variables used to measure the perceived opportunities of crime through degree of seclusion and availability of hiding spots. The study area was divided into four quadrants and the ratio of the type of area in the quadrants was measured.



Map 8, land-use in study area quadrants.

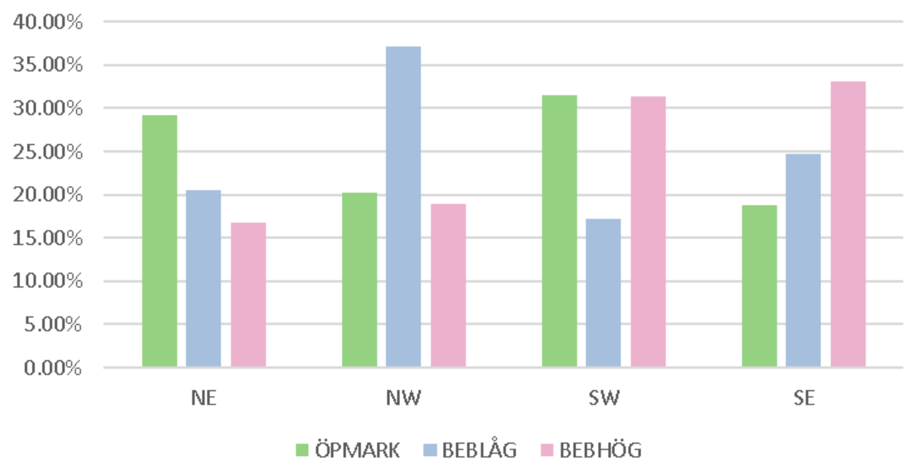


Figure 4, land-use in study area quadrants.

The results showed a fairly equal distribution of ÖPMARK in all four quadrants, with similar numbers regarding BEBLÅG and BEBHÖG, leading to the final conclusion that the environmental backcloth was uniform.

Table 6, percentage of land-use in study area quadrants.

Land usage	Total area (m²)	% of total area	NE	NW	SW	SE
ÖPMARK	5973353	28,35%	29,19%	20,24%	31,53%	18,86%
BEBLÅG	5108047	24,24%	20,49%	37,09%	17,22%	24,78%
BEBHÖG	2990115	14,19%	16,71%	18,88%	31,33%	33,06%

7.1.5 Summary scope conditions

The results of the analysis are presented in a typological table, enabling clarification ofthe expected outcome of the cases in turn enables a deeper understanding of the results of the study (George & Bennett, 2005:163).

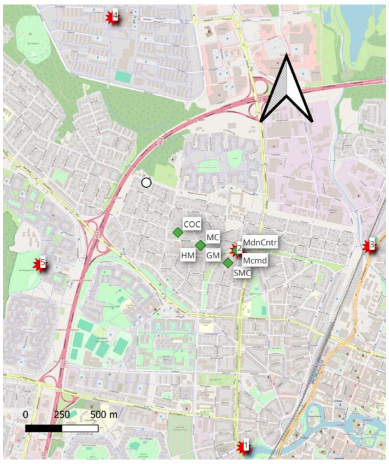
Table 7, summary of scope conditions and expected outcomes.

Variable	Impact[2]	BS	AS	LES
Marauding pattern	High	Yes	Yes	Yes
Crime linkage	High	Yes	Yes	Yes
Single & stable anchor-point	High	Yes	No	No
Uniform backcloth	Medium	Yes	Yes	Yes
Series completeness	Depends	No	No	No
Number of crime-sites	> 8 = high	No	No	Yes
	Expected outcome	Accurate GP	Inaccurate GP	Accurate GP

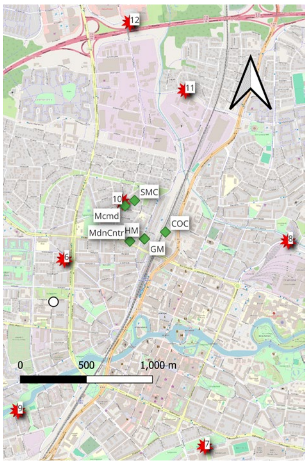
[2] Impact is discussed in section 3.3.

7.2 Results

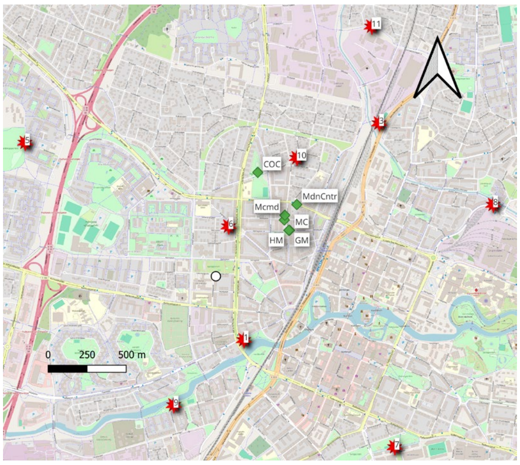
7.2.1 Spatial distribution methods



Map 9, BS (before-series)



Map 10, AS (after-series)



Map 11, LES (law enforcement-series)

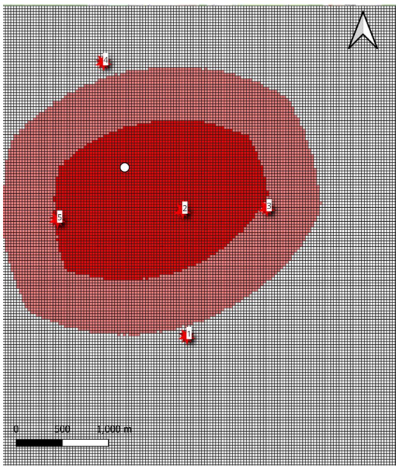
Table 8, Spatial distribution methods, results, (euclidian) error distance (m).

Name	SMC	Geometric mean (GM)	Centroid/Mean center (MC)	Harmonic mean (HM)	Median (MdnCntr)	Center of the circle (COC)	Center of Minimum distance (Mcmd)
BS	790	572	574	571	782	410	574
AS	981	836	837	835	737	1000	837
LES	567	544	556	552	692	131	556

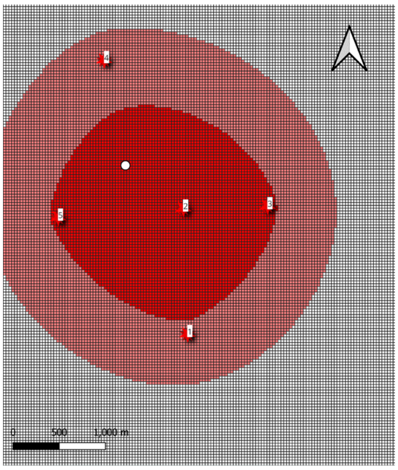
Hypothesis 1: The SMC-method will improve accuracy when compared to the conventional spatial distribution methods.

Result 1: When measuring accuracy using error distance between points of prediction and actual anchor-points, the SMC-method has the worst or second worst result in all three cases.

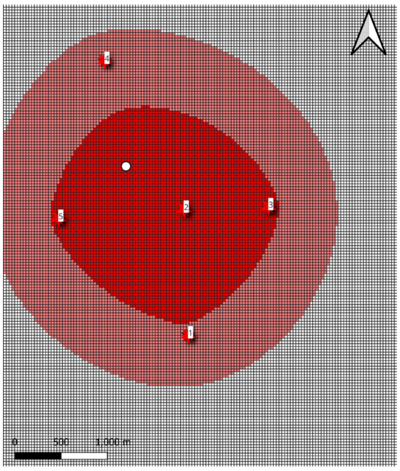
7.2.2 Probability distance methods



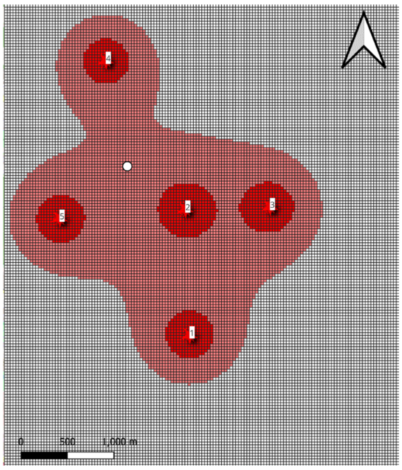
Map 12, SMC (BS)



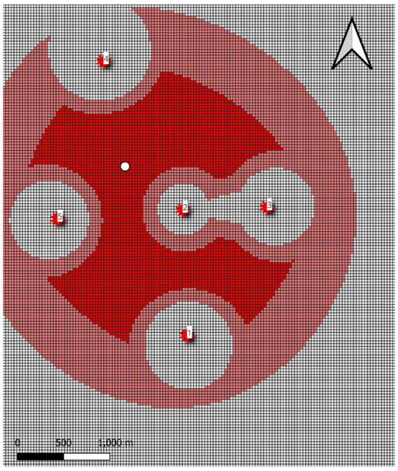
Map 13, Linear, (BS)



Map 7, Negative exponential, (BS)



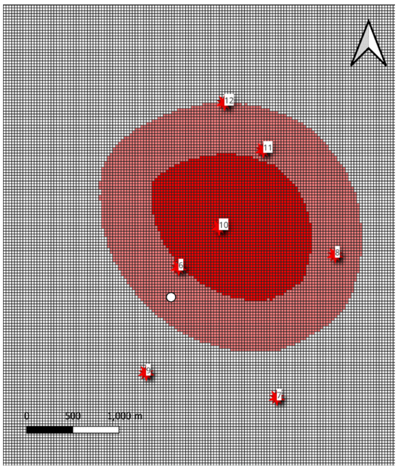
Map 6, Lognormal, (BS)



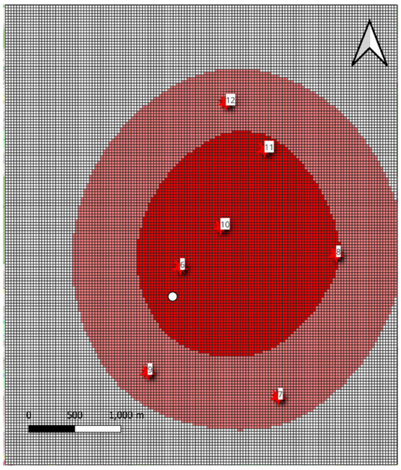
Map 5, Truncated negative exponential, (BS)

Table 9, probability distance methods, results BS.

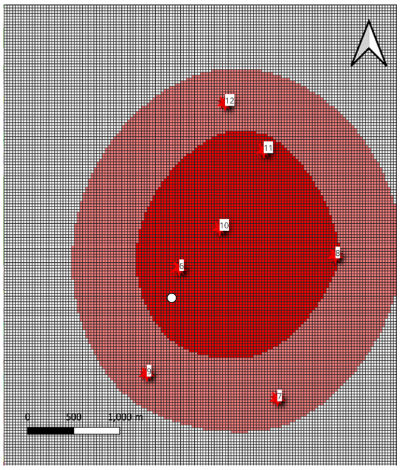
Name	**SMC**	**Linear**	**Negative exponential**	**Lognormal**	**Truncated negative exponential**
Profile error distance (m)	0	0	0	469	0
Top profile area (m^2)	2735341	4134775	4149506	1159136	3790441
Top profile area ratio	12,860%	19,439%	19,509%	33,273%	17,820%
Hit score	11,816%	6,734%	6,842%	25,115%	1,357%
Diagnostic accuracy (m)	810	773	770	925	480
Profile accuracy	Yes	Yes	Yes	No	Yes



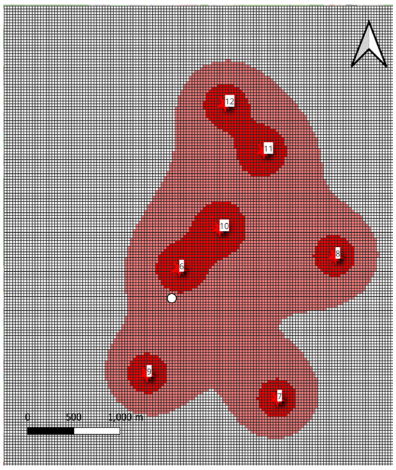
Map 17, SMC, (AS)



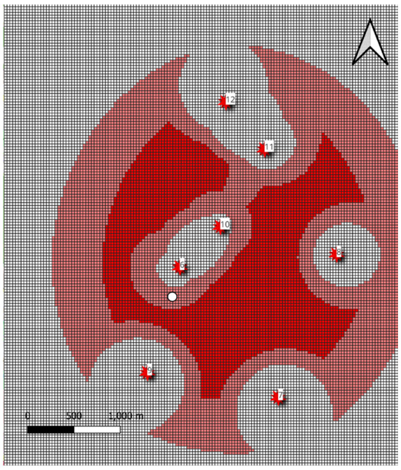
Map 18, Linear, (AS)



Map 20, Negative exponential, (AS)



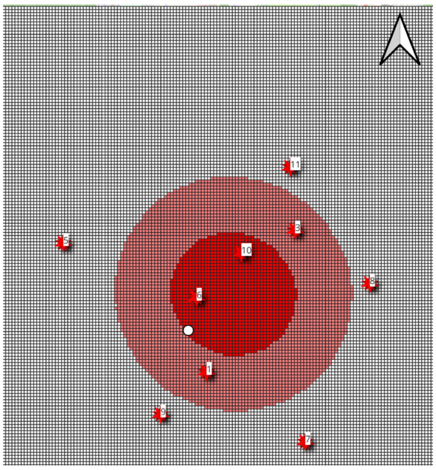
Map 20, Lognormal, (AS)



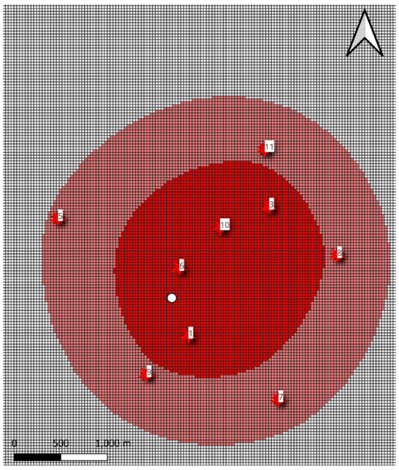
Map 21, Truncated negative exponential, (AS)

Table 10, probability distance methods, results AS.

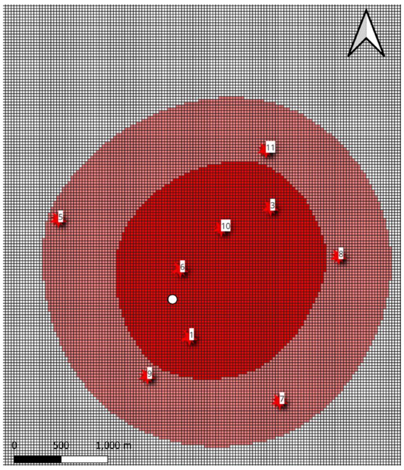
Name	**SMC**	**Linear**	**Negative exponential**	**Lognormal**	**Truncated negative exponential**
Profile error distance (m)	297	0	0	83	141
Top profile area (m²)	2155312	4122804	4115439	1465722	3748087
Top profile area ratio	28,460%	19,383%	19,349%	35,364%	47,389%
Hit score	19,212%	10,530%	10,535%	10,998%	33,032%
Diagnostic accuracy (m)	1095	909	909	1581	765
Profile accuracy	No	Yes	Yes	No	No



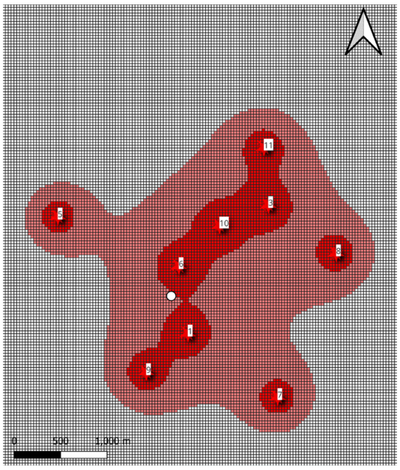
Map 22, SMC, (LES)



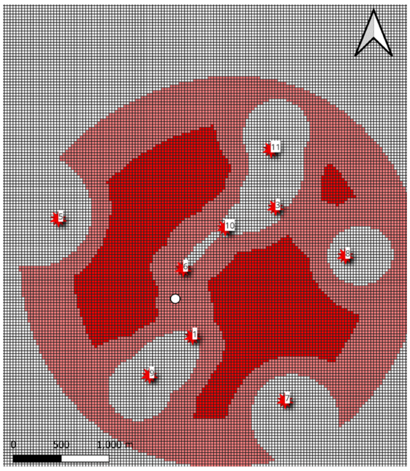
Map 23, Linear, (LES)



Map 24, Negative exponential, (LES)



Map 25, Lognormal, (LES)



Map 26, Truncated negative exponential, (LES)

Table 11, probability distance methods, results LES.

Name	SMC	Linear	Negative exponential	Lognormal	Truncated negative exponential
Profile error distance (m)	0	0	0	17	177
Top profile area (m²)	1166502	4071247	4076771	1805453	3573159
Top profile area ratio	5,484%	19,141%	19,167%	35,148%	49,782%
Hit score	4,937%	4,712%	4,729%	9,400%	32,435%
Diagnostic accuracy (m)	535	598	598	1493	698
Profile accuracy	Yes	Yes	Yes	No	No

Hypothesis 2: The SMC-method will have better preciseness than the conventional probability distance GP-methods.

Result 2: The hit-score is the primary measurement of preciseness (Levine & Block, 2015:14.24). When compared to the conventional GP-methods, the SMC-method had the 3rd 2nd worst hit-score, despite the top profile area being smaller in every case where the GP contained the anchor-point of ÖM.

Hypothesis 3: The SMC-method will have better accuracy than the conventional probability distance methods.

Result 3: The diagnostic accuracy is the primary measurement of accuracy (Levine & Block, 2015:14.23). In the LES case the accuracy of the SMC-method was better than the accuracy of the conventional GP-methods, in both the BS and AS cases the SMC-method had the 2nd worst accuracy.

The results point towards the SMC-method neither being more accurate or precise compared to the best conventional GP-methods instead it was outperformed in all three cases by the Crimestat linear and negative exponential probability distance methods despite the conventional methods not being calibrated.

This does not match earlier results by Spaulding & Morris (2022b). One possible explanation may be that the offender in the case tested using the SMC-method by Spaulding & Morris traveled by car (Spaulding & Morris, 2022b:104) and ÖM traveled by bicycle. The difference in maximum and average speed as well as the different effects the urban environment has on the ability to travel between a cyclist and a car could account for the difference (Eriksson, Niska, Sörensen, Gustafsson, Forsman, 2017:31) (Örebro kommun, 2016:6).

Yet another possible explanation is the fact that one of the highly influential scope conditions of the theory of GP was violated in the studied cases. However, this is contradicted by the fact that the conventional GP-methods were successful in the cases where the SMC-method failed.

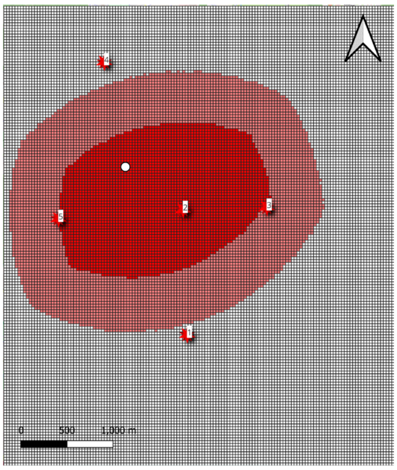
7.2.3 The parts of the SMC-method

The following hypothesis were postulated to aid with analytical evaluation of the SMC-method:

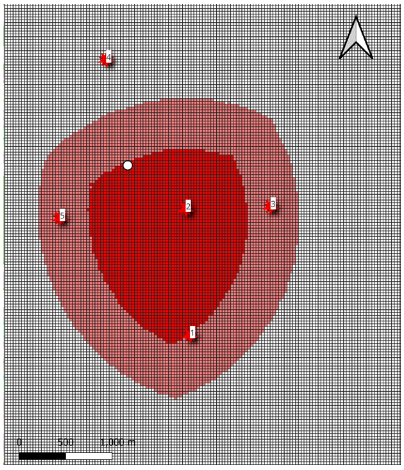
Hypothesis 4: Compared to a GP produced using only a KDE, a GP produced using only the leave-n-out process and KDE will show an improvement in accuracy and preciseness.

Hypothesis 5: Compared to a GP produced using only a KDE, a GP produced using only the combined weights and KDE will show an improvement in accuracy and preciseness.

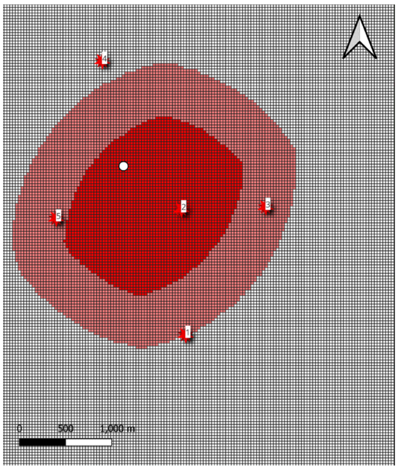
Hypothesis 6: Compared to the possible combinations of KDE using neither or either the leave-n-out process and the combined weights, a GP produced using the SMC will have better accuracy and preciseness.



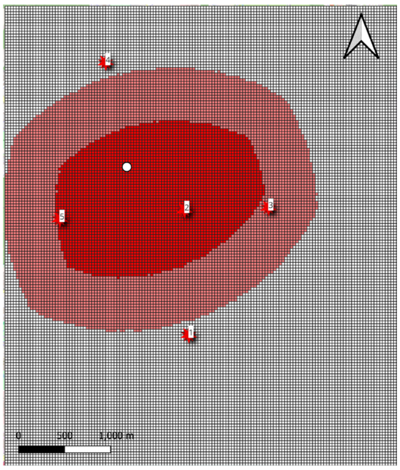
Map 27, SMC, (BS)



Map 28, Leave-n-out + KDE, (BS)



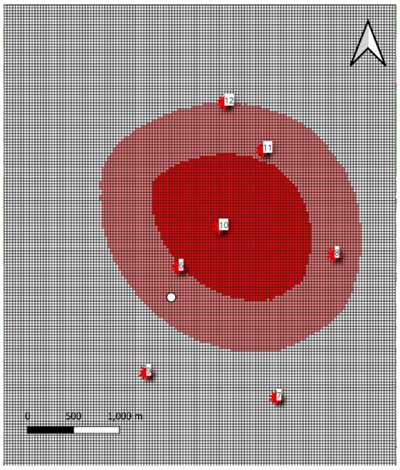
Map 29, Weights + KDE, (BS)



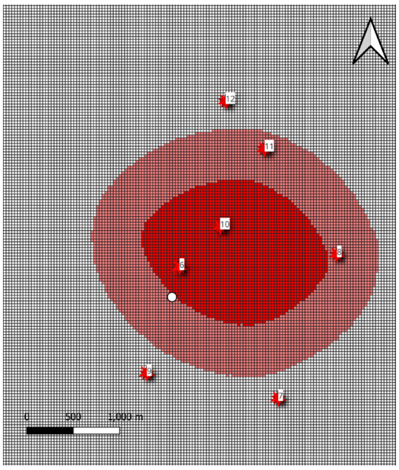
Map 30, Only KDE, (BS)

Table 12, The parts of SMC, results BS.

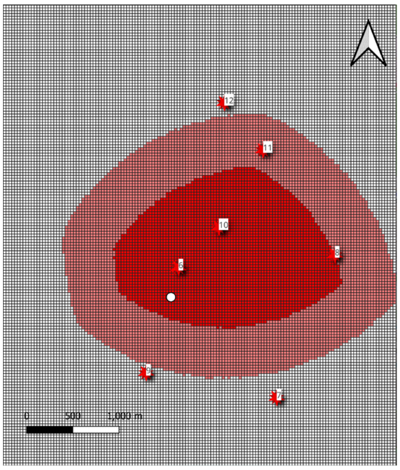
Name	SMC	Leave-n-out + KDE	Weights + KDE	Only KDE
Profile error distance (m)	0	0	0	0
Top profile area (m^2)	2735341	2631304	3059421	3174506
Top profile area ratio	12,860%	12,371%	14,384%	14,925%
Hit score	11,816%	6,082%	5,513%	4,978%
Diagnostic accuracy (m)	810	538	447	447
Profile accuracy	Yes	Yes	Yes	Yes



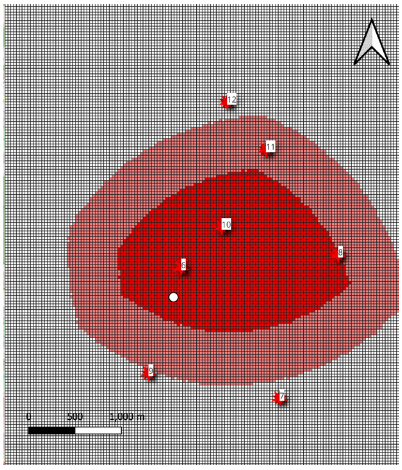
Map 31, SMC, (AS)



Map 32, Leave-n-out + KDE, (AS)



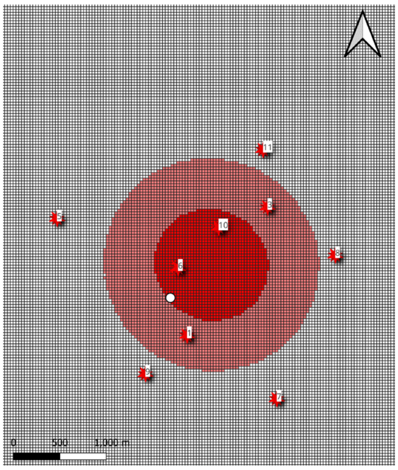
Map 33, Weights + KDE, (AS)



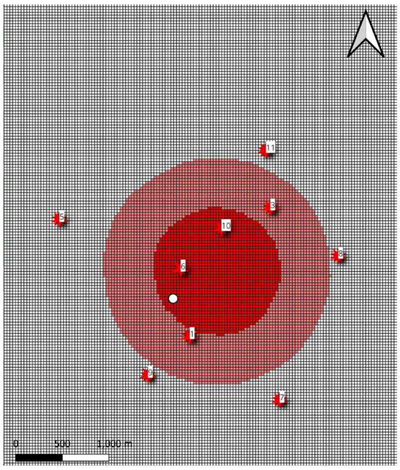
Map 34, Only KDE, (AS)

Table 13, The parts of SMC, results AS.

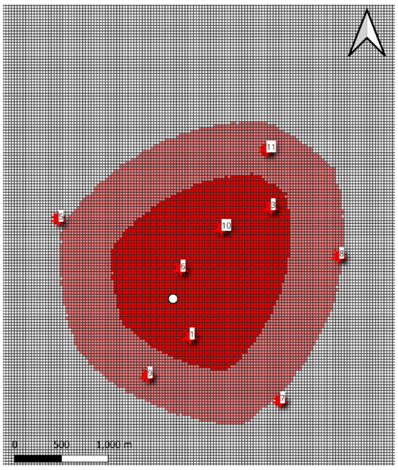
Name	SMC	Leave-n-out + KDE	Weights + KDE	Only KDE
Profile error distance (m)	297	19	0	0
Top profile area (m²)	2155312	2319193	3133994	3182790
Top profile area ratio	28,460%	29,594%	14,734%	14,964%
Hit score	19,212%	11,844%	8,173%	7,868%
Diagnostic accuracy (m)	1095	871	871	871
Profile accuracy	No	No	Yes	Yes



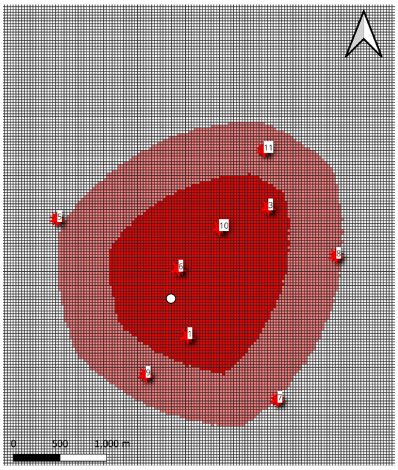
Map 35, SMC, (LES)



Map 36, Leave-n-out+KDE, (LES)



Map 37, Weights + KDE, (LES)



Map 38, Only KDE, (LES)

Table 14, The parts of SMC, results LES.

Name	SMC	Leave-n-out + KDE	Weights + KDE	Only KDE
Profile error distance (m)	0	0	0	0
Top profile area (m²)	1166502	1472167	3018910	3110057
Top profile area ratio	5,484%	5,921%	14,193%	14,622%
Hit score	4,937%	4,647%	2,119%	2,134%
Diagnostic accuracy (m)	535	526	315	315
Profile accuracy	Yes	Yes	Yes	Yes

Result 4: The hit-score was worse in all cases. The diagnostic accuracy was worse in the BS and LES cases and unchanged in the AS case.

Result 5: The hit-score in the LES case was slightly improved and slightly worsened in the BS and AS cases. The diagnostic accuracy was unchanged in all three cases.

Result 6: Both the diagnostic accuracy and the hit-score of the SMC are worse when compared to the possible combinations.

7.2.4 Summary SMC-method

When comparing the SMC-method to the results of only a KDE and a KDE with the combined weights it is clear that in the tested cases the usage of of the leave-n-out process with or without the combined weights produces a less accurate and precise GP.

This is a highly unexpected result that warrants further research using broader datasets as the possibility exists that the BS, AS and LES-cases are somehow deviant.

At first glance the result that a KDE without additions and KDE with combined weights outperformed the best conventional GP-methods would warrant similar curiosity, however this is most likely explained by the fact that the conventional GP-methods did not undergo calibration.

Yet another suggestion for further research is to approximate the optimal amount of crime-sites to be excluded by the leave-n-out process in relation to the total number of crime-sites in a case.

8 Conclusion

This thesis compared the new GP-method SMC with current conventional GP-methods with the aim of exploring the viability of improving the efficiacy of GP. It was unable to reproduce the promising results of the authors of the method. This may be explained by the close connection of the test cases used. The close connection making it more probable that all test cases are deviant or that one or more unidentified variables have effected the outcome.

Before deploying the SMC-method in a real world-scenario, this thesis suggests further exploraratory and confirmatory research.

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