The Berkeley Highway Laboratory- Building on the I-880 Field Experiment

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Abstract

This document presents the development of the Berkeley Highway Laboratory. The laboratory includes a surveillance component, eight dual loop speed trap detector stations and 14 video cameras dedicated to research, as well as an analytical component to advance traffic operations and traffic flow theory. The work builds on our experience with the I-880 Field Experiment and several other traffic studies. The lessons learned from the laboratory will be used to improve traffic surveillance and control, provide new traffic metrics, and enhance traffic models. This paper also presents correction factors that should be beneficial to researchers using the I-880 database.

Keywords: traffic surveillance, vehicle detectors, traffic data, travel time measurement, traffic flow theory

Introduction

This document presents the development of the Berkeley Highway Laboratory (BHL). Several goals underlie this development, including: collecting traffic data for research, extracting meaningful information from this data, furthering traffic flow theory and improving traffic control strategies. The laboratory represents the union of many researchers from the Departments of Civil Engineering, Electrical Engineering, Computer Science, and Statistics at the University of California, Berkeley (both past and present), as well as practitioners from the California Department of Transportation (Caltrans) (see Table 1 for a partial list of participants). The group has been meeting continuously since 1993 to work on a number of traffic related studies.

Table 1, A partial list of researchers and practitioners involved with the Berkeley Highway Laboratory.

Participant	Affiliation
Bickel, P.	Statistics
Chen, C.	Electrical Engineering
Chen, J.	Caltrans
Chen, L.	Caltrans
Coifman, B.	Civil Engineering and Electrical Engineering
Coughlin, S.	Caltrans
Friesenhahn, M.	Statistics
Huang, T	Computer Science
Kwon, J.	Statistics
Lyddy, D.	Electrical Engineering
Malik, J.	Computer Science
Ostland, M.	Statistics
Palen, J.	Caltrans
Petty, K.	Electrical Engineering
Rice, J.	Statistics
Russell, S.	Computer Science
Skabardonis, A.	Civil Engineering
Varaiya, P.	Electrical Engineering
Zhang, X.	Statistics

The first section of this paper reviews preceding work that influenced the development of the BHL or that have been directly incorporated in the BHL. The next section outlines the traffic surveillance component of the laboratory. Finally, the paper discusses the analytical component of the laboratory.

Preceding Work

The I-880 Field Experiment

In 1993, members of the BHL group designed and implemented the I-880 Field Experiment to assess the benefits of Freeway Service Patrols. The Field Experiment collected peak period data from 19 detector stations equipped with dual loop speed traps, extensive incident data, and probe vehicle travel times for 50 week days. Rather than aggregating the detector data into discrete samples, the database contains event data (i.e., individual detector actuations) sampled at 60 Hz [1-3]. Because the database is so rich and the fact that all of the data is available over the Internet, it has become one of the leading resources for traffic research around the world.

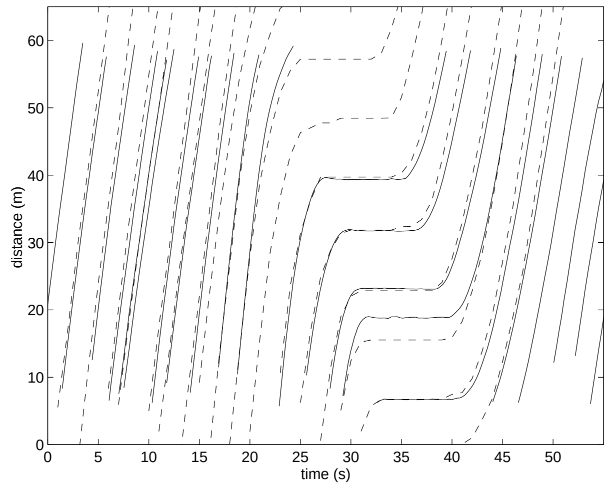
Many lessons were learned during implementation and subsequent analysis. The implementation itself was labor intensive, each day had up to five probe vehicles navigating the 14 mile round trip over the study region and each vehicle had two staff members. On the wayside, the existing communications infrastructure could not transmit the high resolution detector data, so this had to be collected manually. The database was sufficient to assess the benefits of Freeway Service Patrols, but it may not be detailed enough for other applications. For example, with only 50 days, the data set may not be sufficient for long term studies. Next, the data only includes peak periods and does not have any weekend data. The headway between probe vehicles may be too long to verify some applications. Finally, each probe vehicle and detector station had a clock, but these clocks were not coordinated accurately.

Machine Vision Vehicle Tracking

Other members of the BHL group have been working to develop machine vision based vehicle tracking tools and three distinct approaches have evolved from this work. The first approach finds the boundaries between vehicles and the background, then dynamically tracks and updates these closed contours from frame to frame [4-5]. The second approach maintains a continuous update of the scene's background and subtracts this background estimate from each incoming image. The result of this subtraction is then thresholded to form "blobs" corresponding to vehicles. Each blob is tracked as a region using cross-correlation with dynamic updating. Both methods use a rudimentary occlusion reasoning algorithm to keep overlapping vehicle images separate; but both methods require that vehicles be separate when they are first detected, which is not always possible when traffic is heavy. Additionally, the performance of these trackers degrade significantly in the presence of long shadows.

The third approach was developed to improve the vision sensor's performance under all conditions. Rather than attempting to detect entire vehicles, this system locates and tracks corners of vehicles. The history of these tracks is then examined by a grouping algorithm, which uses common motion and proximity cues to group sets of tracks into vehicle hypotheses [6-7]. The advantage of this feature tracking over other tracking strategies is that a given vehicle can be correctly detected and counted as long as at least one feature remains visible throughout the entire tracking region. This fact makes feature tracking more robust in the presence of occlusion. Figure 1 is a plot of several tracker-generated vehicle trajectories (solid lines) along with ground truth (dashed). The ground truth in this figure was generated by a human observer who scrolled through the image sequence and manually marked each vehicle's position. By definition, the slope of each trajectory is simply the given vehicle's velocity at that instant and the horizontal trajectories represent vehicles which have stopped. This figure shows that, unlike most tracking systems, the feature tracker was able to follow vehicles even if they stop momentarily. Finally, note that

Figure 1, Sample vehicle trajectories as a shock wave passes through the surveillance region (dashes = manually generated ground truth, solid = tracker output)



this plot only shows the distance along the roadway, the tracker also extracts the lateral position, so it is a trivial matter to identify lane changes within the surveillance region.

Link travel time (LTT) measurement

The BHL group has looked at many applications of traffic data, highlighting one of these applications, we have developed three different approaches for calculating LTT. The first approach [8] used an empirical semiparametric model for the LTT distribution, which is assumed locally time-invariant. Each sensor measures a cumulative arrival pattern; since each vehicle is modeled as picking its travel time i.i.d., the downstream pattern is given by the upstream pattern convolved with the LTT distribution. A method of moments analysis allows the extraction of the maximum-likelihood travel time distribution from the observed data. This approach proved quite effective in practice when tested on the I-880 loop data.

The second approach [9] tried matching individual vehicles in order to find both LTT and O/D counts. This work used vehicle features extracted by the video tracker, including arrival time, position, speed, color, and size. Vehicle reports from two successive camera sites were *matched* using a combinatorial matching algorithm that computes the probability that a proposed match between two vehicle observations is correct. The system reported as matches any proposed match whose probability exceeded a prespecified threshold on accuracy. With an accuracy threshold of 50 percent, the algorithm was able to match 80 percent of vehicles in a test sequence. With an accuracy threshold of 90 percent, it was able to match 15 percent of the vehicles. Even with such low coverage, the estimated travel time was accurate to within one percent.

The third approach [10] reidentifies vehicles using effective vehicle lengths measured at dual loop speed traps. This approach uses the existing detector and controller hardware to extract a vehicle signature. The basis for this approach is recognizing the fact that the sequence of measured lengths in a platoon provides more information than do the individual measurements. The algorithm was rigorously tested over two sample sets, with a net total over 1,400 vehicles. It matched approximately 60 percent of the vehicles with LTT measurement errors ranging between 0 and 5 percent.

BHL Traffic Surveillance

Work is underway to develop the surveillance portion of the BHL on Interstate 80, just north of Oakland, California, as shown in Figure 2. The site includes eight dual loop speed trap detector stations along the freeway and 14 video cameras on top of the 30 story Pacific Park Plaza. Because of a downstream bottleneck, the westbound traffic (compass southbound) at this location is typically congested for over ten hours during any given weekday. The following subsections provide more detail about the loop detectors, video surveillance system, and video based vehicle tracking.

The Loop Detectors

The standard Caltrans detector station uses a Model 170 controller sampling the loop sensors at 60 Hz. Under normal operation, the 60 Hz event data are internal to the controller, and the output data are typically aggregated into 20 second or 30 second average velocity, flow, and occupancy measurements. Caltrans developed new controller software for the I-880 Field Experiment that preserves the 60 Hz event data. Because the Model 170 controller is based on 20 year old technology, simply outputting this data stream consumes all of a controller's processing power. The I-880 Field Experiment used a laptop computer, in conjunction with each controller, to collect and store this data stream in the field. The BHL uses the same controller hardware and software, but rather than storing the event data locally in the controller cabinets, it is transmitted to campus via a wireless modem and the Internet. Figure 3 shows an overview of the communications system. The controller generates a new data packet each second. An inexpensive PC *client* is placed in each controller cabinet to collect the data packets, manage communications and relay the packets to a central server on campus. Once a packet has been sent, the client waits for an acknowledgment from the server. If no acknowledgment is received in a fixed period of time, the client resends the packet. It is worth noting that the

Figure 2, The Berkeley Highway Laboratory site. Including eight loop detector stations along Interstate 80 and 12 video cameras on top of the 30 story Pacific Park Plaza, just a few feet off the edge of pavement.

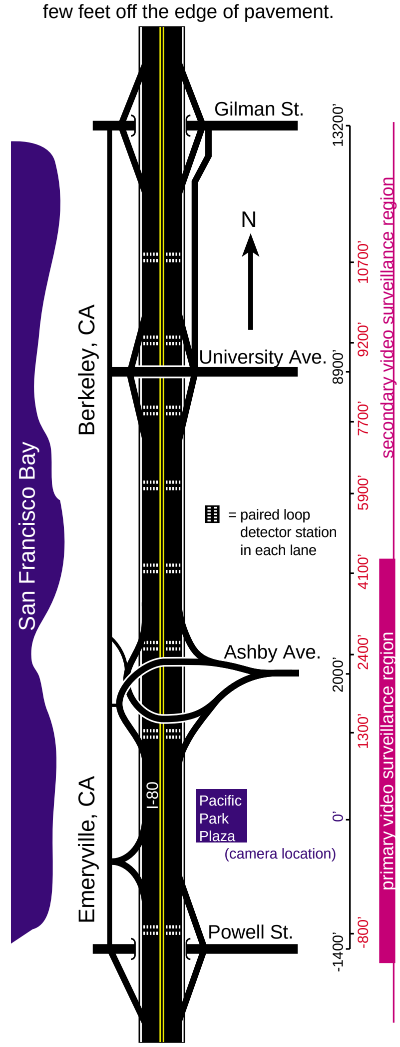
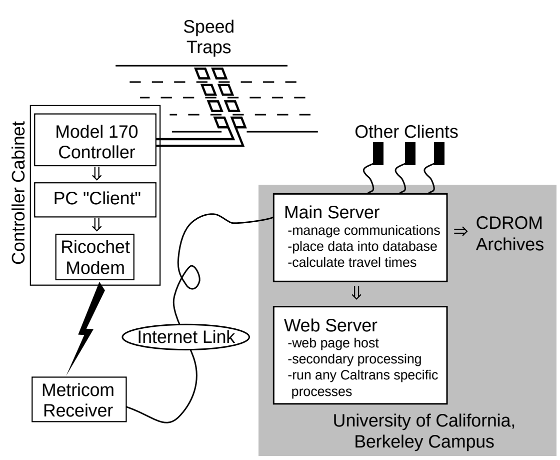


Figure 3, Communications overview showing the data stream from the detectors to campus.



additional hardware cost per station is less than one percent of the cost to install a detector station for conventional traffic surveillance.

The remote data collection system eliminates the need to manually collect the detector data. All of the clients automatically reset their clocks to the same reference each day at approximately 3:00 AM; thereby eliminating any clock discrepancies between stations. Finally, the I-880 Field Experiment was constrained by limited storage capacity on the circa 1993 laptops, as a result, data collection was restricted to weekday peak periods. In contrast, the new laboratory uses a central server with enough disk space to store over 1,000 hours of data from each station in the BHL. The database is periodically backed up to CDROM, thus, allowing the new system to monitor the freeway continuously, 24 hours a day, seven days a week, indefinitely.

Video Surveillance System

As previously noted, the I-880 Field Experiment has relatively long headways between successive probe vehicles. The new laboratory utilizes 12 fixed mount video cameras to overcome this problem, thus allowing any vehicle to serve as a probe. Two additional cameras are remotely controllable "Pan-Tilt-Zoom" (PTZ) units.

The fixed cameras are deployed to provide continuous coverage of the freeway, with one camera's surveillance region overlapping the next. These regions have been selected to optimize automated vehicle tracking from each camera's view. These cameras are connected to studio-grade video tape recorders (VTR's), housed on top of the Pacific Park Plaza, using S-Video format. The S-Video format provides physical separation of color and grayscale signals, allowing for better color constancy than standard composite video, which improves color-based matching. The VTR's record the S-Video signals on S-VHS tapes. The S-VHS format allows for highter bandwidth analo recording, which improves image clarity over standard VHS. This improved clarity leads to more accurate vehicle detection and localization.

The VTR's are capable of recording in several linear and time-lapse modes, ranging from the conventional 30 frames per second to a single frame per second. The VTR's will normally be set to record at five frames per second, which is sufficient for vehicle tracking and allows a standard T-120 tape to store 12 hours of video. In practice, the 12 hours will typically be divided to cover both morning and afternoon commutes. Tapes will be collected and replaced each weekday between the commute periods, and this intensive surveillance will last six to 12 months.

Finally, the PTZ cameras will allow for remote monitoring of the freeway. The video signals from the PTZ cameras will be fed through an on-site computer that will digitize, store, and forward the video frames to a campus-based web server via wireless Ethernet. This link has sufficient bandwidth for two video streams. The web server will also route control commands back to the on-site computer for remote control of the PTZ cameras and the VTR's.

Video Based Vehicle Tracking

Until now, video sensors and loop detectors have been widely regarded as competing technologies for traffic surveillance. Recognizing the fact that each detection system has strengths and weaknesses, the BHL work considers video and loops to be complementary. Loop detectors are widely available, perform under all weather and lighting conditions, and have been refined though several decades of deployment. In contrast, video sensor algorithms provide nearly continuous vehicle trajectories and a large set of features for vehicle reidentification.

Previous work by this group used loop data to verify video sensor performance [6-7] as well as using video to manually verify matches generated by loop based LTT algorithms [10]. The BHL extends this combination of data beyond simple cross-verification by coordinating loop and video data at the vehicle detection and tracking stage. This sensor fusion will yield data sets with the count accuracy of loop detectors and the spatially rich vehicle trajectories of video sensors. These higher quality data sets will in turn allow analysis algorithms to provide a better understanding of both microscopic driver behavior and macroscopic traffic flow. In addition, by comparing data generated by either sensor in isolation to fused data from both sensors, it will be possible to establish the performance tradeoffs one makes when deploying either type of sensor in the field.

BHL Analysis

Several applications are being developed in conjunction with the BHL. This section presents three of them: Real Time Travel Time Measurement, Understanding Traffic Flow and Improving Traffic Models, and Incident Management.

Real Time Travel Time Measurement

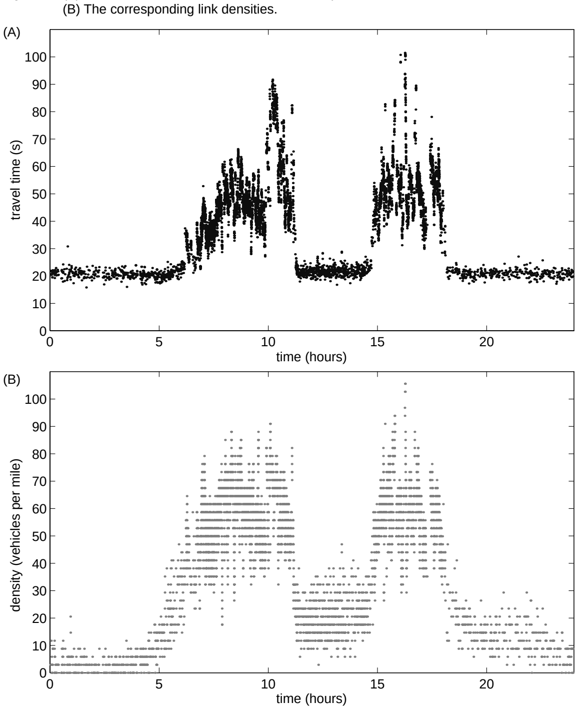
The first application of the BHL surveillance system is measuring travel times in real time. The LTT measurement system reidentifies vehicles from length measurements and is based on [10]. Figure 4A shows an example of travel time measurements across one link, from one lane, over a 24 hour period. This work should help answer questions such as:

- What additional information does travel time provide in real time?
- What are the best ways to integrate this information with traffic management tools?

The lessons learned from this effort will help guide future investments in LTT measurement technology, as well as investments in conventional surveillance technology.

A partial answer to the first question is shown in Figure 4B, which indicates measured link density. A measurement is made whenever a vehicle is reidentified at the downstream detector. The value is the quotient of the total number vehicles to pass the upstream detector during the period that the reidentified vehicle traversed the link divided by the length of the link.

Figure 4, (A) Measured link travel times over a 24 hour period for one lane of one link in the BHL. (B) The corresponding link densities.



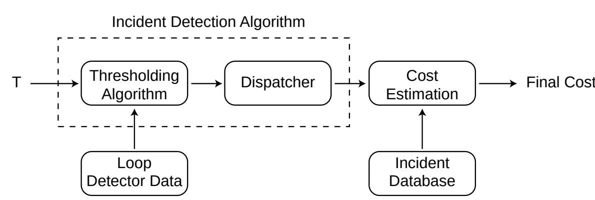
Understanding Traffic Flow and Improving Traffic Models

Most of the current traffic flow theories and models are based on limited empirical data because of the technology limitations in detailed data acquisition and processing. Furthermore, data processing and analysis techniques have been too limited to deal with large amounts of data. The end result is that observed traffic phenomena cannot be well correlated with the interactions of individual vehicles and how they relate to design and control characteristics.

For example, limited information is available on the operation of freeway merging and weaving areas, that involve intense vehicle interactions and lane-changing maneuvers over a restricted distance. Although previous studies videotaped the operation of merging/weaving areas, the recordings were not analyzed microscopically (i.e., vehicle trajectories) to gain a better understanding of vehicle interactions. Additionally, most measurements and analyses are focused on the segment (link) of interest, without satisfactorily considering the spatial and temporal impacts in the network.

The tools developed in conjunction with the BHL for combining, processing and analyzing data from video and loop detectors will provide the basis for better understanding traffic flow and developing improved models. The focus here is not merely to discuss "*what is happening*", but to formulate improved models and consequently predict the impacts of ATMS, ATIS or other scenarios.

Figure 5, Schematic of the analysis framework for estimating the benefits of incident detection/management strategies.



Incident Management

Previous research on incidents have either tried to quantify the problem or develop rapid detection schemes. The effectiveness of incident management measures has been based on simplified techniques with several assumptions about incident impacts to traffic flow. Although countless automated incident detection strategies have been proposed, most of these systems suffer from high false alarm rates and/or long detection times.

A novel analysis framework for estimating the benefits of detection/management strategies was developed by the BHL group and is illustrated in Figure 5. Rather than considering a single facet of incidents, the analysis framework considers the complete system: expected costs from incidents, costs for given levels of detection reliability and costs from mitigations [11].

Using the surveillance tools described above, members of the BHL group will proceed systematically to develop an improved incident management strategy. For example, construct semi-empirical models of the effect of the occurrence of incidents on the evolution of travel times at neighboring points, combine this information with historical models of the relation between data from other sources and incidents, then estimate the probability of an incident given the data.

Given such probability information, we can carry out a utility-directed analysis to compute an optimal policy for responding to suspected incidents. It should be possible to set the "incident detector threshold" to such a level that the value of responding to detected events (e.g., by tow-truck dispatch and changeable message signs) outweighs the cost of false positives. This work should yield the nature and extent of the sensor data required to make emergency response substantially beneficial.

Conclusions

This paper has given an overview of the BHL, starting with preceding studies that have influenced or that have been incorporated into the laboratory. While reviewing these works, this paper presented previously unpublished correction factors that should be beneficial to researchers using the I-880 Field Experiment database. The next section discussed the surveillance components of the BHL, which include event data from dual loop speed traps, extensive video surveillance data, and accurate vehicle trajectories automatically extracted from combined loop and video data. Finally, the paper closes by presenting some of the analytical components in the BHL. The laboratory will be used to demonstrate real time LTT measurement using existing vehicle detectors. The lessons learned from this effort will help quantify the true benefits of LTT data and help guide future investments in traffic surveillance technology. The accurate vehicle trajectories should lead to a better understanding of traffic flow and they will be used to improve traffic models. This work should allow for significant advances over previous studies that only relied on point detector data and/or information manually extracted from video tapes. Finally, the paper discusses a new approach to incident detection and management. Rather than considering a single facet of incidents, this work considers the complete system: expected costs from incidents, costs for given levels of detection reliability and costs from mitigations.

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The Contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification or regulation.

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