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# Space-time Clusters of Crime in Stockholm, Sweden

Adriaan Uittenbogaard[1] & Vania Ceccato[1]

[1] CEFIN - School of Architecture and the Built Environment, Royal Institute of Technology, Sweden

Correspondence: Adriaan Uittenbogaard, CEFIN - School of Architecture and the Built Environment, Royal Institute of Technology, Drottning Kristinas väg 30, 10044 Stockholm, Sweden. Tel: 46-8-790-8732. E-mail: acui@kth.se

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**Abstract**

The aim of the study is to detect geographical clustering of offences over time using Kulldorff's scan test (SaTScan version 9.01; Kulldorff, 2010) and police recorded data over Stockholm city, the capital of Sweden. This technique has a rigorous inference theory for identifying statistically significant clusters. The space–time scan statistics are used in a single retrospective analysis using data from 1st January 2006 to 31st December 2009. A four years' dataset is collapsed into 'one year'. All space-time dimensions of the data are kept except 'year'. Clusters over the hours of the day, weekday and weekend and by seasons were tested. Total population but also day-time and night-time populations were used as reference. Findings show clear distinct patterns of concentration for violence (assault and threat) and property crimes (theft, robbery and burglary) over time and space. Whilst property crimes tend to happen more often in the afternoons in the center and regional commercial centers in the southern and western parts of Stockholm, violence takes place more often in the night, and is heavily concentrated in large parts of the city center. Weekends are more targeted than weekdays for both offences. Regardless of day of the week, the main urban core of the city contains the most likely cluster that extends to commercial and socially disorganized areas in the west and south Stockholm. Whilst property crime levels do not show significant differences over the seasons, violent crimes levels do (winter and summer). The most likely clusters tend to be fairly constant in space over time. The article ends with implications of the results for both research and practice.

**Keywords:** spatial concentration, space-time cluster, poisson discrete model, violent and property offences

## 1. Introduction

Quetelet (1842) in his seminal work suggested that the greatest number of crimes against a person is committed during summer and the fewest during winter. Since then, researchers have found new empirical evidence on how crime levels vary over time and space (for a review see Cohn, 1990; Cohn & Rotton, 2003; Ceccato 2005). Some relate these temporal differences to the influence of weather on behavior (Anderson et al., 2000) whilst others associate them to variations in people's routine activity (Cohen & Felson, 1979). Routine activity theory suggests that an individual's activities and daily habits are rhythmic and consist of patterns that are constantly repeated, moreover most crimes depend on the interrelation of space and time: the offenders' motivation, presence of suitable targets (victims) and absence of responsible guardians (Cohen & Felson, 1979). This is the basis of the explanation of the mechanisms behind seasonal (summer–winter) and weekly (weekend–weekday) variations of crime over time and space.

The advance of new technologies for data storage and analysis such as Geographical Information System (GIS) has led to systems for visualising and analysing the growing amounts of geocoded data, including for crime. Cluster techniques, such as Kulldorff's scan test, can be used for detection of variations of crime over space and time. As suggested by Ceccato (2008), "these techniques are making geographical analysis of crime data more in-depth and interactive than they were in the past and therefore space can now be addressed more dynamically, both in time and space. Spatial analysis of crime data often uses information on the unique location of individual crimes (x, y co-ordinates) or aggregated data (combining individual point data into larger areal units, such as a city's statistical units)". The use of Kulldorff's scan test to detect hotspots of violent and property crimes in Stockholm, Sweden, is assessed.

The Kulldorff's scan test has been chosen because it uses input data based on single events and is a software able to detect statistically significant clusters of point data (such as crime records). The events are assumed to be randomly distributed over space and time (Kulldorff, 2010). Kulldorff's SaTScan has several modelling options available for cluster detection; it is possible to search for only spatial, temporal or space-time clusters. The scan test can be applied to both continuous and discrete data, where the latter data may be aggregated to local area levels, instead of individual point data, and the center point of the polygon will be used as location reference (Kulldorff, 2010). This aggregated method makes the analysis faster as fewer individual points need to be 'scanned', yet not less trustworthy if one is satisfied with using larger area data. The discrete models can be based upon the underlying assumptions of either Poisson, Bernoulli, space-time permutation, multinomial, ordinal, exponential, normal or spatial variation in temporal trends model distributions. The choice of model relies on the input data, as for instance the Poisson model requires the existence of a concerned population at risk while the Bernoulli model involves the use of both cases and controls data for the cluster analysis (Kulldorff, 2010). In order to detect clusters over space and time, the space–time scan statistic is defined by a cylindrical window with a circular geographic base and with height corresponding to time. This cylindrical window is moved in space and time, so that, for each possible geographical location and size, it also visits each possible time period. An infinite number of overlapping cylinders of different size and shape are obtained, jointly covering the entire study region, where each cylinder reflects a possible cluster. This procedure is used to ensure data robustness (there is a higher power to pick clusters up with the collapsed data than one year dataset) (Kulldorff, 2010).

The objective of this study is to assess geographical clustering of offences over time using a Poisson discrete model and police recorded data over Stockholm city, Sweden. This will be achieved by detecting the concentration for violent and property offences in three moments in time: hours of the day, weekend and seasonally. For cluster detection during the day, two different reference populations are tested: day-time and night-time population and results are compared.

The structure of the article is the following. First, we present the area of study and the data used in section 2. The review of literature on space-time clusters followed by a set of hypotheses is presented in section 3. In section 4 the use of the methods is motivated. Section 5 puts forward the results while in section 6 findings are discussed. Conclusions and implications for future research and practice are presented in section 7.

## 2. The Study Area and Data

The study area is the municipality of Stockholm. Stockholm, as the capital city of Sweden, constitutes an interesting study area because the differences in seasonal weather variation are significant. Winters are cold and dark while summers provide warm and long, light days. These variations may affect crime levels and concentrations in space, which can potentially be picked up by space-time cluster techniques. Moreover, analyzing spatial clusters in Stockholm will provide an insight of the distribution of crime in a typical Scandinavian city, planned and built according to rather organized urban planning disciplines following the main infrastructures (e.g. underground and roads). So far, most previous research on cluster of crime has focused on cases in North America.

The data used is within the borders of the municipality, which covers an area of 216 $km^2$ and a total population of 790 642 (2007). The city is divided into 408 small units of analysis (*basomrade*), with an average population of 1937.85 and standard deviation of 1833.11. Crime data is extracted from official records of the Stockholm Police over four years: 2006 to 2009. For the police crime data only the years from 2006 to 2009 were at our disposal but the numbers are robust enough to work with and represent the most recent crime trends we can get hold off. Of all the selected records 6.3 per cent was eliminated as those either lacked coordinates, dates, were outside the study area or were registered before the recorded year. The records included all registered crimes of which five categories were selected: assault, threat, theft, burglary and robbery. For this study, assault and threat were combined as "violent crimes" and theft, burglary and robbery as "property crimes". Violent crimes includes all in- and outdoor violent related reports, of both attempts and completed crimes, e.g.: threat against duty officer, violence against women, rape, murder, limiting rights of freedom, harassment, insult, abuse. Property crimes covers thefts, burglaries and robberies from both persons and buildings, for instance: pick pocketing, theft of vehicle, theft from home or shop, theft of purse or phone, burglary in apartment, burglary in garage, burglary with break-in, robbery with weapon, robbery of shop, robbery of vehicle, robbery of person. The selected records comprehend 349 492 cases. The four years were collapsed into one year in order to create a more robust dataset. The records contained information on the offence, place (x, y coordinates) and time (by minute). Besides the crime records, demographic data of Stockholm municipality was used to run the cluster detection for seasonal variations. Total population for each small unit of analysis as well as night-time and day-time population was available. Night-time population shows a high correlation with total population whilst day-time population reflects people's movement patterns in the city. Table 1 indicates that more offences happen during weekends than weekdays. This finding makes a case for us to check if there is any variation in crime levels in space, which will be examined further in the paper.

Table 1. Average statistics of two types of crime in Stockholm, 2006-2009

| | Total 4 years | Average a year | Average an hour | Average weekdays | | Average weekends | |
|---|---|---|---|---|---|---|---|
| | | | | One day | One hour | One day | One hour |
| Violent | 75 117 | 18 779.25 | 1.84 | 43.51 | 1.81 | 61.99 | 2.58 |
| Property | 274 375 | 68 593.75 | 6.98 | 180.95 | 7.54 | 196.96 | 8.21 |

## 3. Space-time Clusters: Theory and Hypotheses

"Until recently, the role of space (and space-time) was not explicitly acknowledged in the methodology used in crime geography studies, but it is central in a number of respects" (Anselin et al., 2000). An important reason is that knowing where and when crime happens is fundamental for police intervention (Ratcliffe, 2010). Both Ratcliffe (2010) and Anselin et al. (2000) emphasize the importance of spatial techniques to detect and analyze space-time in crime data. More recently, Nakayo and Yano (2010) suggest the need to visualize both crime patterns in space and time to get a grip on the movement of clusters over time and space instead of focusing on all individual clusters. The study on crime clusters in Kyoto showed that the use of both kernel density based analyses and space-time scan statistics analyses are complementary to each other. Johnson et al. (2007) used Monte-Carlo simulations and Knox's ratio results to identify space-time clusters of burglary. Their cross-national findings showed that burglaries tend to be clustered in space but more important in time as well; clusters decayed as time elapsed. Johnson and Bowers (2004) use Knox's ratios but in combination with the Mantel technique to identify burglary clusters in space and time. The result of a two step analysis, firstly for spatial clustering of 'close pairs' and secondly space-time clustering, is that clusters of burglary appear more stable in time and movement in space occurs only in the vicinity in different time periods. Kulldorff's scan test has successfully been applied in the literature for both cities in the North and South hemisphere. LeBeau's study (2000) used the Kulldorff's scan test for a risk based assessment using space-time cluster of crime in the USA. Ceccato (2005) focused on space-time clustering (Poisson discrete model) of homicides in Sao Paulo (Brazil) and showed indications of a seasonal pattern which changes spatially according to months of the year. Other studies focusing on seasonal patterns of crime also found that crime levels vary over the year, but often different types of offences show different patterns (e.g. Anderson et al. 2000; Bromley & Nelson, 2002; Cohn, 1990; Cohn & Rotton, 2003; Farell & Pease, 1994). Nonetheless, these studies do show varying results and are inconclusive on seasonal effects (e.g., whether summers are more criminogenic than winters). Those studies which are concerned with the geography of these clusters, often present indications that crime patterns follow people's routine activity, places where people converge (Cohen & Felson, 1979; Sherman et al., 1989; Brangtingham & Brantingham, 1993) and/or neighborhoods that show signs of poor social control and social disorganization (Shaw & MacKay, 1942).

Taken together, the existing literature on Kulldorff's scan test is encouraging with regards the detection of space-time cluster of crime. Moreover, the suggested link between activity patterns and crime hotspots is a motivation to look closely at the behavior of crime over different periods of time and over space. For the purpose of this study, the recent strand of research is used as a background to hypothesize that the Kulldorff's scan tests provide robust results for the case of Stockholm. The analysis makes use of four years' crime data over Stockholm city to test the following hypotheses:

1) Both violent and property crimes show daily, weekly and seasonal variations over time and space.

2) Crime opportunities tend to be concentrated where people converge (city center, commercial areas, and central stations) but also in areas with signs of poor social control and social disorganization.

3) Hotspots of crime are sensitive to the population basis used in the test. Night-time population tends to shrink hotspots where people live (periphery of the city) whilst day-time population affects the size of hotspots in the opposite direction.

## 4. Method

Crime data sets were selected by using time windows representing peak and low hours of crime during the day.

By inspecting histograms, the highest and lowest crime rates were extracted. For instance, for property crimes the peak hour was 17:00, represented by the events happening from 17:00 to 18:00. This was done manually for total crimes, property and violent crimes, by day and month. As the database included an aggregated set of four years, each hour had enough events to be used in the analysis. Before cluster analysis, A-nova tests (with Scheffe test) were used to test whether there was significant difference in crime rates over time.

The study was based on models assuming a Poisson distribution of the number of cases at each location, under the null hypothesis that the expected number of cases in each area is proportional to the population in that area (Kulldorff, 2010). As the Kulldorff's scan test uses space-time statistics from the user's input, input data was created separately for each different run. In order to have an effective but comprehensive data input, all crime records were linked to their respective small unit areas (*basomrad*), as defined in the Stockholm population database, using GIS (population basis). This implied that the scans were not based on the exact coordinates of each separate crime record but on the coordinates of the centroide of each polygon (reflecting population basis) of the small unit areas. For cluster detection during the day, two different reference populations were tested: day-time and night-time population. Originally, Stockholm municipality consists of 408 small unit areas, but a few of these units have low population counts (less than 50 inhabitants). To improve the population basis for running the scan tests, about 40 units were aggregated to the neighboring polygons using GIS; so that none showed a population count lower than 50. The space-time scans were executed within different time frames defined by the user. In this study, the maximum temporal cluster size window was set to seven days (if applicable) so that the crime clusters were identified at a maximum length of a week. For spatial scan limits, two ranges were used: one being maximum 50 per cent of the population at risk and the other a maximum of 10 per cent of the population.

## 5. Identifying Space-time Clusters of Violent and Property Crime in Stockholm

This study explores when and where crime happens in Stockholm and therefore investigates three different moments in time. The analysis is divided into three parts; crime during the day, between weekdays and weekends and whether there are any seasonal variations. For all three moments the clustering of crime has been assessed using the Kulldorff's space-time cluster test based on a discrete Poisson model.

### *5.1 Clusters during the Day*

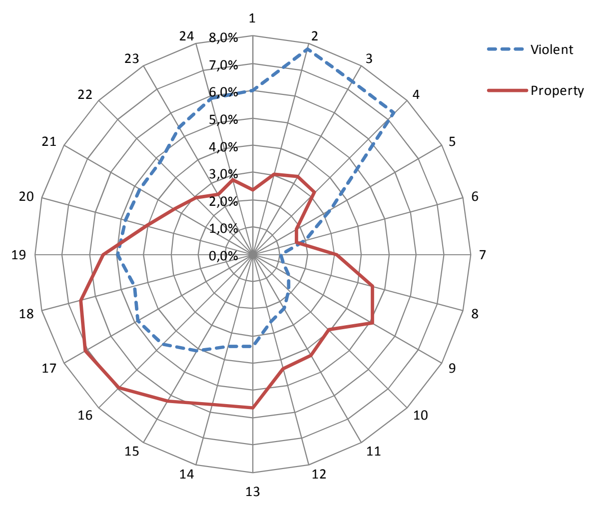


Figure 1. Percentage of violent and property crimes by hour of the day in Stockholm, 2006-2009

Source: Stockholm Police Database, 2006-2009.

During the day people are on the move and execute different patterns related to their destinations and activities. This also relates to the opportunities for different kinds of offences. The two types of crime show two different patterns over the day; property crimes happen more during day-times and violent crimes are more committed during night-times. There is a peak for property crimes at 17:00 and at 02:00 for violent crimes (Figure 1).

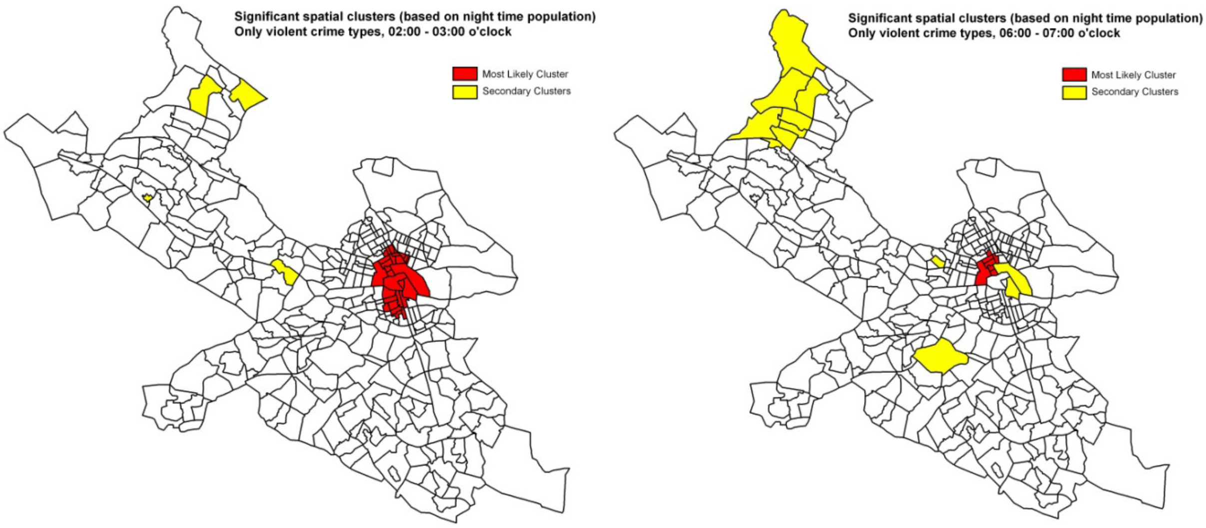


Figure 2. Clusters of violent crimes at a) 2am (peak frequency) and b) 6am (lowest frequency)

The spatial clusters appearing as hotspots during the night show a more concentrated violent pattern (Figure 2) that shrinks when moving towards the lowest peak at 06:00. Property crimes (Figure 3) increase in terms of clusters at the highest peak, 17:00, and creeps into more suburban areas where the population is lower during day-time as people are at not at home but are engaged in work or leisure activities.

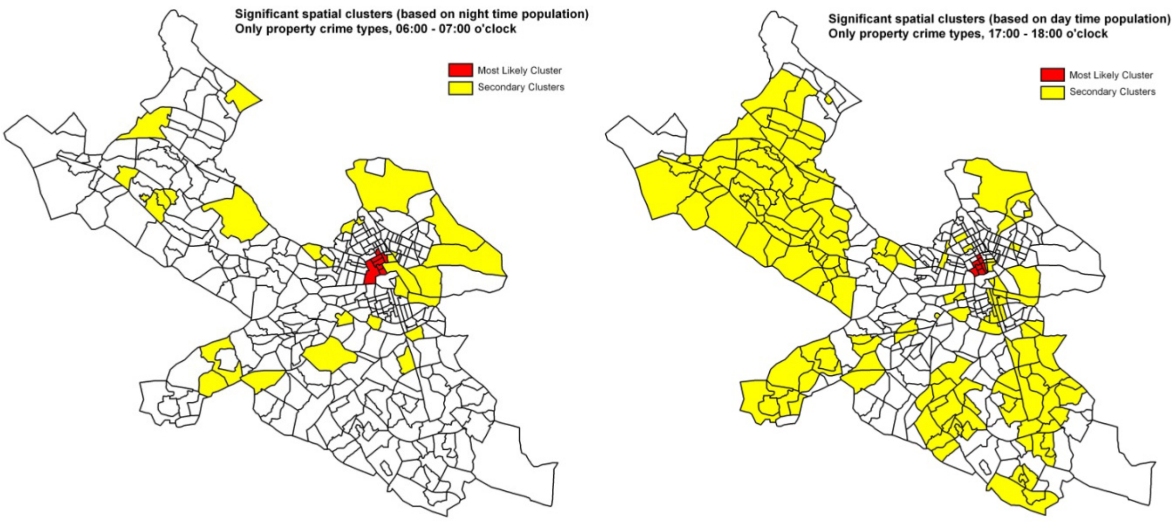


Figure 3. Clusters of property crimes at a) 6am (lowest frequency) and b) 5pm (peak frequency)

*5.2 Clusters in the Week*

The literature shows evidence of a significant difference in crime incidence between weekends and weekdays. Peak periods for assaults and robberies were found to be in the early hours of the morning on weekends, that is, between 00:01 and 03:00 on Saturdays and Sundays. Assault and robbery rates during these times were more than twice the average rates in Sydney, Australia (Jochelson, 1997).

In Stockholm, A-nova tests show a significant difference for both crime types between weekdays and weekends. Property crimes show significance at a 90 per cent level whereas violent crimes are significant at a 99 per cent level (Scheffe test). Results show that weekends tend to be more prone to crime activities as a consequence of the unstructured activities undertaken by people during the weekend, such as leisure. By selecting two data sets, for both weekdays (Monday – Thursday) and weekends (Friday – Sunday), as input for the Kulldorff's scan test, clustering was detected for both periods. Violent crime clusters shrink during the weekend and show a more concentrated pattern for specific locations in the suburbs. The city center shifts in direction for weekends, including the area in the east where more bars and clubs are located, contrary to the weekday's cluster which is more concentrated around the central station where most people meet while daily commuting from home to work.

*5.3 Seasonal Clusters*

Research has been inconclusive on whether crime varies seasonally (Cheatwood, 1988; Landau & Fridman 1993; Ceccato, 2005) but evidence tends to show that crime varies over time. In the Northern Hemisphere, Cheatwood (1988) shows that there was no specific season for homicide but homicide levels where found to be significantly higher during the months of December, July, and August. Landau and Fridman (1993) found that while homicide does not vary significantly over the year, robbery does and would peak during the winter (November through March). Assault and robbery incidents were more prevalent in the summer months in Sydney, Australia (Jochelson, 1997) whilst Hipp et al. (2004) show that both violent and property crimes vary seasonally. They indicate, for instance, that property crime rates are primarily driven by pleasant weather. Homicides show seasonal variations also in Sao Paulo, Brazil, one of the largest cities of the Global South (Ceccato, 2005), with peaks in the hot months of the year, when vacation and many social gatherings occur. Farell and Pease (1994), show that in Merseyside (UK) domestic disputes are highest in summer while burglary and theft peak during the winter. Do violent and property crimes also vary in Stockholm? To detect variations of crime over seasons, the full four year dataset was broken down into four parts (Winter from December till February, Spring from March to May, Summer ranged from June to August and Autumn includes September to November). The A-Nova test showed that levels of violent crimes differ between winter and summer; there is a significant difference of over five crimes a day (Table 2) but property crime does not vary significantly between seasons.

Table 2. Differences in violent crimes by season

| | Crime Levels Mean | F-test | Scheffe |
|---|---|---|---|
| Winter (1) | 48.19 | 2.901* | 1.3/3.1 |
| Spring (2) | 51.90 | | |
| Summer (3) | 53.54 | | |
| Autumn (4) | 51.98 | | |

* Significant at 90% level

Scans for both violence and property crimes were performed using the total population with 7 days as maximum length in time of a cluster (referring to a week). The first test used the default spatial limit of the population (50 per cent), but the results were unsatisfactory. For instance, violent crimes showed at first a surprising pattern where one secondary cluster covered half of the study area at only one point in time: the first of January, in the winter. A common practice is to decrease the spatial limit to 10 per cent of population at risk. Figure 4 shows the difference between summer and winter after adjusting for the spatial limit to 10 per cent of population at risk.

The city center is a stable hotspot for both crime types during different seasons, there is mixed land use, where activities and people converge at the central station on their way to and from places. Stockholm's city center is rather compact and concentrates shops, offices and bars. There is however a variation in time, as violent crimes in the inner city are concentrated during the winter months whereas, for property crimes, the city center comes up as a hot spot during summer months. This finding is in line with previous studies showing the increase of property crimes during the warmer months of the year (e.g. Jochelson, 1997).

Following the A-nova test, the space-time scan clusters show slightly different clusters for violence during the winter and summer. Moreover, the city center cluster has clearly shrunk while moving into summer months, when the violent crime clusters seem to be positioned more in the outer-suburbs of Stockholm (Figure 4). Areas in the periphery of Stockholm municipality mainly concentrate housing areas with (regional) shopping centres located at transportation hubs which present steady crime clusters over time and space.

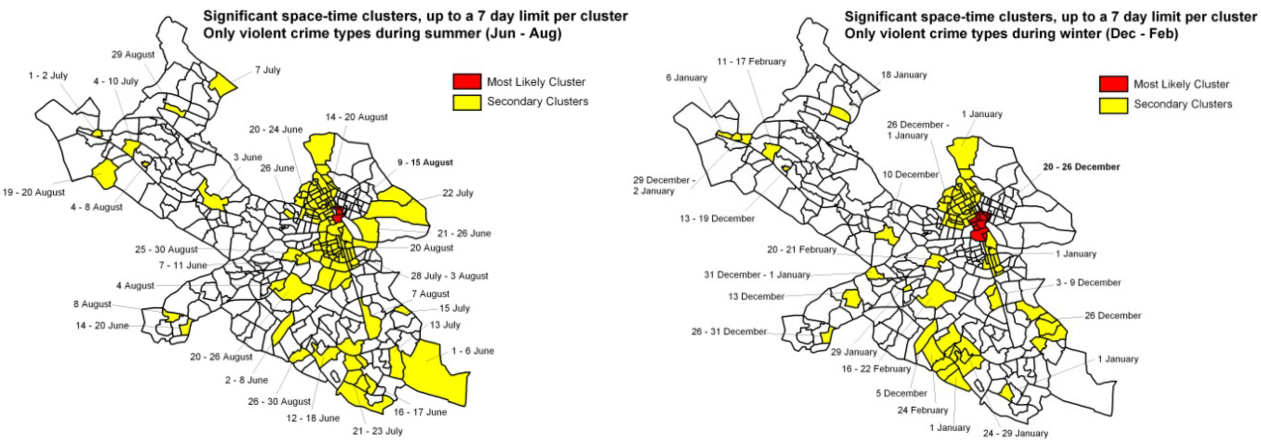

Figure 4. Violent crime clusters during a) summer and b) winter

**6. Discussion of Results**

The Kulldorff's scan test proved to be a useful tool to identify space-time hotspots of crime. This set of techniques was tested using Stockholm city as a case study and the models were built up to test clusters by hour, weekly and seasonally. Findings confirm the first hypothesis that events of different crime types vary over time and space. The change in levels of crime by hour provides a clear distinction between violent and property crimes, which seem to be closely related with individuals' routine activities (Cohen & Felson, 1979). Property crimes take place when people are not at home (burglary) or when people are going from work to home (and vice versa) in rush hour (theft), while violent crimes are committed in places with less social control; during the evening and nights in public spaces or in domestic environments. Seasonal variations as studied by Jochelson, (1997) and Ceccato (2005), amongst others, are also found in this study's results. In Stockholm, most housing areas are located outside the city center where one can find clusters of violence during the winter.

A more spread out pattern can be observed for summers as compared to winters but still clusters of crime tend to happen around some common areas, such as inner city and in suburban areas. This finding corroborates the second hypothesis prompting that crime opportunities are related to the place where people meet. Routine activity theory suggests that these are places where people move around, converge, meet and perform activities. These places can provide the optimal conditions for crime to happen, as offenders can easily access suitable victims without being detected (Cohen & Felson, 1979). Findings also show evidence that corroborates social disorganization theory. Most of the persistent clusters in the suburban areas are neighborhoods with long term social economic problems, and expected low levels of social control.

In a more technical account, findings show the effect of the population base used for the scan test. The Kulldorff's space-time scans provide the undeniable result of a constant hotspot for violent and property crimes in the city center regardless time or date or population base. However, for secondary clusters the night-time population causes the size of hotspots to shrink where people live (in the periphery of the city) while, on the other hand, day-time population increases the size of clusters in the periphery, as people head for work elsewhere (for instance, to the city center) when the population base is then lower, increasing the calculated risk for crime in those areas. These findings indicate that the selection of an adequate denominator such as population base is a fundamental step in the process of detection of space-time clusters.

**7. Conclusions**

This article assessed the detection of geographical clustering of offences over time using Kulldorff's scan test and police recorded data of Stockholm municipality, Sweden. Results showed distinct patterns of concentration for violence and property crimes over time and that the Kulldorff's scan test was a useful tool to identify these space-time hotspots of crime.

This study shares, however, limitations with other studies that deal with crime statistics geographically over time. For instance, crime records depend on the willingness of the public to report crimes to the police and therefore rarely cover all crime occurrences. The times attached to the records, defining the time spans of the events, can be uncertain as victims often do not remember the exact times and events are often recorded from the last time known up to the point the crime is administrated by police officials. For instance, theft is rather difficult to be recorded by the minute or even hour. Theft may happen without one realizing it and is only discovered at a later point in time. The same can be applied for burglary where one is not aware of the exact timing. This study based the daily analysis on hourly aggregated data, thereby avoiding as much as possible uncertainties in between hours.

For future research, the exploration of other types of analysis looking at the relations between the clusters (for examples, see details in Kulldorff (2010)) is suggested. Models with different parameters such as the maximum length of days and population at risk for clusters could be tested. The exclusion of the city center (which now tends to dominate the analysis) could also be an interesting strategy for future analysis. The detection of both hot and cold spots is also an important feature to be tested not only for research but also for crime prevention purposes. The Stockholm case indicates the role of population basis in cluster building - the appropriate population basis is an important step on cluster analysis over time that cannot be overlooked when selecting the dataset.

The results presented in this paper provide evidence for the clustering pattern of crime events in Stockholm - information that can be of importance for crime prevention and improvement of urban safety. With this information in hand, the police may act upon certain crime locations and align their prevention strategies over time. The increased presence of police in these hotspots at particular times might be desirable to deter crime. For instance, resources should be focused on evenings, holidays and weekends, and summer; with regards to space, they should be directed to commercial centers and some specific peripheral neighborhoods. Residents in these most targeted areas may want to engage in activities together with the police and crime prevention groups to define long term strategies (e.g., through safety audits, increased social control at certain times) to improve overall safety.

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