

Video-Based Vehicle Trajectory Data Collection

By

Vijay Kovvali, Ph.D., T.E.
Cambridge Systematics, Inc.
555 12th Street, Suite 1600
Oakland, CA 94607
Phone: (510) 873-8700
Fax: (510) 873-8701
E-mail: vkovvali@camsys.com

Vassili Alexiadis, Ph.D.
Cambridge Systematics, Inc.
555 12th Street, Suite 1600
Oakland, CA 94607
Phone: (510) 873-8700
Fax: (510) 873-8701
E-mail: valexiadis@camsys.com

Lin Zhang, Ph.D., P.E.
Cambridge Systematics, Inc.
555 12th Street, Suite 1600
Oakland, CA 94607
Phone: (510) 873-8700
Fax: (510) 873-8701
E-mail: lzhang@camsys.com

2007 Annual Meeting of the TRB
In consideration for publication in *Transportation Research Record*

August 1, 2006
In revised form: November 15, 2006

Paper Length

5,311 words in text
2,000 words in 8 exhibits
7,311 words total (max = 7,500)

Video-Based Vehicle Trajectory Data Collection

By Vijay Kovvali, Ph.D., T.E., Vassili Alexiadis, Ph.D., and Lin Zhang, Ph.D., P.E., Cambridge Systematics, Inc.

Abstract

Vehicle trajectory data provide detailed information on microscopic phenomena that can be used for behavioral modeling of car-following, lane-changing, gap acceptance, cooperative driving, etc. Vehicle trajectories also provide detailed data needed for safety research. Usually, vehicle trajectory data are extracted from high-resolution images - either from video or camera based data collection to develop a holistic dataset of vehicle positions. In recent years, video data collection and subsequent transcription of video data to vehicle trajectories are being attempted by many transportation researchers. While there have been multiple video data collection efforts conducted across the world, there has been little guidance and recommendations on the selection of data platform, data formats and data elements for vehicle trajectory data collection. As part of the Next Generation SIMulation (NGSIM) program, the Federal Highway Administration's conducted an initial prototype, and three vehicle trajectory data collection efforts. This paper documents the guidelines developed for the NGSIM data collection efforts for obtaining efficiently transcribed vehicle trajectories.

Introduction

Over the years, the greatest challenge for traffic operations research has been detailed, accurate, and valid data. While the lack of detailed and accurate data does not detriment macroscopic and mesoscopic modeling of traffic operations, it significantly affects the microscopic modeling of traffic. In the last decade, due to the heavy congestion present on roadways, it has become imperative that transportation researchers model traffic in great detail to accurately capture the complex traffic operations. This requires that the data used for estimation and validation of the models were both precise and valid. To accommodate these requirements, many researchers are using video data collection as a way of capturing the vehicle interactions on the roadway.

While video data visually captures the vehicle interactions, it does not provide vehicle position information necessary for estimation and validation of microsimulation models. Also, vehicle trajectory data, by itself, does not provide all the data needed to address traffic operations problems. For instance, in order to study permitted left-turn saturation flow rates, one also needs to know the signal timings at the intersection. As part of the Federal Highway Administration's (FHWA) data collection effort for the Next Generation SIMulation program (NGSIM), the NGSIM team created a detailed data plan providing the data collection needs, the data platform to be used, the data elements to be collected and the data collection guidelines to be followed for obtained vehicle trajectories for every 1/10th of a second. A description of the NGSIM program, other trajectory data collection efforts, and the NGSIM data collection framework and process is

provided in the sections below. The vehicle trajectory extraction from the videos is also briefly discussed.

Next Generation SIMulation (NGSIM) Program

Since the 1970's, the FHWA has been a leader in the area of traffic simulation model development. When FHWA undertook this leadership role there were no commercial traffic simulation packages in the market. Today, with the goal of achieving wider acceptance of the use of microsimulation systems and ensuring that the tools can be trusted to provide accurate results, the FHWA's Traffic Analysis Tools Program started the NGSIM program. To undertake the NGSIM program, FHWA has decided to act in a "Market Facilitator" role that manages public resources in a focused way to influence and stimulate the commercial simulation market by fostering a, environment of public-private coordination. In this partnership FHWA coordinates with the private sector and does not compete with it (1).

The products of the NGSIM program are openly distributed and made freely available to the transportation community. These products include:

- Real-world **datasets** with their corresponding data descriptions, which are being used to estimate and validate the core algorithms. The traffic simulation community is also widely using these datasets as a resource to assist in the verification, validation, and calibration of newly developed and existing behavioral models.
- Core **simulation algorithms** that are being developed, estimated, coded, tested, and validated using the validation datasets.
- **Documentation** of the core algorithms (including theory and logic) and documentation of the validation datasets.

At the outset of the NGSIM program, the NGSIM team conducted a market assessment of traffic microsimulation together with experts and stakeholders consisting of software developers, microsimulation modelers, and microsimulation software users. NGSIM team developed a basic scheme for splitting the core algorithms related to traveler behavior into categories based on the decision-making process that is emulated by the algorithm (2):

- **Operational** driving behaviors, such as acceleration and gap acceptance, represent decisions that travelers make on a near instantaneous basis to satisfy an immediate goal of their trip plan. This category generally deals with traveler decisions that take seconds to make and execute, although in many cases – opposing flow gap acceptance on a congested arterial – they could last longer.
- **Tactical** route execution behaviors, such as lane changing represent small, multi-part decisions that are made in order to complete a small, but coordinated, portion of a trip plan. For rough reference, this category deals with traveler decisions that occur on a timescale on the order of tens of seconds, although timeframes vary widely by condition.

- **Strategic** en-route traveler decisions, such as route modification and parking search, involve decisions travelers make that impact the overall structure of their trip plan. These traveler decisions are generally made and executed at a time scale of (roughly) minutes.

The NGSIM stakeholders assessed existing microsimulation models, identified their limitations, and prioritized the NGSIM research objectives (2). The NGSIM stakeholders identified tactical algorithms, such as lane-changing, cooperative merging, and lane selection as the highest priority gap in existing microsimulation systems. The NGSIM team recognized that detailed vehicle position data is needed for accurately validating these algorithms (3). With this objective, the FHWA identified locations for obtaining sub-second video data, which were later transcribed to develop detailed vehicle trajectory datasets. After an initial prototype data collection effort in Emeryville, California; the NGSIM team collected and transcribed data for the datasets shown in Table 1. These datasets are available on the NGSIM website at <http://ngsim.fhwa.dot.gov>.

Table 1 NGSIM Data Collection Efforts

Location	Facility Type	Target Algorithms
I-80, Emeryville, California	1,650 feet Freeway segment with one on-ramp	Freeway Lane Selection, Cooperative Merging, Oversaturated Freeway Modeling
US 101, Universal City, California	2,100 feet Freeway segment with an on- and off-ramp	Freeway Lane Selection, Cooperative Merging, Oversaturated Freeway Modeling
Lankershim Blvd, Universal City, California	1,600 feet Arterial segment with four intersections	Arterial Lane Selection

The following sections will provide brief description of other trajectory data collection efforts, data requirements based on the data collection effort, guidelines for trajectory data collection, and transcription of the video data used NG-VIDEO program.

Literature

Between 1982 and 1985 JHK & Associates (4) developed a series of microscopic vehicular traffic flow data sets for selected types of freeway bottleneck sections. Data were collected at six types of freeway geometry: ramp merges, weaving sections, up-grade sections, reduced width sections, lane drops, and horizontal curves. The data were collected by flying a short-takeoff-and-landing (STOL) aircraft at slow speeds around each site at altitudes ranging between 2,500 and 4,500 feet. Data were reduced for one-hour at each site at a resolution of 1 frame per second. The data sets were digitized using a combination of manual and automatic transcription.

University of Michigan Transportation Research Institute (UMTRI) under the auspices of National Highway Traffic Safety Administration (NHTSA) developed the System for Assessing the Vehicle Motion Environment (SAVME). SAVME (5) is a unique measurement tool that can analyze vehicle trajectories for both low-level driver interactions and high-level general statistical analyses. UMTRI conducted a data collection to demonstrate the proof of concept. Two additional vehicle trajectory data collection efforts were conducted by NHTSA in Columbus, Ohio in 2001. The team used mobile, pole-mounted camera system for the data collection.

The Berkeley Highway Laboratory (BHL) is a 2.7 mile section of Interstate 80 in west Berkeley and Emeryville (6, 7). The facility serves as a research test bed for research in transportation at UC Berkeley, and is operated in coordination with Caltrans (California Department of Transportation), PATH (California Partners for Advanced Transit and Highways), and CCIT (California Center for Innovative Transportation). The project collects vehicle trajectory data via 12 high-rise rooftop-mounted cameras on a highly congested section of I-80, roughly between the Powell and Ashby interchanges in Emeryville, California. The Berkeley Highway Lab test bed has a system of eight video cameras. It uses Sony DFW-VL500 firewire cameras which have 640x480 pixels of resolution and can capture video at up to 30 frames per second. The cameras are mounted on the roof of Pacific Park Plaza (PPP) condominiums in Emeryville, CA near Interstate 80. The building is 100 meters (300 feet) tall. The cameras cover about one kilometer (0.62 miles) of I-80 between Ashby Avenue and Powell Street. The on and off ramps at Ashby Avenue and Powell Street are part of the coverage area.

Delft University in Netherlands is actively involved in developing car-following modeling using camera-based vehicle trajectory data (8, 9). The Delft team collected data using helicopter on a 520 meter section using a 1300 x 1030 pixel B&W digital camera. Pictures taken at $1/10^{\text{th}}$ of a second were stored on a Personal Computer equipped with a frame grabber enabling real-time storage of the digital images. No gyroscopic mounting was used along with the camera. The data were collected at highly congested motorway sites in Netherlands during the afternoon peak. The camera frames are processed off-line to provide the trajectories.

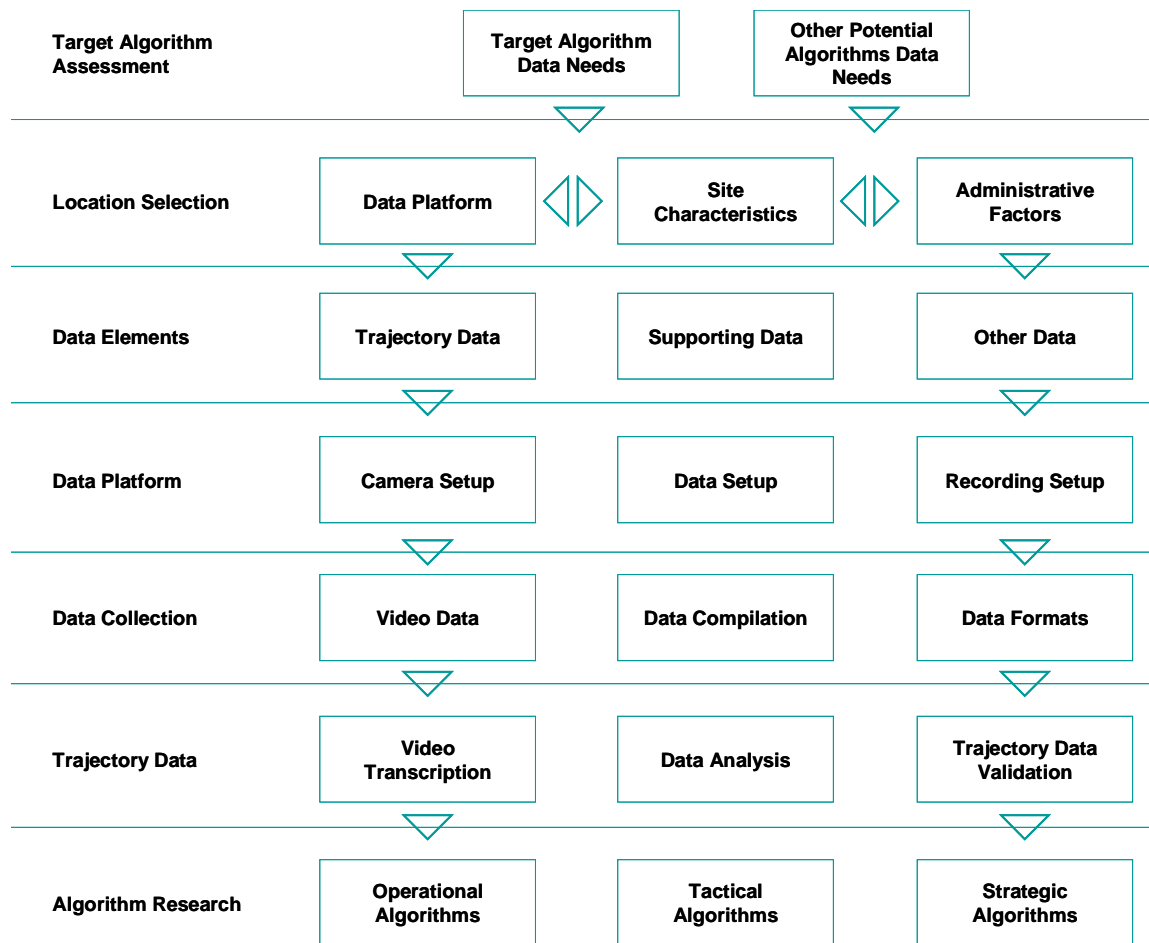
The Advanced Traffic and Logistics Algorithms and Systems (ATLAS) research center, as part of the Real-time Hierarchical Optimized Distributed Effective System (RHODES) advanced traffic signal optimization project, is investigating the potential use and benefits of remotely sensed data, mainly using aerial videos to improve traffic management (10). This project was sponsored by the National Consortium on Remote Sensing in Transportation Flows, the U.S. Department of Transportation (DOT), and the National Aeronautics and Space Administration (NASA). Data collection has been ongoing since 2000 in various parts of Tucson, AZ and Seattle, WA. Most of the data were collected using video cameras mounted on helicopter skids. In some cases, the helicopter hovered above intersections at five-minute intervals to collect the data, but in most instances, the helicopter followed a platoon of vehicles traveling on freeways or arterials. The moving helicopter may cover as much as five-mile segments in a given study period. A Global Positioning System (GPS) device was also used to track the movements and altitude of the helicopter, which must be taken into account when calculating vehicle speeds.

The Center for Advanced Transportation Technology (CATT) laboratory at the University of Maryland (UMD) is working on macroscopic data acquisition from highway cameras. CATT is also attempting full vehicle trajectory tracking of the collected video data (2). Another video-based data collection is an ongoing effort at the University of Minnesota Center for Transportation Studies (11). The site uses fixed CCTV cameras to capture a freeway section for accident research.

NGSIM Data Collection

The NGSIM data collection was conducted with the objective of developing a core of open behavioral algorithms in support of microscopic traffic simulation. In order to develop the behavioral algorithms, it was necessary to collect both the system state (multimodal travelers, vehicles, and highway systems) and influencing factors (traffic control devices, weather, etc.) data. Since, vehicle trajectory data collection is costly and complex; all elements of the data collection effort were planned in advance by developing a data collection framework. The NGSIM data collection framework is shown in Figure 1. A detailed description follows below.

Figure 1 NGSIM Data Collection Framework



Target Algorithm Assessment

NGSIM categorized behavioral algorithms as operational (car-following, etc.), tactical (lane changing, cooperative driving, etc.), and strategic (route choice, etc.). Based on NGSIM Stakeholder input, the team prioritized behavioral algorithm research tasks and selected tactical algorithms as the biggest gap in existing microsimulation systems. Vehicle trajectory data and supporting data were collected to provide estimation and validation datasets for these algorithms. For instance, the first algorithm that the NGSIM program developed, based on stakeholder input, was a tactical algorithm - Freeway Lane Selection Algorithm (12). To develop this algorithm, a freeway segment with vehicle propositioning was required. The I-80 corridor in Emeryville, California was selected as an ideal location due to the heavy traffic conditions and multiple downstream exits. While the trajectory data was collection on a small section of the freeway, the data provided heavy lane changing required to model freeway lane selection. Additionally, detailed loop detector data at eight dual-loop detector stations around the trajectory section were also collected, to validate the freeway lane selection algorithm.

Location Selection

Cameras require clear vantage point to record the vehicles. Generally, the position of cameras for vehicle trajectory data collection has been on top of buildings, long poles, helicopters, and aircrafts. Since the NGSIM vehicle trajectory effort was scoped for collecting 100% of vehicles for 8 hours per day, buildings were selected as the ideal location. Camera fitted aircrafts are ideal for following and collecting platooned vehicles over a long stretch of roadway, but cannot collect 100% of the vehicles in a study section. While, helicopters can hover in the same location, they can collect data for only a couple of hours. Helicopters can provide better, straight down vantage point than buildings as a data platform, but might affect driving behaviors on the roadway due to the distraction it might cause to the roadway users. While blimps, Unmanned Aerial Vehicles (UAV), etc., can also be used for data collection; the cost and logistics are not conducive for NGSIM efforts.

Site characteristics are another important aspect for NGSIM data collection efforts. The site selected for data collection must satisfy the geometry and traffic requirements for modeling of the target algorithm. For NGSIM purposes, the site must have a tall building with a good vantage point next to the site, and the location must provide weather conditions conducive for video data collection. In addition, the view to the roadway from the building should be relatively unobstructed (i.e., trees, overpasses, etc.). Short occlusions due to trees and overpasses can be overcome by estimating vehicle positions using before-and-after shots of the vehicles. But if the occlusions are greater than 40 feet, the estimated vehicle positions can be inaccurate. Also, multiple occlusions within short distances are not conducive for vehicle trajectory transcription. NGSIM guidelines require that the occlusions are shorter than 40 to 50 feet with spacing of at least 80 to 100 feet between the occlusions. The effect of occlusion is also a factor of the traffic conditions (free-flow vs. stop-and-go), area of coverage (single lane vs. multiple lanes), and geometry at the occlusion (presence of ramp/cross street, etc.). Effects of occlusion need to be individually assessed by considering all these factors.

Other criteria for NGSIM site selection are target building management's agreeability for using the building facility, and local agency's capability and willingness to provide the required data for target algorithm research (signal timing sheets, Real-time Split Monitor reports, etc.).

Data Elements

At the onset of the NGSIM data collection effort, a clear scope was defined for the data to be recorded. The data needs for NGSIM included, capturing the morning and afternoon peak periods (around eight hours of data per day), capturing 100% of vehicles during the peak periods, capturing the traffic flow conditions from free-flow back to free-flow, where possible (i.e., free flow to transitional to congested, then back to transitional and free-flow), around 2000 feet of section length, highly synchronized cameras, and data recorded in open formats and made freely available to the transportation community. These NGSIM objectives, dictated the data elements and data collection guidelines.

Estimation and validation of behavioral algorithms require detailed system-state and influencing factor data. Depending on the algorithm being developed, the type, and detail of the data vary. NGSIM created a data matrix based on the data type and level of detail. Data, based on detail, was categorized as microscopic, mesoscopic or macroscopic data; while, based on the data type, it was categorized as system-state (traffic data, signal timing data, etc.) and influencing factor data (geometry data, etc). A listing and description of the data categories and the data elements is shown in Table 2. For the NGSIM data collection effort, the microscopic level data was the primary data, and the mesoscopic and macroscopic level data were the secondary or supporting data. The mesoscopic and macroscopic data were used to validate the microscopic data collection effort, i.e., for example, aggregated vehicle trajectory data were compared against loop detector data to verify the accuracy of vehicle trajectory data. In general, in addition to the data required for the specific algorithm research; all the available data elements in the matrix were also collected to develop vehicle trajectory datasets that can be used for multiple applications. For example, data collected for arterial lane selection (vehicle pre-positioning) can also be used for measuring driver reactions to signal change intervals. Detailed signal timing data (e.g., Real-time Split Monitor Reports), while not required for arterial lane selection algorithm, are essential for studying signal change intervals.

Table 2 Data Collection Categories and Data Elements

	Microscopic Level	Mesoscopic Level	Macroscopic Level
Traffic Data	Video Data <ul style="list-style-type: none"> • provides individual vehicle trajectories. 	Loop-Detector Data <ul style="list-style-type: none"> • provides volume, speed and occupancy data at a specific location at different time aggregations. This data must be collected for the study area, and upstream and downstream of study area. 	Aggregated data <ul style="list-style-type: none"> • provides volumes by lane group or movement.
Geometry Data	CAD Diagram <ul style="list-style-type: none"> • provides detailed geometric information of the study area (individual intersections, grade of links, position of storm drainage, etc.). 	GIS File <ul style="list-style-type: none"> • provides data on signal, sign, and detector locations. Additional data like offset of buildings, etc., will also be provided through the GIS file. 	Aerial Image <ul style="list-style-type: none"> • A high resolution, ortho-rectified aerial image of the study area provides the background image for simulation analysis. The file can also be used for creating the CAD and GIS files.
Signal Timing Data	Phase Change File (format needs to be defined) <ul style="list-style-type: none"> • signal timing file that can provide great detail on which phases are progressing during a particular time step. The data needs to be synchronized with video data. 	Real-Time Split Monitor Report <ul style="list-style-type: none"> • controller output file that can provide the phase split during a cycle. The data needs to be synchronized with video data. 	Controller Timing Sheets <ul style="list-style-type: none"> • provides the signal controller settings and background timings (for actuated phases). • provides ramp metering logic
Other Data	Image Data <ul style="list-style-type: none"> • windshied video recording of the corridor to provide additional information on the signage, etc. • digital pictures of roadway signs and structures. 	GIS Level (support data that will be part of the GIS file) <ul style="list-style-type: none"> • sign location and signage information (text on signs). • offset of structures that can affect sight distance or driving behavior. • light Pole Height, Illumination, etc. 	Macro Data (during data collection) <ul style="list-style-type: none"> • weather information • incident information • sun-rise / sun-set information • shadow information

For the NGSIM data collection efforts, all available data relevant to the study area and the facility type were collected or compiled. The local agencies were contacted before the data collection efforts to find out what data is readily available. These data usually included loop-detector data, CAD diagrams, GIS files, controller timing sheets, and real-time split monitor reports. Additional data, such as aerial images, signage, and wind-shield video were collected by the NGSIM team.

Data Platform

For the I-80 data collection effort, the cameras were used in a fixed camera platform developed by University of California, Berkeley for the Berkley Highway Laboratory (6). This platform provided a rigid system within which the cameras were mounted. The rigid system had the advantage of fixing the camera viewpoint for multiple days. For the second NGSIM data collection effort at US 101 in Los Angeles, California, the cameras were mounted on tripods and tied down to the roof of the building using ropes. The two platforms are shown in Figure 2. The disadvantage of this system is that the cameras were not as rigid as a fixed platform system and have a greater possibility of changing their viewpoint due to wind. For the Los Angeles data collection effort that was in a new location and short-term, the tripod based collection (Figure 2) provided the only viable option.

Figure 2 NGSIM Camera Setup for I-80 Data Collection in Emeryville, CA, and US 101 in Los Angeles, CA.



Intel® Xeon™ CPU 3.00GHz or faster processor with 2.0 GB of Ram were used for recording the data. These computers provided the NGSIM team with equipment that can be used both for collecting, and then for transcribing the data. One of the concerns for these type of machines are that they are not made for rugged use, so are capable of failing if proper care is not taken. Other data collection efforts have used Digital Video Recorders (DVR) or tape drives, but these mechanisms do not provide adequate storage for 8 hours of continuous video data at 30 frames per second.

Data Collection

The data collection guidelines presented in this section are affected by the NGSIM requirements for data collection. Also, there is a degree of symbiosis between the various data collection elements. For instance, the extent of camera synchronization essential for data collection can be a factor of the frame rate – at 30 frames/second, vehicles travel around 2 feet per frame at 60 mph, which is an acceptable error factor for vehicle positions. But if the capture is at 7.5 frames/second, vehicles can possibly move 8 to 10 feet per frame. This will require that the cameras are highly synchronized to remove vehicle position errors between cameras.

NGSIM data collection is a portable setup, where data was collected from one to three days, for about eight hours a day. As stated earlier, the data were collected at 30 frames/second. Video data at 30 frames/second for a time period of eight hours require a stable platform and lot of space to save. These aspects of NGSIM data collection affect the camera type, recording platform, etc. Detailed guidelines for the trajectory data collection are presented below.

Video data

Cameras. Multiple home entertainment, and surveillance type cameras are available in the marketplace. For NGSIM purposes, the video camera selection was based on:

- Internal zoom lens
- Minimum frame rate
- Synchronization trigger
- Digital output
- Resolution
- Cost

Based on these requirements a Sony VL 500, which have a resolution of 640 x 480, but was capable of recording at 30 frames/second, contains internal zoom, has a synchronization trigger, provides digital output, and the cost is reasonable. The internal zoom lens allowed the camera zoom to be controlled from the computer, this allowed the data collectors from bending over building parapets for adjusting the zoom. Other data collection efforts are using high-resolution black and white digital camera with resolution of 1 300 pixels x 1030 pixels cameras, that can take photos at 30 frames per second, or regular camcorders. While these cameras did not satisfy the requirements of NGSIM data collection, they might be ideal for future data collection efforts based on the data needs. The other elements of the camera selection are described below.

Minimum Frame Rate. Video data collection in PAL format can be done at 1/30th, 1/15th or 1/7.5th second granularity. Based on accuracy requirements for behavioral algorithm research, and also the vast amount of data points to be transcribed, the output trajectory data were processed every 1/10th second. Since, video data cannot be recorded at 1/10th second frame rate, to maintain uniform travel between data points, the video data was collected every 1/30th second. This allows that two frames out of three are decimated to create a new video file that is at 1/10th second frame rate, while maintaining equal time gap between frames.

Pixel Resolution. The ideal resolution set for NGSIM data collection efforts was 3 pixels/foot or higher, with an absolute minimum resolution requirement of 1 pixel/foot (at the edges of the study section). These requirements were based on the NGSIM prototype. Lower pixel resolution means more difficulty in vehicle tracking and higher trajectory extraction costs. The cameras are zoomed to the roadway section to provide the necessary pixel resolution.

Camera Vibration. The camera must be stabilized such that the maximum camera vibration still provides a continuous image of the region-of-interest (ROI).

Camera Overlap. A minimum overlap of 80 feet between camera images is recommended for NGSIM data collection efforts. This recommendation accounts for trucks with one trailer in length and moving at free flow speed. At a minimum, no gaps between camera images should exist for the video data collection.

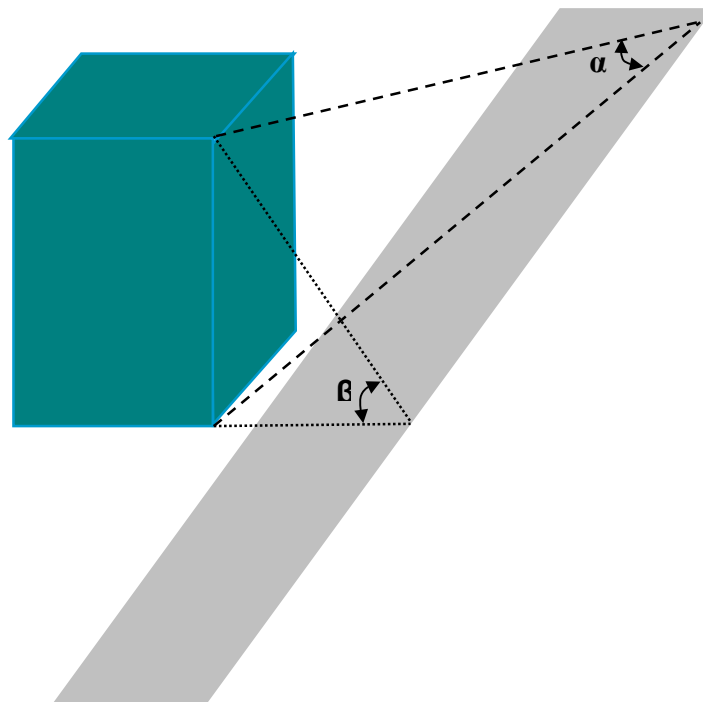
Format. The NGSIM videos were saved as a set of MPEG-4 standard Audio Video Interleave (AVI) files, compressed using the XVID codec at a 5,000 Kb to 8,000 Kb compression rate.

AVI is a widely used video format which compresses individual frames. Since post processing is required for developing orthorectified images, it is necessary to save the data in formats that lend themselves to be broken down to individual frames. Options include avi, ppm, ppd, etc. For saving in AVI format, XVID provides an open and freely available codec that is highly efficient in encoding streaming video data.

Camera Synchronization. Eight cameras were used simultaneously to record NGSIM trajectory data. The synchronization between these cameras is used by developing a custom hardware/software tool that when pressed starts all cameras at the same time. This allowed the synchronization of better than $1/100^{\text{th}}$ of a second.

Longitudinal and Lateral Angles. When cameras are placed on buildings, based on NGSIM data collection efforts, minimum requirements for longitudinal and lateral angles were developed. The longitudinal angle refers to the distance to which a vehicle that this running parallel to the camera should be captured by the video camera for accurate vehicle position transcription, Lateral angle refers to the he perpendicular distance from the camera, and affects the detection of the vehicle, since the roof of the vehicle forms the most important part of the vehicle tracking. The recommended maximum longitudinal angle (α) is less than 11 degrees, while the recommended maximum lateral angle (β) is less than 67 degrees. These limits are based on the NGSIM prototype. It is computationally impossible to extract trajectories when α is lower than 11 degrees. For β , a lower angle than recommended 67 degrees may be possible physically, but it is likely to significantly increase tracking costs as increasing rectification creates more image information loss. Also, lower angles result in trucks occluding more than one-half of cars, which makes vehicle tracking difficulty. An illustration of the longitudinal and lateral angles is shown in Figure 3.

Figure 3 Longitudinal and Lateral Camera Angles for Video Data Collection



Data Compilation

While video data is collected through the NGSIM data collection effort, the rest of the data shown in Table 2, above, is compiled and collated for algorithm research. NGSIM datasets contain the following data:

- Vehicle trajectory data – A text file that provides transcribed vehicle position data of the NGSIM data collection effort.
- Raw and processed video – original raw AVI files from the video cameras and rectified AVI files with vehicle boxes drawn on the individual frames (representing vehicle positions). An example is shown in Figure 4.
- Aerial orthorectified photos – The orthorectified photos were used to provide global coordinates for image correspondence, rotation, and translation of the camera images.
- CAD diagram and GIS files – The CAD and shapefiles provide data on lane geometry, loop detector location (where necessary), sign locations, etc.
- Loop detector data – Local agency’s volume data from loop detectors were compiled and used for NGSIM algorithm development in conjunction with the trajectory data.
- Signal timings – Traffic signal timing sheets, Ramp-metering plans, Real-time Split Monitor (RSM) reports, etc. Signal data for traffic signals within the study area, or adjacent to the study area were collected. Where possible, mesoscopic (RSM reports) and microscopic (second-by-second phase data) signal timing data were collected for arterial data collection efforts.
- Traffic signs – Regulatory, warning and guidance signs information were collected by taking photos of the signs in the study location, or by taking wind-shield video.
- Weather data – All available weather information must be collected for the data collection period
- Incident data – All incident data that can affect the traffic in the study area during the data collection period must be compiled from the local agencies.
- License Information – If the data is going to be made available to the transportation community, open source license that controls the distribution of the data must also be provided. NGSIM data are licensed under the terms specified by the modified creative commons license attribute 2.0 (<http://creativecommons.org/licenses/by/2.0/>).

Figure 4 Raw and Processed Video Snapshot



Data Formats

Before the collection of actual data, the NGSIM team identified the need for data formats for collection and saving the data. Available data formats for graphics and text can be broadly divided as proprietary and non-proprietary formats. There are many types of data files in use, which at a general level can be classified as:

- **Text or Word Processing** – HTML, ASCII, Microsoft Office, Star Office, etc.; and
- **Image** – GIF, MPEG, JPEG, TIFF, PNG, etc.

Each specific file type has a different data structure and internal content. Some of these specific file types are *openly defined*, while others have a *closed* definition. The distinction is between whether anyone can write software to manipulate those file formats, or if there are hurdles to doing so.

In general, the team identified that open, freely identified formats were best suited for NGSIM purposes since the data must be made accessible to the entire transportation community (13). Where proprietary formats are needed, the most widely available formats were selected. All the NGSIM documents are made 508-compliant to conform to the FHWA requirements. Table 3 presents the categorizations applied for NGSIM data formats.

Table 3 Summary of NGSIM Categorizations for Data Formats (13)

Data Collection Type	Research Algorithms	Data Component	Data Collection Method	Data Format Choices
Metadata		Metadata	<ul style="list-style-type: none"> Survey and documentation 	<ul style="list-style-type: none"> XML
GIS-level data	Strategic	System-State Data	<ul style="list-style-type: none"> Wide-area detector data studies Instrumented vehicle data studies 	<ul style="list-style-type: none"> LandXML GIS files (Shapefiles, etc.) XML Text files Graphic Files
		Influencing Factor Data	<ul style="list-style-type: none"> Survey and documentation Aerial photographs 	
CAD-level data	Operational and tactical	System-state data	<ul style="list-style-type: none"> Detailed vehicle trajectory data studies Instrumented vehicle data studies Supplemental Wide-area detector data studies 	<ul style="list-style-type: none"> LandXML CAD files (dxf, etc.) XML Text files Graphic Files
		Influencing factor data	<ul style="list-style-type: none"> Survey and documentation Aerial photographs CAD drawings 	

Trajectory Data

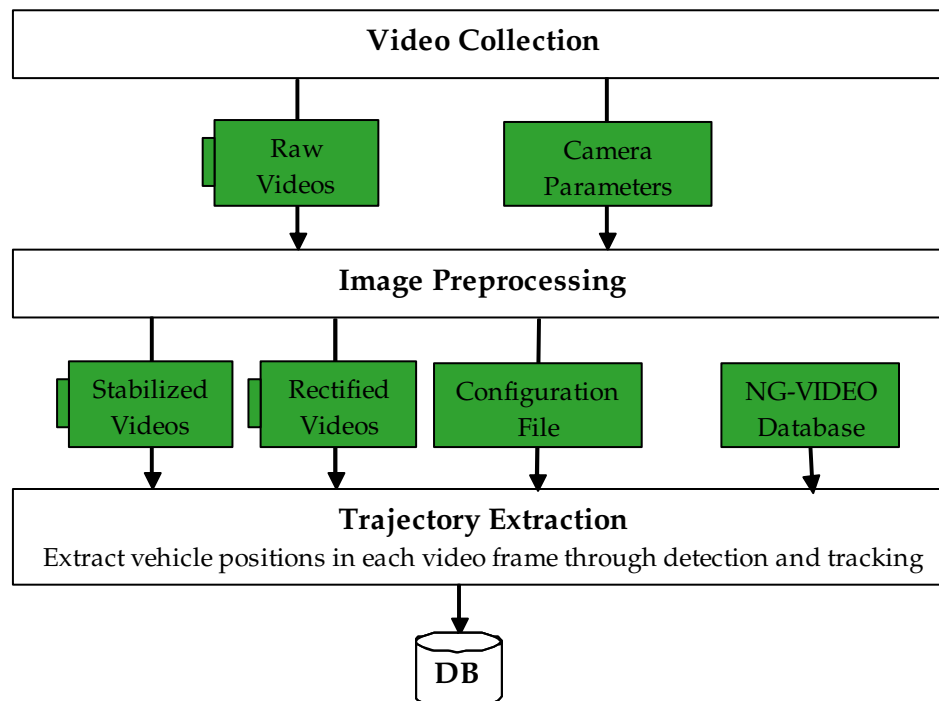
Video Transcription

Following the NGSIM data collection guidelines presented in the previous sections will provide video data that can be transcribed into vehicle positions of within 2 feet of accuracy. FHWA and the NGSIM team developed a video transcription software that uses automatic image processing toolset, along with manual transcription capabilities. The software is called the Next Generation (NG-VIDEO), which stands for **N**ext **G**eneration **V**ehicle **I**nteraction and **D**etection **E**nvironment for **O**perations (14). NG-VIDEO detects and tracks each vehicle from one video frame to the next, and from one camera to the next using orthorectified images, creating a continuous trajectory for each vehicle in the time-space plane for the area of study. It allows the user to manually detect vehicles that are not automatically picked up by NG-VIDEO. It also allows the user to correct individual trajectories that drift out of the true vehicle's path.

The vehicle tracking process consists of capturing video data of a roadway, preprocessing video images, and then extracting the vehicle trajectories from the video. The *Trajectory Extraction*

phase involves using the NG-VIDEO software to track vehicles and put the trajectory data into a database. The vehicles are tracked in global world coordinates for consistency and testing purposes. The overall process is described in Figure 5. NG-VIDEO is an open source software application distributed by the Federal Highway Administration (FHWA) for use by the general public free of charge.

Figure 5 NG-VIDEO Trajectory Processing



Data Processing

The disaggregate trajectory data was processed to provide data inputs for algorithm research. The vehicle positions from the NG-VIDEO software are in global coordinates. For algorithm research, additional data such as local coordinates of the vehicle positions with-respect-to the direction of travel or median are calculated. Similarly, instantaneous vehicle speeds, accelerations, preceding vehicle information, number of lane changes, lead and lag gaps, headways, etc., are also calculated and provided to the users.

Trajectory Data Validation

The trajectory data are validated against loop detector data of the location. Where the data do not match, vehicles are manually counted in the video and compared against the loop detector data.

Algorithm Research

NGSIM program categorized algorithm research as Operational, Tactical, and Strategic algorithms. The algorithm categorization is loosely based on a time scale and behavioral process. The final objective of the video and resultant trajectory data collection is to develop

algorithms that are currently deemed gaps in existing microsimulation systems (15). From the data collections efforts in Table 1, NGSIM has developed a Freeway Lane Selection Algorithm (12), and is in the process of developing three other algorithms that were recognized by the stakeholders as gaps in existing microsimulation models. The NGSIM algorithm research projects till date include:

- Freeway Lane Selection Algorithm
- Cooperative Lane Changing and Freeway Merging Algorithm
- Arterial Lane Selection Algorithm
- Oversaturated Freeway Algorithm

Conclusions

The transportation community is increasingly using transcribed vehicle positions from video data to understand and model driver behaviors and develop smoother and safer traffic operations. While researchers are using many different kinds of systems to conduct the research, there is no out-of-the-box system that can satisfy the requirements of the video data collection. Due to the cost and complexity of trajectory data collection, it is important to develop a structured approach to trajectory data collection that includes identifying the data elements to be collected and providing guidance on the formats of the data to be recorded and compiled. This paper presents guidance on selection of data elements based on NGSIM trajectory data collection efforts consisting of three freeways and one arterial dataset. The paper lists the data elements and data formats for the vehicle trajectory and supporting data, and provides a structured approach for future video data collection efforts. The ultimate objective of the paper was to provide a research framework for collecting vehicle trajectory and supporting data for behavioral algorithm and safety research.

References

1. Halkias, J., Colyar, J., and V. Alexiadis. NGSIM – A New Approach to Federal Research through Public-Private Partnership. Submitted to Public Roads, 2006.
2. Alexiadis, V., Gettman, D., and R. Hranac, Next Generation Simulation (NGSIM): Identification and Prioritization of Core Algorithm Categories, FHWA-HOP-06-008, July 2004.
3. Hranac, R., Margiotta, R. and V. Alexiadis, Next Generation Simulation (NGSIM) Next Generation Simulation (NGSIM) High-Level Data Plan, FHWA-HOP-06-011, July 2004.
4. U.S. DOT, “Freeway Data Collection for Studying Vehicle Interactions,” Report No. FHWA/RD-85/108, JHK & Associates, May 1985.

5. R. Ervin, C. MacAdam, J. Walker, S. Bogard, M. Hagan, A. Vayda, and E. Anderson. System for Assessment of the Vehicle Motion Environment (SAVME): Volume i, ii, 2000.
6. BHL, Berkeley Highway Lab, <http://sprocket.ccit.berkeley.edu/bhl>. 2006.
7. Skabardonis, A., Estimating and Validating Models of Driver Behavior with Video Data, PATH Research Report, UCB-ITS PRR-2005-14, 2005, 43 pp.
8. Schreuder, M., Hoogendoorn, S.P. , Van Zulyen, H.J., Gorte, B., and G. Vosselman. Traffic Data Collection from Aerial Imagery. *Intelligent Transportation Systems*, 2003. Proceedings. 2003 IEEE, Publication Date: 12-15 Oct. 2003 Volume: 1, pp. 779- 784.
9. Hoogendoorn, S.P., Van Zulyen, H.J., Schreuder, M., Gorte, B. and G. Vosselman, <http://www.lr.tudelft.nl/live/binaries/75d50c64-4185-4e28-852c-bf471af9fd05/doc/traffic%20data%20coll%20Ben%20GeorgeV.pdf>, 2003.
10. Angel, A., Hickman, M., Chandnani, D., and P. Mirchandani. Application of Aerial Video for Traffic Flow Monitoring and Management, in *Applications of Advanced Technology in Transportation*, Proceedings of the Seventh International Conference, C.P. Wang, S. Madanat, S. Nambisan, and G. Spring (eds.), ASCE, Reston, VA, 2002, pp. 346-353.
11. Hourdos, J., Garg, V., Michalopoulos, P., and Davis, G. Real-time detection of crash prone conditions in freeway high crash locations. 85th Annual Meeting of the Transportation Research Record, 06-2563, 2006.
12. Chowdhury, C., Toledo, T., and M. Ben-Akiva. NGSIM Freeway Lane Selection Model. FHWA-HOP-06-13, December 2004.
13. Kovvali, V.G., Margiotta, R. Hranac, R., and V. Alexiadis, Next Generation Simulation (NGSIM) Data Format Plan, FHWA-HOP-06-012, July 2004.
14. Zhang, L., V. G. Kovvali, N. Clark, D. Sallman, and V. Alexiadis. NG-VIDEO User's Manual. FHWA-HOP-07-009, October 2006.
15. Hranac, R., Gettman, D., Toledo, T., Kovvali, V., and V. Alexiadis. Next Generation Simulation (NGSIM) Core Algorithms Assessment. FHWA-HOP-06-009, July 2004.