Bayesian Geographical Profiling in Terrorism Revealing

Jana Svobodová [1] | *Masaryk University, Brno, Czech Republic*
Jan Koláček [2] | *Masaryk University, Brno, Czech Republic*

Abstract

A significant part of research in terrorism studies focuses on the analysis of terrorist groups. An important issue for this type of research is that a large number of attacks are not attributed to a specific group. As an appropriate approach to solve the problem of attributing group responsibility we applied the geographic profiling theory. We analyzed several terrorist organizations which typically commit attacks far away from their headquarters. We proposed an innovative method based on Bayesian approach to find the organization's base and to attribute responsibility to perpetrators of terrorist attacks. We compared the results with classical techniques used in criminology. The real data analysis shows rationale for the proposed approach. Analyzed data comes from the Global Terrorism Database which is currently the most extensive database on terrorism ever collected.[3]

Keywords	***JEL code***
Bayesian data analysis, geographic profiling, Global Terrorism Database, anchor point	*C11, C14*

INTRODUCTION

Terrorism is usually understood as the use or threat of violence to further a political cause. Since acts of terrorism across the globe have increased notably in recent decades, this area plays an important role in sociological and political science research. A significant part of research in terrorism studies focuses on the analysis of terrorist groups. Studies of this type explore group attributes, e.g., ideology, size, and state sponsorship, in order to determine their impact on phenomenon such as the number of attacks conducted, their location or the targets of attacks (Asal and Rethemeyer, 2008; Carter, 2012). An important issue for this type of research is, that a large number of attacks are not attributed to a specific group (Arva and Beieler, 2014). Although many terrorist organizations actively seek publicity for their attacks, it is sometimes difficult to attribute responsibility to perpetrators of terrorist attacks. A comprehensive empirical overview of these uncertainties is given in Lafree et al. (2014) in context with the Global Terrorism Database (National Consortium for the Study of Terrorism and Responses to Terrorism (START), 2017) which is currently the most extensive database on terrorism ever collected.

As an appropriate approach to solving the problem of attributing group responsibility could be applying the geographic profiling theory. Geographic profiling is extensively used for finding criminals

[1] Department of Mathematics and Statistics, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic. Email: janyfa@mail.muni.cz.
[2] Department of Mathematics and Statistics, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic. Email: kolacek@math.muni.cz.
[3] This article is based on contribution at the conference *Robust 2018*.

such as thieves, robbers, burglars, rapists or sexual assailants. According to (Canter and Youngs, 2008) these types of perpetrators usually commit offenses at a distance between 0.89 and 3.87 kilometer from their base. This is the reason why the methods of geographic profiling are especially focused on offenders committing crimes near their anchor points.

However, we can find a number of criminal groups in various countries where a large percentage of offenders commute long distances to perpetrate a crime. These include American rapists, Canadian sexual assailants, Finnish thieves or Australian robbers where about 50% crimes are committed up to tens of kilometers away from the perpetrators' anchor point (Lundrigan and Cantter, 2001). According to distance where the offender perpetrates his crime, we distinguish two types of criminals – residents and non-residents (Svobodová, 2018). Terrorists represent a very specific group and a majority of them is an example of the latter. For non-local organizations (non-residents), the usual methods and approaches of geographic profiling are not applicable or do not bring such satisfactory results as for residents.

Bayesian approach (O'Leary, 2009) offers a very strong and useful tool for finding an anchor point of all types of criminals. Applying prior knowledge and a suitable likelihood model, we obtain a posterior function that can be a powerful source of information about the anchor point of both residents and non-residents.

The terrorist attack often occurs hundreds to thousands of kilometers away from the headquarters. The attack sites of one terrorist organization are also more distant from each another than it is usual for other above-mentioned crimes. Thus, we take all considerations in the units of hundreds of kilometers.

1 METHODS

1.1 Global Terrorism Dataset

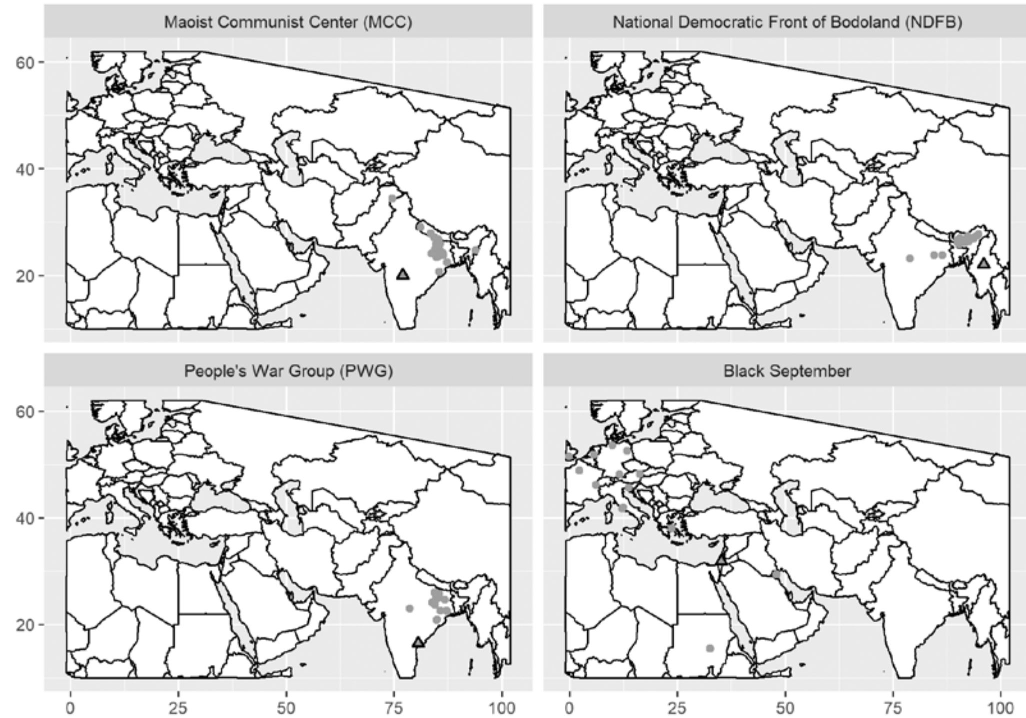
Data comes from the Global Terrorism Database (National Consortium for the Study of Terrorism and Responses to Terrorism (START), 2017). The Global Terrorism Database (GTD) is an open-source database containing the information on domestic and international terrorist attacks that have taken place around the world since 1970. It contains data on place, time and manner for more than 170 000 terrorist attacks. The database is updated annually adding new records of events from the previous calendar year. For each GTD incident, the information is available on the date and location of the incident, the weapons used and nature of the target, the number of casualties, and – when identifiable – the group or individual who is responsible. For our purposes, we turned our attention to the incident location and the perpetrator group name. The location details are specified by the longitude and latitude (based on WGS1984 standards) of the city in which the event took place. In order to ensure consistency in the usage of group names in the database, the GTD database uses a standardized list of group names that have been established by project staff to serve as a reference for all subsequent entries.

In the recent paper, we restricted ourselves to data with known perpetrator group name. We chose 10 well-known terrorist organizations from the region of the middle, south and south-east Asia. Unfortunately, in the GTD database, there is no information on the perpetrator group anchor point. Thus, we needed to study selected organizations from public sources, as Wikipedia or Country Reports on Terrorism 2016, and added their headquarters (anchor point) coordinates manually. The distribution of incidents for considered organizations and their anchor points are depicted in Figure 1.

1.2 Representation of data in UTM

In the original GTD dataset, the incident location was defined by the longitude and latitude based on World Geodetic System standard (WGS, 1984). For this coordinate system, we should consider the orthodromic distance between two points, i.e. the shortest distance between two points on the surface of a sphere. However, the proposed method is based on the Euclidian distance in a plane. Thus a data projection to the Cartesian coordinates was necessary. We used the projection to the Universal Transverse Mercator

Figure 1 The distribution of selected terrorist incidents (points) and their headquarters (triangles)



Source: Own construction

(UTM) coordinate system, which is a global system of grid-based mapping references. The position on Earth is given by the UTM zone number and the easting and northing planar coordinate pair in that zone. The point of origin for each UTM zone is the intersection of the equator and the zone's central meridian. The main idea of the UTM projection is projecting each of the 60 zones onto a plane separately instead of projecting the complete globe into a flat surface. This leads to a minimal scale distortion within each zone. On the other side, the UTM is not suitable for areas that span more than a few zones since distortion and error increase when moving farther from the zone for which the projection is defined.

After transforming the data to the UTM coordinates we chose several points with the biggest distance for each group and compared their Euclidian distances with their original orthodromic distances to supervise the maximal distortion. The considered incident locations are spread over quite a large area. It includes 18 UTM zones starting in zone 30 and ending in zone 47. As the reference zone for projecting we chose the central zone of this area, i.e. zone 38.

The group named "Kurdistan Workers' Party" (PKK) is an organization based in Qandil Mountains, i.e. its anchor point coordinates are 36°N, 44°E (UTM zone 38). Incident locations for PKK are spread through the largest area in comparison to the other terrorist groups, see Figure 1. Thus we chose PKK to demonstrate maximal scale distortion. The most distant PKK incident is located in London with coordinates 51.5°N, 0.12°W (UTM zone 30). The orthodromic distance between the anchor point and the incident location is 3 942 km. After UTM projection (with the reference zone 38), the distance is 4 087 km, i.e., the absolute difference is 145 km which results in 3.7% relative distance distortion. We can supervise the maximal distance distortion for other cases in a similar way and conclude that the relative distance distortion is less than 5% in general. This upper bound is acceptable for our further probability modeling.

1.3 Procedures and models

Methods of geographic profiling are based on the construction of the probability distribution that indicates which areas of the investigation region contain the anchor point with the highest probability. A lot of approaches apply a hit score function to find a prioritized search area.

However, although these procedures are very popular, they do not provide a probability distribution in the true sense. Moreover, there is no option to incorporate geographic features and other background information into the model. Geography of the region may have a great effect on the choice of the crime location (Brantingham and Brantingham, 1993; Canter et al., 2000; Rossmo, 2000). These two aspects are the main reason for criticism of the hit score function methods (Mohler and Short, 2012) and lead to search for other approaches.

Bayesian approach is a very useful and appropriate tool that meets all requirements for the methods of geographic profiling and offers possibility how to implement geography and other important features into the model (O'Leary, 2009). For our case of terrorism, let us denote by $\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n$ the known sites of attacks of one terrorist organization where $\boldsymbol{x}_{\mathrm{i}} = (x_i^{(1)}, x_i^{(2)})$ for $i = 1,2, \dots, n$. We assume that the choice of the attack location is influenced by the headquarters $z = (z^{(1)}, z^{(2)})$ and by other k parameters $\boldsymbol{\theta} = (\theta_1, \theta_2, \dots, \theta_k)$. Then, we can describe the way how the investigated organization chooses a site of its attacks by a function $p(\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}|\mathbf{z}, \boldsymbol{\theta})$. In the terms of Bayesian method, this function is called likelihood function.

Using Bayes rule we obtain:

$$p(\mathbf{z}, \boldsymbol{\theta}\,|\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}) = \frac{p(\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}|\mathbf{z}, \boldsymbol{\theta}) \cdot p(\mathbf{z}, \boldsymbol{\theta})}{p(\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\})}, \tag{1}$$

where $p(\mathbf{z}, \boldsymbol{\theta}\,|\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\})$ denotes a posterior distribution, $p(\mathbf{z}, \boldsymbol{\theta})$ contains information that is available before data analyzing and, therefore, it is called a prior distribution and the denominator $p(\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\})$ is referred to as an evidence. This part of Bayes rule is very important for comparing different models, for our purpose, it plays a role of normalization constant. Therefore we can replace equality (=) by proportionality (∝) and the denominator can be omitted.

To find the probability distribution of the headquarters $\mathbf{z}$, we get rid of unnecessary parameters by integrating over all possible values of $\boldsymbol{\theta}$. When considering the independence between the headquarters $\mathbf{z}$ and the parameters $\boldsymbol{\theta}$, we can simply write:

$$p(\mathbf{z}\,|\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}) \propto \int \dots \int_{M_{\boldsymbol{\theta}}} p(\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}|\mathbf{z}, \boldsymbol{\theta}) \cdot h(\mathbf{z}) \cdot g(\boldsymbol{\theta})\, \mathrm{d}\theta_1 \dots \mathrm{d}\theta_k, \tag{2}$$

where $M_{\boldsymbol{\theta}}$ indicates the region of integration and functions h and g denote prior distributions for headquarters $\mathbf{z}$ and for parameters $\boldsymbol{\theta}$.

There are a lot of possibilities on how to construct a likelihood function $p(\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}|\mathbf{z}, \boldsymbol{\theta})$. In a large number of papers about the Bayesian approach to the geographic profiling (O'Leary, 2009; O'Leary, 2010), we can find the assumption of the independence between offender's crime sites, thus we could write:

$$p(\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}|\mathbf{z}, \boldsymbol{\theta}) = \prod_{i=1}^{n} p_0(\mathbf{x}_i|\mathbf{z}, \boldsymbol{\theta}).$$

When dealing with terrorist organizations, the independence of attack locations cannot be assumed. There is usually a link between a series of attacks. Therefore, there is a need to proceed in a different way.

We use all attack sites to estimate the most likely one that we denote by $\mathbf{x}_H$ and for it we apply the model $p_0(\mathbf{x}_H|\mathbf{z}, \boldsymbol{\theta})$. We can then write the relationship as:

$$p(\{\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_n\}|\mathbf{z}, \boldsymbol{\theta}) = p_0(\mathbf{x}_H|\mathbf{z}, \boldsymbol{\theta}).$$

Another issue is how to model $p_0(\mathbf{x}_H|\mathbf{z}, \boldsymbol{\theta})$. In this paper, we only deal with non-local terrorist groups. Some authors point out (Levine, 2009; Mohler and Short, 2012), that the choice of attack site is, for this type of commuting offenders, influenced not only by the distance between the headquarters and the attack location but also by the angle at which the attack is committed. In (Mohler and Short, 2012), the designed kinetic model with the suitable choice of parameters can be applied to offenders committing crimes at great distances. It has been proved that after some assumptions it can be approximated by the product of a function of the distance and a function of the angle. This result inspires us to solve the problem of commuting offenders by combination of two suitable functions – first, a function that affects the probability of distance in which perpetrator commits a crime and, second, a function that influences probability of the corresponding angle. Construction of this model is presented in (Svobodová, 2018) as follows:

$$p_0(\mathbf{x}_H|\mathbf{z}, \alpha, \vartheta, \sigma_1, \sigma_2) = \frac{1}{N(\alpha, \vartheta, \sigma_1, \sigma_2)} \cdot q_1(\mathbf{x}_H|\mathbf{z}, \alpha, \sigma_1) \cdot q_2(\mathbf{x}_H|\mathbf{z}, \vartheta, \sigma_2), \tag{3}$$

where:

$$q_1(\mathbf{x}_H|\mathbf{z}, \alpha, \sigma_1) = \exp\left(-\frac{1}{2\sigma_1^2}\left[\sqrt{(x_H^{(1)} - z^{(1)})^2 + (x_H^{(2)} - z^{(2)})^2} - \alpha\right]^2\right),$$

and:

$$q_2(\mathbf{x}_H|\mathbf{z}, \vartheta, \sigma_2) = \exp\left(-\frac{1}{2\sigma_2^2}\left[\operatorname{atan2}(x_H^{(2)} - z^{(2)}, x_H^{(1)} - z^{(1)}) - \vartheta\right]^2\right).$$

The median of distance for committing terrorist attacks is denoted by α, σ_1 is the standard deviation corresponding to the function q_1. The average angle from the headquarters to the attack site measured from the horizontal axis with the origin at the headquarters $\mathbf{z}$ is expressed by the ϑ (the function q_2 achieves the highest values at the angle ϑ) and q_2 corresponds to the standard deviation of the function q_2. The functional values of q_2 around the angle ϑ decrease at a rate that is influenced by q_2.

The denominator of (3) is a normalization factor that ensures that the likelihood function $p_0(\mathbf{x}_i|\mathbf{z}, \alpha, \vartheta, \sigma_1, \sigma_2)$ is a probability distribution. If ϕ represents the distribution function of the standard normal distribution, the normalization factor has the form:

$$N(\alpha, \vartheta, \sigma_1, \sigma_2) = N_1(\alpha, \sigma_1) \cdot N_2(\vartheta, \sigma_2),$$

where:

$$N_1(\alpha, \sigma_1) = \sigma_1^2 \cdot \exp\left(-\frac{\alpha^2}{2\sigma_1^2}\right) + \sqrt{2\pi}\alpha\sigma_1\left(1 - \phi\left(-\frac{\alpha}{\sigma_1}\right)\right),$$

and:

$$N_2(\alpha, \sigma_2) = \sigma_2\sqrt{2\pi}\alpha \cdot \exp\left(\phi\left(\frac{2\pi - \vartheta}{\sigma_2}\right) - \phi\left(-\frac{\vartheta}{\sigma_2}\right)\right).$$

We can see in the relationship (2), that in addition to the likelihood function, we need to determine the prior functions for the headquarters $\mathbf{z}$ and for all other parameters – in our case α and ϑ.

The parameters σ_1 and σ_2 are estimated by the sample standard deviation using the known data about other offenders.

The most popular method of the geographic profiling is Rossmo's approach (Rossmo, 2000). In this paper, we use it as benchmark to compare its efficiency with the efficiency of our method. Rossmo uses the hit score function:

$$S(\mathbf{y}) = \sum_{i=1}^{n} f(d(\mathbf{x}_i,\mathbf{y})),$$

where the distance decay function f has the following form:

$$d(\mathbf{x}_i,\mathbf{y})) = \begin{cases} \dfrac{k}{(d(\mathbf{x}_i,\mathbf{y}))^h} & \text{for } d(\mathbf{x}_i,\mathbf{y}) > b, \\ \dfrac{kb^{g-h}}{(2b - d(\mathbf{x}_i,\mathbf{y}))^g} & \text{for } d(\mathbf{x}_i,\mathbf{y}) \leq b. \end{cases} \tag{4}$$

The distance between the crime site $\mathbf{x}_i$ and any place $\mathbf{y}$ is determined by the Manhattan distance, the parameter b denotes the radius of the buffer zone and is set to one half of the average distance of the nearest neighbour between terrorist attacks of the examined terrorist organization. The exponents g and h are recommended by Rossmo to be 1.2.

2 RESULTS AND DISCUSSION

In this section, we present results obtained by using the proposed method on the dataset described above. For all calculations and graph creations we used the software R (R Core Team, 2013). The analysis was performed on selected 10 terrorist organizations.

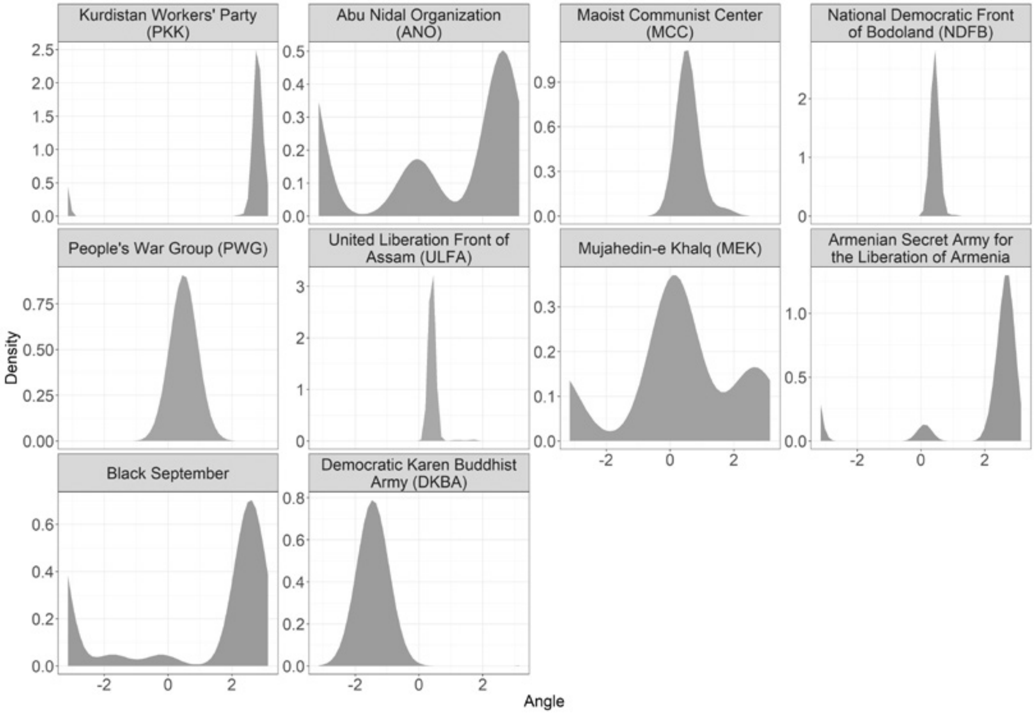
Our aim was to examine the accuracy of the estimate where the headquarters of the non-local terrorist organization is located. For each organization, we chose just the incidents with distance from its headquarters greater than a minimal value. Based on (Canter and Youngs, 2008), this value was set first to 4 units – in our case to 400 kilometers, then to 600, 800 and, finally, to 1 000 kilometers. Accuracy of the estimate was very similar in all cases. This study presents the results for attacks at a distance greater than 800 kilometers from the headquarters of the terrorist organizations.

Firstly, we inspected the angles at which the attacks were committed. The probability distribution of all angles is depicted in Figure 2. It is evident that for many organizations, the angle plays an important role in the incident location selection.

For construction of the prior functions for the parameters $\mathbf{z}$ and ϑ, we used kernel smoothing techniques, and for the parameter α, we applied the logspline density estimation. It allows to limit the range only to non-negative values. When estimating the prior functions, we used all available data. We always excluded only the information about the examined offender. Figure 3 shows the estimated prior functions for the average angle ϑ and the median distance α over all organizations.

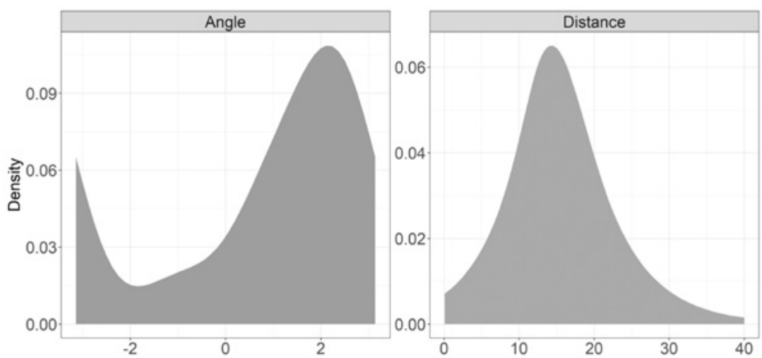
Further, we chose the investigated area to include all attacks and headquarters and increased it by 1 500 km approximately. This space was divided into a grid with the cell dimension of 100 km × 100 km . We evaluated our proposed posterior function (2) and the Rossmo's method (4) in all cells. For each approach, we ordered all cells based upon the score value, from the highest to the lowest, i.e. from the cell that includes the headquarters with the highest probability to the cell that includes it with the lowest probability. The efficiency of the method is given by the number of cells that we had to examine until we found the headquarters of the investigated terrorist organization. The proportion of this number to all cells points out how successful each method is, i.e. a lower proportion (percentage) indicates higher efficiency. The models performance for all organizations is given in Table 1, graphical representation in Figure 4.

Figure 2 The probability distribution of incident directions



Source: Own construction

Figure 3 Estimated prior distributions of angle and distance



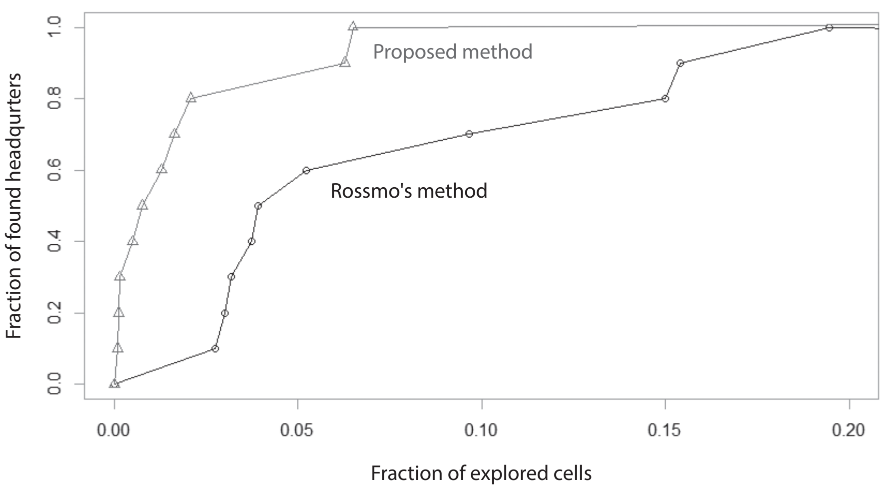
Source: Own construction

Table 1 Comparison of model performance (percentage of the number of cells that we had to examine until we found the headquarters of the investigated terrorist organization)

Organization	Rossmo's model	Proposed model
Kurdistan Workers' Party (PKK)	9.67	1.65
Abu Nidal Organization (ANO)	15.40	1.29
Maoist Communist Center (MCC)	5.24	6.50
National Democratic Front of Bodoland (NDFB)	3.00	0.09
People's War Group (PWG)	3.93	6.28
United Liberation Front of Assam (ULFA)	2.76	0.16
Mujahedin-e Khalq (MEK)	3.75	0.12
Armenian Secret Army for the Liberation of Armenia	14.99	0.51
Black September	19.45	0.76
Democratic Karen Buddhist Army (DKBA)	3.19	2.09

Source: Own construction

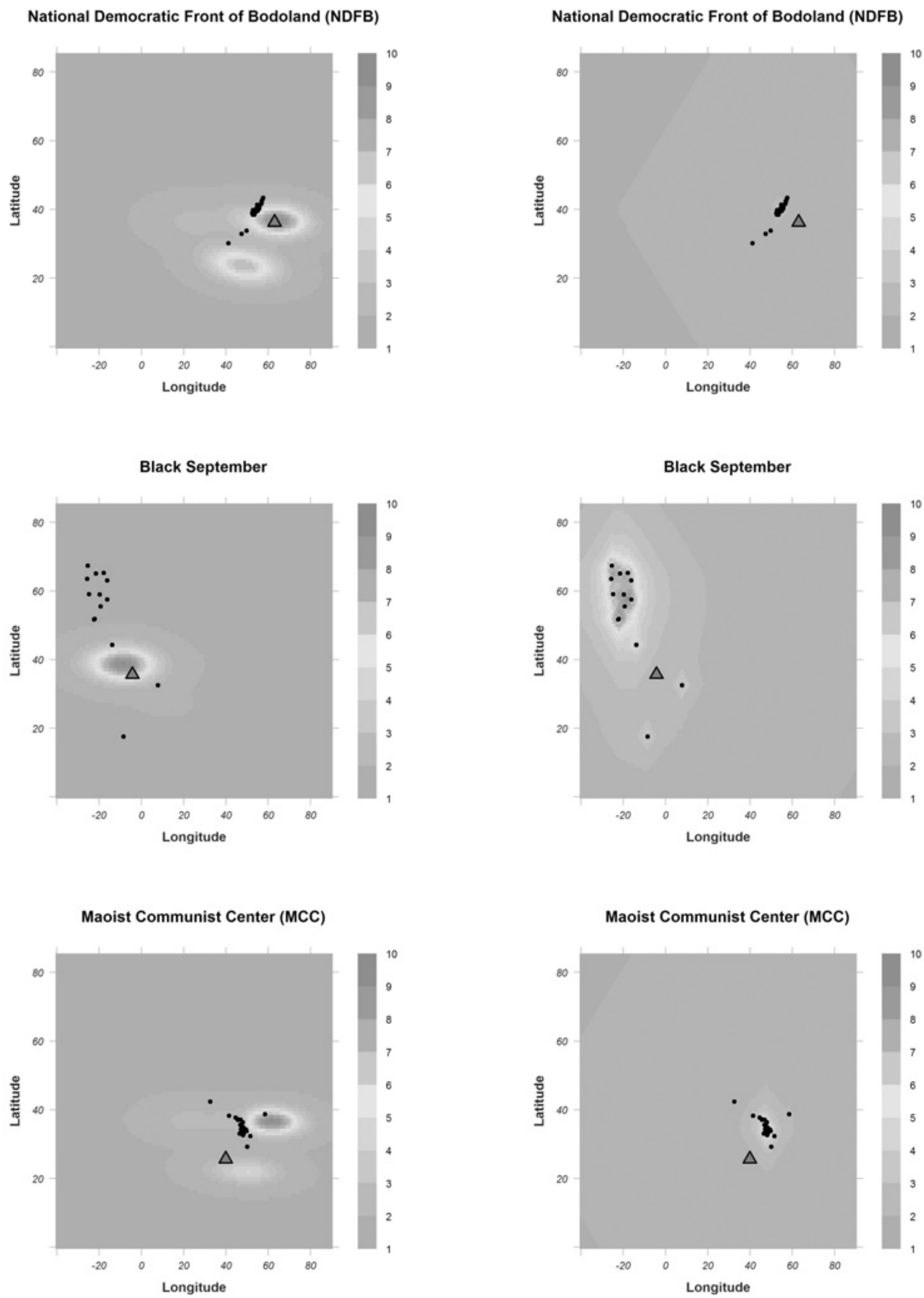
Figure 4 Graphical comparison of the model performance (triangles for the proposed method, circles for Rossmo's approach)



Source: Own construction

In all cases, the proposed method's rate was under 7%. Moreover, if two organizations with highest rate (MCC and PWG) are excluded, the rate was approximately 2% and less. This fact means, that the proposed model was efficient and the unknown headquarters was found quite quickly. It is not surprising that the Rossmo's model was not as efficient as the proposed model. It was suggested for residents, i.e.

Figure 5 Level plots for the proposed method (on the left) and Rossmo's approach (on the right) indicating how likely is that the area contains the offenders' headquarters (the black circles indicate attack sites, the triangle denotes real headquarters)



Source: Own construction

local perpetrators, and it cannot cover the behavior of another type of offenders. On the other side, in two mentioned cases (MCC and PWG), the efficiency of the proposed model was smaller than the efficiency of the Rossmo's model. The reason for it subsists in the incidents angle distribution. Figure 1 shows the two considered perpetrators preferred angles between 0 and $\pi/3$. However, the prior probability distribution (see Figure 3) estimates relatively small probabilities for these angles. In this sense, the prior angle estimate is not sufficient for these two organizations and thus the model results are biased.

In Figure 5, there are some examples of estimates of the terrorist headquarters. We can see that the hit score function with Rossmo's distance decay function assumes that the headquarters lies close to any of the attack sites. Our method admits the possibility that the headquarters is located at a greater distance from the attack sites. It is obvious from Table 1 that the proposed method is less accurate than Rossmo's approach for MCC. However, also in this case, the real headquarters lies very close to the second most probable region in the whole investigated area.

CONCLUSION

In previous works on geographic profiling, several types of offenders were analyzed to detect their anchor point. Perpetrators usually commit offenses at a shorter distance from their base. For these types of offenders the Rossmo's approach is the most popular and used in criminology.

In contrast to previous works, the analysis of offenders commuting long distances to perpetrate a crime seems to be helpful. We analyzed several terrorist organizations which typically commit attacks hundreds to thousands of kilometers away from their headquarters. We proposed an innovative method based on Bayesian approach to find the organization's base and to attribute responsibility to perpetrators of terrorist attacks. The real data analysis shows rationale for the proposed approach. The method is more flexible by covering the perpetrator's preference of incident's angles and distances from its headquarters. On the other side, the Bayesian approach is more sensitive to a quality of corresponding prior distributions estimates. It could cause slightly biased results in some cases. The complexity of the method brings a practical issue as it is more time consuming than the Rossmo's approach.

We see further challenges in the extension of the presented study in following ways. A more detailed criterion of "non-locality" of a perpetrator could be helpful. It would allow setting some weight parameters in construction of a more general model for any kind of perpetrator and it could lead to the development of an automated data-processing algorithm. The determination of a prior for perpetrator's travel direction with assumption of a type of dependency on its starting point could give more accurate results in modelling. Some offenders prefer several locations of attacks with specific angle and distance. Thus the assumption of dependency between them seems to be important in prior estimation.

ACKNOWLEDGEMENT

This research was supported by Masaryk University, project MUNI/A/1204/2017.

References

ARVA, B. AND BEIELER, J. Dealing with missing data in group-level studies of terrorism. In: *APSA Annual Meeting*, 2014, pp. 28–31.

ASAL, V. AND RETHEMEYER, R. K. The nature of the beast: Organizational structures and the lethality of terrorist attacks. *The Journal of Politics*, 2008, 70.2, pp. 437–449.

BRANTINGHAM, P. L. AND BRANTINGHAM, P. J. Nodes, paths and edges. *Journal of Environmental Psychology*, 1993, 13(1), pp. 3–28.

CANTER, D., COFFEY, T., HUNTLEY, M., MISSEN, C. Predicting serial killers' home base using a decision support system. *Journal of Quantitative Criminology*, 2000, 16(4), pp. 457–478.

CANTER, D. V. AND YOUNDS, D. *Applications of geographical offender profiling.* Burlington. VT: Ashage Pub, 2008.
CARTER, D. B. A blessing or a curse? State support for terrorist groups. *International Organization*, 2012, 66.1, pp. 129–151.
LAFREE, G., DUGAN, L., MILLER, E. *Putting terrorism in context: Lessons from the Global Terrorism Database.* Routledge, 2014.
LEVINE, N. Introduction to the Special Issue on Bayesian journey-to-crime modeling. *Journal of Investigative Psychology and Offender Profiling*, 2009, 6, pp. 162–167.
LUNDRIGAN, S. AND CANTER, D. A multivariate analysis of serial murderers' disposal site location choice. *Journal of Environmental Psychology*, 2001, 21(4), pp. 423–432.
MOHLER, G. O. AND SHORT, M. B. Geographic profiling from kinetic models of criminal behavior. *SIAM Journal on Applied Mathematics*, 2012, 72(1), pp. 163–180.
NATIONAL CONSORTIUM FOR THE STUDY OF TERRORISM AND RESPONSES TO TERRORISM (START). *Global Terrorism Database* [globalterrorismdb_0617dist.csv], 2007. <https://www.start.umd.edu/gtd>.
O'LEARY, M. The mathematics of geographic profiling. *Journal of Investigative Psychology and Offender Profiling*, 2009, 6(3), pp. 253–265.
O'LEARY, M. Implementing a bayesian approach to criminal geographic profiling. In: *Proceedings of the 1st International Conference and Exhibition on Computing for Geospatial Research & Application*, 2010, New York, NY, USA, pp. 59:1–59:8.
R CORE TEAM. R: A *Language and Environment for Statistical Computing* [online]. R Foundation for Statistical Computing, Vienna, Austria, 2013. <http://www.R-project.org/>.
ROSSMO, D. *Geographic profiling.* CRC Press, Boca Raton, Fla, 2000.
SVOBODOVÁ, J. *Bayesian models in geographic profiling.* ArXiv e-prints, 2018.
UNITED STATES DEPARTMENT OF STATE. *Country Reports on Terrorism 2016* [online]. 2017. <https://www.state.gov/j/ct/rls/crt/2016>.
WGS – World Geodetic System website of the NGA [online]. National Geospatial-Intelligence Agency, 1984. [archived from the original on 2.4.2012].