Journal of Location Based Services

ISSN: 1748-9725 (Print) 1748-9733 (Online) Journal homepage: http://www.tandfonline.com/loi/tlbs20

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To cite this article: Andreas Keler & Jean Damascene Mazimpaka (2016) Safety-aware routing for motorised tourists based on open data and VGI, Journal of Location Based Services, 10:1, 64-77, DOI: 10.1080/17489725.2016.1170216

To link to this article: http://dx.doi.org/10.1080/17489725.2016.1170216

Published online: 22 Apr 2016.

JOURNAL OF LOCATION BASED SERVICES, 2016
VOL. 10, NO. 1, 64–77
http://dx.doi.org/10.1080/17489725.2016.1170216

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Safety-aware routing for motorised tourists based on open data and VGI

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ABSTRACT

In this work, we present a routing approach avoiding relatively dangerous areas within a city. The information of how dangerous some urban areas are is derived using volunteered geographic information (VGI), governmental open data for detecting properties and functionalities of the urban infrastructure and historical crime data from police departments for detecting crime hot spots. Therefore, we present the basics of crime mapping and analysis with GIS, the practical use of VGI for routing and describe our contribution within the field of routing solutions. Afterwards, we explore our test data in detail. For the practical use, we simplify all the urban infrastructure information and propose a safety index, which represents the relative safety in the investigation area. Additionally, historical crime hot spots are detected and used as routing obstacles. The arcs in the road network are weighted by our safety index and the historical crime hot spots are introduced as obstacle polygons. We test our safety-aware routing design on Los Angeles (LA) and assume its use during night times. In this regard, from two relatively far away situated origin and destination points, we calculate the least dangerous path and compare it with the calculated shortest path. Vehicle drivers without knowledge about the dangerous areas in the city may use the least dangerous path, which is based on our calculated safety index. Finally, we discuss the effectiveness of our method and consider further extensions using freely available geodata.

ARTICLE HISTORY
Received 15 December 2015
Accepted 17 March 2016

KEYWORDS
Routing; crime hot spots; VGI; open data; safety index; least cost; shortest path

Introduction

In our today's society, we face a variety of problems connected with crimes. Besides the actual political conflicts and global terrorism, there are areas of the world that appear as parallel societies inside countries with great economic power due to social segregation (Aas 2008). These areas imply high degree of crimes connected with violence, drug abuse and prostitution. Nevertheless, the perception of urban danger goes often together with globally supported stereotypes (Aas 2008; Body-Gendrot 2001). This urban fear was already inspected by processing mental maps with GIS modelling and spatial-statistical methods for the city of Los Angeles (Matei, Ball-Rokeach, and Qiu 2001). Some of those 'dangerous' districts are

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sidestepped by the locals and are only locally known. This knowledge is often absent in the minds of tourists who have no idea about their personal safety in certain areas. This assumption is used for designing a safety-aware routing solution for tourists.

Another important term is the geography of transit crime, which sets the type of crime in correlation to the transportation infrastructure. Examples for already inspected cases are crimes in metro stations (Loukaitou-Sideris, Liggett, and Iseki 2002) and bus lines (Levine and Wachs 1986a, 1986b) in Los Angeles. From the point of view of transit crime geography, we want to detect vehicle paths within a navigation solution, which do not allow to drive into 'dangerous' areas of a city. Our idea arises from this situation and includes the usage of freely available information in the form of open data and Volunteered Geographic Information (VGI). Since one idea of VGI is to provide local knowledge on locations, it can be used as information source for tourists. Another type of information source is governmental open data, which is partially coming from the local police departments and other governmental institutions of the inspected areas. Using selected indicators from OpenStreetMap (OSM) and governmental open data, we introduce a definition for a local safety index and additionally inspect historical crime information from the communal police department. On these factors, we build a routing application for motorised tourists to avoid driving in relatively dangerous areas.

Crime mapping

The acquisition of crime data by the crime position in space has a long history and its visualisation includes often the use of dots within an overview map. There are numerous methods how crime hot spots can be detected and analysed (Eck et al. 2005; Leitner 2013). In several studies, crime hot spots are detected by clustering techniques (Chakravorty 1995; Murray and Grubesic 2013; Nasridinov and Park 2014; Zhang et al. 2010). The spatial positions of crimes, represented as points, are often used for significant clustering (Weisburd, Morris, and Groff 2009). This significance is not dependent on the specific unit of analysis (Weisburd et al. 2004) and may be tested by a nearest neighbour analysis (NNA) routine, which checks for randomness in the point patterns (Craglia, Haining, and Wiles 2000). In addition to using clustering and NNA for crime point data, Formosa (2012) propose Kernel Density Estimation (KDE) and Getis-Ord GI* (Getis and Ord 1992; Ord and Getis 1995) as methods for crime hot spot detection.

Taylor (2009) observes the detection of crime hot spots critically and states that hot spots can exist in the data world but not necessary in the real world. This comes from the idea that a point cluster consists of different types of events and its simplification into a hot spot entity is very abstract and without validity (Taylor 2009). Nevertheless, crime hot spots are of central meaning in crime research especially in combination with GIS methods. Since we can represent crime hot spots as area polygons with varying size and shape, we can immediately set them in connection with an investigated road network.

VGI for routing applications

One source of freely available information on the road network is OpenStreetMap (OSM) and has its origin from the mapping process by numerous volunteers. This type of data is widely known as Volunteered Geographic Information or VGI (Goodchild 2007). One popular routing application based on VGI with a multiplicity of variants is OpenRouteService (Neis and Zipf 2008).

OpenRouteService[1] (ORS) is based on standards of the Open Geospatial Consortium (OGC), and besides services for vehicle drivers, it was one of the first tools for planning pedestrian or bicycle routes (Schmitz, Neis, and Zipf 2008). Those user-tailored solutions may be extended by additional data as, for example, near real-time traffic information from the Traffic Message Channel (TMC) (Mayer, Stollberg, and Zipf 2009) or elevation information coming from DEM's (Schilling, Lanig, and Neis 2008).

Besides these applications, VGI can help to improve the quality of already established routing and navigation services (Bakillah et al. 2014). In a case study, the quality of the OSM road network was already evaluated for its suitability for vehicle routing (Graser, Straub, and Dragaschnig 2014).

Additionally, it is to mention that the accuracy and validity of OSM data is difficult to detect, because of the different kinds and aspects of accuracies (Helbich et al. 2010). There are several possibilities to determine the geodata quality of the OSM project (Goodchild and Li 2012), which may give answer about its reliability (Haklay et al. 2010). Besides OSM, there are photo-sharing websites such as Panoramio[2] and Flickr,[3] which provide VGI as geo-tagged photos. This information is accessible and can be used for detecting the most scenic routes for tourists (Alivand and Hochmair 2013)

This implies that besides street segments from the OSM project, there are numerous other information available as, for example, points of interest (POIs). Therefore, it is worthwhile to inspect the transportation infrastructure information in combination with land use, housings or POIs from various sources, which may be useful for the design of a routing solution.

Idea of combining freely available data for routing applications

The idea for our method arises from the combined use of several freely available data sources of the same investigation area. Within our approach, we combine open governmental data and VGI from OSM for a routing solution for tourists.

Our contribution lies in the idea of qualitatively describing abstract feelings about areas using discrete object information. The feeling of unsafety is described in our approach by a combination of the following information: the distances to police stations, street lights and highways.

Based on this information, namely the supposed safety, we interpolate object positions into cost surfaces. Afterwards, we set weights to each arc of a road network dependent on the supposed safety index surface and add crime hot spots of the last days as routing restrictions.

Our case study is about routing in Los Angeles during the night times. We assume a higher violent crime incidence frequency in night times, as it was already inspected in Philadelphia in 2008 (Ratcliffe 2012). Therefore, we inspect the positions of street lights, which might be indications for safer places during the night.

With expected differing results to usual shortest path or least cost routing, we try to detect new context based on the given VGI and open data, which may give answer about the quality of the routing solution.

State of the art – routing applications

Route planning implies a great variety of applications as, for example, indoor routing (Goetz 2012) with special preferences (Karimi and Ghafourian 2010) and within a 3D environment (Donaubauer et al. 2013; Steuer 2013), maritime routing for ships, routing for disabled people who need more detailed information on the transportation infrastructure for their movement (Neis 2014; Neis and Zielstra 2014) or even routing on a road network by air quality parameters (Karrais, Keler, and Timpf 2014).

Another example is a routing solution for different types of car drivers or pedestrians. One type of car driver may be a driving beginner, who wants to know not the shortest path between two points in space, but the 'easiest to drive', which includes the previous definition of 'easy to drive' (Krisp and Keler 2015; Krisp, Keler, and Karrais 2014).

Many of the popular routing applications provide a route based on geometric data from the street network; often as the shortest route. However, the satisfaction of users in terms of route is not based on the length of the route only but also on other factors such as safety and points of interest. This consideration leads to an increasing interest in developing routing approaches that take into account the user's context including personal context and user's environment, which is commonly called personalised routing.

While personalised routing is commonly considered as a route computation based on the preferences of a specific individual such as preferences expressed in terms of types of points of interest (Peregrino et al. 2012), our work focuses on considering a factor that may be very important to a class of people. The factor we consider is safety. Previous studies that considered safety have integrated it into the routing process in different ways. Huang et al. (2014) considered safety as one of the routing factors and the safety of different locations in a city was collected through crowd-sourcing as people's perception about these locations. Galbrun, Pelechrinis, and Terzi (2014) developed a safe urban navigation application using crime data. Using crime data, they develop a risk model for the urban street network, which allows estimating the relative probability of a crime on any road segment. They use publicly available crime data-sets to assign a risk score to each street segment such that in one variant, the risk of a path is defined as the total probability of a crime happening along all its segments. De Domenico et al. (2015) included a crimes layer to represent the safety factor among different factors considered for a routing application. They used a list of crimes that occurred within 12 months in Milan and were reported in newspaper articles. They interpolated the data into a surface. Depending on the value of an individual grid cell, it is considered as either a repelling cell which should be avoided, an attracting cell which can be considered, or a neutral cell which can be avoided or considered during route computation. Like De Domenico et al. (2015), we interpolate the available data into a surface but unlike their approach of considering only crime data for safety factor, which was also followed by Galbrun, Pelechrinis, and Terzi (2014), our approach integrates different types of data that contribute to the safety factor.

A common observation to most of the above-mentioned studies is that they use one specific data-set to customise the route computation. Some work proposed an improvement to routing by integrating different types of data. For instance, De Domenico et al. (2015) have proposed an approach of integrating pollution, events, crimes and traffic data for route planning. However, in their approach, the routing is performed on a cost surface ignoring the road network. Real life constraints such as road networks need to be considered for taking the proposed approach beyond simulation to the real world. The contribution of our paper goes in this direction of combining multiple types of data for a specific case of safety-aware routing.

Additionally to the information on the road network and its connectivity, we add object data for our routing solution with the aim of describing the abstract feeling of unsafety. Without local knowledge, we want to model unsafety by different object type that may have only association with safety or danger. Additionally, we have daily changing data on local crimes, which will be used as obstacles for our routing solution.

Properties of the test data-sets

Our test data for the, to be described, approach consists of four different data-sets from the area of the City of Los Angeles. This includes point data representing the position of:

- Street lights
- Police stations
- Highways
- Uniform crime reports of the last 30 days in Los Angeles (group: Part I offences)

In the following, we will describe each of the used data-sets for our approach in detail.

Street lights in Los Angeles

The data about the street light positions are coming from the Traffic and Lighting Division of the Department of Public Works of the County of Los Angeles and were provided by Joaquin Cabrera.[4] The original purpose of this data is to maintain inventory of street lights (reference date: 2007).

Each geolocated street lamp is defined by a specific pole number. Other interesting attributes are luminous flux (in lumen) and watt consumption. Additionally, there are attributes in each street light position giving the type of pole (concrete, fibre glass, steel or wood) and the type of lamps (high-pressure sodium vapour, mercury vapour and incandescent).

In our approach, we consider street light positions as one of the indicators for more safety during night times. As this assumption is quite abstract, we do not consider the luminous flux values for a possible weighting of this supposed safety.

Police stations in Los Angeles

The police station positions are included within a data-set of different emergency facilities in California coming from a project result of the UseIT[5] 2012 GIS and data team (Authors/Creators: Greenwood R, Jara M, Gerbi L). The data were created on 24 July 2012 and include in addition to the geolocation as well the attributes zip code, address, tract and police station number. Another interesting attribute ('Contact') gives answer about the affiliation to the Sheriff or the Police departments. Nevertheless, we do not differentiate between these affiliations.

We assume in our approach that positions of police stations represent locations of high safety. This assumption is made by the idea that people are not likely to commit a crime in front of a police station.

Highways in Los Angeles

We use a data extract of the OSM project for deriving point representations of highways in Los Angeles. As highways, we define only the road segments that have the tag highway[6] equal to motorway or primary. These road types have the highest order of recommended speed.

As already mentioned, we use only point elements for our approach. Therefore, we convert our polyline elements into points by extracting the vertices of the highway elements. After this extraction, it is detectable that the areas of crossroads include more highway points than in the areas of straight highway elements.

This may appear realistic due to more frequent vehicle movement in crossroads. An optional method to increase the number of extracted points is to raise the number of vertices using densification of polyline elements.

In general, it is to say that points representing the highway give some indication to higher safety. The idea behind this statement arises from the assumed higher possibility of a vehicle stoppage by pedestrians on lower level street elements due to lower average velocities. Following this statement, a stoppage and robbery of a vehicle driver is less realistic on highways, because the recommended speed does not allow a stoppage and it is too dangerous for robbers to do this.

Uniform crime reports in Los Angeles

In Los Angeles, crime reports are mapped frequently and the recent accessible reports refer to the data of the last 30 days. In our case, we extracted the crime data-set from 19 January 2015 until 17 February 2015. For the inspection of only ‘heavy’ crimes, we only selected uniform crime reports from offence group Part I. This kind of classification is based on the Uniform Crime Reporting Program and includes besides Part I crimes also Part II crimes (Kennedy, Chaiken, and Carlson 1985). The Federal Bureau of Investigation (FBI) defines Part I crimes as the following: criminal homicide, forcible rape, robbery, aggravated assault, burglary, larceny theft, grand theft auto and arson.

It is to mention that the 30-day partition of reported Part I crimes is coming from the Los Angeles County Sheriff’s Department’s jurisdiction.[7]

Proportion of used data and introduction of weights

The total number of inspected points in our investigation area n_i and the corresponding weights w_i are presented in Table 1. We selected fixed weights w_i for the three types of point data based on the previous assumptions about the safety level associated with the three types of points and after performing a number of tests.

These three different weights are the base for the creation of a cost surface for the safety of vehicle drivers. For a short overview of the used point data, Figure 1 pictures our investigation area and the three different types of weighted points.

Table 1. Number of points n_i and introduced weight w_i of the three different types of points.

	Police stations	Street lights	Highways	Crimes
Number of points n_i	166	125883	7701	4667
Cost/Weight w_i	0.9988	0.0588	0.9424	Not weighted

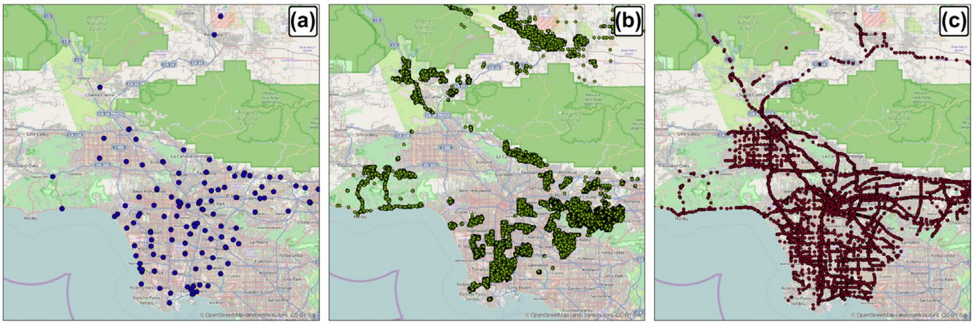

Figure 1. Selected investigation area of LA and three types of input point data for creating a cost surface, with (a) police stations, (b) street lights and (c) highway points.

Design of a safety-aware routing application for car drivers

In this section, we will present our design of a vehicle routing application based on the estimated degree of safety in LA. We first want to define a safety index for car drivers and generate a cost surface based on the data described in the previous section. The further steps are connecting the cost surface with arcs of a road network and the derivation of obstacles based on crime hot spots. Using these two types of elements, we calculate the relatively least dangerous path.

Defining a safety index and its representation as a cost surface

Our first step in creating a cost surface is to merge the three mentioned types of point data elements. We have three different data-sets: positions of police stations (set A), street lights (set B) and highways (set C), which are combined into one point data-set. For the combined point data-set, we use point interpolation for generating a surface. Nowadays, there are numerous already implemented point interpolation methods in GIS software in use. Popular point interpolation techniques are Kriging, which was first described by Krige (1951), linear point and spline interpolation. Another method is inverse distance weighting (IDW), which was introduced by Shepard (1968). The main idea behind IDW interpolation method is that each measured value has a weight that is inversely proportional to the distance to the estimated point values. According to Watson and Philip (1985), one restriction of IDW is that estimated values have to be within the range of the extrema of the sample values.

For our approach, we use IDW and do not consider this as a disadvantage, due to the value range of w_i and the simplicity of this method. We apply this point interpolation technique using a variable search radius, which is dependent on the number of input points. In our case, we use 100 input points to perform interpolation. The resulting cell size of the cost surface raster representation is 100 metres. The grey values or z-values of the raster representation, that we call I_{safe}, are interpolated values of the weights w_i.

After the calculation, we provide an inversion of the whole cost surface raster representation. We call the inversion of safety index I_{safe} 'danger index' I_{dang}:

$$I_{dang} = \text{inv}\left(I_{safe}\right)$$

After the calculation of I_{dang} for the whole area of Los Angeles, we use each I_{dang} value for the connection to a routable road network. This connection is provided by introducing averaged I_{dang} values as weights to the arcs of the road network.

Generation of weighted arcs by connecting safety index cost surface with OSM road elements

The reason for inverting the cost surface and connecting to road network arcs is that we want to find the least cost path on a routable network. In our case, the costs are based on the danger index I_{dang} and higher costs represent more dangerous locations. Each raster surface value that intersects one road element of the routable OSM street network is kept as an attribute value of the respective polyline element. We provide this connection by averaging pixel values. The number of associated pixels to each road segment varies greatly and is only dependent on the length of each road polyline.

Based on these weighted polylines, we build a routing application for motorised tourists to avoid driving in relatively dangerous areas.

Introduction of routing restrictions based on crime data

Similar to Craglia, Haining, and Wiles (2000), we first perform a nearest neighbour analysis (NNA) on the investigated crime points for determining a suitable Euclidean point clustering distance. In our case, we selected a search radius of 500 metres, for using the OPTICS algorithm, which was implemented as a tool within the V-Analytics (a.k.a. CommonGIS)[8] software of Natalia and Gennady Andrienko and first described by Ankerst et al. (1999). This density-based clustering algorithm (Shah, Bhensdadia, and Ganatra 2012) takes a distance function to compute a relative distance between two objects (or trajectories) and was already tested for vehicle movement data (Rinzivillo et al. 2008).

We use this density-based clustering method on our crime points with the mentioned distance threshold of 500 metres. We selected the parameter settings for the OPTICS algorithm after performing a number of tests. The minimum number of neighbourhood objects is set to three, which results in an outlier proportion of 21% of the overall points. The generated clusters represent crime hot spots with 79% of the crime points and are then converted into area polygons using convex hull generation based on Jarvis (1973).

Afterwards, we use these polygons as obstacles for our routing solution. This means that besides the search for the safest path between origin and destination based on the safety index cost surface, there are additional restrictions of historical crime hot spots, which are not allowed to be traversed.

In case of sparse distribution of crime positions, we would use circular buffers around each point with a fixed radius or with a varying radius based on the degree of the crime.

Combination of weighted road network and obstacle polygons for computing the 'safest' path

Additionally to the weighted arcs of the road network, there are obstacle polygons representing hot spots of crimes of the last 30 days.

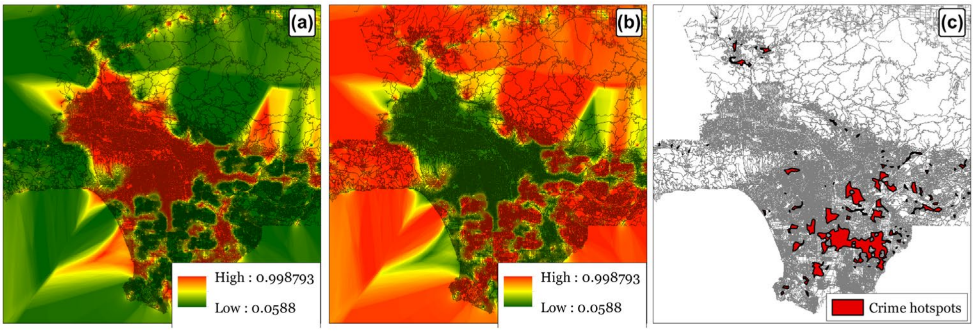

Figure 2. Comparison of the safety index (a) and danger index (b) surfaces and the created crime clusters (c).

An overview of the surfaces for I_{safe} and I_{dang} and the distribution of the created obstacles are shown in Figure 2.

In Figure 2, the used road network for routing is pictured, respectively, in grey with 50 per cent opacity.

Results and discussion

In the following, we will present the practical use of our approach for a personalised routing solution using one routing example.

A case study on safety-aware routing

Our case study includes, as already mentioned, routing during the night times for motorised tourists without local knowledge. Because of the higher violent crime incidence frequency in urban areas (Ratcliffe 2012), we expected some dependency on street lights in our routing solution. Since our safety-based routing application considers besides costs (I_{dang}) as well as routing obstacles ('crime hot spots'), we expect a relatively different route in comparison to the usual shortest path using Dijkstra's algorithm (Dijkstra 1959). For showing useful results, we select origin and destination points, which are relatively far away from each other (air distance of around 24 miles). We selected as a starting point the Long Beach Airport in the south of our investigation area and a destination point in the Hollywood Boulevard in the north. Here, it is to mention that at least two dangerous areas in LA are situated in-between the selected two points. The different routing results between these points are pictured in Figure 3, which shows three different routing strategies: shortest path, 'safest' path without considering obstacles and 'safest' path with consideration of obstacles.

As we compare our computed result in Figure 3(b) with the shortest route in Figure 3(a), we can detect a great difference in the course of the route. The shortest path in Figure 3(a) shows a nearly straight-lined shape and the 'safest' route in Figure 3(b) has a big half-circle around the City of Compton but then intersects other smaller crime hot spots. With the introduction of obstacle polygons as additional routing restrictions (see Figure 3(c)), which represent our derived crime hot spots, the shape of the route changes again quite strongly. This has its reason in the routing restriction of not intersecting certain crime hot spots. The

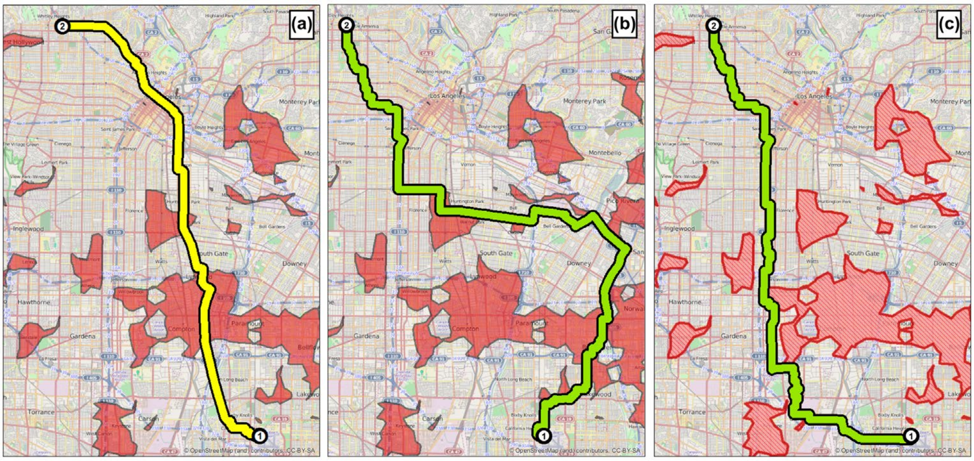

Figure 3. Comparison between the shortest route (a) the 'safest' route without consideration of obstacle polygons (b) and the 'safest' route with consideration of obstacles (c) for tourists between Long Beach Airport and Hollywood Boulevard.

effect of considering obstacles can be seen by comparing the two proposed 'safest' routes in Figure 3(b) and Figure 3(c). This comparison shows that the first parts, where obstacles are, are different, while the last parts, where there are no obstacles, are the same. Crime clusters may not correspond to our safety index in the case that they are time-dependent and differ between day and night times. This time information is unfortunately not given in our case (only the date is given). Nevertheless, the comparison between different routing strategies may give more insight on the data in the way of having a microscopic view on documented crimes and estimated unsafety.

Critical issues on applying the routing approach

The focus of our approach was to provide a routing application for vehicle drivers. For this purpose, we exemplify only a selection of possible input data for creating a cost surface. We can expand or change this selection dependent on the sensation of certain information. The perception of highways with their surrounding areas as safe places might be difficult for vehicle drivers, especially in case of no available link roads. Besides the selection of the input data, there is the problem of how to define weights.

One possibility includes the inspection of the spatial distribution of the different point data. The latter is useful for choosing the interpolation parameters for creating the cost surface. The linkage between a cost surface and a road network has numerous possibilities and consequently can deliver different routing results.

The second big variation in the routing results may come from the generation of routing obstacles. Dependent on the set parameters for density-based clustering, we receive different results: mainly variations in shape, size and number of obstacle polygons.

The designed approach uses a selection of crime records, which is more dynamic than the other data-sets. One possible option for the case of field deployment of the application is to use the most recent crime data with deductive and updated crime hot spot polygons.

Outlook

One further research question might be to investigate if it is useful to provide routing on streaming crime data. This concept can include crime hot spots as moving obstacles similar to the approach of Wang and Zlatanova (2013). Using data streams for routing purpose needs extended algorithms. Another question is whether historical crime hot spots are useful for predicting future crime hot spots to support efficient routing on streaming data, for instance. Similar to traffic status prediction, which cannot be based on historical traffic data alone, the historical crime data might not be sufficient to predict future crime hot spots. Beside this, there are still different ideas about how to define crime hot spots and the connections between them. Further beneficial information for the design of safety-aware routing applications may include indicators on the levels of unsafety perceived by people.

Another direction of work consists of establishing a taxonomy of dangerous features. Within a routing approach design, a ranked list of routes may follow this taxonomy.

The safety-aware routing discussed in this paper can benefit from advanced approaches of collecting insecurity-related data. For instance, the integration of different types of information to detect not only locations of occurred crimes but also potential locations of future crimes such as gang structures that develop in the neighbourhood of important POIs like airports, train stations and bars.

Routing applications based on various freely available data might help to get more insight into massive crime data. Additionally, they might be useful for the analysis of movement data in the form of vehicle trajectories and the correlation between 'unsafety' feeling and, for example, traffic congestion.

Notes

1. http://openrouteservice.org/
2. http://www.panoramio.com/
3. https://www.flickr.com/
4. http://egis3.lacounty.gov/dataportal/2011/01/27/street-lights/
5. Undergraduate Studies in Earthquake Information Technology (USEIT) is a team-based undergraduate research programme run by the Southern California Earthquake Center (SCEC) at the University of Southern California (USC).
6. http://wiki.openstreetmap.org/wiki/Key:highway
7. http://www.lasd.org/
8. http://geoanalytics.net/V-Analytics/

Disclosure statement

No potential conflict of interest was reported by the authors.

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