# Automatic incident detection along freeways using spatiotemporal Bluetooth data

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**Abstract.** Magnetic induction loop detector technology is considered as the traditional and reliable sensors for monitoring the traffic flow at freeways. These detectors are used to monitor traffic on freeways, and many automatic incident detection models have been developed based on this detector data. However, the magnetic induction loop detectors installation is complicated and expensive. This research focuses on a special group of cross-sectional sensors, Bluetooth readers, as a "low-cost" replacement for loop detectors. In this work, a novel deep-learning algorithm was developed to automatically detect incidents in an unsupervised fashion based on Geotagged Bluetooth readings only. Preliminary experiments show promising results in correctly detecting road incidents.

**Keywords.** Geotagged Big-Data, GIS-based urban analytics, Deep-learning, Automatic Incident Detection

## 1. Introduction

With the rise of the information era, cities start to integrate various physical devices (Internet of Things) to optimize the efficiency of city operations and services, and to connect citizens. These cities are commonly categorized as Smart Cities. Smart city technology allows city officials to interact directly with the city's infrastructure, and to monitor what is happening in the city. One of the critical needs for such interaction is transportation. In today's urban environment, the ability to forecast future traffic conditions, like travel time, speed and flow, are crucial. This is vital information not just for the benefit of traveler's route planning but also for city authorities who seek to know in real-time the reason for temporal congestion at a route node, whether it is a recurring congestion pattern or incident congestion.

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Automatic incident detection (AID) along freeways is a challenging task due to the prominent level of variance in traffic behavior. The needed data collection and its processing require expensive resources allocation for freeway sensor installation and for their continuous operating. Although radar and video detection technologies for traffic monitoring have been implemented in several urban transportation management systems, magnetic induction loop detector technology continues to be common (Williams et al., 2007), and for many years, they are considered as the traditional and reliable sensors for monitoring the traffic flow at freeways. However, the magnetic loop detectors installation is complicated and expensive.

This research focuses on a special group of cross-sectional sensors, which has the ability to receive data only from a sample of the vehicles at the cross-section and to re-identify these vehicles at other cross-sections over the traffic network. The type of sensors that this research will mostly refer to is the Bluetooth readers, since this is a relatively innovative technology for traffic sensing with a grown potential to have a high penetration rate: most navigation/entertainment systems in vehicles today are equipped with Bluetooth sensors, meaning that approximately 15-20% of all vehicles are documented in the Bluetooth reader network. Those sensors are easy to deploy, and their privacy issues can be addressed (Friesen et al., 2015). In this study we formulate the problem of incident detection as anomaly detection in Big-Data, and solve it with a deep-learning algorithm, DeepAID, we developed. Deep-learning is known to perform better than traditional machine-learning methods when it comes to large volumes of data, as will be presented in the promising preliminary results.

## 2. Methodology

Traffic incidents are anomalies compared to usual hour traffic, thus the problem of incident detection can be transformed into the anomaly detection problem. This means that it can be described as a task where the goal is to model the time-series data and, given this model, find regions where the predicted values are too different from the actual ones. Thus, the method developed in this research for AID for freeways is based on anomaly detection, known as an unsupervised learning methodology, and the use of the data provided by Bluetooth sensors. Such learning methodology does not require incident information (a.k.a. Labels) to train and build the model. The algorithm developed in this research, depicted in Figure 1, is based on CNP (Conditional Neural Process). CNPs are inspired by the flexibility of stochastic processes, such as Gaussian processes, but are structured as neural networks (Garnelo et al., 2018).

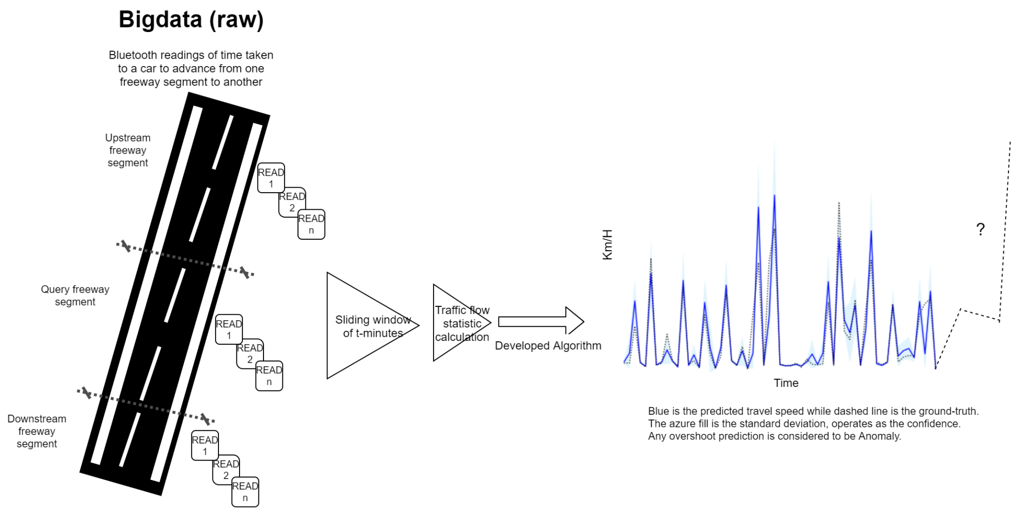


**Figure 1.** A high-level depiction of the automatic road incident detection algorithm.

The algorithm flow, depicted in Figure 1, is given as follows:

1) Raw samples (Travel Time) are bucketed into windows of size t-minutes.
2) Each window, i.e., context-point, is aggregated by its speed and the traffic flow. Spatiotemporal statistics are calculated, as follows:
    a. Time of the day measured in 1 minute time intervals, t.
    b. Velocity in query segment during the time interval t.
    c. Relative change of velocity in the query segment with respect to the previous time interval.
    d. Relative change of velocity with respect to upstream.
    e. Relative change of velocity with respect to downstream.
    f. Relative change of velocity with respect to upstream at the previous time interval.
    g. Relative change of velocity with respect to downstream at the previous time interval.
3) The inputs for the algorithm are C number of context points, at the current segment; supposedly, the more the context points the more confident model with the prediction.
4) The algorithm forecasts T number of target points (context-points in the future) with their confidence; any target point in the current segment that is out of the confidence interval is considered an anomaly. Since an overshoot anomaly exceeds the confidence interval, a consecutive set of overshoot anomalies is an unambiguous measure for an incident because incidents cause unexpected slowdowns. Figure 2 depicts an example of a consecutive set of overshoot anomalies, indicating a road incident at the red circle.

The algorithm exploits neural processes in a way that models Big-Data - like Bluetooth spatiotemporal sensory readings - in order to detect freeway incidents automatically. Some of the algorithm novelties include:

1) Not posed to pre-determined input or output lengths but offering dynamic input and output sizes.
2) Model interpretability – the model's output mean and STD velocity values are easy to visualize.
3) Unsupervised training methodology (no labels are needed).

## 3. Preliminary Results

The algorithm was tested and analyzed on real traffic data collected by Bluetooth sensor readers placed along the Ayalon Highway, Tel-Aviv, Israel. The freeway traffic flow was aggregated by its raw speeds [km/hour] measured by the Bluetooth sensors in time-windows of size 1 minute. The data were collected during August 2017, and corresponds to an 11 km segment that is divided into 7 sections, quantified in millions of Bluetooth readings. Respectively, some traffic incidents during that month were recorded by the freeway operator, and were used to assess the algorithm quality in automatically detecting road incidents. The algorithm analysis was performed on several case studies, the most important one depicted in Figure 2, using 5 central cross-sections due to the need for data corresponding to the downstream and upstream sections. In Figure 2, the green line corresponds to the algorithm input (context, ground truth); the blue line depicts the algorithm output (context and target prediction); the dashed black line depicts the ground truth speed flow; the light blue buffer depicts the prediction confidence (in STD). It is apparent that the developed algorithm qualitatively models anomalies with high confidence values, clearly showing road incidents.

## 4. Conclusions and Future Work

This research presents an algorithm that structures spatio-temporal descriptors as neural-networks, DeepAID, to mine and interpret road incidents by learning to differentiate between the normal to the abnormal. This algorithm opens new opportunities in road incident detection based on travel time and other spatiotemporal data. It shows that Bluetooth sensors can be used to automatically detect road incidents on freeways without the use of other data. Further research is required in order to model trends in time more precisely.

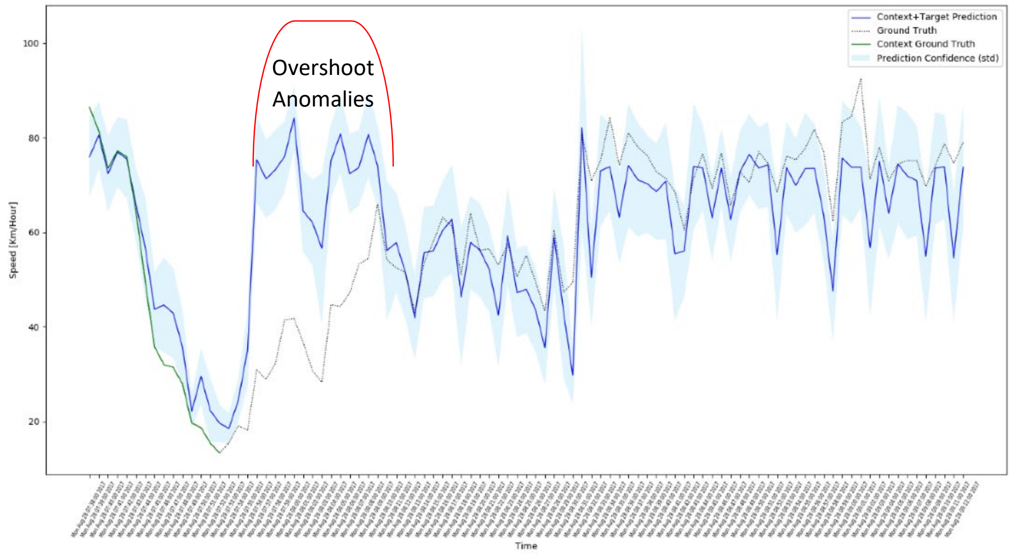


**Figure 2.** Automatic road incident detection and model generalization – the algorithm detects an incident (in red) caused by car accident along a testing freeway segment. The traffic slowdown afterward is reflected with consecutive set of overshoot anomalies. Moreover, it successfully models and predicts traffic flow on never-seen freeway segment data.

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