Spatio-Temporal Traffic Anomaly Detection Methods on the Urban Road Network: A Literature Review

Kvalifikacijski doktorski ispit

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Fakultet prometnih znanosti

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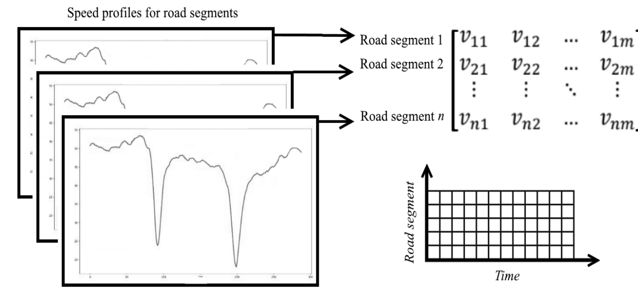
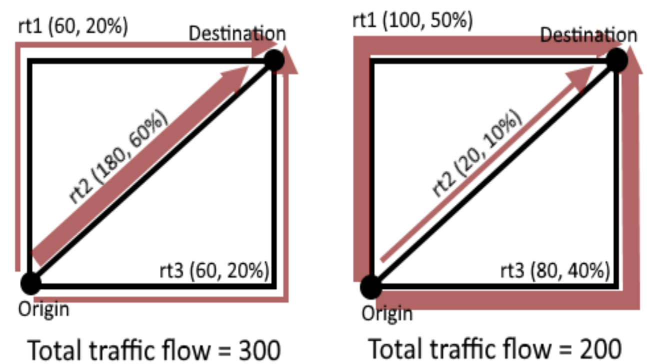
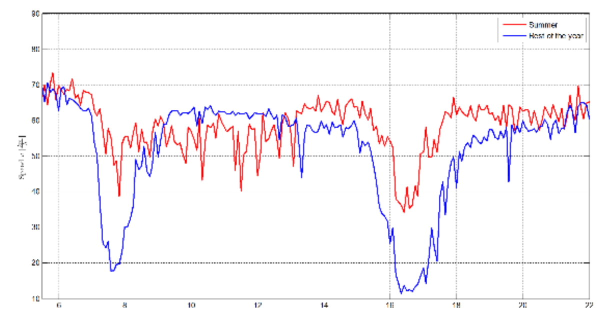
Rujan, 2019.

SADRŽAJ

1. Uvod
2. Prostorno-vremenski podaci
3. Prostorno-vremenske anomalije
4. Metode detekcije anomalija
5. Zaključak







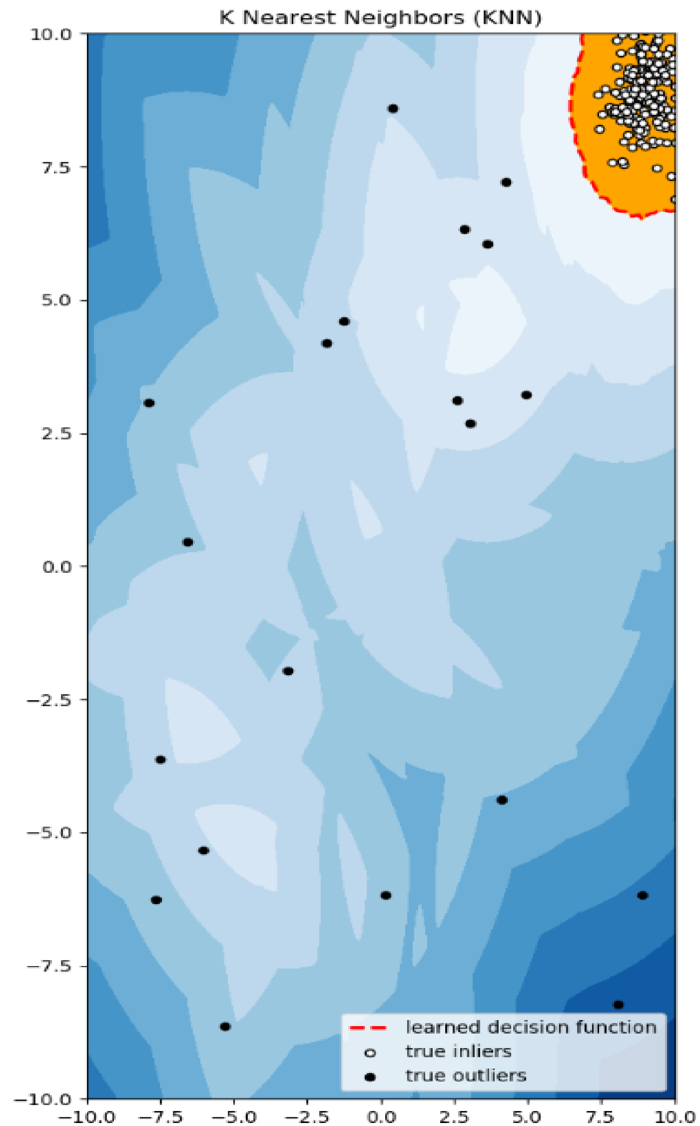
Uvod - Anomalije

Detekcija anomalija

problem pronalaska neočekivanog “ponašanja” podataka

Jedna od prvih definicija

anomalija je podatak koji se toliko razlikuje od ostalih podataka, da postoji opravdana sumnja da je generiran iz nekog drugog izvora [1]



[1] D. M. Hawkins, *Identification of Outliers*. London: Springer Science, 1980.

UVOD – MOTIVACIJA

SUSTAVI ZA DETEKCIJU ANOMALIJA SU VAŽAN DIO INTELIGENTNIH TRANSPORTNIH SUSTAVA (ITS)

aplikacije definirane nekim od jedanaest funkcionalnih područja ITS-a zahtijevaju neku vrstu sustava za detekciju anomalija [2]



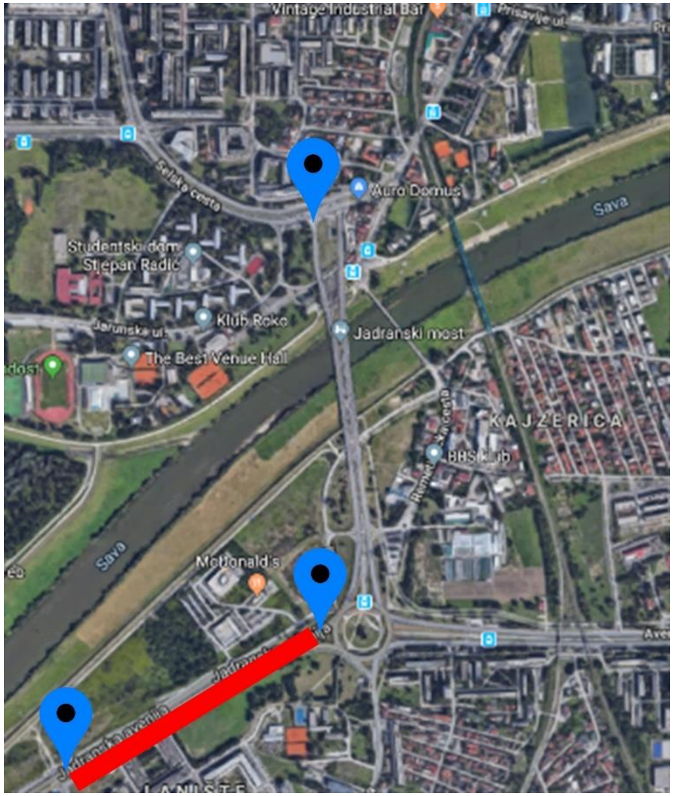


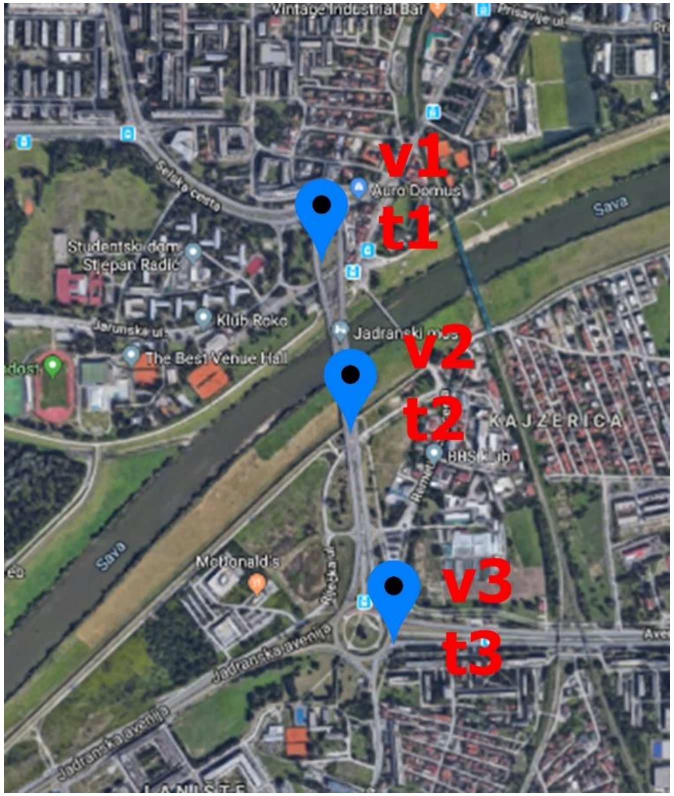
[2] ISO 14813-1:2015 - Intelligent transport systems - Reference model architecture(s) for the ITS sector - Part 1 2015. [Online] Available: https://www.iso.org/standard/57393.html.

Prostorno-vremenski podaci

Kombinacija

Prostornih i Vremenskih





PROSTORNO-VREMENSKI PODACI

IZVORI PODATAKA

Globalni Navigacijski Satelitski Sustavi (GNSS) – privatne osobe, javni gradski prijevoz, taxi

$$id\_korisnika, x\_korisnika, y\_korisnika, timestamp, \ldots$$

Mobilne mreže

$$id\_korisnika, timestamp, x\_stanice, y\_stanice, \ldots$$

Senzori na prometnicama

$$br\_vozila, brzina, timestamp, \ldots$$

Društvene mreže

[3] X. Kong, X. Song, F. Xia, H. Guo, J. Wang, and A. Tolba, "LoTAD : Long-Term Traffic Anomaly Detection Based on Crowdsourced Bus Trajectory Data," World Wide Web, vol. 21, no. 2018, pp. 825–847, 2018.
[4] F. Lipan and A. Groza, "Mining Traffic Patterns from Public Transportation GPS Data," in Proceedings of the 2010 IEEE 6th International Conference on Intelligent Computer Communication and Processing, 2010.

Prostorno-vremenski podaci

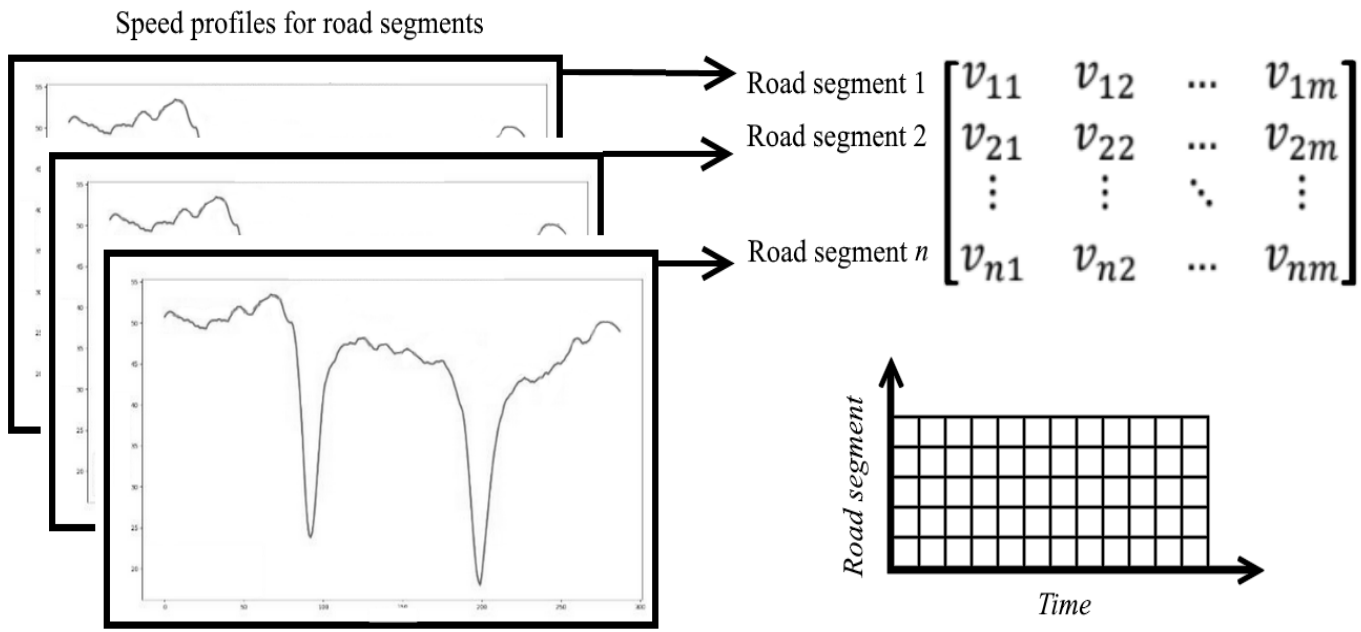
Uz detekciju anomalija, prostorno-vremenski podaci nalaze svoju primjenu u raznim područjima vezanim za transport

- Predviđanje stanja prometne mreže [5]
- Detekcija propagacije zagušenja [6]
- Pronalazak uzroka zagušenja [7]
- ...

[5] X. Ma, Z. Dai, Z. He, J. Ma, Y. Wang, and Y. Wang, "Learning traffic as images: A deep convolutional neural network for large-scale transportation network speed prediction," Sensors, vol. 17, no. 4, pp. 1–16, 2017.
[6] H. Nguyen, W. Liu, and F. Chen, "Discovering Congestion Propagation Patterns in Spatio-Temporal Traffic Data," IEEE Trans. Big Data, vol. 3, no. 2, pp. 169–180, 2017.
[7] F. Sun, A. Dubey, and J. White, "DxNAT - Deep neural networks for explaining non-recurring traffic congestion," in Proceedings - 2017 IEEE International Conference on Big Data, Big Data 2017, 2018, vol. 2018-January

NAČIN PRIKAZA PODATAKA - PROFILI BRZINA

$$M = \begin{bmatrix} SP_1 \\ SP_2 \\ \vdots \\ SP_n \end{bmatrix}$$



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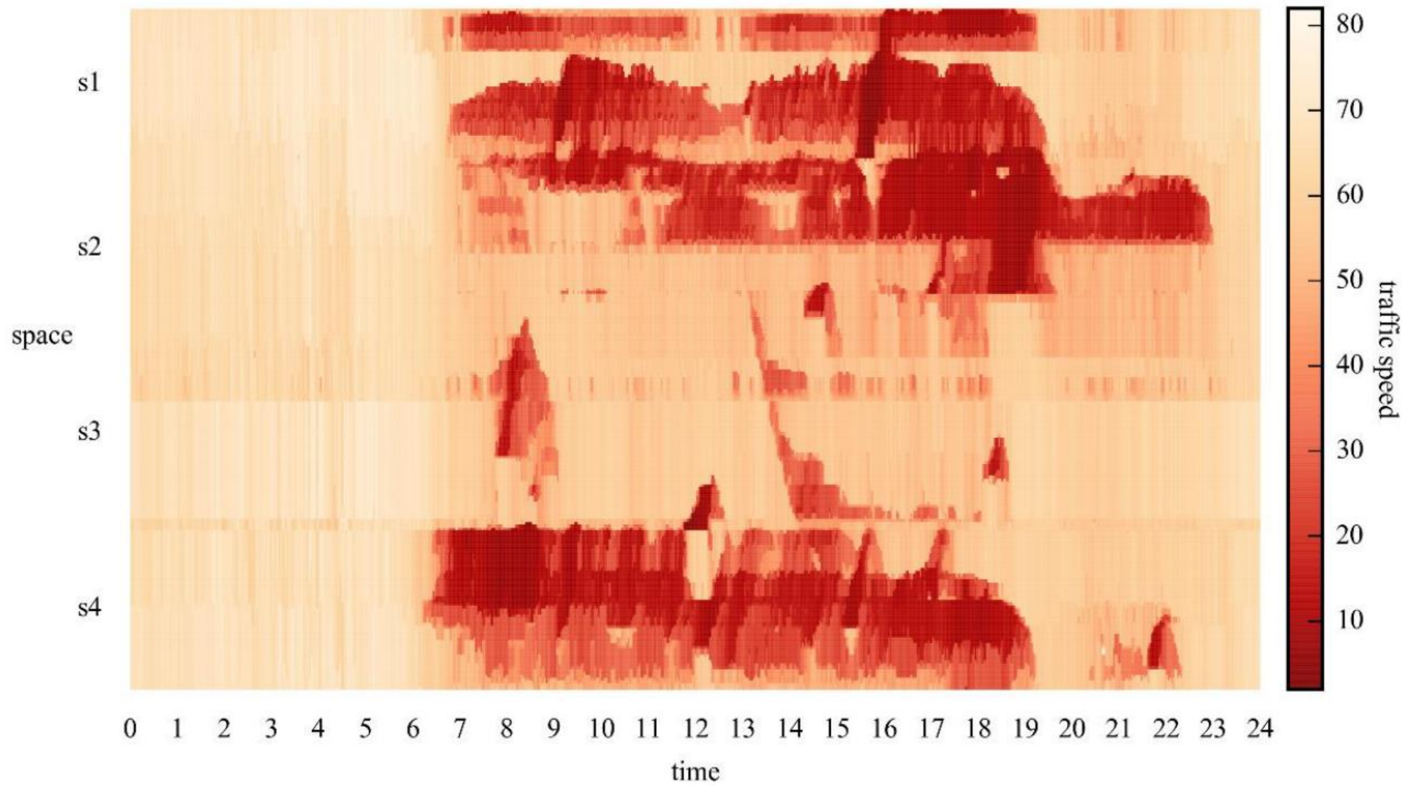


[5] X. Ma, Z. Dai, Z. He, J. Ma, Y. Wang, and Y. Wang, "Learning traffic as images: A deep convolutional neural network for large-scale transportation network speed prediction," Sensors, vol. 17, no. 4, pp. 1–16, 2017.

NAČIN PRIKAZA PODATAKA

Profili prometnog toka [8]

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1m} \\ v_{21} & v_{22} & \cdots & v_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ v_{n1} & v_{n2} & \cdots & v_{nm} \end{bmatrix}$$

Proizvoljna struktura [3]

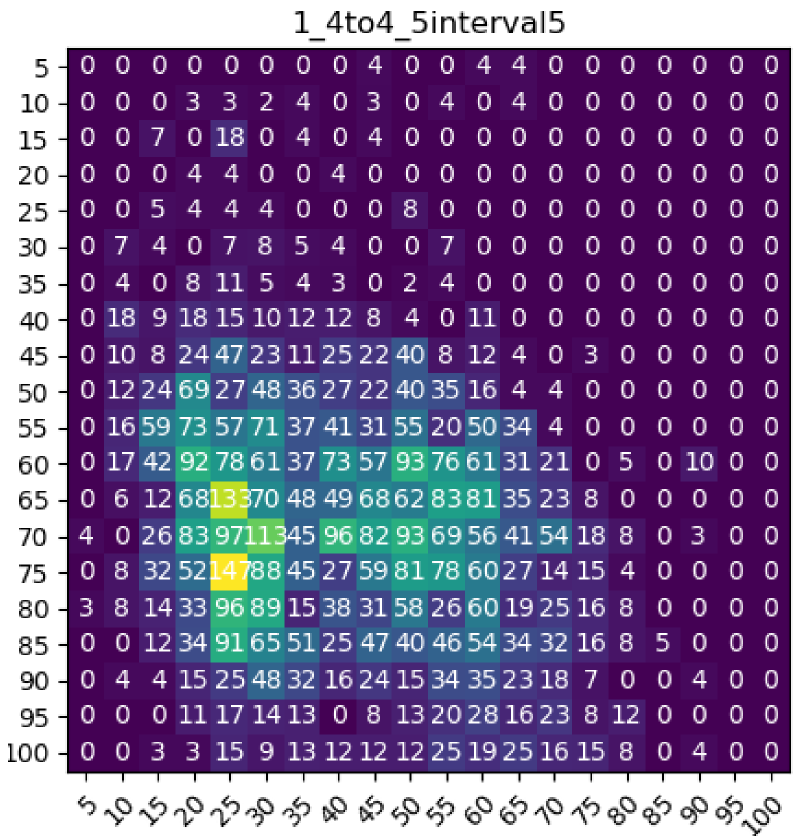
$$M = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix}$$

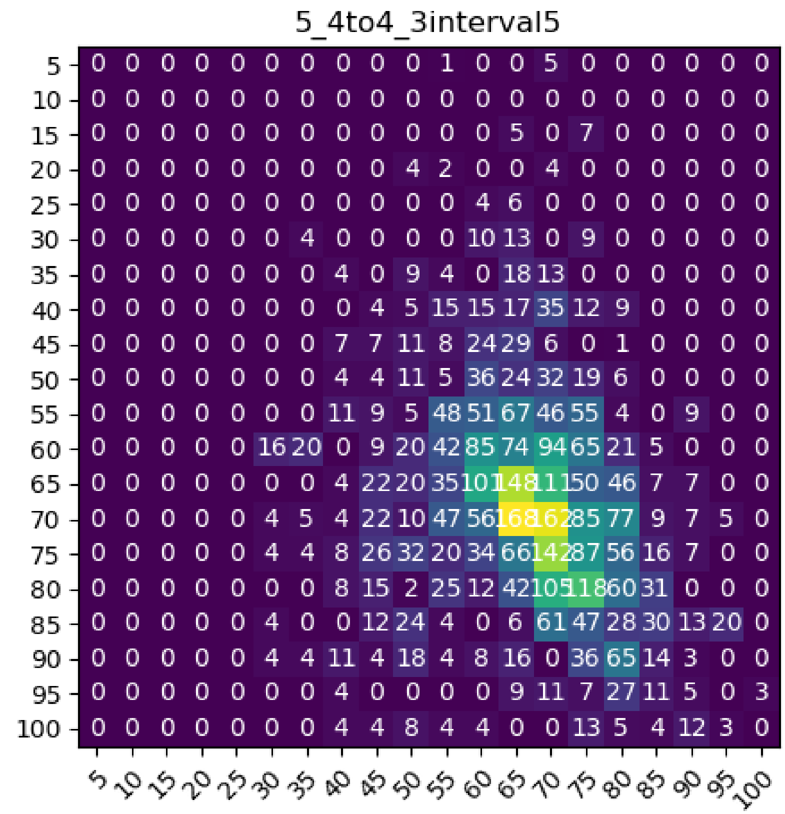
$$a_{ij} = (\bar{v}, \bar{t}_{stop})$$

$i \in 1, 2, \dots, n$ Cestovni segmenti
$j \in 1, 2, \dots m$ Vremenski intervali

[8] X. Liu, X. Liu, Y. Wang, J. Pu, and X. Zhang, "Detecting Anomaly in Traffic Flow from Road Similarity Analysis," *Lect. Notes Comput. Sci.*, pp. 92–104, 2016.

NAČIN PRIKAZA PODATAKA (PRIJELAZNE MATRICE)

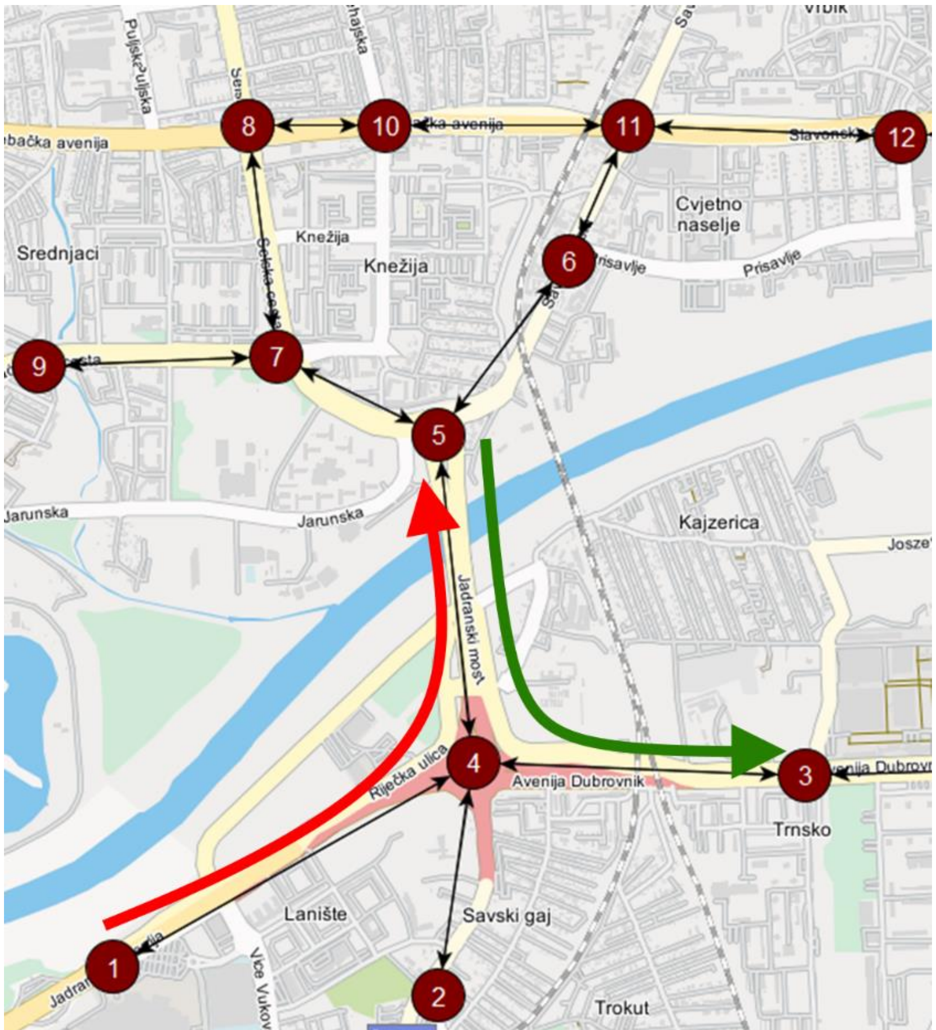




[9] J. Topić, B. Škugor, and J. Deur, "Neural Network-Based Modeling of Electric Vehicle Energy Demand and All Electric Range," Energies, vol. 12, no. 1396, pp. 1–20, 2019.

Prostorno-vremenski podaci

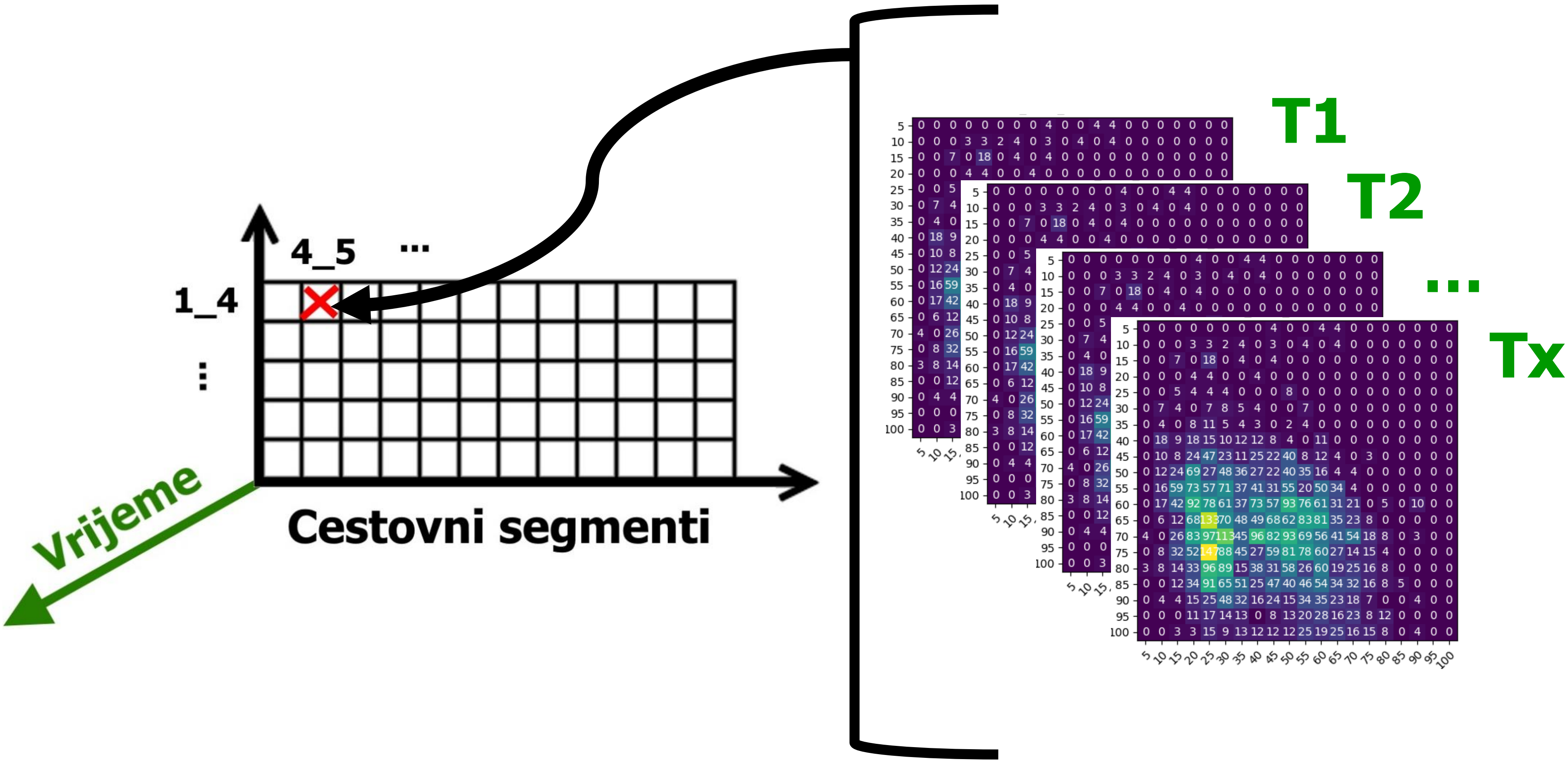
Način prikaza podataka (Prijelazne matrice)



1_4 → 4_5

5_4 → 4_3

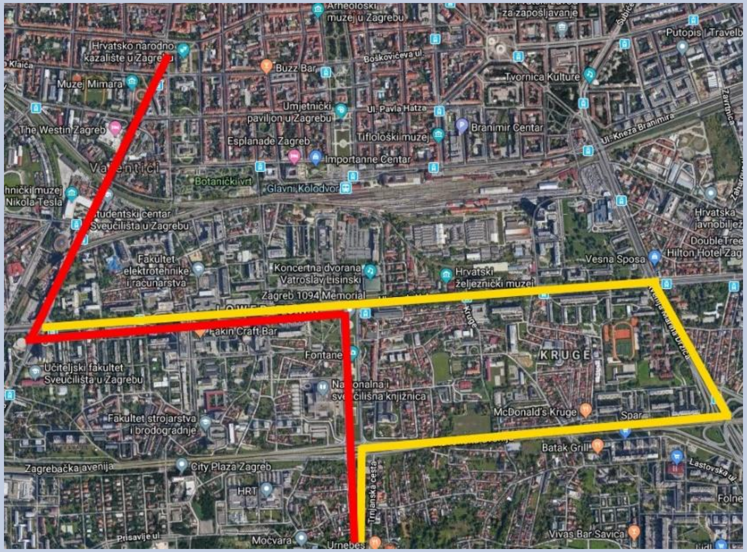
NAČIN PRIKAZA PODATAKA (PRIJELAZNE MATRICE)

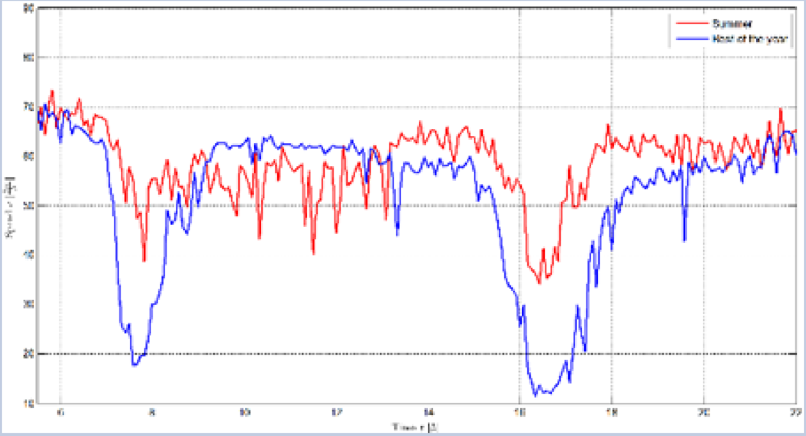


Podjela pristupa

Generalna podjela	Anomalije u trajektorijama *(engl. Trajectory anomaly)*		Anomalije u prometnom toku *(engl. Traffic anomaly)*
Prema metodama	Zasnovane na modelu *(engl. Model based)*	Zasnovane na udaljenosti *(engl. Proxyimity based)*	Zasnovane na gustoći *(engl. Density based)*
Prema implementaciji	Uzorak usmjeravanja *(engl. Routing patterns)*	Razina anomalije *(engl. Anomaly scoring)*	Podjela na regije *(engl. Region-based methods)*

PODJELA PRISTUPA





Anomalije u trajektorijama

Anomalije u prometnom toku

PODJELA PRISTUPA

ANOMALIJE U TRAJEKTORIJI

odnose se na detekciju anomalija koje su vezane za trajektoriju jednog vozila

Primjeri:

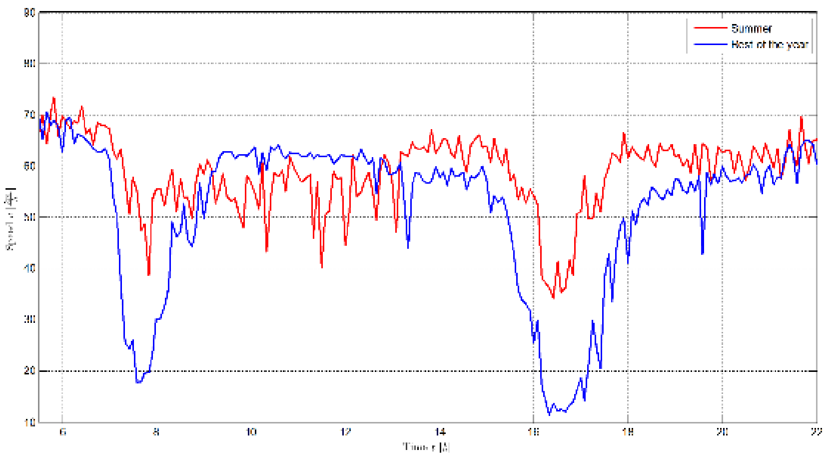
- Detekcija prevare prilikom vožnje taksijem [10]
- Detekcija opasnih vozača [11]

[10] C. Chen, D. Zhang, P. S. Castro, N. Li, L. Sun, and S. Li, "Real-Time Detection of Anomalous Taxi Trajectories from GPS Traces," in *Mobile and Ubiquitous Systems: Computing, Networking, and Services*, 2012, pp. 63–64.
[11] Y. U. Zheng, "Trajectory Data Mining : An Overview," ACM Trans. Intell. Syst. Technol., vol. 6, no. 3, pp. 1–41, 2015.

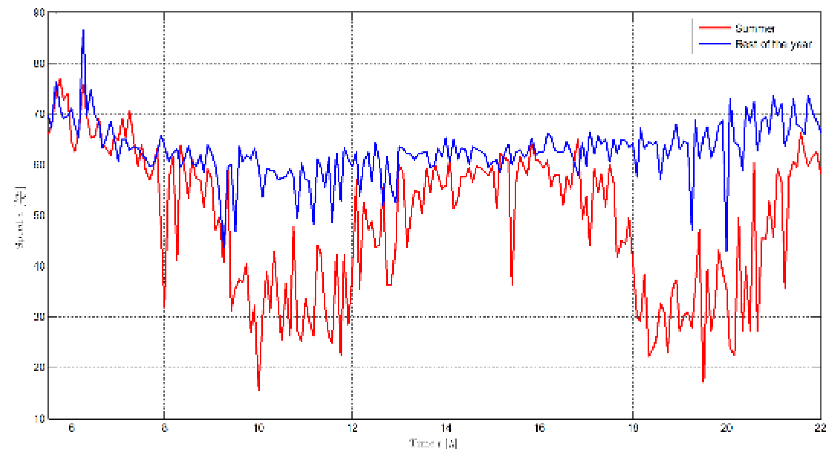
PODJELA PRISTUPA

PROMETNE ANOMALIJE

vezane za anomalije nekog od prometnih parametara (npr. brzina, volumen…) [6][12]



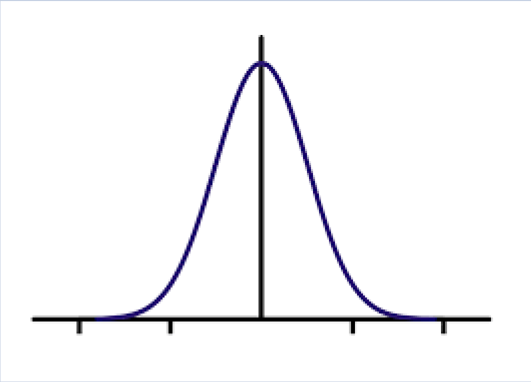
a) Speed profiles for the City of Zagreb



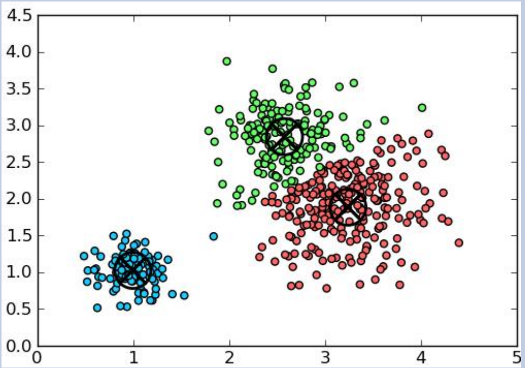
b) Speed profiles for the City of Zadar

[12] W. Liu, Z. Yu, S. Chwala, J. Yuan, and X. Xie, "Discovering Spatio-Temporal Causal Interactions in Traffic Data Streams," in Proceedings of the 17th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, 2011, pp. 1010–1018.

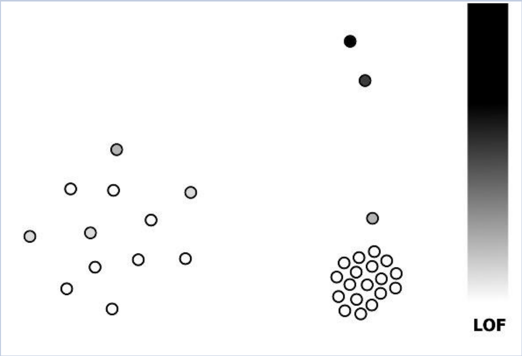
PODJELA PRISTUPA - METODE



Zasnovane na modelu



Zasnovane na udaljenosti



Zasnovane na gustoći

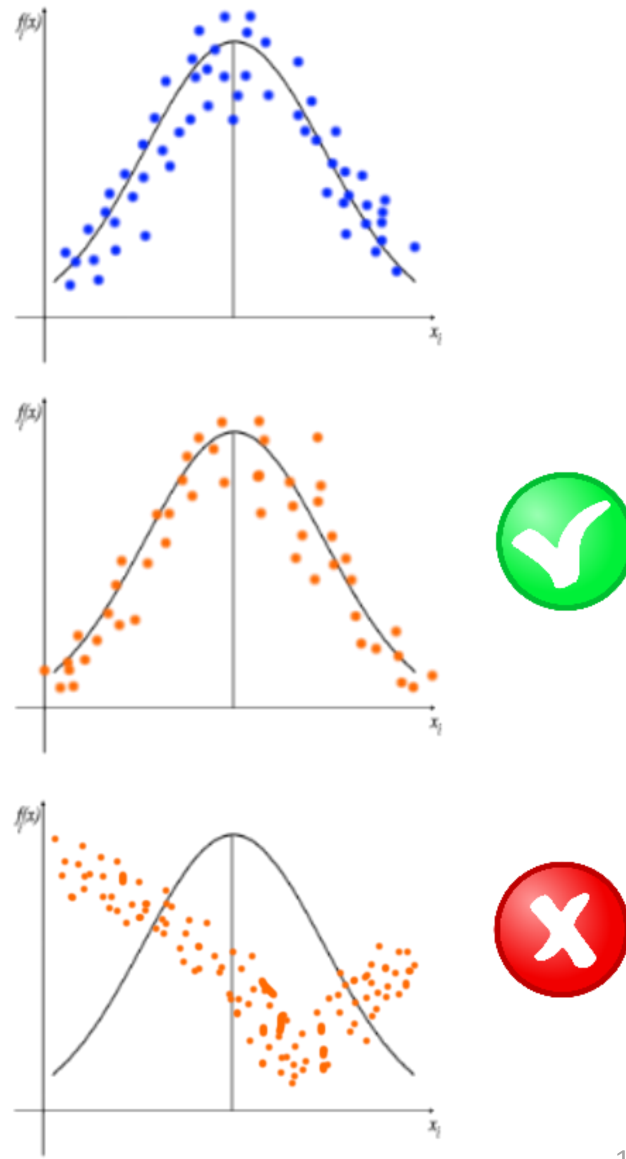
Podjela pristupa - Metode

Zasnovane na modelu

opisivanje podataka nekom od distribucija (npr. normalna)

Novi set podataka se uspoređuje s modelom.

Najčešća upotreba je u svrhu klasifikacije



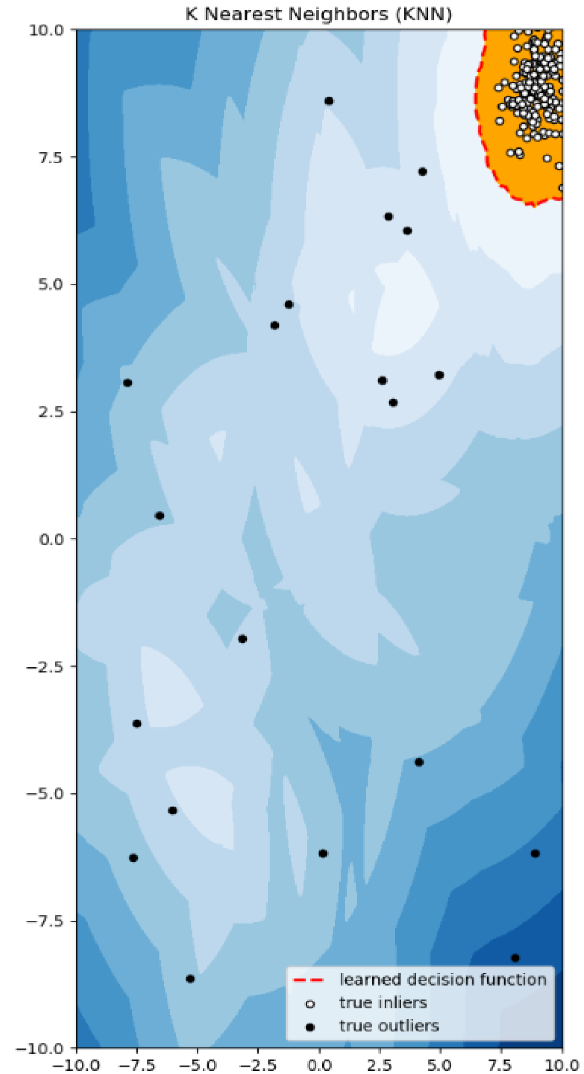
PODJELA PRISTUPA - METODE

ZASNOVANE NA UDALJENOSTI

anomalije su one vrijednosti koje su najudaljenije od vrijednosti koje se smatraju očekivanima

Npr. k-means algoritam

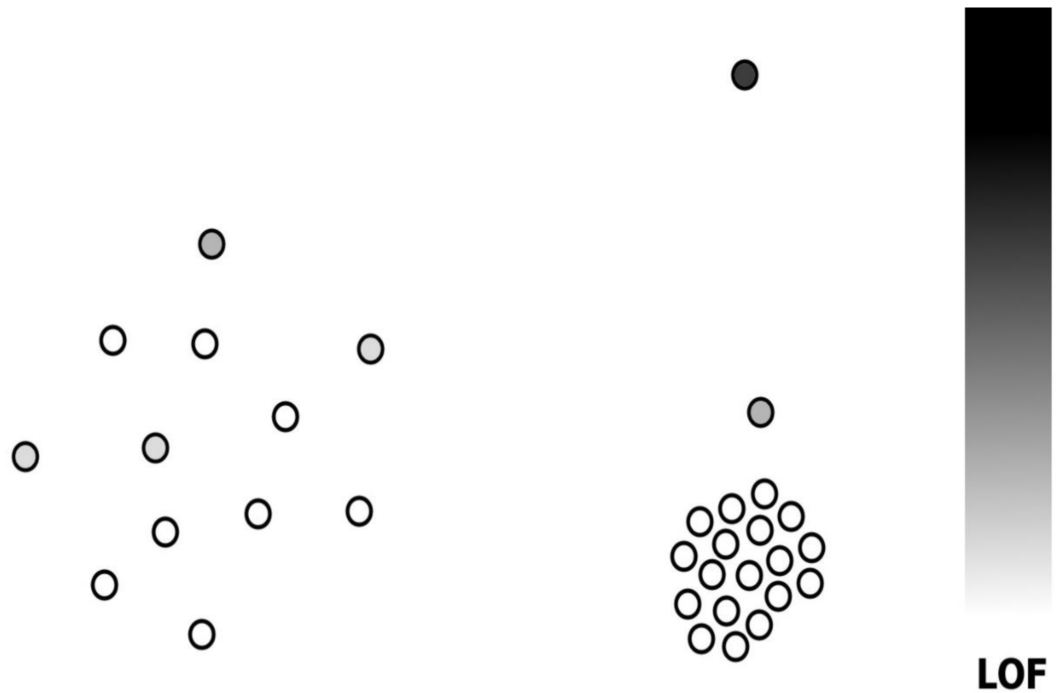
$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \|x_i^{(j)} - c_j\|^2$$



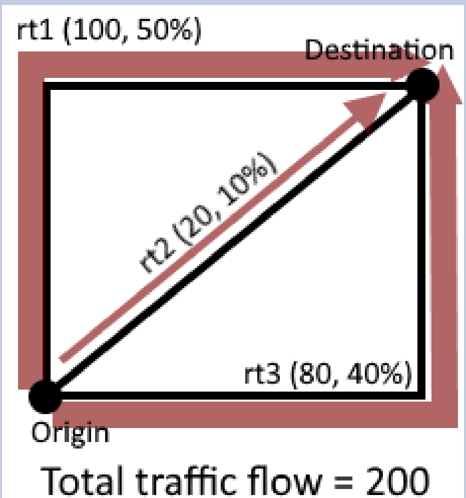
PODJELA PRISTUPA - METODE

ZASNOVANE NA GUSTOĆI

anomalije su one vrijednosti koje su najraspršenije u odnosu na vrijednosti koje se smatraju očekivanima



Podjela pristupa - Implementacija



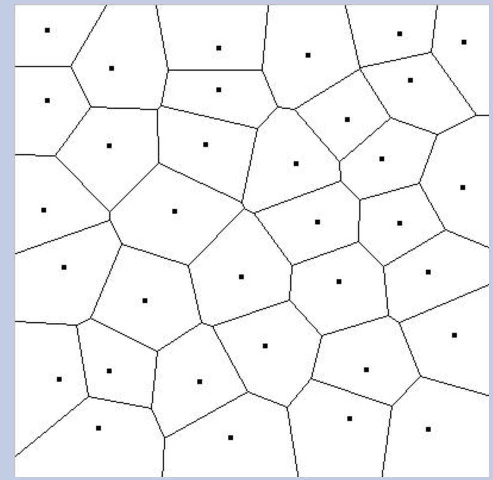
Uzorak usmjeravanja (engl. *Routing patterns*)

$$O = [o_1, o_2, \dots, o_n]$$

$$S(o_i) > S(o_j)$$

$$\text{for every } o_j \in O$$

Razina anomalije (engl. *Anomaly scoring*)

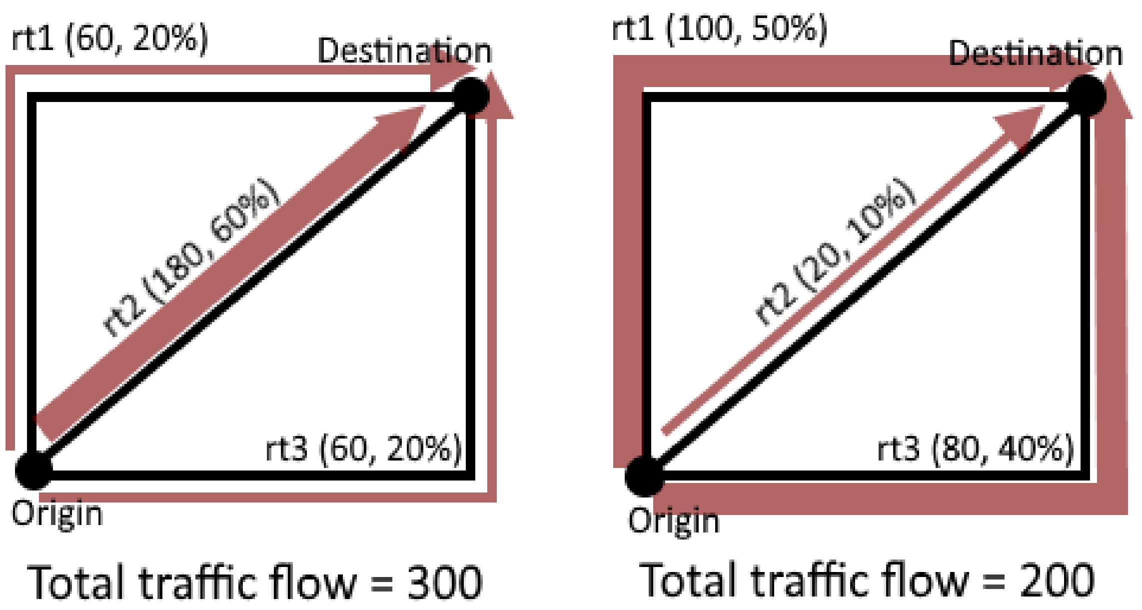


Podjela na regije (engl. *Region-based methods*)

Podjela pristupa - Implementacija

Prema uzorku usmjeravanja

Primjer 1 [13]



$$[f_1, p_1, f_2, p_2, \dots, f_n, p_n,]$$

[13] B. Pan, D. Wilkie, and C. Shahabi, "Crowd Sensing of Traffic Anomalies based on Human Mobility and Social Media Categories and Subject Descriptors," *ACM International Symposium on Advances in Geographic Information Systems*, 2013, pp. 344–353.

Prema uzorku usmjeravanja

Primjer 1 [13]

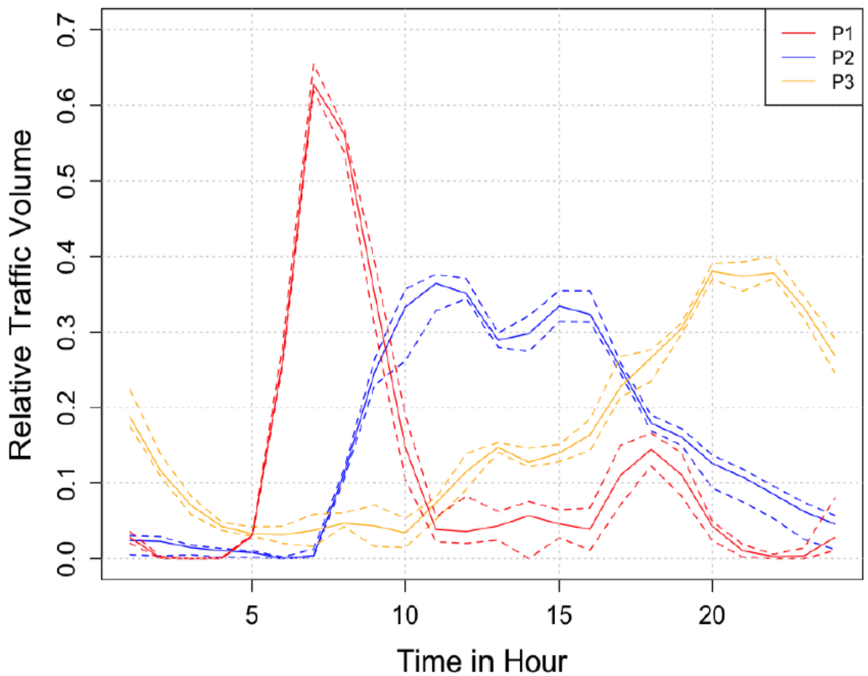
Anomalija je detektirana ako je udaljenost između uzorka usmjeravanja i srednjeg uzorka usmjeravanja veća za 3 standardne devijacije:

$$d_M\left(RP_{t1}, \mu_{[t_0,t_1\rangle}\right) \geq 3 \sqrt{\frac{1}{N} \sum_{t \in [t_0,t_1\rangle} \left(RP_t - \mu_{[t_0,t_1\rangle}\right)^2}$$

Podjela pristupa - Implementacija

Prema uzorku usmjeravanja

Primjer 2 [8]



Nonnegative Matrix Factorization (NMF)

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1m} \\ v_{21} & v_{22} & \cdots & v_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ v_{n1} & v_{n2} & \cdots & v_{nm} \end{bmatrix}$$

$$V \approx CP$$

$C \in \mathbb{R}^{n \times r}$ Matrica koeficijenata

$P \in \mathbb{R}^{r \times m}$ Matrica uzoraka

r Broj uzoraka

Podjela pristupa - Implementacija

Razina anomalije

ne postoji jednoznačna definicija anomalije, stoga postoji mnogo načina određivanja razine anomalije

$$S_{it}^{d} = \beta P_{a}^{T}\left(v_{it}^{d}\right) + (1-\beta)P_{r}\left(v_{it}^{d}\right) \text{ [8]}$$

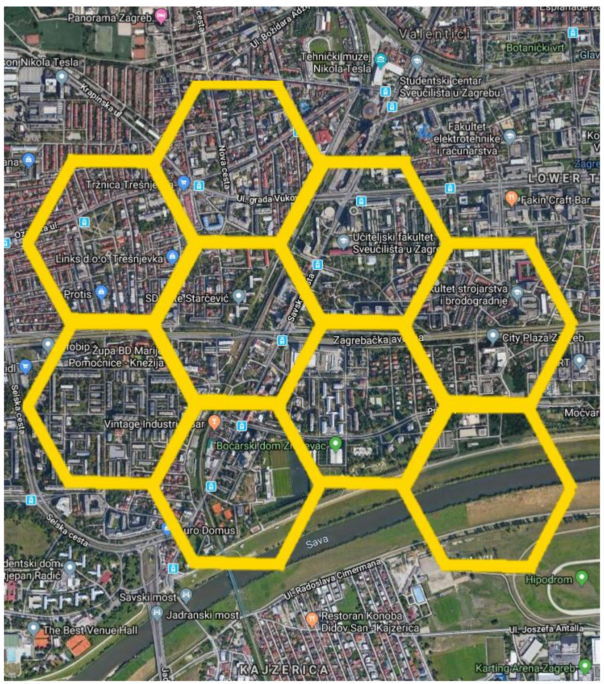
$$AI_{i} = \frac{\sum_{j \in M} \frac{density_{i}}{density_{j}}}{size(M)} \text{ [3]}$$

$$d_{M}\left(RP_{t1}, \mu_{[t_0,t_1\rangle}\right) \geq 3\sqrt{\frac{1}{N}\sum_{t \in [t_0,t_1\rangle}\left(RP_{t} - \mu_{[t_0,t_1\rangle}\right)^{2}} \text{ [13]}$$

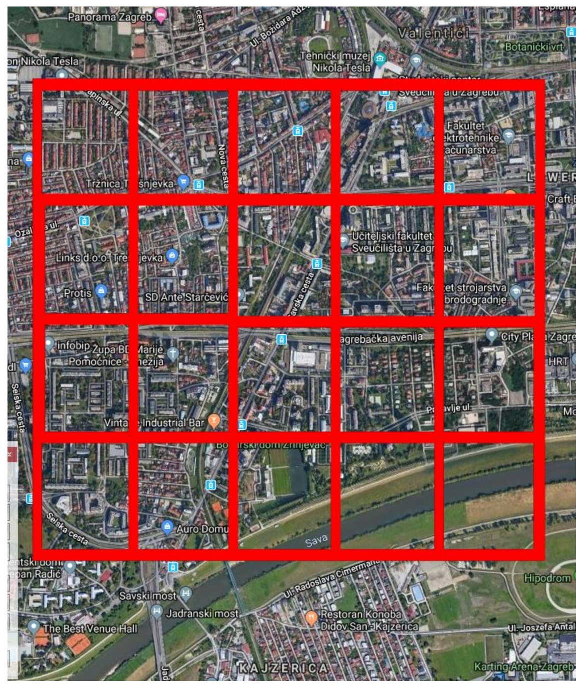
PODJELA PRISTUPA - IMPLEMENTACIJA

PODJELA NA REGIJE

najčešće se određuje razina anomalije za geografski definirano područje



Heksagonalne ćelije



Raster polja

Voronojeve ćelije

ZAKLJUČAK

Detekcija anomalija vrlo je važan dio mnogih ITS aplikacija (putno informiranje, upravljanje prometom, …)

Buduća istraživanja:

1) NOVA STRUKTURA PROSTORNO VREMENSKIH PODATAKA I ALGORITMI ZA DETEKCIJU ANOMALIJA
2) OPISIVANJE UZROKA NASTANKA ANOMALIJA
3) RAZVOJ METODA ZA DETEKCIJU ANOMALIJA KORIŠTENJEM METODA DUBOKOG UČENJA

[14] L. Tišljarić, M. Erdelić, T. Erdelić, T. Carić, „Traffic State Estimation Using Speed Profiles and Convolutional Neural Networks," MIPRO 2019, Opatija, 2019.

Hvala Vam na pažnji!

LITERATURA

- [1] D. M. Hawkins, *Identification of Outliers*. London: Springer Science, 1980.
- [2] ISO 14813-1:2015 - Intelligent transport systems - Reference model architecture(s) for the ITS sector - Part 1 2015. [Online]. Available: https://www.iso.org/standard/57393.html.
- [3] X. Kong, X. Song, F. Xia, H. Guo, J. Wang, and A. Tolba, “LoTAD : Long-Term Traffic Anomaly Detection Based on Crowdsourced Bus Trajectory Data,” World Wide Web, vol. 21, no. 2018, pp. 825–847, 2018.
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- [10] C. Chen, D. Zhang, P. S. Castro, N. Li, L. Sun, and S. Li, “Real-Time Detection of Anomalous Taxi Trajectories from GPS Traces,” in *Mobile and Ubiquitous Systems: Computing, Networking, and Services*, 2012, pp. 63–64.
- [11] Y. U. Zheng, “Trajectory Data Mining : An Overview,” ACM Trans. Intell. Syst. Technol., vol. 6, no. 3, pp. 1–41, 2015.
- [12] W. Liu, Z. Yu, S. Chwala, J. Yuan, and X. Xie, “Discovering Spatio-Temporal Causal Interactions in Traffic Data Streams,” in Proceedings of the 17th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, 2011, pp. 1010–1018.
- [13] B. Pan, D. Wilkie, and C. Shahabi, “Crowd Sensing of Traffic Anomalies based on Human Mobility and Social Media Categories and Subject Descriptors,” *ACM International Symposium on Advances in Geographic Information Systems*, 2013, pp. 344–353.
- [14] L. Tišljarić, M. Erdelić, T. Erdelić, T. Carić, „Traffic State Estimation Using Speed Profiles and Convolutional Neural Networks,” MIPRO 2019, Opatija, 2019.