A Microscopic Simulation Modelling of Vehicle Monitoring Using Kinematic Data Based on GPS and ITS Technologies

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***Abstract*—This paper presents an en-route anti-terrorism security system for commercial vehicle operations (CVO) using kinematic data based on Global Positioning Systems (GPS) and Intelligent Transportation Systems (ITS) technologies. The real-time information of the coordinate position and speed of the concerned vehicle as well as the speed of and the gap to the vehicle ahead was taken into account during the terrorism detection. Two typical cases studies, i.e. container trucks running through a freeway network and a bank-armored vehicle traveling across a metropolitan Central Business District (CBD) area, were conducted to test the performance of the proposed system. The designed terrorism scenarios included mixtures of hijack behaviors like deviation from the original route, forced slowdown/stop by the in-vehicle terrorists and forced slowdown/stop by the vehicle ahead. Commercial vehicle operations under such terrorism scenarios were simulated by a customized microscopic traffic simulation model using real networks with real OD data. Experiment results from the simulations show that the proposed system is capable of being efficient in detecting the strange behaviors of commercial vehicles involved in a possible terrorist attack.**

***Index Terms*—Anti-Terrorism, Security System, CVO, GPS, ITS**

I. Introduction

"911", the tragic events have pushed the issues of transportation security and terrorism to the front of government, public and related researchers.

Analyses of trends of all terrorist attacks in recent years indicate that while the number of acts of terrorism has decreased, their lethality has increased. In addition, the number of attacks against transportation systems increased in the 1990s [1-3]. Passenger transportation especially air transportation has been receiving a great deal of attention for the risks of further terrorist attacks. However, safety and security-related risks involving land transportation should not be ignored [4]. It will have severe consequences when the commercial vehicles transporting hazardous cargo enter into a densely populated urban area.

The scope of this paper is focused on the problem area of en-route anti-terrorism security for commercial vehicle operations, which is a security issue of a special type. A terrorist act is intentional and planned; the commercial vehicles can be hijacked to deploy weapons to harm a large number of people. These weapons of mass destruction or harm include nuclear devices and harmful "germs", which can be placed inside the vehicle and exploded or activated when the vehicle travels across a large metropolitan area, or any other location en-route [4].

Therefore, the tracking of commercial vehicle en-route has become an important issue that is receiving more attention from both public and private sectors. The tracking of vehicle movements along the predetermined routes can be helpful for identifying and locating a problem such as hijacking and/or intentional diversion from a legitimate route of travel for destructive purposes.

Effective and alert detection system based on the data from en-route tracking is crucial in the successful execution of response and emergency plans, which are central to establishing a defense against terrorist tactics. Although there exist many Automated Incident Detection (AID) systems in the pertinent literature, the differences between AID systems and the desired terrorism detection system are obvious:

Firstly, the focal point of AID systems is more on the incident location such as freeway sections, while the later should pay more attention on the concerned vehicle itself to detect whether it is affected by a terrorism act.

Furthermore, most AID techniques rely on traffic measurements acquired at stationary sensors such as inductive loop detectors or video detection cameras. The input data are then processed by the various techniques at fixed intervals (such as 20-second, 30-second or 1-minute interval) to detect the occurrence of an incident. Examples of the data processing techniques include pattern recognition [5], catastrophe theory [6], low-pass

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filtering [7], neural networks [8], hybrid neural-fuzzy [9], hybrid neuro-genetic [10] and hybrid fuzzy-wavelet-neural [11]. Therefore, a few minutes of interval in the term of Mean Time to Detection (MTTD) is necessary to identify an incident from the time when it first occur for many promising freeway incident detection systems [12-14]. As a result, those incident detection approaches might be only served as an alternative means since the encountered incident actually can be reported manually to the Traffic Management Center (TMC) less than one minute, with the recent advances of mobile telephones and other two-way communication technologies.

However, for the topic of commercial vehicles en-route security, response time is actually the most critical factor. An effective anti-terrorism system should be capable of quickly and automatically detecting any strange behaviors of the vehicle caused by terrorists such as hijacking, without the aid of manual report from drivers or other related persons who are actually under the terrorism attacks and may not be able to report.

The objective of this paper is to introduce and test an anti-terrorism security system using the vehicle location data from GPS system, the vehicle speed and the gap ahead based on ITS technologies as inputs. This algorithm is named VERTADS, as the acronym for Vehicles En-Route Terrorism Auto-Detecting System.

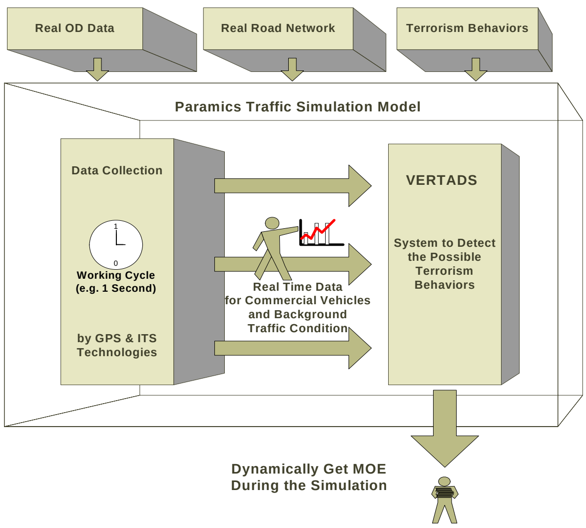

Figure 1. Framework of this study

As shown in Figure 1, the proposed system was tested under several sets of terrorism scenarios generated by a customized microscopic traffic simulation model. After this introduction, a description of VERTADS is described. Next, discussions on the performance measures and the study road network are provided. This is followed by sections that illustrate the experimental scenarios and the selection of algorithm parameters as well as examines the simulation results and evaluates the performances of VERTADS system. Finally, the concluding remarks and needs for future research are presented.

II. COMMERCIAL VEHICLES EN-ROUTE TERRORISM AUTO-DETECTING SYSTEM

Commercial products using GPS/DGPS receivers have already been widely available on the market. Automatic vehicle location (AVL) system based on GPS data and two-way communication devices has enabled the fleet dispatcher to identify the current location of trucks and to communicate with the drivers in real-time. In Singapore a GPS-based taxi dispatching system is currently employed by taxi operators to handle taxi bookings. GPS receivers are installed in every taxi with the primary objective of providing accurate monitoring of the vehicle locations.

It is assumed that, for the concerned commercial vehicle, its DGPS receiver or “black box” will continuously record the instantaneous speed, meanwhile its in-vehicle devices such as laser telemeter or laser speedometer will continuously record the instantaneous speed of and the gap to the vehicle ahead at regular interval of (Δ t) say, 1 second. Therefore, the commercial vehicle installed with such positioning and tracking systems, will continuously report those real time data, which are the inputs used by TERTADS to detect en-route terrorism acts.

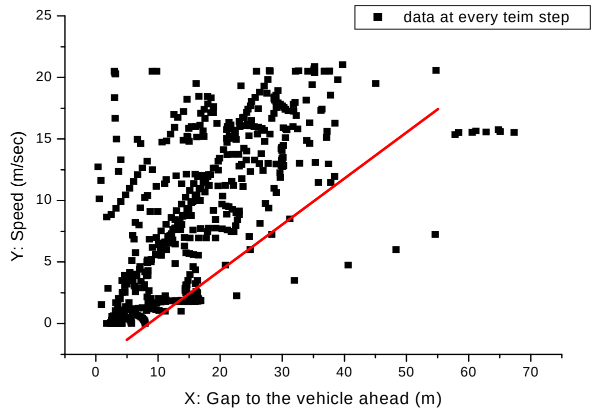

Figure 2. The relationship between speed and gap ahead

Based on our observation of real and simulated traffic data, vehicle speed has a tendency to vary according to the gap ahead, which might be slightly different between individual drivers’ habitual drive behaviors. Such characteristics and its potential in en-route terrorism detection were suggested in this study. Refer to Figure 2, this was the results from simulation of a commercial vehicle running along a freeway in Singapore, each data point represents a pair of vehicle speed and the gap to the ahead vehicle, it can be observed that the majority of the data are distributed within a portion of area higher than the solid line in Figure 2.

This means that although there exist certain random fluctuations during the driving along the trip, a driver does tend to follow his/her own habitual drive behavior in response to the traffic condition he/she encountered, which could be reflected as a relatively stable ration between speed and gap ahead. Of course, the relationship between speed and gap is one of the indexes of a driver’s driving habit or driving philosophy, to implement this index into a detecting system used to monitor the vehicles’ behavior, a calibration work should be carried out for a specified driver and the specified routes along which would be traveled.

Based on the aforementioned discussion, the real-time information of vehicle position and speed of the concerned commercial vehicle as well as the speed of and the gap to the vehicle ahead was used by VERTADS to detect vehicle's abnormal behavior caused by terrorism. At every Δt interval, by checking that (i) whether the current vehicle's coordinate position is deviating from the original route, (ii) whether the current speed is lower than a user defined speed threshold (VTH1), (iii) whether the current speed is reasonable according to the speed of and the gap to the vehicle ahead, (iv) whether the current speed is lower than a user defined low bound speed threshold (VTH2) which is set as lower than the walking speed, and (v) whether the vehicle is near an intersection if it is traveling across a downtown area.

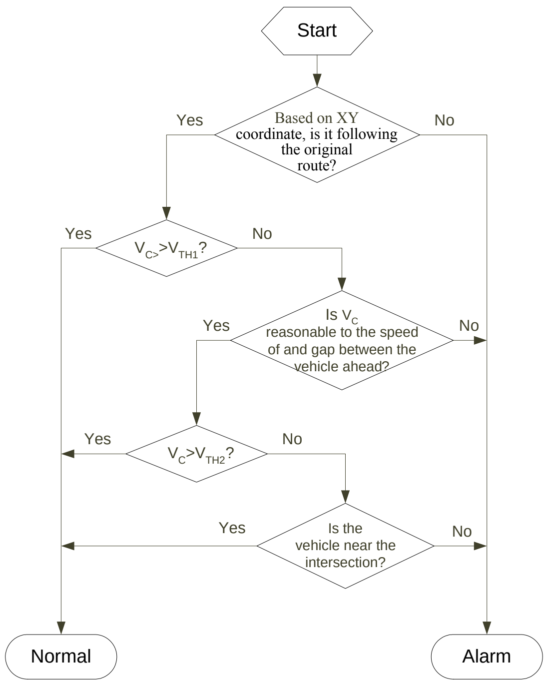

Figure 3. The algorithm logic of VERTADS

The algorithm logic of VERTADS is illustrated in Figure 3. When the coordinate positions indicate that the commercial vehicle is deviating from the original route, the VERTADS would report the alarm information at once. When the speed is lower than the speed threshold (VTH1), the VERTADS will further check whether this speed is reasonable in relation to the speed of and the gap to the ahead vehicle to decide whether the vehicle's slowdown is actually affected by the vehicle ahead, in other words, to ensure whether the slowdown is due to the in-vehicle terrorism act, if so, an alarm will be reported. While the slowdown is due to the vehicle ahead, then another speed threshold (VTH2) will be used to check whether the vehicle is still running at a slow speed (between VTH1 and VTH2) or almost forced to stop (lower than VTH2). In the latter case, if the vehicle is not near the intersection of a downtown area or the vehicle is along the freeway, the state of commercial vehicle should be alarmed to an operator, since the concerned vehicle is too vulnerable to be hijacked no matter the forced stop (or close to stop) by the ahead vehicle is due to a deliberate terrorism act or a normal heavy traffic congestion.

The VERTADS will continuously receive data from the concerned commercial vehicle. These data need to be processed temporally to conclude that there is a terrorism act that warrants an operator's attention. To filter out false alarms caused by random fluctuations in traffic flow, a persistence test (PT) is used in the VERTADS. To declare an alarm and alert an operator, the VERTADS will wait until (i) it has received PT+1 alarm reports from the truck, and (ii) the time difference between the first and (PT+1)th reports is shorter than time period T*max*.

III. Performance Measures

Although the VERTADS is not a kind of incident detection system, the similar performance measures are employed in terms of:

- Detection Rate (DR): defined as the ratio of the number of terrorism cases correctly detected by the system to the total number of terrorism cases known to have occurred;
- False Alarm Rate (FAR): defined as the ratio of the number of false alarm cases to the total number of applications or decisions made by the system;
- Mean Time to Detection (MTTD): defined as the average time to detect an terrorism act from the time it first occurred, computed from all correctly detected cases;
- Misclassification Rate (MCR): defined as the ratio of the number of misclassified data patterns to the total number of data patterns presented to the system.

A good terrorism auto-detecting system should keep the balance of high DR, low FAR, low MTTD and low MCR.

IV. Simulation Software

It is very costly, time-consuming and laborious to collect an extensive set of vehicle speed, vehicle position and the surrounding traffic data simultaneously for the same set of experimental events on a real road network. Therefore, a microscopic traffic simulation tool named PARAMICS [15] capable of modeling the functions of various types of vehicles, en-route terrorism acts, and normal traffic incidents was used to test and evaluate VERTADS.

PARAMICS is a suite of high-performance customized microscopic simulation software used to model the movement and behavior of vehicles in urban and highway road networks. Its Application Programming Interface (API) allows advanced users to customize many features of the underlying model. In this research, the authors have developed an API plug-in to monitor a concerned vehicle along its trip, record and process the data of speed and gap between related vehicles, perform en-route terrorism detections, accumulate and output performance statistics.

IV. Cases Studies

Two typical cases studies, i.e. container trucks running through a freeway network and a bank-armored vehicle traveling across a metropolitan Central Business District (CBD) area, were conducted to test the performance of the proposed system.

A. *Case Study 1: Container Trucks Along A Freeway Network*

- The Study Network

In this case study, the proposed VERTADS was evaluated based on an actual suburban network of Singapore in the Clementi area. A 6.7 km segment of the eastbound direction of Ayer Rajah Expressway (AYE) within this area, between Jurong Town Hall Road and North Buena Vista Road, was modeled in PARAMICS. This site was selected partly because it is a major expressway linking the port, central business district and the main industrial area.

For the network coding, the details of the geometry and physical layout of the roads were collected via field surveys including the information such as the number of lanes (mid-block and at intersections), turning restrictions, post speed limit, etc. The data of signal timing and phasing, origin-destination (OD) statistics and information on the demarcation of zones in this area were collected by related transportation authorities [16].

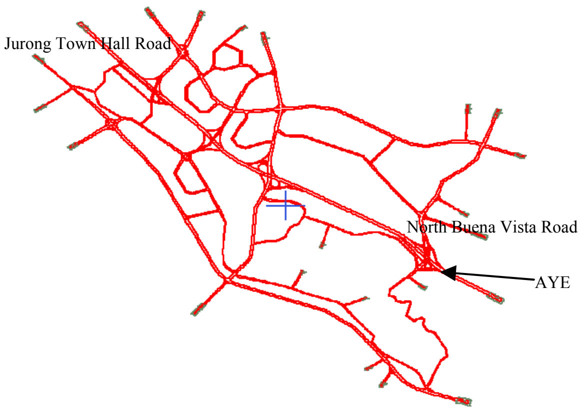

Figure 4. Clementi road network

The coded network is shown as Figure 4. It includes 9 main arterials, 22 secondary roads, and an expressway with 4 interchanges. The network was represented by 986 links, 397 nodes and 22 OD zones in PARAMICS simulation model. There are also 34 signalized intersections within the network.

- Selections of Parameters

As illustrated in Figure 5, the data from simulation under normal traffic conditions without incidents show that, the relationship between speed and gap for a specified truck traveling along AYE can be approximately expressed by the following linear equation:

$$\text{Gap} = 4 \times \text{Speed}$$

In addition, the implementation of VERTADS will require a user to specify the following parameters: Δt, VTH1, VTH2, PT and T*max*. The selection of these parameter values were made by means of trial and error, incorporating the author's prior experience in incident detection and traffic engineering. We have set Δt =1 second and T*max*=10 seconds. Using PARAMICS simulation, we have experimented with PT=1, 3 and 5 intervals, VTH1= 30, 40 and 50 km/h, and VTH2 = 1, 2 and 3 km/h. Based on the initial results, VTH1= 40 km/h, VTH2 = 2 km/h and PT=5 have been selected to reduce the number of false alarms.

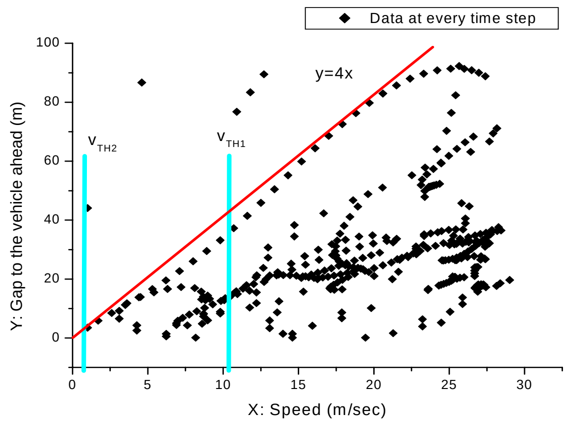

Figure 5. The relationship between speed and gap ahead

- Experimental Scenarios and Simulation Results

The simulation experiments are conducted for the traffic conditions with and without traffic incidents as well as the movements of container trucks with and without terrorism attacks. In the simulation experiments, a container truck will travel along the AYE from Jurong Town Hall Road to North Buena Vista Road (See Figure 4) after ten minutes time of the simulation warm-up running.

First, the performances of VERTADS system in response to different scenarios of terrorism behaviors were studied under normal traffic conditions without incidents. Subsequently, those experiment scenarios were again studied under unstable traffic conditions with the disturbances from incidents.

The following three en-route terrorism scenarios were designed for the experiments:

(1) The container truck is hijacked and diverted from an original legitimate route of travel for destructive purposes.

(2) The container truck slows down/stops due to an in-vehicle terrorists' act such as hijacking by the persons inside the vehicle who have been bribed or belong to the terrorism group.

(3) The container truck slows down/stops due to a terrorists' attack such as hijacking by the terrorists from the vehicle ahead.

An API program was developed to simulate the above terrorism scenarios. Next, another program based on the logic of VERTADS system was embedded into the API program. Meanwhile, traffic incident data was generated by PARAMICS simulation model.

The performance of VERTADS is evaluated under every one of the above listed terrorism scenarios and the mixture with each other at five randomly selected locations along the AYE expressway. For each location five simulation times were randomly selected as well. Hence, there were 200 simulation runs in total conducted in this study (See Table I).

TABLE I.
DETAIL OF THE SIMULATION RUNS

Designed Scenarios	No. of Locations	No. of Time	No. of Runs	Decisions
1	5	5	25	25
2	5	5	25	25
3	5	5	25	25
1&2	5	5	25	50
1&3	5	5	25	50
1&normal incident	5	5	25	50
2&normal incident	5	5	25	50
3&normal incident	5	5	25	50
Total			200	325

The simulation results illustrated in Table II-I and Table II-II show that under normal traffic conditions, the performance of VERTADS was excellent in terms of the balance of high DR, low FAR, low MTTD and low MCR. While the performance level decreases considerably when the possible terrorism acts were mixed with other traffic incidents.

TABLE II-I.
SIMULATION RESULTS FOR SYSTEM PERFORMANCES UNDER NORMAL TRAFFIC CONDITION

DR	FAR	MTTD	MCR
100%	0%	Less than 10 Sec	0%

TABLE II-II.
SIMULATION RESULTS FOR SYSTEM PERFORMANCES WITH TRAFFIC DISTURBANCES

DR	FAR	MTTD	MCR
76.9%	23.1%	Less than 10 Sec	23.1%

B. Case Study 2: A Bank-Armored Vehicle Across A Metropolitan CBD Area

- The Study Network

For this case study, a portion of the CBD network in Singapore, which is bounded by the Electronic Road Pricing (ERP) gantries, covering an area of approximately 3.0 km by 2.5 km is used for the simulations.

As shown in Figure 6, the network consists of 894 nodes (inclusive of 113 signalized intersections), 2,558 directional links and 100 traffic zones. Similarly, the necessary data for the network coding were collected from field surveys as well as related transportation authorities. The CBD network was chosen because it is a popular location for city logistics activities and commercial vehicles movements.

- Selections of Parameters

As illustrated in Figure 7, the data from simulation under normal traffic conditions without incidents show that, the relationship between speed and gap for the concerned vehicle traveling from point I to point O can be approximately expressed by the following linear equation:

$$Gap = 2.5 + 3 \times Speed$$

In addition, we have set Δt =1 second and T_{max}=10 seconds, and based on the initial simulation results, VTH1= 20 km/h, VTH2 = 1.5 km/h and PT=5 have been selected to reduce the number of false alarms.

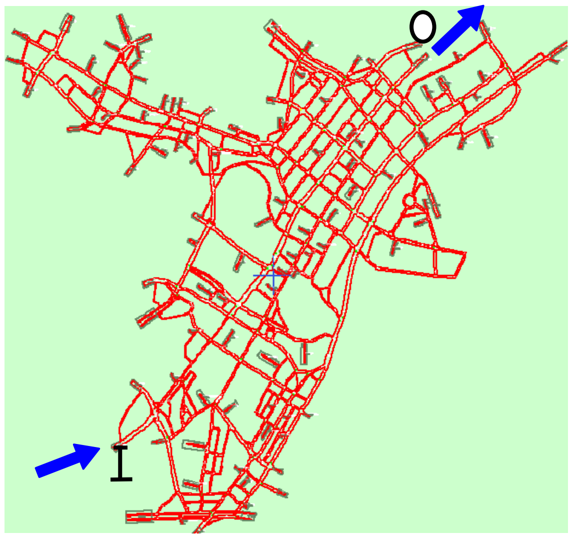

Figure 6. CBD areas in Singapore

- Experimental Scenarios and Simulation Results

In the simulation experiments, a bank cash vehicle will travel across the CBD area from point I to point O (See Figure 6) after ten minutes time of the simulation warm-up running. Then, similar simulation experiments are conducted for this case study (See Table I).

The simulation results illustrated in Table III-I and Table III-II show that under normal traffic conditions, the performance of VERTADS was quite good in terms of the balance of high DR, low FAR, low MTTD and low MCR but inferior to case study 1 due to the queue length near the intersection. And the performance level also decreases considerably with the disturbances caused by other traffic incidents.

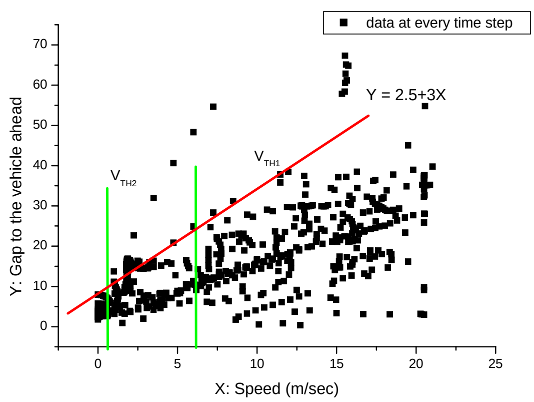

Figure 7. The relationship between speed and gap ahead

TABLE III-I.
SIMULATION RESULTS FOR SYSTEM PERFORMANCES UNDER NORMAL TRAFFIC CONDITION

DR	FAR	MTTD	MCR
88.6%	11.4%	Less than 10 Sec	11.4%

TABLE III-II.
SIMULATION RESULTS FOR SYSTEM PERFORMANCES WITH TRAFFIC DISTURBANCES

DR	FAR	MTTD	MCR
70.8%	29.2%	Less than 10 Sec	29.2%

V. CONCLUSION

This research identifies and explores the potential employment of the GPS and ITS technologies for the efficient detection and protection of commercial vehicle operations from terrorist attacks.

Different sets of experiments consist of the mixtures of hijack behaviors like deviation from the original route, forced slowdown by the in vehicle terrorists or by the vehicle ahead. Simulations results show that the proposed system is capable of being efficient in detecting strange behaviors of a commercial vehicle, which was in the danger of a possible terrorist attack.

Presently, as the availability of Automatic Vehicle Location (AVL) and wireless communication technologies improves, and as the costs for vehicles to be equipped with these technologies decrease, more and more fleets will incorporate these technologies into their daily operations.

Commercial vehicle operations as one component of the city logistics and transportation systems are especially vulnerable to exploitation and disruption by criminal and terrorist groups. This research will ultimately prove beneficial to the logistics companies as well as related public sectors to set up their en-route security systems.

VI. LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The proposed anti-terrorism system has proven to be effective in the sense of detecting terrorism symptoms under normal traffic conditions, but under a fluctuating traffic condition with many disturbances due to non-recurring traffic incidents, it was still not capable of identifying what kind of abnormal clues was actually caused by typical traffic incident like lane closures or traffic congestions.

To further develop a more intelligent system to detect and prevent commercial vehicles from terrorist attacks under different kinds of network traffic conditions, some directions for future research are proposed.

The advanced anti-terrorism system in future might consist of two subsystems (models); the main terrorism detection subsystem would be coupled with a filter subsystem to avoid the incorrect alarms due to normal traffic disturbances. The basic en-route terrorism detection system like VERTADS is expected to combine with another effective incident detection system hence to further enhance the performance level in the future.

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