

Traffic Flow Registraton for Unmanned Aerial Vehicle Detection

Gui-Yuan XIAO^{1,2,a}, Rong-Yi DU^{3,b,*}

¹School of Transportation Engineering, TongJi University, Shanghai, China, 201804;

²Guangxi Key Laboratory of geomechnics and Geotechnical Engineering, Guilin University of Technology, Guilin, China, 541004

³Nanning Municipal Public Security Bureau Transportation Science Engineering Institute Nanning, China, 530000

^axiaoguiyuangit@163.com, ^bdry1024w@163.com

* Corresponding author

Keywords: Intelligent Transportation, Unmanned Aerial Vehicles, Time-Space Registration, Traffic Information Collection, Time Effectiveness.

Abstract. Registration of detection data is to ensure the time-space consistency and effective fusion of air-ground traffic detection data. In this paper, we aim to propose a space-time registration method for the vehicle detection data of unmanned aerial vehicle (UAV). Considering temporal and spatial distribution characteristics of UAV detection, we define time effectiveness and two evaluation indicators for UAV data registration, namely absolute and relative effective times. These two indicators are used to characterize the quality of UAV detection data. Based on time effectiveness of UAV detection, space and time registration methods are developed. Data verification is conducted by Matlab programming with the holographic vehicle trajectory data of I-80 highway. Results of the case study show that, registration largely improves the data accuracy of UAV traffic flow detection data from 68.4% to 88.8%.

Introduction

Aerial detection technologies show great potential in the road traffic information acquisition applications[1]. Although satellites are initially considered for traffic surveillance purposes, their applications in transportation are limited not only by the transitory nature of satellite orbits which lead to be difficult to obtain the right imagery to address continuous problems such as traffic tracking, but also by the bad image quality caused by the cloud covers[2]. Besides, manned aircrafts are deemed “expensive for traffic surveillance studies and non-operational in severe weathers as well as potentially unsafe environments due to presence and safety concern of operators”[3]. As a low cost (fixed and marginal costs) and flexible ‘eye-in-the-sky’, unmanned aerial vehicle (UAV) equipped with video cameras, geo-positioning sensors and communication hardware to relay data to the ground is a good alternative to monitor traffic and collect detailed space/temporal data in real-time for both off-line planning and real time management applications, which doesn’t involve risk of operators[4]. However, there are few literatures to study the time effectiveness of UAV traffic collection information and the methodology for the calculation of road traffic parameters based on UAV detection.

UAV Traffic Detection Technology

UAV Video Detection Technology

UAV video detection technology, also known as UAV aerial photography technology, refers to the use of high-performance UAV which is integrated with GPS positioning system, wireless communication systems and high-resolution video camera system to obtain image/video data and extract required information.

Scenarios of UAV Detection

When UAV is flying in the direction of traffic flow, according to the time sequence of UAV and vehicles entering and leaving a detected road, there are nine scenarios as shown in Fig. 2, where the dashed line denotes UAV trajectory on the detected road and the solid lines denote vehicle trajectories. In Fig.2, width L_u is the detection distance of UAV with a certain flying height, the length Δt is the time interval between the leading end and the tail end of the UAV detection region entering or leaving detected road. t_{ui} is the time of the leading end of the UAV detection region entering detected road; t_{ui}' is the time of the tail end of the UAV detection region entering a detected road; t_{uo}^1 is the time of the leading end of the UAV detection region leaving detected road; t_{uo}^2 is the time of the tail end of the UAV detection region leaving detected road; t_{vi1} , t_{vi2} and t_{vi3} are the times of vehicles entering a detected road; t_{vo1} , t_{vo2} and t_{vo3} are the times of vehicles leaving detected road; and L is the length of detected road.

Time Effectiveness UAV Detection

Definition and Indicators of Time Effectiveness

The analysis of Section II shows that, UAV traffic detection in flight is spatially distributed, i.e. UAV traffic detection system in flight state is based on mobile detection region for vehicle information sampling. So it will make the collected vehicle data distributed in time and space. The spatial and temporal distribution of detected vehicles and the detected vehicle trajectory (length) not only depends on UAV flight status (direction, height and speed, etc.), but also directly depends on traffic operation status on the detected road (such as vehicle speed and vehicle distribution).

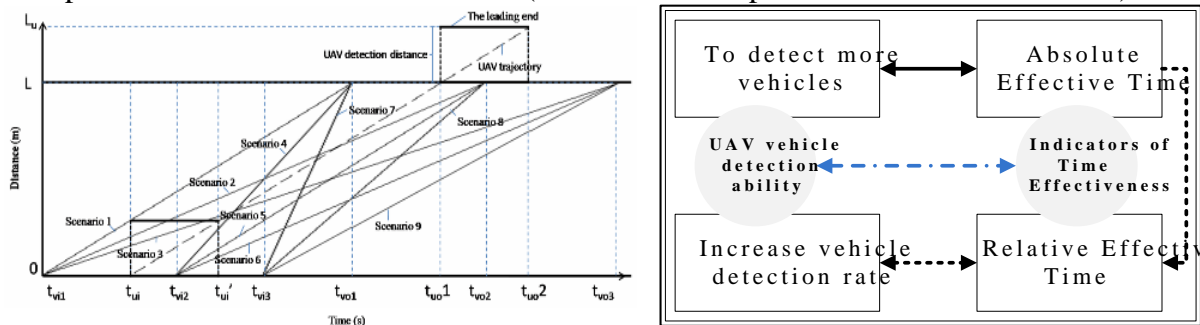


Fig.1 Time and space variation diagram of UAV detection region Fig.2 UAV time effectiveness indicators and their symbolical meanings

In order to characterize and investigate the impact of various UAV detection states and UAV flight parameter setting on road vehicle detection, the definition of time effectiveness was proposed. Effective time (ET) for UAV vehicle detection refers to the time span of the vehicles detected by UAV passing through some road section. Two indicators are introduced to evaluate the ET of UAV detection, i.e. absolute effective time length (AET) and relative effective time length (RET). AET is defined as the time interval of the vehicles detected by UAV passing through a detected road section, while RET is defined as the ratio of AET and the detection time of UAV on a detected road. The UAV test data to be effective and relatively effective time is used to measure the vehicle detection capability of UAV in various detection states. As shown in Fig. 2, AET of UAV vehicle detection data will be used to characterize the capability of detecting the number of vehicles, while RET will be used to characterize the UAV vehicle detection rate, which takes in account the time interval when vehicles on objective road can be detected and detection time of UAV.

Effective Time Analysis of UAV Detection

First, analyzing the ET of vehicle data based on UAV detection in same direction. Assuming V_{us} , V_{uf} and V_{ue} as the flight speeds of UAV, and there are $V_{us} < V_v$, $V_{uf} > V_v$ and $V_{ue} = V_v$.

(1) When $v_u = v_{us} < v_v$,

As shown in Fig. 3, if the vehicles with speed V_v can be detected by UAV with flight speed V_{us} , a condition should be satisfied that,

$$\begin{cases} t_{vi} > t_{ui} \\ t_{vo} < t_{uo}2 \end{cases} . \quad (1)$$

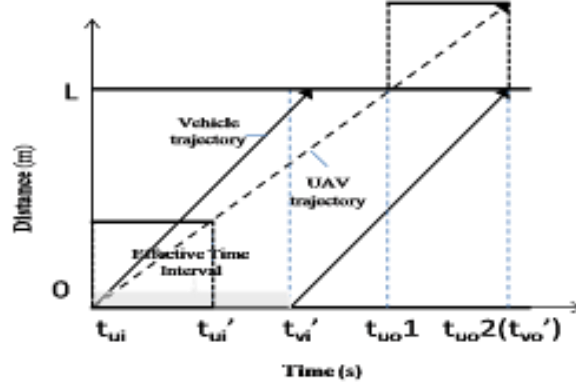


Fig.3 Time intervals entering detected road of detected vehicles in same direction

Obviously, when $t_{vo} = t_{uo}2$, there are

$$\begin{cases} V_v = \frac{L}{t_{vo}' - t_{vi}'} \\ t_{vo}' = t_{uo}2 \end{cases} . \quad (2)$$

Then the time of the detected vehicles entering a detected road reaches the maximum t_{vi}^{max} ,

$$t_{vi}^{max} = t_{vi}' = \frac{V_v t_{uo}2 - L}{V_v} = t_{uo}2 - \frac{L}{V_v} . \quad (3)$$

So, when the vehicle speed is greater than the UAV speed, the time interval of the detected vehicles entering a detected road is $(t_{ui}, \frac{V_v t_{uo}2 - L}{V_v})$.

Let $\Delta t_f = t_{vi}^{max} - t_{vi}^{min}$ and there is,

$$\Delta t_f = t_{uo}2 - \frac{L}{V_v} - t_{ui} = \frac{L}{V_{us}} + \frac{L_u}{V_{us}} - \frac{L}{V_v} . \quad (4)$$

Hence, Δt_f is the AET of the detected vehicles with the speed v_v , when the UAV flight speed is set smaller.

The corresponding RET is

$$\lambda_f = \frac{\Delta t_f}{\Delta t_u} = \frac{\frac{L_u}{V_{us}} + \frac{L}{V_{us}} - \frac{L}{V_v}}{\frac{L + L_u}{V_{us}}} = 1 - \frac{L}{L + L_u} \cdot \frac{V_{us}}{V_v} . \quad (5)$$

(2) When $V_u = V_{uf} > V_v$

we can figure out that

$$\Delta t_s = t_{ui}' - (t_{uo}1 - \frac{L}{V_v}) = \frac{L_u}{V_{uf}} - \frac{L}{V_{uf}} + \frac{L}{V_v} . \quad (6)$$

Hence, Δt_s is the AET of the detected vehicles with speed v_v , when setting a larger UAV flight speed.

Thus, the corresponding RET is

$$\lambda_s = \frac{\Delta t_s}{\Delta t_u} = \frac{\frac{L_u - L}{V_{uf}} + \frac{L}{V_v}}{\frac{L + L_u}{V_{uf}}} = \frac{L_u - L}{L + L_u} + \frac{L}{L + L_u} \cdot \frac{V_{uf}}{V_v} . \quad (7)$$

(3) When $V_u = V_{ue} = V_v$

So Δt_e is the AET of the detected vehicles with the same speed as UAV. The corresponding RET is equal to

$$\lambda_e = \frac{\Delta t_e}{\Delta t_u} = \frac{t_{ui}' - t_{ui}}{t_{uo}2 - t_{ui}} = \frac{L_u}{L + L_u} . \quad (8)$$

Obviously, $\lambda_e < 1$.

From the above analyses, we can summarize that the AET and the RET of UAV vehicle detection data in same direction are shown in below.

Applying the same method, we can find that when UAV detect traffic flow in reverse direction, the time interval of the detected vehicles with speed V_v entering a detected road is $(t_{ui} - \frac{L}{V_v}, t_{uo}2)$ and

the corresponding AET Δt_{rev} and RET λ_{rev} are

<i>AET</i>	<i>RET</i>	<i>Cond.</i>
$\frac{L}{V_u} + \frac{L_u}{V_u} - \frac{L}{V_v}$	$1 - \frac{L}{L + L_u} \cdot \frac{V_u}{V_v}$	$V_u < V_v$
$\frac{L_u}{V_u} - \frac{L}{V_u} + \frac{L}{V_v}$	$\frac{L_u - L}{L + L_u} + \frac{L}{L + L_u} \cdot \frac{V_u}{V_v}$	$V_u > V_v$
$\frac{L_u}{V_u}$	$\frac{L_u}{L + L_u}$	$V_u = V_v$

$$\left\{ \begin{array}{l} \Delta t_{rev} = t_{uo}2 - (t_{ui} - \frac{L}{V_v}) = \frac{L}{V_u} + \frac{L_u}{V_u} + \frac{L}{V_v} \\ \lambda_{rev} = \frac{\Delta t_{rev}}{\Delta t_u} = \frac{\frac{L_u}{V_u} + \frac{L}{V_u} + \frac{L}{V_v}}{\frac{L + L_u}{V_u}} = 1 + \frac{L}{L + L_u} \cdot \frac{V_u}{V_v} \end{array} \right. . \quad (9)$$

Obviously, $\lambda_{rev} > 1$. The reason is that the detected vehicles can be divided into two parts: the vehicles which are already presented in detected road before UAV entering and the vehicles entering detected road within the UAV detection time.

Traffic Flowdata Registration Method

In Section III, time effectiveness of vehicle data from UAV detection was analyzed considering temporal and spatial distribution characteristics of vehicle detections. In order to estimate the road traffic parameters based on the obtained vehicle data from UAV detection and realize the fusion of air-ground traffic detection data, it is necessary to carry out space/time registration for UAV vehicle data based on the time effectiveness of UAV detection data to ensure the space-time correlation consistency of the detection data from UAV system and other sources.

Space Registration

Space registration of multi-source traffic data refers to the transformation of multi-source traffic data to a uniform spatial reference system, i.e. making the transformed traffic data associated with corresponding detection object (e.g., road section). After space registration, detection data from various sources would associate with same detection object. In this section, taking the space registration of traffic flow data between UAV detection and ground point detection for example to

introduce the space registration oriented traffic data fusion of air-ground traffic detections. Usually, road traffic flow detection is based on ground fixed detectors, so the reference cross-section is set where there are fixed detectors. Hence, the space registration of traffic flow data between UAV detection and ground point detection mainly refers to the transformation of UAV detection data into traffic flow data of the cross-section where is ground fixed detector.

Supposing the detected vehicle number by UAV detection is N and the driving distance, first time and last time of the k th ($k = 1, 2, 3, \dots, N$) vehicle detected by UAV on objective road are d_k , t_{1k} and t_{2k} respectively, the driving time t_k of the k th vehicle is equal to

$$t_k = t_{2k} - t_{1k} . \quad (10)$$

Applying the calculation approach proposed by Edie [5], the average speed of the road traffic flow

$$V_v = \sum_{k=1}^N d_k / \sum_{k=1}^N t_k . \quad (11)$$

Supposing the time when UAV entering the objective road with the length L is t_{ui} , the detection distance is L_u and the flight speed is V_u , we can know the time of the leading end of the UAV detection region leaving detected road t_{uo1} is equal to

$$t_{uo1} = \frac{L}{V_u} + t_{ui} . \quad (12)$$

And the time of the tail end of the UAV detection region leaving detected road t_{uo2} is

$$t_{uo2} = \frac{L + L_u}{V_u} + t_{ui} = t_{uo1} + \frac{L_u}{V_u} . \quad (13)$$

Meanwhile, based on Formula (1), we can figure out the time of the tail end of the UAV detection region entering the objective road, which is shown in Formula (13).

$$t_{ui}' = \frac{L_u}{V_u} + t_{ui} . \quad (14)$$

So, based on the conclusion of Section 3.2, the transformation of UAV vehicle data into the traffic flow information of a cross-section where there are ground fixed detectors will be carried out under the following rules:

i. when UAV flight direction is the same with traffic flow:

① if $V_v > V_u$: the detected vehicles by UAV is corresponding to the vehicles entering the objective cross-section within the time interval $(t_{ui}, (V_v t_{uo2} - L) / V_v)$;

② if $V_v \leq V_u$: the detected vehicles by UAV is corresponding to the vehicles entering the objective cross-section within the time interval $((V_v t_{uo1} - L) / V_v, t_{ui}')$.

ii. when UAV flight direction is opposite to traffic flow, the detected vehicles by UAV is corresponding to the vehicles entering the objective cross-section within the time interval $(t_{ui} - \frac{L}{V_v}, t_{uo2})$.

Obviously, space registration of UAV traffic flow data is mainly to identify effective time interval which is corresponding to the time when the detected vehicles driving through an objective cross-section. The obtained effective time interval of UAV traffic flow data after space registration is generally not uniform with the sampling period or sampling time interval of ground fixed detector traffic flow data, so time registration is necessary to ensure the uniform of the aerial and ground detection data for fusion purpose or other application.

Time Registration

Time registration of multi-source traffic data refers to the transformation of multi-source traffic data after space registration into a uniform time section division through the procession of accumulation and translation^[6].

Taking two detectors A and B as example, supposing their sampling periods are τ_1 and τ_2 respectively,

(1) If $\tau_1 : \tau_2 = n$ (n is positive integer)

As shown in Fig. 4, obviously, in the time interval between two consecutive sampling of detector A, detector B has n times of sampling, that is, detector B has n sampling data.

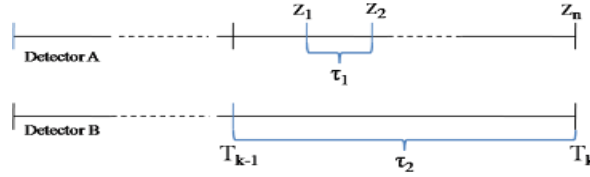


Fig.4 Sampling period of integer times contrast diagram

There are two methods to carry out time registration for the detection data of detectors A and B: adding method and least square method^[7]. According to adding method, the virtual measurement values of detector B will be taken as the sums of its n sampling data in each sampling period of detector A. As for least-squares method, the virtual measurement values of detector B will be the results of the n sampling data in each sampling period of detector A based on least square rule. Both methods are simple and practical, but not suitable for the situation that the data of detectors for time registration have different time base and don't conform to the requirement of integer times of sampling periods.

(1) In general case

the data of detectors for time registration have different time base and don't conform to the requirement of integer times of sampling periods. For this case, Wang et al.^[8] proposed an interpolation and extrapolation method for the time registration of multiple target tracking data. This method is to form a series of equally spaced targets observation data through interpolation and extrapolation operation of high accuracy observation data in each time slice. The time registration method is shown in formula (15).

$$\begin{cases} x_{\tau_i t_j} = x_{\tau_i} + (t_j - \tau_i) v_{x_{\tau_i}} \\ y_{\tau_i t_j} = y_{\tau_i} + (t_j - \tau_i) v_{y_{\tau_i}} \\ z_{\tau_i t_j} = z_{\tau_i} + (t_j - \tau_i) v_{z_{\tau_i}} \end{cases} \quad (15)$$

Where, $(x_{\tau_i}, y_{\tau_i}, z_{\tau_i}, v_{x_{\tau_i}}, v_{y_{\tau_i}}, v_{z_{\tau_i}})$ is the target observation data of detector A, $x_{\tau_i t_j}$, $y_{\tau_i t_j}$ and $z_{\tau_i t_j}$ is $x_{\tau_i}, y_{\tau_i}, z_{\tau_i}$, $i \in [1, m]$, $j \in [1, n]$.

Extend the interpolation and extrapolation method to the time registration of traffic flow data of UAV and ground fixed detectors. Corresponding to some sampling time k , the number of the detected vehicles by UAV is x_k and the effective time interval is $[t_k, t_k + \tau_k]$. τ_k is the absolute effective time of the UAV vehicle data. So the value of the UAV data in sampling time k after registration can be figured out according to Formula (15).

$$\bar{x}_k = x_k + (T - \tau_k) v_k \quad (16)$$

Where, \bar{x}_k is x_k after time registration; T is the sampling period of ground fixed detector; v_k is the vehicle detection rate of UAV, $v_k = x_k / \tau_k$.

Data Verification

The data developed by Cambridge Systematics, Inc. as part of the Federal Highway Administration's (FHWA) Next Generation Simulation (NGSIM) project [9] were used for data verification. The data include detail vehicle trajectory data and are collected by seven video cameras mounted on a 30-storey building, Pacific Park Plaza, which is located in 6363 Christie Avenue and adjacent to the Interstate freeway I-80. The sampling interval is 0.1seconds and the data properties include vehicle ID, vehicle length, time, geographical coordinates, lane number and so on so forth. In addition, the road length L is about 535.7m and the average speed of the vehicles on the detected road is 6m/s~9m/s. We set that UAV flew in the same direction with traffic flow, the detection distance L_u is 88.5m and the flight speed V_u is 5m/s. Meanwhile, to facilitate the calculation and verification, the sampling period of section flow detection is set as 125s which is equal to Δt_u . Through Matlab programming simulation, comparing with the real traffic flow data, the average detection rate of UAV is 68.4 percent, i.e. the detection error is 31.6 percent. Based on the vehicle trajectory data obtained by UAV detection, link average speeds can be estimated using Formula (21) and the results are shown in Fig. 5. Obviously, $V_v > V_u$. Based on the results of Section 3.2, the estimated AET values of the UAV detection data can be obtained using Formula (17)

$$\Delta t_f \approx \frac{L}{V_u} + \frac{L_u}{V_u} - \frac{L}{V_v} \quad (17)$$

Let $T = \Delta t_u$, $\tau_k = \Delta t_f$, Formula (16) can be changed into Formula (18).

$$\bar{x}_k = \left(1 + \frac{L}{\left(\frac{L}{V_u} + \frac{L_u}{V_u} - \frac{L}{V_{vs}}\right) \bar{V}_{vs}}\right) x_k \quad (18)$$

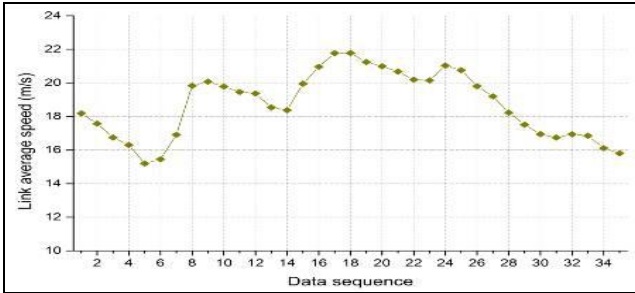


Fig. 5 Estimated link average speeds based on UAV detection

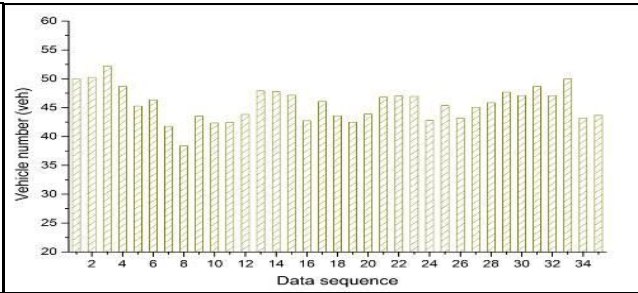


Fig.6 Traffic flow data of UAV detection after registration

The vehicle data of UAV detection after registration are shown in Fig. 6.

After registration, the average error of traffic flow data by UAV detection is 11.2 percent, which shows great improvement of the traffic flow precision for UAV detection.

Conclusions

In this paper, we have analyzed the UAV detection characteristic and proposed two time effectiveness evaluation indicators for UAV vehicle detection. Through vehicle detection scene analysis and theoretical derivation, we investigate the impacts of UAV flying parameter settings (e.g. detection distance and speed), road length, and vehicle speed on time effectiveness of UAV vehicle detection data. Subsequently, based on the time effectiveness analysis of UAV detection, space and time registration methods are developed. Finally, by Matlab programming with the holographic vehicle trajectory data of I-80, we carry out a registration example of UAV detection data. In the case study, it was shown that, the registration enhances the data accuracy of UAV traffic flow detection data from 68.4% to 88.8%. The future research can be envisaged as follows. First, although the

registration result is promising, we still can improve the effectiveness and applicability of the proposed registration model by considering the characteristics of traffic flow. Second, to address a practical traffic scenario, real UAV data registration study should be conducted and compared with the simulation results in this paper.

References

- [1] Z.S. Yang. Basic traffic information fusion technology and its applications. Beijing: China Railway Publishing House, 2005.
- [2] Gerhardinger, A., Ehrlich, D., and M. Pesaresi. Vehicles detection from very high resolution satellite imagery. In: *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXVI, No. E/W24, 2005, pp. 83-88.
- [3] Srinivasan, S., Latchman, H., Shea, J., et al. Airborne traffic surveillance systems: video surveillance of highway traffic. In *proceedings of the ACM 2nd international workshop on video surveillance & sensor networks*, 2004, pp. 131-135.
- [4] Coifman, B., McCord, M., Mishalani, R.G., and K. Redmill. Surface transportation surveillance from unmanned aerial vehicles. Presented at *83rd Annual Meeting of Transportation Research Board*, Washington, D. C., 2004.
- [5] L. Edie. Discussion of traffic stream measurements and definitions. In *proceedings of second international symposium on the theory of traffic flow*, OECD, 1963, pp. 139-154.
- [6] Luo, R.C., and M.G. Kay. Multisensor integration and fusion in intelligent systems. *IEEE transactions on systems, man, and cybernetics*, Vol. 19, No. 5, 1989, pp. 901-931.
- [7] Wang, J.J., and J.J. Huang. A spatial alignment algorithm for time varying biases of radar and infrared sensors. *Procedia engineering*, Vol. 15, 2011, pp. 2614-2618.
- [8] Wang, B.S., and F.S. Li. Multiple target tracking algorithm based on data fusion technology (in Chinese). *Journal of Xidian University*, Vol. 25, No. 3, 1998, pp. 269-272.
- [9] Federal Highway Administration. *Traffic analysis tools: Next generation simulation (NGSIM)*. Available at: <http://ops.fhwa.dot.gov/trafficanalysistools/ngsim.htm>, accessed on May 16, 2013.