Network based spatial analysis of traffic accidents in Stockholm, Sweden

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Abstract

In order to improve an already well implemented infrastructure system that exists in the city of Stockholm, Sweden today there is a need for methods to analyze its functions and flaws. There exist many analysis methods in various forms and qualities; however there are many factors that need to be taken into account when studying a road network and its traffic, an analyst must take care when choosing a method.

In this study, two spatial analysis methods and two visual analysis methods will be implemented on Stockholm’s road network in combination with road accident data to find what spatial patterns and clustering that may exist. Also, the study will cover possible reasons to why the patterns might differ from each other and what they may imply.

The data was gathered from several Swedish administrative authorities and divided into specific subsets such as years, seasons and streets in order to be analyzed. The methods were performed with the help of the GIS (geographic information system) software ArcMap and an extension program called SANET used for spatial analysis along networks. With the help of these programs, plots of the spatial patterns and maps of the accident density for the subsets were created. Accident density estimation was used to find places with high densities in order to compare subsets with each other. An analysis of how reconstructions of the road structure may affect the number of accidents that occur was also made.

The result of the analysis is that accidents tend to cluster in large and more general subsets such as an entire year. In smaller and more specific subsets the patterns differ a lot and in some cases the reason behind the patterns became more or less clear. With the help of accident density estimation, outliers were found and plausible reasons behind them could in some cases be found. When studying how the road structure reconstructions changed the accident patterns, it was found that the number of accidents varied before and after, and so no one-sided results were found.

Although it is hard due to many different factors, patterns can be found that may help explain why and where accidents occur and hopefully improve the safety of future road constructions. Also, without being statistically proven, visual analysis can be used to spot problematic areas in an existing road network that may need reconstruction. When analyzing reconstructions made on the road network it was found that they may contribute to a lower amount of accidents, however more research needs to be conducted in this area to yield a certain conclusion.

To continue the research further, information about traffic volume along the network could be useful in order to weigh the results according to the amount of traffic. It would also be interesting to study a larger area with the help of a computer that can handle more complex computations. Lastly, to immerse the issues from research of the past and present, to a study of predicting the traffic accidents in the close future could be done.

Keywords: Network Spatial Analysis, Network Kernel Density function, Network Cell Count, Point Pattern Analysis, network k function, network G function, network constrained point events, process
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1 Introduction

In the year of 1997 the Swedish parliament introduced Vision zero, a goal stating that no one will die or get seriously hurt in a traffic accident (Trafikverket 2014). This is a challenge since many different factors can cause an accident; speed of the car, geometric properties of the road, weather and human factors to only mention a few. The safety on the road often depends on factors that are tied to geographic locations such as the sharpness of a certain curve or how a specific intersection is designed. The search and finding of such locations is a central part of achieving the goals of Vision zero but also the road safety in general. Analysis of traffic accidents is a subject that has been explored and researched many times (e.g. Black & Thomas 1998; Hauer & Ng 1989; Thomas 1995). Mostly it is about analysis of so called “black spots” or “black zones” (Flauhaut, Mouchart, San Martin & Thomas 2003; Steenberghen, Dufays, Thomas, Flahaut 2004) which is an indicator of where there is a high density of traffic accidents based on historical data.

To detect these black spots one must identify clusters of accidents and determine if these are statistical significant. Sometimes, identifying clusters is a task that our eyes and brains do naturally. When analyzing traffic accidents (or point patterns in general) it is interesting to look at patterns; they can be clustered, uniform (regular/dispersed) or random, see Figure 1 and Figure 2 below. The question is whether there is a reason behind a pattern or if it is created by coincidence; this is a task not easily done by the human brain and this is where a point pattern analysis is useful. With a statistical method an analyst can determine if a given set of points, representing some kind of event in a study region, follows a random distribution or if they form any kind of clustered or uniform pattern (Steenberghen, Aerts & Thomas 2010). There exist a number of methods to perform a point pattern analysis, e.g. Ripley’s $K$ function, nearest neighbor distance and the quadrat approach (see e.g. O’Sullivan and Unwin, 2010). In addition to the statistical part, the patterns found can in some cases deviate from the common perception of how and where a traffic accident may happen and thus the question of where and why these patterns form is interesting to investigate.

![Figure 1: Different point patterns. Source: Shirabe, 2016](image-url)

Figure 1: Different point patterns. Source: Shirabe, 2016
1.1 Goal of study

In this thesis, the goal is to analyze what spatial patterns that occurs in different subsets of collected accident data, projected and bounded onto a road network, and why they may differ from each other. Also, a study of where accident black spots can be found in Stockholm City will be made as well as investigate if reconstruction of a certain location in the road network has improved the safety of the road in terms of a decreased number of accidents.

For this study, traffic accident data dated more than 10 years back in the City of Stockholm, Sweden, have been collected, divided into subsets and mapped onto a road network in order to perform statistical operations as well as visual analysis to determine if any patterns can be found in the different subsets and also where black spots tend to occur. Each subset contains a number of accidents sharing some attribute, e.g. year, day or season of when the accidents occurred or geographical or geometrical factors of the underlying road. Mainly the “network K function” (referred to as K function, see Okabe & Sugihara, 2012) but also the “network-constrained global nearest neighbor distance” (referred to as G function, also see Okabe & Sugihara, 2012) will be used to test for randomness in the point patterns created by the accidents. Both of these methods are based upon distances to other point events and they compare these distances to a randomly generated point pattern. They are more thoroughly described in section 3.1.1 and are implemented by the help of a software called SANET (Spatial Analysis along NETworks, SANET 2009-2016) that has been developed to take into consideration a network-defined study region. Two density estimation-methods, “network kernel density estimation” (referred to as kernel density estimation or as KDE, Okabe & Sugihara, 2012) and “network cell count” (O’Sullivan & Unwin, 2010), will be tested for visualization of black spots, i.e. locations with a high density of accidents. KDE is a method provided in SANET and the results are displayed with the help of the GIS (geographical information system) software ArcMap version 10.2. The network cell count is done manually in ArcMap. After analyzing the data, theories and hypothesis will be discussed regarding any conspicuous patterns and locations of black spots.

1.2 Previous work

In the late 1990s, the state of Iowa started to discuss the improvement of their accident location and analysis system which produced accidents numbers and statistical figures for a user-specified location (Pawlovich & Souleyrette 1996). Previously the accidents had been aggregated into nodes which were spread out over the state; thus the user could not type in a specific location but was constricted to choose a node that was closest to the area of interest. The improvement would involve the implementation of a GIS based system in order to extend the analysis to spatial features. This project is an example of how GIS can improve the possibilities to analyze accident data with a more precise location which gives the opportunity to study black zones, similar to the goal of this thesis.
As mentioned, a lot of studies focus on the task of locating black zones. Flahaut et al. (2003) used and compared two methods; autocorrelation index and the kernel method to locate black zones on motorways in Belgium. The autocorrelation index compares both location and attributes values to a random sample to see how they deviate from each other (Griffith, 2009). Steenberghen et al. (2004) tries a linear and an area-based technique to find black zones. It is concluded that an area approach can be used in a dense road network such as in the heart of a city where the traffic patterns are uniform; though it is mentioned that the traffic flow along the network is not taken into account in this method and thus may give false results about the accident distribution. Black and Thomas (1998) also use the autocorrelation index and study the dependence of variables and accidents rates on a network. Similar, KDE is used to find black spots in the sample data of this study.

In the state of Ohio, USA, the state highway patrol uses historical accident data to locate accident hot spots during holidays in order to distribute their patrol cars (Gorder, 2007). Bennett (2010) wrote a thesis about spatial analysis of motor vehicle accidents based on reported 911-calls. She used the software ArcGIS to study the spatial distribution of accidents and to find locations that acted like outliers relative the expected frequency; however, this analysis did not take into account the underlying road network but instead considered the Euclidean 2D-plane as the accident sample space. In India Lavrac, Jesenovec, Trdin and Kosta (2008) studied both spatial and temporal patterns of traffic accidents, but just like Bennett they used Euclidean distance and not network distance between accidents when analyzing the data. What differentiates these studies from this thesis is the use of a method which utilizes Euclidian distance instead of analyzing the spatial pattern along a network, with the data points locked to it. This kind of network method is used in this study since the use of a planar method on network constrained events has been questioned, see succeeding text.

Yamada and Thill (2004) demonstrates how the general planar K function often over-estimates clusters on a data set of traffic accidents in Buffalo, New York. They investigate a conclusion made by Levine, Kim and Nitz (1995) who claimed that accidents tend to cluster more on weekdays than on weekends, based on Euclidean distances. Yamada and Thill found that their conclusion was true, using the planar K function; however it was not true with the network K function, hence strengthening the theory that the planar method over-estimates clustering behavior in a network constrained point pattern. This type of comparison of planar and network based methods has also been done by Okabe, Okunuki and Shiode (2006) who also discusses the tools provided by SANET, the software used in this thesis. They reach the same conclusion as Yamada and Thill (2004) regarding the misleading results given by a planar method used on network constrained events. The quadrat approach is another point pattern analysis method which has also been tested along a network (Shiode 2008). Also, in this case it was concluded that the planar method applied to events locked onto a network have a tendency to overestimate the clustering of events.

2 Study area and data description

The following section will describe how and where the data for the study was acquired and how it was prepared for the analysis.
2.1 Study area
The area chosen for this study is the capital of Sweden, Stockholm. The name Stockholm can refer to Stockholm County, the municipality of Stockholm or just the inner part of the city. In this study, the inner part of the city is used; the reason for this is because of the large amount of data for the area. In Figure 3 below, the study area is shown.

![Figure 3: Map over Stockholm, the pink area covers the inner city of Stockholm](image)

2.2 Data description
In order to complete the study some data needed to be collected in beforehand. Most important was data over accidents in Stockholm, complete with spatial referencing, and also a road network which the accident data could be tied to. These form the base pillars of the study which would not be possible to complete without them.

2.3 Data acquisition
The data needed for the traffic accident analysis were gathered from several Swedish administrative authorities, most of this data is so called “open data” and is free to use. In the reference section these sources are listed. A road network spatially referenced in SWEREF 99 (the official Swedish reference frame) of Stockholm County could be found at Trafikverket (Swedish transport administration). A vector file containing the borders of all districts in
Stockholm (district division before 2016, congregations for population count) in the form of a polygon layer was extracted from Lantmäteriet, the Swedish land surveying administration, which also provided another road network with speed limit attributes. This road network is presented in Figure 4 below which also will give the reader an idea of the size and shape of Stockholm City.

A document containing some of the reconstructions made in the road network in the municipality of Stockholm was provided by Stockholms Stad¹ (The municipality of Stockholm). Lastly, the traffic accident data over Stockholm County between the years of 2003 to 2014 was provided by Transportstyrelsen² (The Swedish Transport Agency) in the form of a table with XY-coordinates for every accident along with other attributes regarding the characteristics of each accident. These coordinates are either from address matching or from the communications system of the Swedish police. It should also be noted that not all accidents are recorded in this table but only those reported to the police. According to the Swedish Transport Agency (Transportstyrelsen 2016a), all fatal outcomes are reported to the police but only half of the serious and a third of the minor accidents are reported. Another note is that the data from 2014 is incomplete.

Figure 4: Display of a part of the road network in the inner city of Stockholm.

¹Ellen Tavvo, Traffic analyst, Stockholms Stad, email, May 16 2016
²Magnus Berg, Regional coordinator, Transportstyrelsen, email, May 7 2016
2.4 Preparation of data

The data obtained displayed locations of traffic accidents over the whole Stockholm County and contained approximately 40,000 points. In order to analyze this large dataset, it was plotted into ArcMap with the help of XY-coordinates and then it was cut down to the inner city and surrounding areas with the help of the Stockholm district polygon layer. In order to find patterns in the accident data it needed to be divided further, creating subsets based on different temporal attributes made it easier to spot outliers since there was a suspicion that patterns varied with time. The subsets described below were the initial subsets; however, more subsets were created during the analysis of the initial ones and these will be described in section 3.1.1.

All of the subsets described below create three basic categories in which further analysis can be done:

- Year
- Season
- Time of day

Based on the accident attributes given by the Swedish Transport Agency, subsets of all accidents for each year of 2010-2013 were created; because of the amount of data only accidents from the recent years were selected for the year category. The year category was followed by four seasonal subsets based on all accidents dated back to 2003. According to Nationalencyklopedin (2016), spring lasts between March 20 and June 19, summer between June 20 and September 21, autumn between September 22 and December 20, and winter lasts between December 20 and March 19. Also, a subset based on which time of the day the accidents had happened was created. Morning was considered between 6 AM and 11 AM, daytime between 11 AM and 16 PM and night between 16 PM and 21 PM. The hours between 9 PM and 6 AM are not used in any subset due to the low amount of traffic during these hours.

3 Methodology

This section will provide a description of the statistical and the visual analysis methods that were used and also their functioning.

3.1 Analysis method

In the following subsections the methods used for the statistical and visual analyses are described and also how they are implemented for this study.

3.1.1 Statistical analysis

One of the most basic spatial analysis methods is the nearest neighbor distance method (O’Sullivan & Unwin, 2010). In its simplest form it calculates the nearest neighbor distance from every point event over a study area. The method was originally developed for a planar study region using Euclidean distances, but the principle is the same for a network region as described by Okabe and Sugihara (2012). These distances are then evaluated to determine if they are significantly short or long; by comparing these results with a random base case it can be determined if the point events follows a random distribution or not. SANET uses an extension of this method called the network global auto nearest neighbor distance (also G
function, see O’Sullivan and Unwin, 2010) and it examines the cumulative number of points that have a nearest neighbor distance lesser than a distance $d$. It describes how point events are placed in a pattern. A drawback of this method is that it only looks at a single nearest neighbor which in some cases can conceal “patterns within patterns”. This is occurring especially in clustered patterns where relatively short nearest neighbor distances loses their meaning in comparison to other larger distances in the pattern, see Figure 5 below. Exactly how the function is implemented in SANET is explained by Okabe and Sugihara (2012).

![Figure 5: "Patterns in patterns". The pattern is considered clustered on a smaller scale, but if each cluster is analyzed separately, their points are randomly distributed.](image)

The K function, also Ripley’s K function by Ripley (1976), as mentioned can analyze patterns on different scales. Imagine a circle of varying radius that is moved to every point event, calculating the mean number of events inside each radius. The mean count is then divided by the overall density in the study region. This makes it possible to detect patterns on different scales; an example of such a pattern is displayed in Figure 5. The same procedure is done for a randomly generated pattern which will produce an envelope in which the original pattern must fit into to be random; else it is considered either clustered or uniform. Just as the G function, it was initially created for a planar study region but the principles are the same for a network region as described by Okabe and Yamada (2001). A disadvantage of this method is that the resulting graphs or plots can be hard to interpret if the pattern is complex.

SANET creates a plot for both the G function and the K function which is described in the results, section 4.1, and then discussed in section 5.1. Both the K function and the G function were used with the following parameters, their meaning are explained in the succeeding text: 99 iterations, a bin width of 10 (default by SANET) and a statistical significance level of 5%. The default in SANET for number of iterations was 1000 for both methods; however no difference was noticed with 99 iterations so for the computing powers sake the lower number was preferred. The bin width decides at which intervals the pattern is examined; the lower the bin width the smoother the resulting curves. The statistical analysis was done initially with the G function method; the reason for this was that the computers used (a personal laptop and school-provided stationary computer) could not perform the K function with the amount of data collected. Hence the K function was only used on small subsets (single roads or intersections). The reason why the K function was preferred before the G function is that the K function can analyze patterns on different scales, as mentioned above.
Early on it was noticed that the initial subsets, the three categories from section 2.4, were too large in the meaning that the scope was too great. In order to detect patterns of interest they needed to be cut down into smaller subsets. When choosing subsets, it is important to look at different processes. A process describes how a spatial point pattern has been created, for a set of traffic accidents there can be many different processes involved. An example of where there is a collision of two processes is where a minor road meets a major road. Since the two roads have different properties (e.g. speed limit or size) their individual accident patterns comes from different processes. It is difficult to know how many processes may be involved in a set of point events but the subsets were chosen as to only contain accidents that presumably were derived from the same process as much as possible. Other subsets were chosen because of the expectancy of an interesting change in patterns. These subsets were:

- Rush hour and non-rush hour. The time intervals were based on the amount paid for the congestion tax in Stockholm (Transportstyrelsen, 2016b), for rush hour the times were 07.00-09.00 and 15.30-18.00 and for non-rush hour it was all other hours. Some change in the pattern of accidents between these two time intervals was expected and thus was interesting to investigate.
- Minor roads and major roads; these categories were based on the road type attribute in the road network from Lantmäteriet. Both of these presumably include different processes and so the subsets were chosen to distinguish between them.
- Specific roads. These were roads in Stockholm that is frequently used and/or showed a high density in the visual part of the analysis with the density estimation methods. It seemed natural to choose these as subsets.
- Specific intersections. The intersections got their own category since the authors believed that they have their own process, and do not share the process of the roads they are made of. The specific locations were chosen because of their high density in the maps created by the density estimation. A circle with a radius of 30 meters was placed with its middle at the intersection and all accidents and road segments within this circle were extracted for analysis. The radius were chosen so as to include all accidents that either had been displaced from the actual intersection center, due to the lack of address in the intersection, or had been caused by the intersection but the actual accident happened outside of it.
- Streets with slopes during winter season versus non-winter season. This subset was chosen as to find out if the accident pattern changes in slopes during winter and non-winter season due to slippage.
- Streets with common speed limit. Resembles the subset of major and minor roads and was chosen for the same reason.
- Streets before and after prohibition of studded wheels during winter season. It would be interesting to see if the pattern changes because of this ban.

3.1.2 Visual analysis with density estimation
In order to display the accident data of the inner city all at once, and still be able to find areas of interest, e.g. black spots, density estimation was used to highlight these areas. Two methods were tested. The first one, KDE, was implemented with the help of SANET that uses it along the road network instead of a planar study region. The KDE method basically moves a small bell shaped “hill” between intervals and both counts and weights the number of
point events within this hill, see Figure 6 below. The height of the hill at the different point events decides the weight, e.g. weight one at the center of the hill and zero at its base. All of these small hills will create a continuous surface displaying the density of accidents in the road network, see Okabe and Sugihara (2012). In order to get good results in SANET, a bandwidth and cell size were carefully selected that suited the data. The bandwidth decides the size of the hill in form of its radius and the cell size decides the intervals at which the kernel stops to count events. After some tryouts and research (Okabe, Satoh & Sugihara, 2009; Okabe & Sugihara, 2012) a bandwidth of 100 meters and a cell size of 10 meters were chosen. In SANET there exists a choice for what the algorithm should do when reaching an end node where the network continues, for example a road junction. The choice is for the kernel to be continuous or discontinuous at these nodes. For this study, a continuous kernel was preferred since it was desirable to see how the density of accidents behaved around the crossings of several roads.

Figure 6: Kernel density estimation for a planar study region. Note that the principles are the same for a network region. Source: Bailey and Gatrell (1995)

The next method, the network cell count, is one of the most frequently used in accident analysis (Okabe and Sugihara, 2012) and also the most intuitive. The number of accidents per road segment is divided by segment length to get the density. However, this method can yield biased results, something that will be further discussed in section 5.2. The method was done manually in ArcMap by snapping all accident points to the closest road segment, count them and divide by segment length. This produced the density of each segment; the density was then standardized by division with the overall density of the subset to be able to compare it to other subsets.

After the two methods had been tested they were displayed in ArcMap. Since every subset has its own maximum and minimum values, five value ranges of densities had to be defined in order to compare the visual results from the two methods between subsets in the same category. These value ranges were displayed in grayscale with high densities in black, low in white; this can be seen in the results of the visual analysis, section 4.2. Grayscale was chosen to keep the analyst or viewer from biased assumptions as is easily made with a colored scale.
3.1.3 Analysis of road reconstructions

As mentioned in the introduction, a particular design of the road might increase the risk of collision while driving along it or crossing it. Therefore a closer look on some roads and junctions that have been rebuilt during the datasets timeframe follows in this section. Note that these places are located around the whole County of Stockholm.

Given the list of reconstructions from Stockholms Stad, three places were picked out where the date of the finished construction was before or during 2012, this leaves data from 2012, 2013 and 2014 which can be used to see the result of the rebuilt road segments. The locations of interest and their period of reconstruction were:

- Älvsjövägen/Johan Skyttes väg (October 2010 - October 2011), was rebuilt from a roundabout to a traffic light regulated junction.
- Rinkebystråket/Rinkebysvängen (2012), reconstructed from a three-way junction to a roundabout.
- Kammakargatan/Sveavägen (2010), thoroughgoing walkway was built and a change of direction of one way street was made.

All accidents before and during the reconstruction of each site were extracted from the total accident data, were counted and compared to the amount of accidents after the reconstruction. Figures of these three junctions and their accidents were made, see section 4.3.

4 Results

Bellow follows the results from both the statistical and the visual analysis described in the method above.

4.1 Statistical analysis

Before the results of this section are presented, a brief explanation of how the resulting graphs and plots are interpreted is given. The plots provided by SANET have an x-axis with distance and a y-axis with cumulative number of points. The G function x-axis represent the nearest neighbor distance, the K function x-axis represent the size of the scope, namely the extent to which the road is analyzed. Both the K and G function provide an envelope where the results are considered random; it is marked by the green and pink curves, see the figure below. Within this envelope there is a red curve describing the mean value of the simulated random pattern. Finally the observed points are described by the blue curve; by looking at its relative position to the envelope, conclusions can be made of what kind of pattern they form. Above the envelope, the pattern is clustered and below the pattern is uniform. The shape of the blue or observed curve can vary a lot depending on the distance (the x-axis); sometimes the authors will refer to a pattern as e.g. “clearly clustered”. By this it is meant that the whole observed curve, or most of it, is above the envelope and thus the pattern is clustered no matter the distance. Note that for the G function it is important to take regard to the number of points on the y-axis; looking at Figure 8 below we see all curves merge into one at the end. But since the y-axis display the cumulative number of points, the merge has little meaning since there are barely, if any, points that have that kind of nearest neighbor distance.
The results below are only a description of the resulting plots of the analysis. All plots can be found after every description of each subset below. For some of these subsets, a picture of the point pattern in ArcMap has been added. After the statistical analysis of the three initial categories: year, season and time of day, it was clear that all of these showed signs of clustering. Within these categories the following subsets were examined. Note that subsets will be marked with a K if analyzed with the K function and a G if the G function has been used.

4.1.1 By year
The G function was performed on all year subsets (from 2010-2013) including all accidents and as mentioned in the piece above, the results were clustered for every year. It was visually clear that clustering appeared near the city center.

In the year of 2010, Stockholms Stad prohibited studded wheels on Hornsgatan, the results below is taken from before and after the ban during winter time.

- Winter before 2010 (G): Clustered up to 250m, then random up to 2000m with a short cluster period at 1000m
- Winter after 2010 (G): Random
Figure 8: G function plot for accidents in the year of 2010

Figure 9: G function plot for accidents in the year of 2011
Figure 10: G function plot for accidents in the year of 2012

Figure 11: G function plot for accidents in the year of 2013
Figure 12: K function for accidents on Hornsgatan during winter season before 2010

Figure 13: K function for accidents on Hornsgatan during winter season after 2010
4.1.2 By season
The results for spring, summer, autumn and winter are all clustered, shown in the plots below.

Up hill winter time:
- Kungsgatan, between the intersection of Sveavägen and Norrlandsgatan (K): When not winter, the results were random up to 300m, and then uniform. Accidents during winter showed signs of being random up to 40m and then it becomes uniform.
- Odengatan, from the intersection with Sveavägen to Odenplan (K): For winter the results were random close to uniform and for not winter it became random as well but close to clustered

**Figure 14: G function plot for accidents in summer**
Figure 15: G function plot for accidents in spring

Figure 16: G function plot for accidents in winter
Figure 17: G function plot for accidents in autumn
Accidents in the slope of Kungsgatan between Sveavägen and Nordlandsgatan, to the left is during winter and to the right is non winter season.

Figure 18: K function plot for accidents in the slope of Kungsgatan during winter and non-winter season
Figure 19: K function plot for accidents in the slope of Odengatan during winter and non-winter season.
4.1.3 By the time of day

The subsets of morning, day and evening hours all became clustered.

Rush Hour/ Non-rush hour:

- Whole study area (G): Clustered during rush hour up to 150m, then the observed curve passes over the random envelope and is uniform. For non-rush hour the accidents are clustered up to 80m, and then also transcend the envelope to be uniform.
- Sveavägen (K): Mostly clustered but follows the upper limit of the envelope between 200-300m and just above 1500-2000m during non-rush hour. For rush hour the curve is much closer the upper envelope edge for all scales.
- Essingeleden (K): Shifts between random and clustered but looking at the whole road it is random during rush hour. For non-rush hour it is clearly clustered up to 4000m, but still random for the whole road.
- Stadsgårdsleden (K): For non-rush hour the patterns is random up to 300m and then uniform. For rush hour the pattern is clustered but goes towards random at the very end.
- Götgatan (K): During non-rush hour, the pattern changes very much depending on distance: 0-150 clustered, 150-300m random, 300-570m uniform, then random up to 1000m. At rush hour the result is clearly random.
- Korsning Fleminggatan/St Eriksgatan (K): Clearly clustered under non rush hour. During rush hour the patterns is random close to the upper envelope up to 20m, it then gets clustered.
Figure 20: K function plot for accidents in the morning

Figure 21: K function plot for accidents during the day
Figure 22: K function plot for accidents in the evening

Figure 23: G function plot for rush hour over the whole study area
Figure 24: G function plot for non-rush hour over the whole study area
Figure 25: K function plot for accidents on Sveavägen during rush hour and non-rush hour
Accidents during rush hour (to the left) and non-rush hour (to the right) on Stadsgårdsleden (road 222).

Figure 26: K function plot for accidents on Stadsgårdsleden during rush hour and non-rush hour.
Figure 27: K function plot for accidents on St Eriksgatan during rush hour and non-rush hour
Figure 28: K function plot for accidents on Götgatan during rush hour and non-rush hour
Figure 29: K function plot for accidents on Essingeleden during rush hour and non-rush hour
4.1.4 Specific streets

- Götgatan (K): Clustered up to 200m, random 200-300m, uniform 300-600, random up to 900m
- Hamngatan (K): Random mostly but small clustering tendencies at 0-50m and 225-300m
- Hornsgatan (K): Clustered between 0-200m and then random up to 1400m.
- Odengatan (K): Clustered
- Sveavägen (K): Clustered result up to 1500m though close to random at 200m, random between 1500-2000m
- Valhallavägen (K): Clustered
Figure 30: K function plot for accidents on Götgatan

Figure 31: Accident points for Götgatan
Figure 32: K function plot for accidents on Hamngatan

Figure 33: Accident points for Hamngatan
Figure 34: K function plot for accidents on Hornsgatan

Figure 35: Accident points for Hornsgatan
Figure 36: K function plot for accidents on Odengatan

Figure 37: Accident points for Odengatan
Figure 38: K function plot for accidents on Sveavägen
Figure 39: Accident points for Sveavägen
Figure 40: K function plot for accidents on Valhallavägen

Figure 41: Accident points for Valhallavägen
4.1.5 Specific intersections

- Götgatan/Ringvägen (K): Clearly clustered
- Hamngatan/Norrlandsgatan (K): Random until 12m, then quite clear clustering to 60m
- Kungsgatan/Sveavägen (K): Clearly clustered
- Odengatan/Sveavägen (K): Clustered for all distances
- St Eriksgatan/Fleminggatan (K): Clustered for all distances
- Stureplan (K): Random up to 35m, then clustered

Figure 42: Accidents points in the intersection of Götagtan and Ringvägen

Figure 43: K function plot of accidents in the intersection of Götagtan and Ringvägen
Figure 44: Accidents points in the intersection of Hamngatan and Norrlandsgatan

Figure 45: K function plot of accidents in the intersection of Hamngatan and Norrlandsgatan
Figure 46: Accidents points in the intersection of Kungsgatan and Sveavägen

Figure 47: K function plot of accidents in the intersection of Kungsgatan and Sveavägen
Figure 48: Accidents points in the intersection of Odengatan and Sveavägen

Figure 49: K function plot of accidents in the intersection of Odengatan and Sveavägen
Figure 50: Accidents points in the intersection of St Eriksgatan and Fleminggatan

Figure 51: K function plot of accidents in the intersection of St Eriksgatan and Fleminggatan
Figure 52: Accidents points in the intersection at Stureplan.

Figure 53: K function plot of accidents in the intersection at Stureplan (Kungsgatan, Birger Jarls gatan and Sturegatan).
4.1.6 Other

- Speed limits:
  - 50 km/h (G): Clustered 0-50, uniform for all other distances
  - 30 km/h or lower (G): Clustered 0-40m, uniform for all other distances
  - Minor roads (G): Clustered up to 40m, then uniform for all other distances
  - Major roads (G): Clustered up to 50m, then uniform for all other distances

![Observed and expected nearest neighbor curves](image_url)

Figure 54: K function plot for accidents on roads with a speed limit of 50 km/h
Figure 55: K function plot for accidents on roads with a speed limit of 30 km/h or lower

Figure 56: K function plot for accidents on minor roads
4.2 Visual analysis with density estimation

Below follows the maps from the density estimation. Maps for many different subsets were created, however this section will only provide the maps from the season category and also of the years from 2010-2013 made with the KDE method. Also one picture with the network cell count method is displayed for comparison reasons; why not more pictures from this method are presented is explained in section 5.2.

Figure 57: K function plot for accidents on major roads
4.2.1 Seasonal subsets

Figure 58: Grayscale Kernel density map of Stockholm city accidents during the winter season. Darker tone indicates higher density.

Figure 59: Grayscale Kernel density map of Stockholm city accidents during the summer season. Darker tone indicates higher density.
Figure 60: Grayscale Kernel density map of Stockholm city accidents during the autumn season. Darker tone indicates higher density.

Figure 61: Grayscale Kernel density map of Stockholm city accidents during the spring season. Darker tone indicates higher density.
4.2.2 Yearly subsets

Figure 62: Kernel density map of accidents in Stockholm City 2010. Darker tone indicates higher density.

Figure 63: Kernel density map of accidents in Stockholm City 2011. Darker tone indicates higher density.
Figure 64: Kernel density map of accidents in Stockholm City 2012. Darker tone indicates higher density.

Figure 65: Kernel density map of accidents in Stockholm City 2013. Darker tone indicates higher density.
4.2.3 Network cell count

Figure 66: Network cell count method for summer subset. Darker tone indicates higher density.

4.3 Analysis of road reconstruction

The following pictures are of the locations listed by Stockholms Stad\(^3\) that has been reconstructed, here displayed with the road network and accident data. Two out of three reconstructed locations had no recorded accidents at all the years after the reconstruction, thus these places only have one picture. The third location has one picture of the accidents before and one of accidents after it had been rebuilt.

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\(^3\) Ellen Taavo, traffic analyst, Stockholms Stad. Email May 16 2016
Figure 67: All recorded accidents during 2003-2011 at Älvsjövägen/Johan Skyttes Väg.

Figure 68: All recorded accidents during 2012-2014 at Älvsjövägen/Johan Skyttes väg
Figure 69: All accidents in the junction Rinkebystråket/Rinkebyvägen between 2003-2011. The total amount of accident connected to the junction was four before the reconstruction. The dataset did not contain any accident in 2012-2014.

Figure 70: Accident that occurred in the junction at Kammakargatan/Sveavägen. Eight accidents were in the records and, once again, all the accidents were from before the reconstruction and change in direction of the one way road made in 2010.
5 Discussion

Firstly we will discuss some general problems of the study and later all the individual results will be evaluated.

The accident data used in this study is very general, it contains accidents involving cars, pedestrians, buses, cyclist, trucks and more. It may have been interesting to narrow it down to only involve some vehicles, it is possible then that the number of processes involved would have decreased. However, it was chosen to include all since they are all a part of the daily traffic. Also the accident data stretches far back, nearly 11 years. But the road network is dated quite recently (exactly is unknown) so it may be that some accidents are caused by road features that does not exist in the road network, reconstructions of the road network is later discussed in the section 5.3. The placement of all the accident points are based on coordinates, however the police claim that when an accident is recorded they assign it an address and GPS coordinates only if possible to improve the positioning. Magnus Berg, regional coordinator at Transportstyrelsen, says that the positioning should be as precise so there should be no doubt of where the accident has taken place; however some policemen are more meticulous than others hence the positioning can be of varying quality. This makes it impossible to know exactly how precise the positioning of the accident data is but it can be assumed that errors up to around tens of meters can be expected due to inaccuracies in GPS equipment and also the uncertainty of how an accident is tied to a specific street address. This is a problem that is not easily solved and it may be that data that is more accurate is impossible to find.

When performing the G- and K function in SANET it was unclear what the significance level was based upon, normally this is decided by number of iterations (O’Sullivan & Unwin, 2010); e.g. 99 iterations yields a significance level of 1 percent. Since the user is given the alternative to enter both of these it is difficult to tell the difference between the two parameters. The authors have tried to clarify this with Atsu Okabe, project manager at SANET. He explains that the number of iterations are related to the accuracy of the statistical test, however no further explanations was given. Unfortunately, a more in depth answer was not given before the time of completion of this study. Also, it is worth mentioning that the version of SANET used is only a beta-product and might decrease the reliability of the study. Using SANET in the future, other tools or functions might be available which may deliver different results.

5.1 Statistical analysis

The following subsection will discuss the results from the statistical analysis.

5.1.1 By year

The clustered results of all accidents for each year of 2010-2013 were expected since a lot of different processes meet all around the city, e.g. minor roads, major roads and also different speed limits and traffic flows. The apparent clustering of accidents around the city center is

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4Patrick Ivani, traffic manager at Polisen Stockholm (the police in Stockholm), phone call the 26 of April 2016
5Magnus Berg, Regional coordinator,Transportstyrelsen, email the 19 of May 2016
6Atsu Okabe, project manager at SANET, email May 24 2016
most likely caused by the higher amount of traffic there. Instead of analyzing this specific clustering closer, specific streets were analyzed, which results are described in section 4.1.4 and discussed in section 5.1.4.

On Hornsgatan with the ban of studded wheels, the expected results where a clustered pattern before 2010 and a random one after 2010. This may be because expectedly, accidents tend to cluster around intersections, but after the ban it was expected an increase in accidents caused by slipping and hence a more random pattern to the accidents. When looking at the plots both cases yield a random result. However, before 2010 there were some tendencies of clustering at 25 and around 1000 meters. This coincides with our hypothesis, but it should be noted that there are very few accidents recorded after 2010 making the result less trustworthy. Also, it is known that the traffic volume on Hornsgatan decreased after this ban was introduced and could be a contributing factor to the low accident number. Another fact is that Hornsgatan mainly has a speed limit of 30 km/h and that winter wheels without studs work quite well, so it may be that the accident pattern is not affected by the ban.

To make any type of conclusion on this type of subset, there is a need to study the accident pattern on Hornsgatan after more years have passed since the ban to gather more data. Also other roads with this type of scenario with a higher speed limit and more traffic volume need to be included to get trust worthier results. Not enough places have been studied to make any conclusion.

5.1.2 By season

As in the case with the ban of studded wheels on Hornsgatan, the same hypothesis was expected for roads with a slope during winter time. When looking at the resulting plots for the slopes part of Odengatan and Kungsgatan they are difficult to interpret. For Kungsgatan, the pattern is mostly uniform during winter. Some of the accidents are located at the intersections of Sveavägen and Norrlandsgatan, however in between these two there are a few accidents that form a pattern that visually looks uniform. We believe this is due to most of the accidents between the intersections involves a pedestrian in combination with the high amount of pedestrian crossings along Kungsgatan; these crossings are not signaled and are evenly spaced which explains the uniform pattern. Outside of the winter season the pattern changes to random for all distances up to 300m but for the whole road the pattern is uniform as well. The uniform pattern may be explained by the crossings as well since nearly 40 percent of the accidents involve a pedestrian. This implies that the safety of the pedestrians may need some improvement, maybe by installing signaled crossings.

The results on Odengatan for both winter and non-winter are random, however the number of accidents during winter is only six, hence the result may not be trustworthy and no conclusion is made.

Since only two slopes were studied, it is not possible to draw any solid conclusions. The road network in Stockholm is relatively flat; there are very few or none long street segments with significant slope that could be used in the subset. However, outside of Stockholm’s inner city there are more possibilities.
5.1.3 By time

The analysis of rush hour and non-rush hour on all accidents in the study region resulted in a clustered pattern. This is not surprising, just as in the case of all accidents in certain years the result will always be clustered for the whole region since a lot of different processes meet. Looking closer, we find more interesting results on certain roads. The hypothesis was that during non-rush hour, the accidents tend to cluster, probably at intersections and slip roads. For rush hour the hypothesis were that the crucial factor would change from geographical position to human factor and the volume of traffic thus giving the accident points a more random distribution. On Essingeleden at non rush hour, the pattern is consistently clustered. During rush hour the pattern varies between clustered and random depending on scale. A similar pattern is displayed on the plots for Sveavägen and in the plot of the junction Fleminggatan and St Eriksgatan. All three of these confirm our hypothesis on some limited scales. When looking at Götgatan the hypothesis for rush hour is correct since the result is clearly random; however this is not the case when it is not rush hour. Here it is shown that the pattern is uniform between 300-600m but else it is random. Why this is might have something to do with the uniformity of the blocks and the clusters of accidents at the intersections.

These results are interesting since it may indicate that it is possible to predict some temporal trend to the accident distribution which may help to improve the road safety.

The expected result for Stadsgårdsleden was a little bit different than the ones above. Stadsgårdsleden is the entrance to the city from Nacka, a large suburb, with a lot of traffic of cars, trucks and buses and we believed the patterns for both rush hour and non-rush hour would be random since few obstacles for the traffic flow exists. During non-rush hour the result is clustered, even though there are no or few intersections, traffic lights or pedestrians crossings where the accidents can cluster. Because of the lack of these features on the road, the result for non-rush hour is very peculiar, why does the accident cluster one may ask. An answer to this could not be found.

Also for rush hour on Stadsgårdsleden the result is strange, it became uniform and we can find no reasons for this. As mentioned there are very few geographic features where the accidents can cluster which would create a uniform pattern if they were evenly spaced. Visually it is very hard to see that the accidents actually are uniform. It may be that the data for this road contains errors in placements since the addresses at Stadsgårdsleden are diffuse, making the pattern seem uniform.

5.1.4 Specific streets

The results show that Valhallavägen, Odengatan and Sveavägen are clustered for all distances and the remaining roads, Götgatan, Hornsgatan and Hamngatan, are clustered at smaller distances but random for the whole street-length. An interesting find is that the clearly clustered roads all have speed limits of 50 km/h; the remaining roads have 30 km/h except for Hornsgatan which partially have both 50 km/h and 30 km/h. The clustering on the roads with higher speed limit probably depends on a higher accident density at intersections. Most likely, the speed limit affect the accident number at intersections since the driver is given less time to stop for traffic lights, other vehicles or pedestrians. At
Hornsgatan, it looks like there are clusters forming at intersections; however the plot says that clustering is only on a scale up to 200 meters, and then it becomes random. This could be caused by the fact that the intersections are not always a cross-junction but sometimes a T-junction thus creating fewer accidents at that point. Another explanation is that the division of blocks is relatively uneven compared to previously analyzed roads. The plot for Hamngatan varies between clustered and random, it is likely that the lower speed limit reduces the accident risk at intersections. On Götgatan the pattern is mostly random but on some scales it is uniform. When looking at the accidents visually, the reason for the uniform result is quite clear. The intersections of the roads together with some pedestrian crossings are equally spaced, thus the clustering of accidents at these places form a uniform point pattern.

These results show that there are tendencies in the accident data to cluster at intersections or other road features that in some way act as an obstacle for the traffic flow. These tendencies strengthen when the speed limit is 50 km/h compared to 30 km/h.

5.1.5 Specific intersections
All intersections have a clustered point pattern; this probably depends on the clustering of points just around the center. Only a few or no points at all are located precisely in the middle, it could be that the intersection causes the accident but the actual accident does not happen until the vehicle has left the central part or that after an accident has happened, the involved vehicles drives out of the intersection to stop, hence making the recording of the actual accident location misplaced. Another aspect is that there is no address at an intersection causing the police to choose an address that is closest to the accident location (if not GPS is used). The radius of this analysis was chosen to 30m to catch the accidents just mentioned, but it could also include other point events that have nothing to do with the road junction.

As seen in the subsets mentioned above, some clustering of accidents seems to take place around the intersections. In this subsets it is shown that the accidents still cluster when the scope of the study is smaller (just around the intersection). Since the clustering is displaced from the center, this may imply that it is the entering and exiting of the intersection that is the problem. However, the data is not that accurately positioned to make that kind of final conclusion.

5.1.6 Other
Both results from the 0-30 km/h and 50 km/h roads were clustered which very likely means there are more than one process involved in these subsets; meaning that in order to isolate patterns, the subsets need to be divided further. Also both plots for minor and major roads shows clustered patterns. These four subsets cannot be broken down easily to more specific subsets since then the speed limit or the size of the road would no longer be the main factor. Hence the conclusion is drawn that all of these subsets are too large and contain too many different processes to analyze with an interpretable result. If further analysis would to be made on these subsets, they would have to be combined with other factors such as major roads with high traffic volume or perhaps divide the major roads by more specific size criteria (“major major” roads, “minor major” roads and so on).
5.2 Visual analysis with density estimation

After comparing the results of the network cell count and the KDE it was concluded that the KDE method had the best results. This conclusion was made since the network cell count does not regard the size of the road segments and thus can give biased results. This is displayed in Figure 71. The black lines represent a network (e.g. road network), the black dots are nodes in the network, the white dots are point events (e.g. accidents) and the grey lines are a histogram where each staple represent how many point events there are on a network segment. In (a) the segments are of different lengths, in (b) they are all the same. In (a), the analyst is made to believe that L1 and L2 have the same density (point events per segment length) but look at L3 and L4 in (b), now they suddenly have different densities. When comparing network segments with each other, an equally divided network is preferable. Okabe and Sugihara (2012) describe this further, however they point out that an equally divided network is not always possible. Even though an equally divided network is better, the fact that the output changes with the division of the network tells us that this method is unstable and care should be taken when using it. Another fact that is disturbing with the network cell count method is displayed in the left part of Figure 72. It shows how a junction on Södermalm (south of Stockholm) gets visually presented in this method and how misleading it is. The white line, the north part of Ringvägen, in this picture might be seen as a “safe” road (low accident density) and the black road (south part of Ringvägen) as a “dangerous” road even though they are the same street just divided by another street (Hornsgatan). The result is due to all the accidents being joined to Hornsgatan and the south part of Ringvägen and non to the north side of Ringvägen. Our data is not accurate enough to make this kind of conclusion since the coordinates given are not that precise. Another disturbing fact is that the whole left part of Hornsgatan gets a quite high density, even though accidents only takes place close to the intersection. Both of these problems are solved using the KDE, also displayed in the Figure 72.

![Figure 71: Division of road segments for network cell count. Source: Okabe and Sugihara, 2012](image-url)
After visual inspection of the seasonal maps from the KDE it can be observed that the summer map contains the largest amount of areas with a high number of accidents. This result occurs naturally since the summer accident data contains more accidents than the other subsets. In reverse the winter map has the least amount of high density areas.

Some intersections, such as Fleminggatan/St Eriksgatan and Götgatan/Ringvägen are shown as black spots in all the maps which might indicate that improvements may need to be made in these areas. Fleminggatan/St Eriksgatan has already been rebuilt and a left turn prohibit has been applied. Unfortunately we do not have the data to see how the reconstruction has affected the junction since it was finalized just before the summer of 2015. Other junctions such as Odengatan/Sveavägen and Stureplan are indicated as black spots in all maps except in the winter subset where they have a dark gray tone instead of black. The lower density during winter season might be due to the overall lower amount of accidents happening during the winter.

When comparing the kernel density layers from year to year a black spot could be found at Tegelviksslingan/road 222 in 2010 that seemingly decreased or disappeared the following years. When searching the web it turned out that the junction got rebuilt 2011 due to the danger for the cyclists. This was later confirmed from the municipality of Stockholm; the bicycle path was broaden and moved to improve the vehicles visibility of the cyclists, trees were removed and additional warning signs were added⁷.

An important note is that the kernel density estimation has no ability to conclude how a point pattern is distributed. E.g. if several black spots are found in a KDE map, it does not indicate that the point pattern is clustered. A randomly distributed point pattern also contains some clustering which would be displayed as black spots in visualization by the KDE. However, the KDE is very useful when looking for high density areas. If black spots appear in the same place several times for different subsets, e.g. for each year; this implies that the area actually has a steady high density of accidents and not just a temporary black spot that may have been created by chance.

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⁷Björn Hansson, regional manager Södermalm, Stockholm Stad, email the 23 of May 2016
5.3 Analysis of road reconstructions

Firstly it should be mentioned that this part of the analysis was only meant to be an addition to the overall accident analysis. The subject was initiated relatively late in the study time frame and was not meant to contribute to any statistical or certain findings; only to give a faint picture of what may be achieved with reconstructions of road features.

It is interesting to see how changes in the road structure can affect the amounts of accident that occur. It seems that the reconstruction gave a much lower amount of accidents for two of the areas and increased in the last area. However, the results are too few in order to draw any certain conclusions. With more locations taken into account it would be easier to tell in which way reconstruction can help to increase the safety of the roads. Further, some things that should be taken into consideration is that the time frame for the accident data after the rebuilt roads and junctions is smaller than the time frame before (fewer years that can provide accident numbers) and also that accidents may have occurred and not been reported to the police both before and after the reconstructions; hence there might be some hidden statistics.

6 Conclusions and further studies

In this section some conclusion will be made based upon the results and the discussion. Also a short discussion will follow on how this study could be continued and improved.

6.1 Conclusion

When analyzing a point pattern spatially along a network, care need to be taken to the scale at which the analysis is done. In this study the perception has been that small subsets give the best result in form of interpretation; it is hard to analyze traffic accident patterns in a road network if too many processes are involved. The results of the statistical analysis imply that some trends in the accidents patterns can be found, both temporal and geographical. This kind of study would need to be elaborated in order to draw any certain conclusions, but the results point in a direction that indicates that spatial analysis of accidents can help to understand the cause and distribution of accidents in the road network.

Some of the most interesting results of the statistical analysis have been the difference in significant clustering around intersections for 30 km/h and 50 km/h roads, and also the changes in the accident patterns during rush hour and non-rush hour. With further studies this kind of discovery may help traffic planners predict the overall accident pattern in a city.

In the visual analysis with the kernel density estimation, black spots could be located that was not temporary, but lasting over several years. This kind of information can help point out places in the road network where improvements could be made; regarding both design of road features as well as changed regulations of the current traffic rules.

The remaking of road features is a known way of dealing with unsafe locations in a road network. In some of the studied places of this study the accident number has decreased after such a remaking; however not enough rebuilt locations has been studied and hence any certain conclusions cannot be made.
6.2 Further studies

Many interesting results have been discovered in this study and they have a lot of potential for further development given the large dataset provided and the high amount of aspects possible to analyze. There are almost an infinite number of different subsets to be analyzed and due to time restrictions some of the more interesting ones were not studied. It would have been desirable to look at patterns that occur on weekdays versus weekends since Levine, Kim and Nitz (1995) came to the conclusion that accidents tend to be more clustered on weekdays, even though this was not based on a network study region. Other interesting subsets would have been how specific streets or areas change annually or investigate how the accident patterns changes during holidays. In a continuous study other parameters such as traffic volume at different roads and the seriousness of the accident could be taken into account during the analysis to further narrow down the amount of involved processes. Of course, some accident types, such as the once with deadly outcome, are more important to prohibit then the minor accidents. Therefore they could be a focus point in a further study.

Another approach would be to immerse the issues from a look at the past and present to a study of predicting the traffic accidents in the close future. The prediction of accidents is a subject that is in the progress; as mentioned in the introduction, in Ohio, USA, a software that can predict accident hot spots is used by the state highway patrol (Gorder, 2007). For this kind of analysis a lot of computational power is needed, something that has been a constant limitation for this study; e.g. the performance of the methods in SANET such as the K-function on large datasets. If the study would be continued, the whole County of Stockholm could be analyzed with a more advanced computer.
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Figures


Data sources
