Abstract – This paper provides a summary of data needs and field data collection technologies used in the simulation of traffic on freeways. Sensor test results, and successful deployments of traffic sensor data retrieval via satellite communication for use in simulation, archival or planning applications are presented.

Keywords: freeway simulation, traffic sensors, sensor testing, satellite telemetry

1 Introduction

A long running project (1996-2005) has been investigating freeway conditions using simulation for bottleneck identification and evaluation of mostly low-cost actions for improving traffic flow on Honolulu’s central freeway [11]. The project is conducted at the University of Hawaii at Manoa with support from the Hawaii State DOT (HDOT) and the FHWA. Major requirements for traffic simulation are traffic volume data from all freeway entry and exit points as well as average speed at selected cross-sections for the calibration of traffic models.

Most traffic volume data were gathered with permanent inductive loop stations. Past experience shows that properly installed loops in good condition produce accurate counts. This also was our experience, as the sample in Fig. 1 shows. However, loop installation is traffic-disruptive, expensive and loops succumb to failures that require traffic-disruptive repairs. Double loop installations are required for accurate speed measurements.

Data collection with temporary pneumatic tube installations stretched across the pavement is also fairly common worldwide. This practice involves a high risk for the field crew and our comparisons showed that some of the data collected in this manner were grossly inaccurate. Fig. 2 shows that when traffic is flowing, pneumatic tubes produce reliable counts, but when traffic is congested and tires stop on top of the tube, the accuracy of counts drops considerably (Fig. 3).

Due to occlusion problems caused by the typical location of surveillance cameras on the side instead of the middle of the freeway, Autoscope video image processors were used only for the assessment of speed which was tested to be reliable using probe vehicles which were subsequently identified on the video picture. Fig. 4 shows 15-minute average speed measurements by Autoscope and the corresponding measurements by the data from several HDOT instrumented vehicles conducting travel time surveys. The figure demonstrates the quick on-set and subsequent dissipation of congestion at a freeway segment upstream of a major bottleneck.

Sensors that circumvent all or most of the disadvantages of loops and tubes were tested as part of another HDOT and FHWA-sponsored project (2000-2004) [10]. Various tests were conducted with intrusive sensors such as inductive loops, pneumatic tubes, piezoelectric and fiber-optic. A number of unintrusive sensors also were tested: video (Autoscope), acoustic (SAS-1) and microwave (RTMS X1). On-site visits for data retrieval are expensive and demanding in terms of staff needs, and can be hampered by adverse conditions. Data collection from field stations via satellite modems and digital pagers was tested and is reported herein.

2 Freeway simulation data

Regardless of the type of freeway simulation model used (micro or macro-simulation model), the data needed fall into two major categories: essential data for running the model and desirable data for calibrating the...
Figure 1. Volume data on east bound H-1 Fwy. exiting tunnel

Figure 2. Volume data on east bound Ward Ave. on ramp (free-flowing merge)

Figure 3. Volume data on West bound Lunalilo St. on ramp (merging at crawl speed)

Figure 4. Average speed data on east bound Moanalua Fwy.
model. Essential data include:

1. Freeway volumes on several screen lines; the minimum requirement is freeway volume at the entry segment. If the entry segment is congested, adjustments need to be made so that true demand is modeled instead of using the amount of traffic that was able to get through the congested section.

2. Volumes are required for all freeway on-ramps and off-ramps. Demand volume is required for on-ramps, so counts should be adjusted for congestion effects. Off-ramps may also be congested because of an intersection or other capacity restriction at the terminus of the ramp, therefore, off-ramp capacity needs to be adjusted accordingly. Both freeway and ramp data is usually polled from sensors in 30 seconds or smaller intervals. However, most simulations are done using intervals of 5 or 15 minutes.

3. Data on freeway segment lengths, number of lanes and other alignment details such as curves, uphill/downhill sections and shoulder availability and width are needed. Some models make better use of geometric features than others. Typically the analyst may use the Highway Capacity Manual [15] to adjust segment capacities in accordance to geometric features.

4. Freeway simulation models require either aggregate flow parameters (e.g., the relation between volume, density and speed on each segment) or driver behavior characteristics (i.e., headway between vehicles, lane changing propensity, etc.) or both. Model defaults are reasonable starting points, but significant adjustments are needed often [17].

5. Vehicle classification denotes the mix of traffic in terms of light duty (i.e., passenger cars, vans, SUVs) and heavy duty vehicles (e.g., per HCM [15], all vehicles with one or more axles with double tires); the latter have significantly larger size and lower acceleration, deceleration and lane changing capabilities.

Desirable data may include the following:

1. Freeway speed measurements at specific sections which can be compared with model outputs. A feedback or trial-and-error process is usually necessary for the adjustment of model parameters so that model output matches field observations with acceptable error.

2. Instrumented vehicle data are collected by several DOTs as part of their Congestion Management System (CMS). These data provide travel time estimates which can be compared to model output.

3. On ramp survey of motorists destinations or complete origin-destination data are desirable when freeway scenarios are planned that include modifications to the freeway that affect demand (i.e., ramp closures, ramp metering, ramp or mainline widening, etc.) In addition, some models require inputs in origin-destination for-

mat. In several applications, origin-destination data are synthesized from segment volume data [16].

Other data that were available for our specific study and are likely to be beneficial for similar large-scale freeway studies:

1. Comparisons of data from more than one source to determine volume count accuracy.

2. Helicopter observations during congested periods offered valuable, nearly simultaneous insights on freeway operations and queuing areas.

3. Historical data throughout the 1990s showed trends in volume growth, reduction or stability on on-ramps and freeway cross-sections.

4. Traffic accident reports are invaluable for removing data from days or periods affected by accidents or other non-recurring events.

Electronic sensors or traffic detectors were instrumental in gathering volume and speed data. In-pavement inductive loop detectors, and overhead mounted image-processing based Autoscope, microwave-based RTMS and acoustic technology based SAS-1 were used extensively for data collection for freeway simulation model building and calibration.

3 Traffic sensor tests

This section presents sensor test results of accuracy in volume counts, classification counts and speed measurements. Besides volume counting accuracy, a number of attributes and characteristics should be considered when selecting traffic detection devices. These also formed part of the basis for selecting devices for our field testing. They are listed in no particular order because, depending on the application and technology choice set, some may be critical and others may be irrelevant.

- Expertise requirement and set up/calibration time.
- Reliability, typically represented by the mean time between failures (MTBF).
- Number of lanes detected by each sensor.
- Mounting (i.e., overhead, overlane or sidefired location and offset, height requirements.)
- Installation difficulty.
- Transportability.
- Remote communication for testing, adjustments, and data retrieval.
- Solar/battery power capability.
- Traffic data types (i.e., volume counts, classification, speed, occupancy.)
- Effects of light, weather and traffic conditions on performance.
- Purpose of the detection (e.g., data collection for real-time traffic management, archival purposes or controller actuation).
Device selection was based on recommendations from relevant studies in Hawaii (e.g., HDOT’s ITS deployment project, Honolulu’s ITS deployment plan), existing infrastructure (e.g., Honolulu’s traffic surveillance camera system [2]), and devices which, based on tests elsewhere, (i) have produced good results in real-world applications, (ii) fulfill a sub-set of the aforementioned criteria, and (iii) fulfill HDOT requirements as specified below.

The needs of HDOT can be covered by devices that are able to:

1. Count the volume of traffic at user-selected intervals (i.e., 1, 5, 15 or 60 minute intervals). Create average daily traffic (ADT) summaries for record-keeping purposes and for use in planning studies.

2. Measure the speed of traffic for a given lane or cross-section and produce average estimates at user-selected intervals; 20 to 30 second intervals may be required for incident detection purposes. A dense coverage of freeways and other routes along with statistical modeling can yield models that estimate travel times on routes and corridors as well as predict expected travel times for traveler information systems.

3. Classify traffic according to vehicle types. FHWA classification can be accomplished by axle counting or profiling sensors. Axle counting sensors were tested in this project.

The following scale was used to describe the percent errors qualitatively, based on maximum % errors for hourly statistics:

<table>
<thead>
<tr>
<th>Classification</th>
<th>Volume or Speed</th>
</tr>
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<tbody>
<tr>
<td>Excellent</td>
<td>±1</td>
</tr>
<tr>
<td>Very Good</td>
<td>±3</td>
</tr>
<tr>
<td>Good</td>
<td>±5</td>
</tr>
<tr>
<td>Possibly adequate</td>
<td>±10≤</td>
</tr>
<tr>
<td>Inadequate</td>
<td>&gt;±10</td>
</tr>
</tbody>
</table>

The tests were conducted at eight sites in Honolulu: Four sites were on 6 and 8 lane freeway cross sections, three sites were on a 4 lane major arterial leading to the primary container facility serving Honolulu (heavy truck traffic) and one site was on a four lane collector street serving the University of Hawaii. The following sensors were tested:

**Underground or underbridge**
- 3M Microloops and Canoga [1]

**On-pavement**
- OSS FlexSense fiber optic sensor [8]
- JAMAR TRAX RD pneumatic tube counter [5]
- Roadtrax BL piezoelectric sensor [6]

**Above ground, side-fired**
- EIS RTMS microwave radar sensor [4]
- Smartek SAS-1 acoustic sensor [12]

Most of the tests of unintrusive sensors used the experimental setup shown in Fig. 5. The portable trailer houses 2 to 4 batteries (the trailer is a “light plant” diesel powered generator, but it was not ran as a generator due to noise and vibration concerns), sensor termination units, satellite modem (black box in Fig. 5), satellite digital pager (white box) and its external antenna (small black dish attached to the side.) Several ventilation openings were closed to protect electronics from rain.

![Figure 5. Portable trailer with 25 ft. boom.](image)

The sensors and the antenna for the satellite modem are shown in Fig. 6. SAS-1’s microphone array covered by a black screen is clearly seen. The height-adjustable boom was utilized in the tests to assess sensor performance at various heights.

![Figure 6. RTMS, SAS-1 and antenna.](image)
Figure 7. Traffic classification: comparison of distribution by class

Figure 8. SAS-1, RTMS and loop volumes with thunderstorms and heavy rain

Figure 9. SAS, RTMS and loop measurements of speed on right lane
Sensor tests are on-going. Testing methodology details are available in a report [10]. Preliminary conclusions are as follows:

1. The fiber optic sensor produces very good traffic measurements but it is not durable, it is not easy to remove from the sticky tape without damage and it is expensive to replace. It is an intrusive, on-pavement installation that requires lane closure, exposes crew to danger from traffic and usually leaves residue on the pavement such as sticky tape and nails. Its ability for classification was not tested.

2. The piezoelectric sensor performed almost as good as the fiber optic sensor and was able to reproduce a classification profile reasonably well as shown in Fig. 7. It is far sturdier than the fiber optic sensor and much easier to remove from the sticky tape without damage. However, it is an intrusive installation, so the aforementioned pitfalls apply to this one as well.

3. Both the SAS-1 and the RTMS are competent unintrusive sensors for obtaining both volume (Fig. 8) and speed (Fig. 9) data. They can be cost-effective to deploy on any heavy volume highway with coverage of up to 5 lanes for the SAS-1 and up to 8 lanes for the RTMS. They provide data on a per lane and per time period basis. Concerns and weaknesses include the following:
   - A pole that allows installation at an offset and height of over 20 ft. Often an offset larger than 25 ft. is required which makes the deployment of these sensors impractical because poles are not commonly available at such a distance from the nearest travel lane.
   - A small, weatherproof cabinet for batteries and their termination (counter) units or the telemetry device (mobile phone, modem, pager, etc.) is required. This increases costs and mounting difficulty.
   - A portable computer and expertise in the setup software is required. The setup should be conducted in the presence of light-to-moderate traffic, otherwise the “blips” (vehicle signatures) on the computer screen can be difficult to associate with actual traffic. This is harder for the RTMS because of its brief time lag.
   - If highly accurate volume counts and speed measurements are required, sample data with a reliable on-pavement sensor should be collected for comparisons and fine-tuning of SAS-1 and RTMS parameters. This can be avoided if a crew of two people can spend several hours for the setup along a 4-lane highway in the field by collecting multiple 5-minute data per lane (volume counts and speeds with a portable laser gun.)
   - Sideward deployment of SAS-1 and RTMS on roadways with fixed median barriers and similar objects should be avoided because of loss of lane coverage or false counts due to signal reflection/refraction on the barrier. It is best that two devices, one for each direction, are installed.
   - Deployment of the SAS-1 in areas where loud music or loud stationary machinery are likely to be present should be avoided. In our tests, both lawn mowers and very loud music from student dormitories affected SAS-1 performance.
   - Both devices have diametrically opposing issues in the detection of bicycles and mopeds. The RTMS has difficulty in detecting these whereas the SAS-1 has difficulty excluding these if they are not desired to be a part of the volume counts.

4 Satellite retrieval of sensor data

HDOT has over one thousand road count stations on Oahu alone. A small fraction of them are connected with a center for regular communication and data retrieval. Some stations are connected with analog cellular telephony, but there have been reliability issues in addition to the relatively high price for the service. Another test is currently being run with CDPD (cellular digital packet data) modem service. [3]

Over 90% of the stations are not continuously connected to a counter. The sensor stations (many of them inductive loops; but most are temporary installations of pneumatic tubes or piezoelectric sensors) are connected to portable counters for a few days per year in order to collect FHWA-mandated sample data. Installation of relatively inexpensive unintrusive sensors has solved several problems regarding crew size, safety and sensor portability. One remaining issue is data retrieval. This was addressed by the experimental testing of satellite-based modems and digital pagers provided by TrafInfo.

TrafInfo’s [14] modems and digital pagers interface between traffic sensors and Orbcomm satellites. “ORBCOMM LLC is a wireless telecommunications company providing narrow band two-way digital messaging, data communications, and geo-positioning services on a global basis. The company owns and operates a network consisting of 30 Low Earth Orbit (LEO) satellites and terrestrial gateways deployed around the world.” [9]

TrafInfo’s modems collect sensor volume data every 30 seconds and aggregate them by lane in user-determined intervals (usually 5, 15, 30 or 60 minutes). At the end of a 24-hour period (midnight local time), the modem searches for satellite(s) and upon contact, it uploads the data to the satellite. The satellite keeps the data until it communicates with the nearest terrestrial gateway station. From the gateway, the data are forwarded to TrafInfo’s server and are stored until the user (with unique account
and password) accesses the server and downloads the data (Fig. 10). This can be done daily or in longer intervals.

Upon accessing TrafInfo’s server, the data are downloaded and stored in a specified directory on the hard drive of the user’s PC. The data are in rather small (2 to 15 KB), printer text files like: D0510001.PRN which corresponds to the May 10 data file. Each modem or pager has its unique identification. The user must be careful to define separate directories for the files because if there are \( N \) sensors and Trafmate devices deployed in the field, a download from the server will retrieve \( N \) identically named files.

The user can also access Trafmate units from the office via e-mail commands to Orbcomm. Available commands include [S] for checking the status of the unit, [B] for the status of the battery, [EI] for setting the counting interval (i.e., IE05 sets the interval to 5 minutes), and [ST] to update the unit’s clock time.

A problem unique to Hawaii is the lack of gateways for over 2,000 miles which hampers the relay of information to and from satellites. In early tests, a command could take several days to execute. Data, however, were always retrieved without problem. In order to reduce the delay in commanding a field unit, NOVA was used.

As of June 2003, software run in Trafmate units makes them usable with Canoga, RTMS and SAS-1 sensors. Trafmate operating software can be updated or changed altogether by connecting it to a PC with a programmer’s cable and downloading the version of software desired. Currently, only volume counts are polled from the sensors and saved on the Trafmate. A forthcoming improvement includes the storage and transmission of both volume and speed data.

5 Summary

Major data needed for freeway traffic simulation are traffic volumes from all freeway entry and exit points and average speeds at selected cross-sections for the calibration of the models. These data can be collected with intrusive (on- or under-pavement) sensors or with unintrusive (overhead mounted) sensors. Several sensors were tested in various conditions and configurations.

Data collection with fiberoptic (FlexSense) and piezoelectric (RoadTrax BL) sensors can be accurate but their deployment is dangerous for the field crew and expensive in the long term because of the rapid deterioration of the on-pavement components, particularly so for the fiberoptic sensor tested. Pneumatic tubes tend to provide unreliable data if the traffic is not free-flowing.

Tests of unintrusive detectors including the acoustic (SAS-1) and microwave (RTMS X1) revealed that these two sensors have a combination of positive attributes such as being reasonably accurate, fairly easy to deploy and relatively inexpensive to acquire. Offset and height requirements as well as the presence of medians on the highway may create deployment and detection problems, which may be solved by increasing the number of deployed sensors (one sensor for each direction of traffic in sidefired operation or one sensor per lane in overlane operation.)

On-site visits for data retrieval are expensive and demanding in terms of staff needs. In addition, on-site data retrieval can be hampered by weather and other adverse conditions. Data collection from field stations via satellite modems and digital pagers (TrafInfo/Orbcomm service) was tested. It was found to be convenient, economical and reliable in most cases.

6 References


[14] Trafinfo, trafinfo.com


Figure 10. TrafInfo software interface (top right), files on server (top left), data files downloaded on user’s computer (bottom left) and sample data file (bottom right).