ABSTRACT
Nowadays, the public transportation safety situation continues to deteriorate, and malignant incidents occur sometimes. Therefore, there is great need for the improvement of safety levels by the authorities. To this end, we propose PTEMS, a novel public transportation emergency management system based on GIS, aiming to help the authorities solve the problem. The system is capable of collecting and managing extremely large amounts of monitoring data, enabling the emergency enforcement to respond to the incidents effectively. The validity and reliability of our design is demonstrated by its real-world deployment.

Keywords
Public transportation safety, system architecture, GIS, path planning, crime hotspot prediction

1. INTRODUCTION AND MOTIVATION
As the society develops fast, car ownership of the whole world increases greatly, and the growing intensity urban traffic has become a very much pending issue yet to be settled. In addition to ordinary traffic incident, traffic crimes, such as vehicle theft, vehicle robbery, and vehicle arson, have negative impact on people’s life and undermine the social stability.

Public transportation vehicles are prone to serious traffic crimes, which may lead to heavy casualties and losses. On Jun 5, 2009, a mass murder-suicide attack occurred on a bus in Chengdu, Sichuan, China. It resulted in 27 deaths, and 76 injuries [1]. On Dec 22, 2011, seven passengers were killed in a spree of shooting attacks on buses in northern Mexico [2]. During the first half of 2012, there were 811 cases of kidnapping in Ecuador, about 30% of them used taxis [3].

As a result, the improvement of the management efficiency of public transportation vehicles in the public transportation safety situation becomes an urgent issue to be solved. To this end, we propose a novel public transportation emergency management system based on GIS in this paper. We make use of the spatial visualization, spatial navigation and spatial thinking features of Geographic Information System (GIS) to provide a more intuitive way to monitor the status of public transportation vehicles, to optimize paths for the police force to reach the public transportation crime scene, and to analyze public transportation crime hotspot trend to guide policeman deployment.

The remainder of this paper is organized as follows: Section 2 surveys the related work of PTEMS; Section 3 introduces PTEMS design in detail; Section 4 describes the key technology used by PTEMS, with the real-world system deployment description given in Section 5. At last, Section 6 concludes the paper.

2. RELATED WORKS
GIS is a computer system for capturing, managing, integrating, manipulating, analyzing and displaying data which is spatially referenced to the earth, and it is a comprehensive application system developed which integrates geography, geometry, computer science and all the application objects [4]. It is widely used in a variety of fields, such as finance, communication, transportation, land resource, power, irrigation, forestry, environment protection, mining and other sectors.

In the transportation emergency management field, GIS provides the forum within which transportation data can be layered with base maps and other geographic data that represent the landscape of the area where the transportation data is associated. Combined with data monitoring technology of Remote Sensing (RS) and data collecting technology of Global Positioning System (GPS), GIS has been extensively used in transportation emergency management.

Fabien, et al. developed a methodology by gathering data from the GPS trace, matching it to the planned routes within in a GIS and then use mathematical algorithms to propose a new schedule with new routes to achieve real-time route planning and arrangement [5]. Isabelle, et al. used pub-
lic participation geographic information systems (PPGIS) mapping and GPS tracking to monitor mountain bikers frequenting national parks for tourism and recreation [6]. Some researchers also focus on application and management of public transportation safety based on GIS. They established forewarning systems for analyzing, forecasting and evaluating the accident spots based on the local landform and physiognomy and the characteristics of accidents, which gives the alarm on the basis of real time data matching results [7]. However, none of them takes into accout crime and police service, and therefore unable to solve the problem of deterioration of public transportation safety level.

3. PTEMS: DESIGN

In this section, we first introduce the design philosophy of PTEMS briefly. Then we present the architecture of our design and its main components. At last, we elaborate on the key functions of PTEMS in detail.

3.1 Design Philosophy

The design of PTEMS follows the concept of “awareness, transmission, perception and usage”, which is widely adopted by public safety related systems. Awareness means monitoring the situation of public transportation and sensing abnormal status in time. Transmission means letting back-end business system acquire the sensing result in a reliable and efficient way. Perception means understanding the intrinsic meaning of the sensing data and predicting the development tendency of the public transportation incident. Finally, usage means helping corresponding personnel for decision making and incident handling.

By the seamless integration of awareness, transmission, perception and usage, PTEMS is able to help the authorities to establish awareness of the public transportation safety situation, from both macroscopic and microscopic view, and improve the safety level effectively.

3.2 System Architecture

Fig. 1 illustrates the basic architecture of PTEMS. It is mainly composed of five layers:

1) Information Awareness Layer: It is composed of a series of hardware devices equipped in taxis, buses and coaches, including camera, mobile digital video recorder (MDVR), GPS module, anomaly detection sensor and one-key alarm button. The camera is used to monitor the situation inside the vehicle. MDVR contains large capacity hard drives and is able to store monitoring videos of different formats. GPS module is used to locate vehicles, and anomaly detection sensor is responsible for vehicle abnormal behavior awareness, such as abnormal door open, overspeed, etc. In addition to this, when emergency happens, the drivers or passengers could press the one-key alarm button to generate an alarm signal. The monitoring video, vehicle position, abnormal situation and alarm signal are sent to the remote servers by built-in communication modules.

2) Business Support Layer: It provides infrastructure services for the upper-layer business application. In the proposed architecture, it consists of three basic services, including geographic information service, data access service, and security and authentication service, respectively. Geographic information service provides spatial information management, analysis and visualization. Data access service is responsible for the availability and partition tolerance guarantee of mass access data (i.e., GPS data, video data, etc.). Security and authentication service provides a unified access portal for both bottom-layer devices and top-layer end users, and any unauthorized devices or users will be refused to get access to the databases and business servers.

3) Data Layer: It is in charge of heterogeneous data storage. Seven types of databases are supported in this layer. Geographic information system stores electronic map, remote sensing image, natural geographic information, and social attribute information. Basic information database stores public-transportation-safety-related department information, contact information, system user information, user role information, authorization administration information, and configuration information. Vehicle information database stores vehicle information, affiliated unit information, and driver information. Device information database stores serial number the manufacturer, version, remote server IP, port, and electronic fence configuration. Location information database stores vehicle license number, longitude, latitude, speed and direction. Video database stores video starting time, video length, video format and video storage paths. Alarm database stores license number of the alarm vehicle, alarm time and alarm position.

4) Business Application Layer: it is the most important layer in our design, which performs core functions to ensure the efficiency of public vehicles management and safety of public transportation. It contains four business systems, including data management system, vehicle monitoring and management system, emergency enforcement scheduling system, and incident hotspot prediction system. We will describe their function in detail in the next subsection.

5) User Layer: the system is designed to provide services for three types of users. For the transportation management bureau, PTEMS facilitates the overall management of vehicles and drivers information, operation status monitoring of public transportation and response to ordinary traffic accident. For the public vehicles operating company,
PTEMS helps to manage company information, plan the route of operating vehicles and monitor the vehicle status. For the police service center, PTEMS helps to solve public transportation criminal cases and improve the effectiveness of police deployment.

### 3.3 System Function

1. **Data Management**: The data managed by the system is stored in the data layer mentioned in the sub-section. Any basic data update, such as license plate number change, monitoring device replacement, driver demission or road reconstruction are reflected in the system. In this way, the user is provided with the latest basic information and ensure that data stored in the database is valid.

2. **Vehicle Monitoring and Management**: In normal times, system user could set paths or regions for the specific vehicle in advance. By trajectory tracking using locating information, the user may know whether the travel path of the vehicle deviates from the preset path. During the process of vehicle running, if the door opens unexpectedly or the driving speed is out of the range (both overspeed and underspeed) of regulated speed, the user would be informed likewise. Moreover, the status of data collection device is monitored, and when device exception occurs, such as abnormal temperature, GPS signal loss, antenna abnormality, camera shielding, power failure, etc., the situation would be reported. When emergency occurs, for example, traffic accident, armed robbery, kidnapping, etc., drivers or passengers may press the one-key alarm in secret, and then the police officers would retrieve the surveillance video on the vehicle, both real-time and historical, to determine the criminal suspect and acquire criminal proof. Furthermore, the police officers could monitor the vehicle trajectory, and dispatch the policemen to intercept the criminal accordingly.

3. **Emergency Enforcement Scheduling**: Although vehicle monitoring and management system is able to provide police force with locations of criminals, unreasonable policemen scheduling and path planning may still make the criminal escape. The system comprehensively considers the geographic location information of the alarming vehicle and the surrounding policemen presence, and then chooses several nearest ones. After that, the system combines road network and road congestion information, works out optimized interception path, and then sends them to the corresponding policemen.

4. **Incident Hotspot Prediction**: Effective accident handling and criminals fighting is a direct and reliable way to solve individual public transportation safety incident. Nevertheless, accurate accidents and crimes prediction, as well as policemen deployment is a more effective way to deter criminals and reduce the occurrence of vicious events, which may dramatically improve the overall public transportation safety level. The system is capable of analyzing of historical incident records and visualizing incident hotspot diagram. Hence, the system may help to implement a targeted patrol in hotspot areas.

### 4. KEY TECHNOLOGIES

#### 4.1 Optimal Police-dispatching Path Planning

The Optimal Police-dispatching Path Planning is aimed primarily at quick response of the police, so the shortest time to arrive at the destination or the minimum traffic impedance on the road is the most basic criteria for the police vehicles path selection. Actually, the road length involved in the optimal path planning should be the relative length that is the product of the traffic impedance coefficient and physical length.

The relative length of each road is the product of the traffic impedance coefficient and physical length, and the traffic impedance coefficient is affected by many factors (primarily the conditions of the road network), our system takes the average traffic flow, the number of road lanes, road traffic conditions, and personnel density as factors to evaluate traffic impedance, and the traffic impedance coefficient of each road is equal to the weights achieved by Analytic Hierarchy Process (AHP) [8] multiplied by the evaluation indices.

The system can calculate the optimal path planning for police-dispatching using Dijkstra algorithm [9] based on the relative length of each road. The network nodes in original Dijkstra algorithm are divided into unmarked, temporarily marked and permanently marked nodes. The temporarily marked nodes are disorderly stored in the list, which greatly reduces the efficiency of algorithm, especially when the scope of the network is broad. Therefore, for these shortcomings, the system in this article uses Heap Optimizing Method and Beeline Optimizing Method to improve Dijkstra Algorithm for police-dispatching path planning.

Heap Optimizing Method is able to sort the temporary marked nodes based on the relative length of the shortest path that serve as the keyword of heapsort, which means the algorithm does not need to traverse all or most of the temporary marked nodes in each search process. Therefore, the algorithm can make full use of the existing heap data, and greatly reducing the frequency of the data comparison. Beeline Optimizing Dijkstra Algorithm makes the searching direction intelligently tend to the target node, and also reduces the number of nodes during entire traverse process, thereby improving the search speed.

#### 4.2 Crime Hotspot Analysis and Prediction

The system can make an analysis on crime hotspot of public transportation safety field, including determining the clustering status of criminal activities and identifying the location of crime hotspot. Nearest Neighbor Index (NNI) method and Global Moran’s I method are adopted in this system to determine whether the distribution status of criminal activities is clustering status. Among the two methods, the first one is applied in criminal activities which show point pattern, while the latter is used when criminal activities show surface pattern. The nearest neighbor method judges the random distribution of node depending on whether the distance between nearest adjacent node and itself obeys the random distribution. The Global Moran’s Index method is applied to analyzing the significant spatial relationship among regions of spatial variables. The value range of Global Moran’s Index is [-1,1]. When the index is greater than 0, it indicates a spatial positive correlation among the variables, or else the spatial correlation is positive.

The crime hotspot identifying methods in the system include Kernel Density Estimation (KDE) method and Local Moran’s Index method [10], which are separately used in the hotspot identifying of point pattern and surface pattern. The KDE method indicates the spatial distribution of criminal activities by kernel density function of all criminal activities which is a spatial statistics method based on prob-
ability distribution. The Local Moran’s Index is an index describing the space aggregation degree among significant similarity value areas around region.

The system we designed adopts time series forecasting methods [11] including weighted average method and exponential smoothing method to predict the future development of crime hotspot in a short term, which mainly highlight the importance of time factor.

5. REAL-WORLD DEPLOYMENT

PTEMS presented above has been refined, deployed and implemented nationwide in Ecuador since April 9, 2014. We deployed the monitoring devices in more than 150,000 public transportation vehicles, run by hundreds of companies. We also constructed a high performance data center in Guayaquil, Ecuador’s largest city. The data center is responsible for data collection and analysis. It collects hundreds of gigabytes of data and accepts tens of thousands of alarms every day. It provides monitoring and management services for Agencia Nacional de Tránsito (ANT) and domestic public transportation vehicle companies directly. Moreover, the system is integrated with ECU911, an existing nationwide alarm call-taking and dispatch system. Fig. 2 shows its user interface. Since its operation, it provides large quantities of first-hand evidences for criminal capture and deters criminals greatly, and the domestic public transportation crime rate is dramatically reduced [12, 13].

6. CONCLUSIONS

In this paper, we have focused on the deterioration of public transportation situation, and proposed a novel public transportation emergency management system based on GIS, trying improve the management efficiency of public transportation vehicles and improve the public transportation safety situation. The design philosophy, architecture, function and key technologies of PTEMS are discussed in detail. A real-world nationwide deployment of PTEMS has been carried out since last year, and the highly praised official statement has demonstrated the validity of our design.

As for future work, we intend to develop more dynamic route planning algorithm, since the criminals will not wait to be caught after alarm report. We are also interested in the escape path prediction algorithms to improve criminal capture efficiency.

7. REFERENCES