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USING VEHICLES EQUIPPED WITH TOLL TAGS AS PROBES FOR PROVIDING TRAVEL TIMES

John Wright and Joy Dahlgren

April 2000

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ABSTRACT

The introduction of electronic toll collection on the eight bridges crossing San Francisco Bay has provided the means for a relatively simple and low cost system for measuring travel times on many Bay Area bridges and roads. The toll tags used for electronic toll collection can be read by readers at various locations on congested roads. The time of reading is recorded so that the time difference between when a vehicle passes one reader and passes the next can be computed. Such as system is already operating in Houston, where it is the primary source of travel time data. Capital costs per reader site where such systems have been implemented range from $18,000 -$38,000 and for the operations center from $37,000 to $86,000. Annual operating costs range from $4,000 to $6,000 per detector site and $48,000 to $96,000 for the operations center. The Bay Area bridges and their approaches are prime candidates for such a system. Most of the congested freeways and a few arterials near the Bay are also good candidates. The extent of the area for which toll tags would provide satisfactory travel time estimates will depend on how many vehicles choose to use electronic toll collection. This, in turn, will depend on Caltrans policies on tolls and the number of lanes available for toll tags and cash payment.

Key words:
Vehicle probes
Travel time measurement
Toll tags

EXECUTIVE SUMMARY

Around the United States and internationally, toll agencies are turning toward electronic toll collection (ETC) to make their facilities more efficient and to reduce delay for their users. Vehicles are equipped with toll tags that are usually placed on their windshields, and as they pass through a toll facility, the vehicles are automatically charged the toll without the drivers having to stop. Because these tags can be read as vehicles travel at high speeds, they can also be read wherever tag readers are installed along the highway and on surface streets, making each vehicle with a toll tag a probe vehicle that can be used to determine travel times between tag readers. Travel times are currently calculated using this method in New York/New Jersey, San Antonio, and Houston.

In the San Francisco Bay Area, the FasTrak ETC system is now in operation on the seven state-operated toll bridges and the Golden Gate Bridge. With so many ETC systems in the area, there will soon be a large number of Bay Area vehicles equipped with toll tags. Installing a network of tag readers would allow accurate travel time information to be gathered over much of the Bay Area. Drivers could use this real-time travel time information to make decisions regarding their route, departure time, or destination in order to reduce their delay, in the process improving the efficiency of the entire system.

There are four components in a probe vehicle system based on electronic toll collection tags: electronic tags, antennas, readers, and a central computing and communication facility. As a vehicle approaches a detection site, an overhead antenna emits a signal, which is reflected back by the tag on the vehicle's windshield. As the signal is reflected it is slightly altered by the tag, providing the system with a unique code to identify the vehicle. The on-site reader then stamps this data with the time and location and sends it to the central facility, where the time between a particular vehicle's tag reads at sequential locations is used to calculate travel times. Detection sites are generally spaced one half to three miles apart, depending on local infrastructure, information needs, and available resources.

Toll tag probe vehicle systems generally cost less than competing surveillance options, such as loop detectors, microwave radar, and video detection, in terms of both capital and operating costs. Capital costs for one detector site on a six- lane highway (three lanes in each direction) are estimated at $18,000 to $38,000. Capital costs for the operations center are estimated at $37,000 to $86,000. Annual operating costs are estimated at $4,000 to $6,000 per detector site and $48,000 to $96,000 for the operations center

A case study on I-880 from Oakland to San Leandro, finds that this section of highway is likely to have sufficient tag-equipped vehicles for accurate travel time estimates soon after the ETC system is fully implemented. It is estimated that for this nine-mile stretch of highway, ten detection sites would provide excellent travel time data; one site is actually located approximately two miles from I-880 in order to accurately calculate travel times to the Oakland Airport. Creating this system would have initial capital costs of approximately $378,000 and yearly operations and maintenance costs of $117,000.

Such systems could provide good travel time information in much of the Bay Area. The Bay Area toll bridges are prime candidates for this system because of the high numbers of toll tag-equipped vehicles, the difficulty of installing other types of surveillance systems on bridges, and the existence of one reader on each bridge already. Most of the bridges are very congested at some times of day, so good information on travel times at various times of day would be very useful to travelers. The capital cost for such a system on all of the bridges would be approximately $385,000, including communications and the central computing facility operations.

Other good candidates for toll tag travel time estimation are congested freeways near bridges, especially those near time critical activities, such as air travel and athletic events. These would include I-80 between San Francisco and Vallejo, US 101 in many locations between SR 85 and Marin, I-880 between Oakland and Hayward, and I-580 between San Rafael and Hayward. Detection sites could be set up at airports or sports stadiums to measure travel times between the freeway and these sites. Detector sites would be spaced every one to two miles. Capital cost per site would be on the order of $35,000 including installation.

High volume arterials might also use toll tag probes. Likely candidates are Sir Francis Drake Boulevard from Highway 101 through Fairfax and 19th Avenue in San Francisco.

Its relatively low cost makes a toll tag-based probe vehicle system an attractive choice for the Bay Area. The technology is fully developed, and there are no major uncertainties as there are with cell-phone probe systems and the possibility that cell phone use in cars may be banned. If calibrated with FasTrak databases the system could also be used to determine changes in origin-destination patterns. It could be more effective than other surveillance methods in warning of a possible incident, because it could sense an incident as soon as vehicles did not reach the next reader in the expected time.

The extent to which a toll tag system can be usefully employed in the Bay Area will depend on the proportion of vehicles equipped with tags, which in turn will depend on how aggressively these are marketed by Caltrans and the Golden Gate Bridge District. At the end of 3 months of operation of the ETC system on the Golden Gate Bridge, 39% of the vehicles crossing were using transponders, and FasTrak staff estimated the 60,000 tags had been sold. Incentives to increase the use of toll tags are: setting up the toll plaza so that vehicles with toll tags can pass through much more quickly than other vehicles, charging a lower toll for tag-equipped vehicles than for other vehicles, and providing free toll tags.

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CHAPTER 1

BACKGROUND

1.1 Introduction

Travel time data has historically been used for long- or medium-term decision making, such as designing new highways or adjusting ramp metering. However, advances in traffic surveillance methods and communication technologies have allowed travel time information to be useful in the short-term; individuals in some cities can now adjust their routes or plans based upon current travel times, gathered through a variety of means. An example is the use of tags used for electronic toll collection (ETC) to track travel times in real time wherever large numbers of tag-equipped vehicles travel.

Chapter 1 begins with a general discussion of historical and current methods of calculating travel times. It continues with an examination of design considerations for toll tag surveillance systems (including costs) and a survey of such systems around the nation. Chapter 2 investigates how such a system might operate on a section of I-880 in the East Bay. Chapter 3 explores the potential for using such a system elsewhere in the San Francisco Bay Area. Chapter 4 presents conclusions and priorities for system implementation.

1.2 Travel Time Computation Methods

The traditional method of calculating travel times has been to use a test vehicle as a “floating car” that drives along the highway at speeds similar to the cars around it. Unfortunately, this method is too resource-intensive to provide anything more than sporadic data. Agencies can significantly increase their effective fleet by utilizing vehicles that are already being driven by government employees, transit drivers, or the general public. By monitoring the time it takes a probe vehicle to travel a known distance, it is possible to estimate the average travel time. The Texas Transportation Institute has identified several different types of probe vehicle systems already in use or being tested (TTI, 1998):

- *Automatic Vehicle Identification (AVI):* Probe vehicles equipped with electronic tags/transponders communicate with overhead antennas/transceivers to recognize specific vehicles at successive locations. An individual vehicle’s travel time is then calculated between these points. Generally, electronic tags are placed in vehicles as part of an electronic toll collection (ETC) system.
- *Signpost-Based Automatic Vehicle Location AVL:* Probe vehicles (generally transit vehicles) communicate with transmitters on signpost structures. Travel time is calculated similarly to AVI.
- *Ground-Based Radio Navigation:* Probe vehicles (generally transit or other fleet) communicate with local radio tower infrastructure. There are no fixed detection

points, so the system must calculate the position of the vehicle at different times to determine travel times.

- *Cellular Geo-location:* The location of a cell phone currently in use can be monitored over time and used to calculate travel times between locations on its route
- *Laser-Based Detector Systems:* With laser devices mounted over roadways, the length of vehicles can be calculated precisely, even at high speeds. By using these lengths to identify individual vehicles, travel times can be calculated.
- *Video-Based Detector Systems:* Using the shape and other defining characteristics of vehicles passing underneath, this system uses videos to match vehicles at different locations.
- *Inductive Loop Detectors:* Using software to detect characteristic inductive loop "signatures" of individual vehicles, it may be possible to use inductive loops to calculate travel times.
- *Global Positioning System (GPS):* Vehicles equipped with GPS hardware communicate their position to orbiting satellites. This information is then correlated with known highways and used to determine travel times.

PATH has recently developed a method for using the vehicle lengths from double loop detectors (also known as speed traps) to match vehicles or groups of vehicles between adjacent loops in order to estimate their travel time between the two sets of loops. This method is currently in use on a short section of I-80 near the San Francisco-Oakland Bay Bridge. (See http://www.its.berkeley.edu/projects/freewaydata/)

Most of these technologies can be considered "passive" applications of probe vehicle technology, since obtaining travel times is not the reason the vehicles are being driven and the communication devices' primary purpose is often not for travel time computation but rather for toll collection, transit operations, or phone calls. This reduces costs, since the primary user pays part of the cost, but it makes it difficult or impossible for the agency to change the number, location, and timing of vehicles.

1.3 ETC Tagged Probe Vehicles Components

Nearly 50 commercial and government agencies in 20 states currently operate, or plan to open, toll facilities utilizing ETC technologies (ETTM, 2000). Three types of systems are used by these facilities: Laser, Radio Frequency (RF), and Infra-Red (IR). A laser ETC systems (as opposed to the laser-based detector system discussed above), uses a scanner to read a bar code on a sticker attached the vehicle windshield. Because of the difficulties of guaranteeing a "clear" read on a moving vehicle, this option is losing market share. Newer systems generally use overhead RF and IR systems that communicate with tags/ transponders mounted on the windshield, roof, or bumper of a vehicle passing beneath. RF systems are the most popular in the United States. The Bay Area ETC systems use RF, and the analysis in this report is based on RF systems.
There are four key components of systems designed to calculate travel times:

- Electronic tags placed in the probe vehicles,

- Overhead and/or roadside antennas to communicate with the tags,
- Roadside readers (generally one per site per direction) to bundle and transmit the data received from the tags, and
- A central facility where the vehicle data are matched and travel times computed and transmitted to users.

Tags, or transponders, are small devices that typically contain an RF-detector, RF-demodulator, microprocessor, lithium battery, and an antenna (Sirit, 2000). As a vehicle approaches a tollbooth or other detection site, even at high speeds[1], a RF field from an on-site antenna activates the tag. The signal from the antenna is then slightly remodulated as it bounces off the tag, transmitting its own unique identification sequence.

At tollbooths this sequence is used for billing purposes and is therefore generally matched with a specific user. For travel time analysis a vehicle's identifying sequence is usually altered to protect the privacy of the individual while still allowing the system to identify a vehicle as it passes multiple detection sites.

The type of tag is generally dictated by the needs of toll facility and is paid for by either the facility or the individual users. "Type I" tags are encoded with information that cannot be altered while they are read by the system. "Type II" tags have a writable area and can store information locally. Smart toll tags are capable of storing and updating account balance information. Advanced tags can also be used in conjunction with other hardware to provide the driver with information about traffic conditions or can communicate with individuals' smart cards.

The antennas can either be placed directly above the road or elevated above the side of the road (sidefire antennas). Sidefire antennas are as reliable as those mounted overhead, although their range may not be as wide. Another alternative is to build dedicated overhead gantries.[2] In high traffic areas there are usually many overhead structures on which the antennas can be placed.. Programs like TranStar in Houston utilize both narrow and broad RF-range antennas. The narrow antennas are designed to read tags from only one lane each, such as HOV lanes, while the broad range antenna type covers many lanes. Antennas operate by emitting RF signals across one to nine lanes (possibly bi-directional), either continuously or only when a vehicle passes over a loop detector (TTI, 1998). The signal is reflected and slightly altered by the toll tag and then received by the transceiver on the antenna. This data is sent to the roadside reader along a coaxial cable. The reader creates a record of the vehicle, along with the location and the time (it is therefore critical that times on all readers be synchronized). The roadside reader is equipped with a communications device and sends data to the computing facility regularly: after each tag read, as in San Antonio, every five to 15 minutes if required for real-time data needs, or less frequently for historical archives. The communications can be via radio or telephone modem or ISDN line. The system is diagrammed in Figure 1.1.

[1] Over 100 mph with some systems.
[2] In San Antonio, Amtech installed guide wires that were occasionally too low and did not provide adequate clearance for mobile homes.

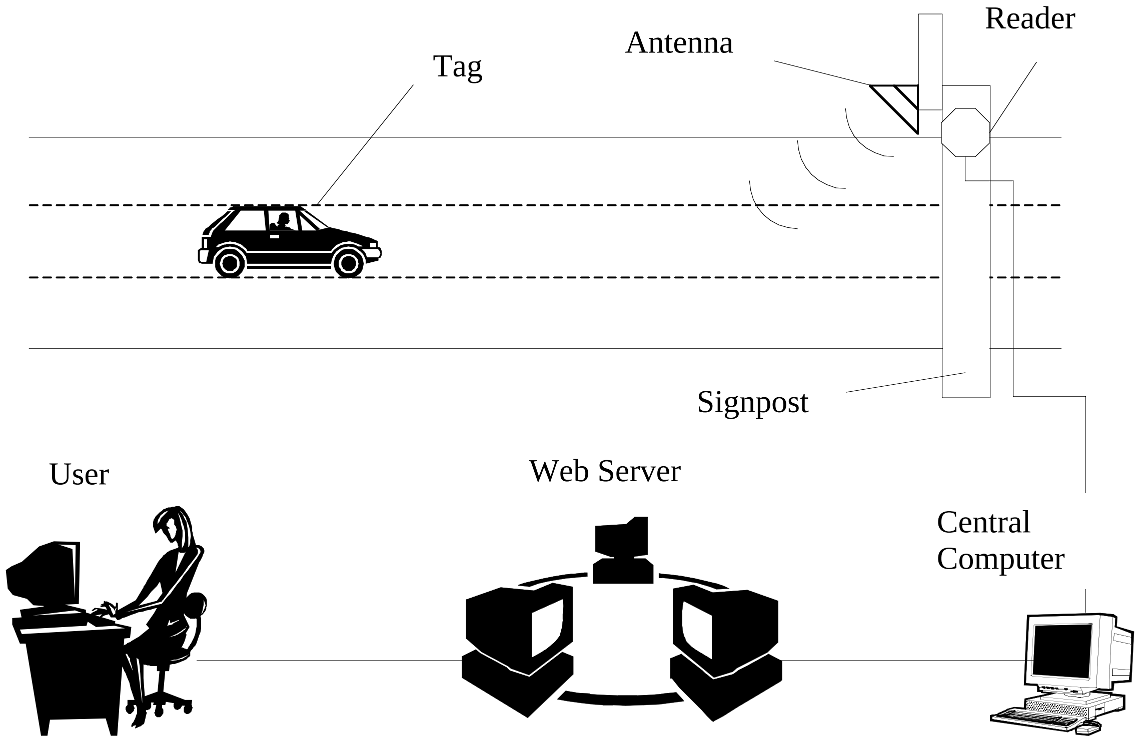


Figure 1.1: Toll Tag-Equipped Vehicle Surveillance System Schematic

The central computer goes through several steps as it processes this raw data and converts it into a convenient form. First, it stores the incoming data from all the different readers into a single database; the computer may create a shared file in order to allow another computer to determine travel times in real-time (TTI, 1998). Second, it finds records with the same tag sequence and calculates travel times between antenna sites for each vehicle. As it does this, the program removes vehicles that have taken an excessively long time to drive between sites; in this way, vehicles that have stopped or taken a circuitous route do not contribute to the average travel time. An algorithm calculates average travel time by using historical data, each new vehicle's travel time, and sometimes information on the particular vehicle or highway segment (e.g., vehicle classification, type of lane). This data is then stored in an archive and may be used immediately for real-time applications (see examples in "Existing Projects"). An AVI system with 450,000 tag reads per week will have daily file sizes of 15 to 20 megabytes (TTI, 1998). In order to protect the privacy of individuals, the tag number is reassigned to guarantee anonymity; some residence location information may be kept in order to assist origin-destination studies.

1.4 Potential Uses of ETC Tagged Probe Vehicles

ETC tagged vehicles have the potential to provide a wide range of information:

- *Basic Traffic Parameters:* Space-mean speed, link travel time, and path travel time (flow can also be roughly estimated by linking tag counts to the proportion of vehicles with tags).
- *Incident Detection:* Using algorithms that note when vehicles are “late” in arriving at a reader site, incidents can be automatically detected.
- *Current Travel Times:* Travel times are calculated almost instantaneously and can be quickly disseminated to the public, emergency vehicles, and transit fleets via the Internet, telephone, traveler information kiosks, highway advisory radio, in-vehicle navigational systems, and variable message signs.
- *Transportation Research:* The extensive data sets created permit a wide variety of transportation research projects:
    - Traffic analysis on hourly, daily, weekly, monthly, and yearly levels;
    - Detailed comparisons of before and after conditions when traffic management strategies are implemented or capacity increased;
    - Tracking of specific classes of vehicles;
    - Analysis of specific lanes, including HOV and HOT lanes;
    - Origin-destination studies; and,
    - Determining bottleneck areas.
- *In-Vehicle Information:* It is possible to upgrade the communication hardware to allow the driver to receive information about traffic conditions, etc. However this might better be done in conjunction with other communication equipment, such as GPS.
- *Fleet Information:* Transit and commercial fleet dispatchers could track their vehicles as they move along instrumented highways. This would require a decision on the part of the appropriate agency to authorize the selling or sharing of specific information to other parties. Furthermore, the tag reader infrastructure would have to cover most of the party’s geographical area for it to be a viable alternative to GPS and other systems.

1.4.1 Advantages and Disadvantages of ETC Tagged Probe Vehicles

The advantages of using vehicles equipped with ETC transponders/tags as probes are:

- *Utilizes existing vehicles and tags:* The vehicles being monitored are already being driven with working toll tags. Neither the interested agency nor the individual driver has to make any alterations at the vehicle level to implement the system.
- *High volume of data:* The volume of data depends only upon the market penetration of ETC tags on the link in question. Therefore, links near or on toll facilities will have large numbers of vehicles, especially as the ETC system matures.
- *Wide data range:* Data may be collected continually, 24 hours a day. The times of greatest congestion (i.e., rush hour) will usually have the highest percentage of tags.
- *Automatic Recording:* The travel time data is recorded automatically. This leads to less error than traditional floating car techniques or estimating travel times from estimated speeds at road-based detector locations.

- *Low operating cost:* For the volume of data collected, there is a relatively low cost and low staff needs.
- *Convenience:* There is no disruption of traffic while monitoring travel times.
- *Accuracy:* ETC tagged vehicles have been found to be accurate-at high speeds and with multiple vehicles (TTI, 1998). There is less opportunity for bias than with traditional floating car techniques since the probes drive naturally.
- *Can provide lane specific data:* Antennas can be installed to detect vehicles in only one lane if so desired (e.g., HOV or HOT lanes).

The disadvantages of such a system are:

- *Startup costs:* While startup costs are not high relative to comparable systems (see Section 1.6.4. below), they may still be significant
- *Dependence upon market penetration of tags:* The system's utility depends upon how many drivers choose to equip their vehicles with toll tags. In areas far from toll facilities, or on segments bypassing toll roads, there may be an inadequate number of probe vehicles to provide meaningful information. If data is required 24 hours a day, there may be times without sufficient probe coverage.
- *Permanent infrastructure:* Once in place, it is costly to transfer components to different locations, as opposed to techniques like floating cars, cellular geo-location, or GPS systems.
- *Privacy concerns:* Although most, if not all, agencies using electronic toll tags as travel time probes take pains to ensure that individuals can not be tracked, the general public may still distrust the technology.

1.5 Existing Projects

Several programs in the United States and around the world are using toll tags to gather travel time information.

1.5.1 TransGuide Travel Tag Program, San Antonio, Texas

This five-year TxDOT project began in 1996 to calculate travel times for the city of San Antonio. Southwest Research Institute of San Antonio is the primary contractor and the tags are supplied by the Amtech Systems Division of Intermec Technologies Corporation. The TransGuide team found that good public relations were important, which they built through a telephone hotline and by developing media support (Rodrigues, 1998) There is not a toll facility in the area, so TransGuide has recruited volunteers to place travel tags on their cars. Because of difficulties in attracting volunteers, TransGuide was forced to scale back their distribution projections from 200,000 to 78,000 toll tags (TransGuide, 2000). The total cost of the project is $3,484,000, which is part of a $13.5 million Model Deployment Initiative grant (TransGuide, 2000).

Fifty-three detection sites were installed at one to two mile intervals, based on existing congestion levels. TransGuide provides current travel time information to San Antonio residents in a variety of ways. There are numerous changeable message signs along the major highways that report current travel times. At key points throughout the city there are 40 TransGuide Traveler Information Kiosks that the public can access, updated every hour (Dellenback, 1999). Information can also be obtained through the TransGuide website and by emergency vehicles with in-vehicle navigation units. Users accessing the web page, for instance, can select a highway and direction. They are then shown various links on that highway and the current travel time for each link, as well as the cumulative time to traverse successive links. They can also click on their entry and exit points on a map and receive a readout of their estimated travel time, Table 1.1. (For more information, please see http://www.transguide.dot.state.tx.us/index.php).

Table 1.1: Sample TransGuide Web-Based Travel Time Readout

Starting Point	Ending Point	Distance	Segment Travel Time	Cumulative Travel Time
[Loop 1604 Eastbound] Chase Hill Blvd. / La Cantera Pkwy.	I 10 / Loop 1604 Interchange	1.4 mi.	1_ min.	2 min.
I 10 / Loop 1604 Interchange	[I 10 East Upper] Exit 569C: Santa Rosa / Downtown	13.3 mi.	17_ min.	19 min.
[I 10 East Upper] Exit 569C: Santa Rosa / Downtown	I 10 / I 35 Interchange (North of Downtown)	0.2 mi.	_ min.	19 min.
I 10 / I 35 Interchange (North of Downtown)	I 35 / I 37 / US 281 Interchange	2.6 mi.	3_ min.	22 min.
I 35 / I 37 / US 281 Interchange	[I 35 Northbound] Exit 160: Splashtown Dr.	2.7 mi.	3_ min.	25 min.
[Loop 1604 Eastbound] Chase Hill Blvd. / La Cantera Pkwy.	**[I 35 Northbound] Exit 160: Splashtown Dr.**	**20.2 mi.**	**25 min.**	

1.5.2 TranStar Traffic Monitoring System, Houston, Texas

TxDOT, Texas Transportation Institute, and the Amtech Systems Division of Intermec Technologies Corporation started designing the TranStar system to collect traffic information in real-time in 1992. Although originally designed as a three-year project, its popularity has kept it funded and operating. The Houston TranStar Center uses this system for incident detection and to provide information to the general public through the Internet, news media, and variable message signs. There are 290 reader sites, two to three miles apart on average. The local toll facility has distributed over 500,000 tags that can be used in the TranStar system. This represents over 5% of the traffic passing tag readers and yields an average of 900,000 and 1,000,000 tag reads each weekday.

Travel times are fed into TranStar's website (see their "Freeway Route Builder" at http://traffic.tamu.edu/transtar.html). Users choose their origin point and then click on successive freeway links to learn distances, travel times, and speeds. TranStar claims that travelers can avoid five to 15 minutes of congestion by using the website's real-time traffic map (TTI, 1997).

1.5.3 New York/New Jersey TRANSMIT System

The TRANSCOM System for Managing Incidents and Traffic (TRANSMIT) is operated by a consortium of transportation organizations in the New York and New Jersey areas. The $1.4 million system has been installed on 22 miles of roads on the Garden State Parkway and the NY State Thruway and will be expanded to 200 miles of roads in the greater metropolitan area (Mouskos, 1998; Niver and Mouskos, 1999). The system consists of 22 roadside readers, spaced one half to two miles apart, with one antenna for each direction.

Currently there are more than 2 million vehicles equipped with E-ZPass tags; it was estimated that as much as 65% of the Garden State Parkway rush hour traffic will have toll tags after the toll increase in August 2000 (Gilbert, 2000). Overall, the reliability of detection, transmission, and travel time computation was found to generally be between 90% and 100%, with some anomalies at specific sites (Mouskos, 1999). One site, in particular, that used a radio link consistently fell below expectations.

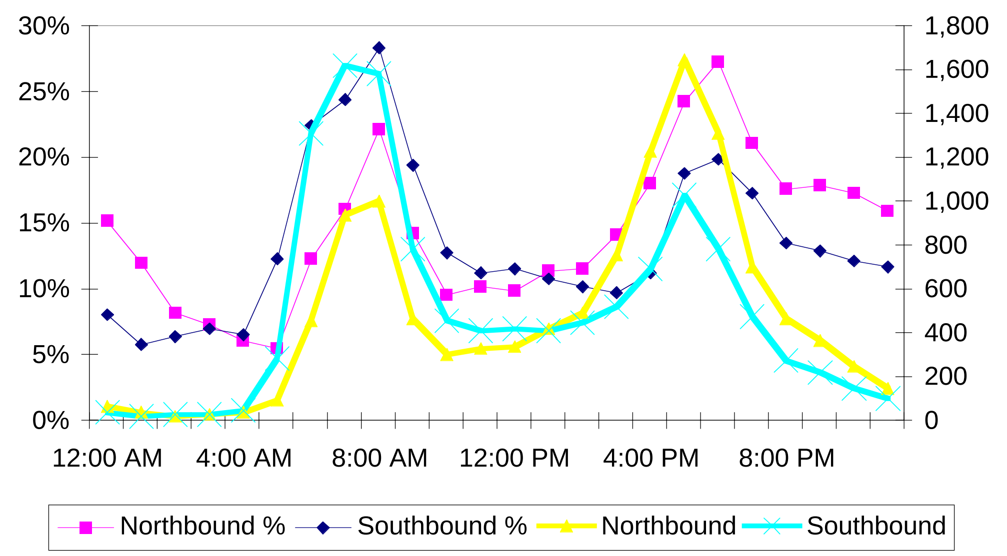
When an E-ZPass-equipped vehicle enters the capture zone of an antenna/reader site, its identification sequence, detection time, location, and lane position are bundled by the roadside terminal and sent to the Operations Information Center in Jersey City, New Jersey where it is immediately processed. Travel times are calculated, with the identification sequence being recoded to guarantee privacy. When a certain number of vehicles take an excessively long period of time to reach their next detection site, a potential incident alarm is triggered and local authorities are notified. Stand-by operators monitor the travel time data processing 24 hours a day.

1.6 Design Considerations

1.6.1 Sample Size

The sample size of an ETC tag travel time project is simply the number of vehicles with activated ETC transponders traveling between two readers over a given time (usually five to 15 minutes). This number depends on the market penetration of the toll tags, the proximity of the highway in question to a toll road, the spacing of the readers, the proportion traversing the distance between readers, and the time of day. As an example, Figure 1.2 shows the percentage of vehicles passing two tollbooths in New York and New Jersey's TRANSMIT system in 1996, as a function of the time of day. The percentage of ETC users out of the total traffic volume varies from approximately 5% to nearly 30%, with rush hour vehicles being more likely to use the ETC system than vehicles at other times (Mouskos *et al.,* 1998).

Figure 1.2: Transmit EZPass Usage at Two Tollbooths (1996



Because agencies interested in travel time have little direct control over the number of vehicles equipped with toll tags[3], the question of sample size becomes one of determining if the number of vehicles equipped with toll tags is adequate to accurately determine travel times for the links deemed important. Furthermore, each agency must determine when it needs the information. As can be seen in Figure 1.2 there may be long periods with low numbers of vehicles passing through; in the middle of the night, for instance, it may only be possible to calculate travel times for a few vehicles. However, since agencies are more interested in the congested time periods, it is most important to determine the number of vehicles during rush hour. Figure 1.2 shows that in the TRANSMIT system, rush hour marks both the highest percentages and numbers of vehicles throughout the day; this is logical since these drivers have the most to gain by saving time with ETC and are also less likely to be casual users.

Sanwal and Walrand (1995) found that to accurately determine travel times approximately 4% of vehicles should be probe vehicles. Srinivasan and Jovanis (1996) investigated the number of probe vehicles needed for reliable travel time measurement under various scenarios. They found that the number of probes required increases non-linearly with degree of reliability required and inversely with the length of the sampling time period. Furthermore, they determined that with a given number of vehicles, more freeways links can be covered reliably than major arterial links. In the TRANSMIT program in New York and New Jersey, it was determined that a sample size of less than 15 vehicles per 15-minute period was sufficient on 85.5% of their links (Mouskos *et al.*, 1998). Furthermore, as the percentage of vehicles with toll tags is expected to grow, the number of links with adequate coverage is expected to increase. The TranStar Traffic

[3] In locations without an existing ETC system, such as San Antonio, agencies are forced to recruit volunteers to place transponders in their vehicles. In the future, these efforts may be aided as large garages, airports, and even drive-thru restaurants begin allowing customers to pay for services with transponders.

Monitoring System in Houston, Texas was able to establish accurate travel times with only two or three vehicles per 15-minute period, although they often actually receive three to four tag reads per minute (TTI, 1998). In the TransGuide system in San Antonio each pair of matched tag reads are run through an algorithm to filter out vehicles that exit the highway and return again; a single vehicle is sufficient to provide travel time, "expiring" after 20 minutes. During testing in Oslo, Norway in 1994, at least five vehicles were needed every five minutes for the algorithm to function properly, even though generally four times this number were recorded (Christiansen and Hauer, 1996).

1.6.2 Spacing of Detection Sites

The distances between antenna/reader sites will vary both between and within systems, based upon each agency's needs and resources, as well as the layout of the highway. Typically, they are more closely spaced in areas with high congestion or when being used to detect incidents. Placing them further apart decreases the overall costs, but reduces the number of matches and provides less location specific information. In practice, they are generally spaced one half to three miles apart, and occasionally as far apart as five miles.

1.6.3 Reliability

One of the benefits of using ETC technology to calculate travel times is the degree of reliability. Because toll facilities demand near perfect detection in order to reduce toll evasion, the vendors have developed the technology to a high level of reliability. Manufacturers claim a "99.9% accuracy rate even under the most adverse environmental conditions at highway speeds" (Sirit, 2000). In the TRANSMIT program in New York/New Jersey, they determined that occasional poor performances could be attributed to specific antenna/reader sites that needed adjustments; one site in particular, using radio communication rather than coaxial cables, was found to be wanting. This emphasizes the importance of proper maintenance, which can significantly increase the operations costs of a program. At sites functioning properly, TRANSMIT found that their detection and transmission rates were near 100% and that their link travel times were within 95%.

1.6.4 Costs

Every system will have different needs and requirements, and each site within a system will have unique characteristics. A site with pre-existing overhead structures already wired for electricity will have lower costs than a site where a gantry must be built to span the road or in an area without electricity. If an agency needs to know travel times on a lane-by-lane basis, then they will need an antenna for each lane.

Toll tag probe vehicle systems compare favorably to other traffic surveillance systems, such as those using inductive loops, video images, or microwave radar. A 1998 comparison analysis found that TRANSMIT's transponder detection program was 55% to 73% less expensive than these other detection systems, as shown in Table 1.2 (Mouskos, 1998).

Table 1.2: TRANSMIT Evaluation of Costs per Detection Site for Various Probe Vehicle Techniques (Mouskos *et al.* 1998)					
Description		TRANSMIT	Inductive Loops	Video Image	Microwave Radar
Capital Costs	Hardware	$14,700	$4,100	$24,500	$26,500
	Installation	$21,700	$50,560	$45,100	$25,200
Total Capital Costs		**$36,400**	**$54,660**	**$69,600**	**$51,700**
Maintenance Costs/Year		$2,900	$7,950	$3,300	$2,900
Operations Costs/Year		$2,040	$2,040	$2,040	$2,040
Total Annual Operating Costs		**$4,940**	**$9,990**	**$5,340**	**$4,940**

1.6.4.1 Equipment Costs

Except where noted, all antenna/reader site costs are for one direction on a six-lane highway (three lanes in each direction). These costs were collected from existing programs and estimates from technology vendors.

The costs of equipment are a significant part of the overall program costs. Equipment needs include the following, although not all systems will need all components:

- *Toll Tag/Transponder*: $10 to $55. The unit cost depends on the volume. A system that utilizes tags already used for a toll facility will have no costs for tags.
- *Antennas and Roadside Readers*: $4,000 to $10,000 each. These costs are lower than a few years ago when antennas cost $1,500 to $2,000 (now approximately $200) and readers cost $6,000 to $30,000 (TTI, 1998; Mouskos, 1998; Turner, 1998). While antennas can theoretically monitor up to nine bi-directional lanes of traffic, in most locations it will be necessary to have at least one for each direction of a six-lane highway. If detection of vehicles in specific lanes (such as HOV lanes) is desired then multiple antennas will be needed. Houston's TranStar system uses Yagi and Sinclair antennas, which detect vehicles over one and two lanes respectively; TranStar's cost per site, including readers and installation was $50,000 (Turner, 1998). This cost does not include the mounting structure.
- *Modem*: $100 per Operations Center modem. In-field modem costs are aggregated into modem installation costs below.
- *Control Center Computer*: $2,000 to $5,000.
- *Computer Data Storage*: $10 to $20/gigabyte
- *Channel/Digital Service Units:* $1,000. The TRANSMIT system in New York/New Jersey has six CSU/DSUs to channel multiplexed data to the de-multiplexer (Mouskos, 1998). This component, and the following equipment items are all especially mentioned in TRANSMIT reports. At most agencies these costs are often bundled into existing Traffic Management Center costs, since it is independent of the detection technology (i.e., if an agency wants to disseminate information over the internet, it will have many of the same costs whether it uses ETC tags, inductive loops, or floating cars).
- *Communications Concentrator:* $10,000. TRANSMIT uses one concentrator at its traffic operations center (Mouskos, 1998).

- *Server:* $10,000 to $30,000. TRANSMIT uses two servers (Mouskos, 1998).
- *Remote Workstations:* $20,000. TRANSMIT has two remote workstations (Mouskos, 1998).
- *Routers:* $4,000. TRANSMIT has three routers (Mouskos, 1998).
- *Specialized Software in Center*: Varies, depending on whether it can be performed in house or requires an outside consultant. TRANSMIT estimated their software/operations support costs $12,000 per year. As more and more agencies around the country and the world utilize these systems, it should become possible to purchase software off the shelf that will need only minimal customization.

1.6.4.2 Installation Costs

These costs do not include the cost of the structure on which to mount the equipment; it is assumed that the equipment will be mounted on an existing overhead structure. Installation costs depend on the distance to the electrical supply. One current vendor in California estimates average installation costs to be approximately $6,000 per reader. Assuming electrical utility services are reasonably close by, the following costs were estimated for the TRANSMIT system (Mouskos, 1998, except where noted):

- *Reader cabinet*: $3,500
- *Exposed Conduit:* $60/foot (160 feet for $9,600)
- *Underground Conduit:* $30/foot (20 feet for $600)
- *Cabling:* $10/foot (300 feet for $3,000)
- *Antenna installation:* $500 (4 for $2,000)
- *Modem installation/line testing*: $500
- *Telephone connection*: $25 to $40 (TTI, 1998). A line is needed for each reader location. In some locations ISDN lines can be set up, possibly bringing down long-term costs. Alternatively, radio modems can be used to transmit data (e.g., TranStar in Houston).
- *Maintenance and Protection of Traffic:* $2,500

1.6.4.3 Operations Costs

While there are certain maintenance costs that will incur at every reader site, the overall operations costs will also depend on what the information is used for, and how much staff time this will require. Continuing costs include:

- *On-Site Maintenance:* Up to $3,000 per year. Maintenance of readers ranges from $100 to $150 per month (Turner, 1998; TTI, 1998). TRANSMIT purchased a warranty from Mark IV to maintain their readers at $2,000 per site per year. On top of this $2,000 was $400 for the project manager to coordinate maintenance and $500 for ancillary equipment, such as cables. In their first four years of operation, none of TRANSMIT's antennas needed adjusting or maintaining (Mouskos, 1998).
- *On-Site Electricity:* $250 per year.

- *Communications*: Varies. The telephone costs may be substantial, particularly with frequent dialups. Costs may be even higher in regions like the Bay Area, where readers may be located in different area codes. TRANSMIT found their costs to be approximately $1,800 per year per site (Mouskos, 1998). TranStar had costs of $30/month and was attempting to consolidate phone lines into fiber to reduce costs. If available, ISDN lines may cost more initially but can bring down overall costs. Radio modems can also be used.
- *Central Computer/Communication*: $12,000 per year (Mouskos, 1998).
- *High Speed Data Circuit*: $6,000. TRANSMIT uses a high speed data circuit for its remote workstations and multiplexed RST's.
- *Staff*: Varies. Depending on the program, staff needs can vary from one to several people. If the ETC system is being used for incident detection purposes, continuous monitoring may be desired to investigate and verify alarms. The amount of analysis that the agency wishes to perform will also determine the staff requirements. For project management, an estimate of $50,000 per year is reasonable.

1.6.4.4 Overall Costs

Costs for one roadside location including an antenna and reader for each direction of traffic on a six-lane with reasonable access to telephone and electricity lines are:

- *Capital Costs* $18,000-38,000
  - *Site Equipment* $6,300-$15,510
  - *Installation* $12,000-$21,740
- *Annual Operating Costs* $4,000-6,000
  - *Maintenance* $2,500-$3,000
  - *Operations* $1,750-$2,750

Costs for the operations center are:

- *Equipment Costs* $37,000-$86,000
- *Annual Operating Costs* $48,000-$96,000

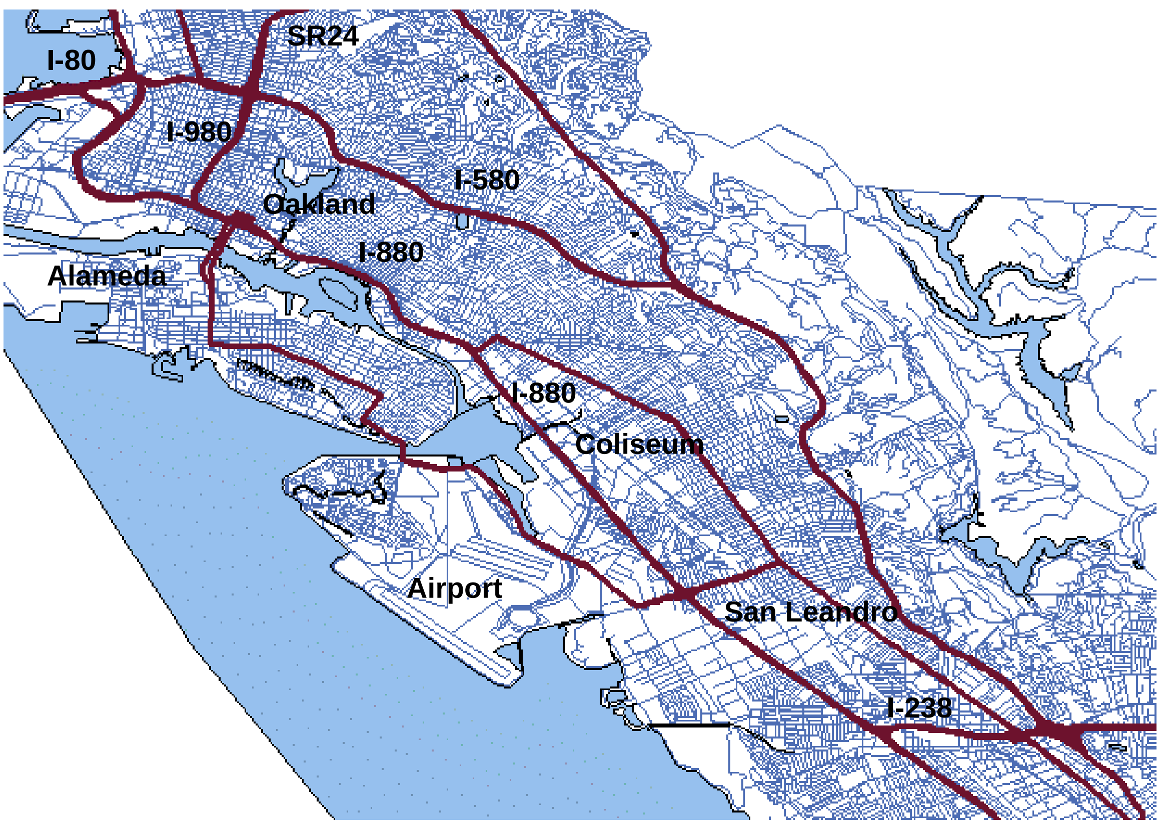
CHAPTER TWO

CASE STUDY: INTERSTATE 880 IN OAKLAND, CALIFORNIA

2.1 Description of Site

To test the feasibility of a travel time measurement system based on toll tags, we estimated their effectiveness and cost on a nine-mile section of Interstate 880 (I-880), between I-980 and I-238. This route runs south from downtown Oakland through the town of San Leandro to San Lorenzo. Major activity points along the way include downtown Oakland, the entrances to the town of Alameda, the Oakland Alameda County Coliseum Complex, and the Oakland International Airport. I-880 runs near the shore of San Francisco Bay and is a primary thoroughfare for north/south travel along the East Bay and into San Jose. Caltrans data (Caltrans, 2000) show an annual average daily traffic volume of 238,000 vehicles at the I-880/I-238 interchange and 150,000 vehicles at the I-880/I-980 interchange in Oakland..) I-880 is roughly paralleled by I-580 to the east, which runs through the East Bay hills.

Figure 2.1: Interstate 880 Case Study Site



2.2 Number of Vehicles on I-880 That Have Crossed a Bridge During Their Trip

The key characteristic determining the success of a toll tag-based travel time probe vehicle system on a given stretch of highway is the number of vehicles with transponders traveling on it. This depends upon the highway's proximity to toll facilities. The case study site is near three toll bridges: the San Francisco-Oakland Bay Bridge (I-80) to the north and the San Mateo Bridge (SR92) and the Dumbarton Bridge (SR84) to the south. The Richmond-San Rafael Bridge (I-580) and the Carquinez Bridge (I-80) are secondary sources for travelers. Some users of the Golden Gate Bridge (US 101), the Antioch Bridge (160) and the Benicia Bridge (I-680) may also use the test section of I-880.

In order to estimate the number of vehicles that would travel both on the test section of I-880 and a bridge, we examined Caltrans traffic counts on the bridges and various points along I-880 from 1998 and 1999 and ramp counts from 1992 to 1998.[4] In the absence of complete origin-destination information, assumptions were made about bridge crossers' travel patterns. At every exit ramp or interchange it was assumed that the number of bridge crossers exiting was in proportion to the number on the highway at that point (i.e., if 20% of highway travelers at a certain point had at some point crossed a bridge, then it was assumed that 20% of vehicles exiting at the next ramp were bridge crossers).

These estimates were approximately the same as were found in Systan's (1995) origin-destination survey on a section of I-880 between SR92 and SR84, just south of the case study section. The Systan report found that over 4.1% of travelers were found to have crossed the San Mateo Bridge; our method found 4.25%. This increases our confidence in the validity of our method.

From these calculations it was estimated that bridge crossers made up approximately 10 to 14% of the traffic on I-880, 21,792 to 27,114 vehicles per day (see Figures 2.2 and 2.3), or 908 to 1,130 vehicles per hour on average. Figure 2.4 shows how the volumes of crossers of the San Mateo and the Dumbarton bridges to the south complement the volumes of crossers of the Bay Bridge to the north. Because of this, the total proportion of bridge crossers remains relatively constant across all sections of I-880, although it is slightly lower in the middle sections.

[4] Unfortunately, ramps are generally only surveyed every three years and therefore portions of the data come from different years.

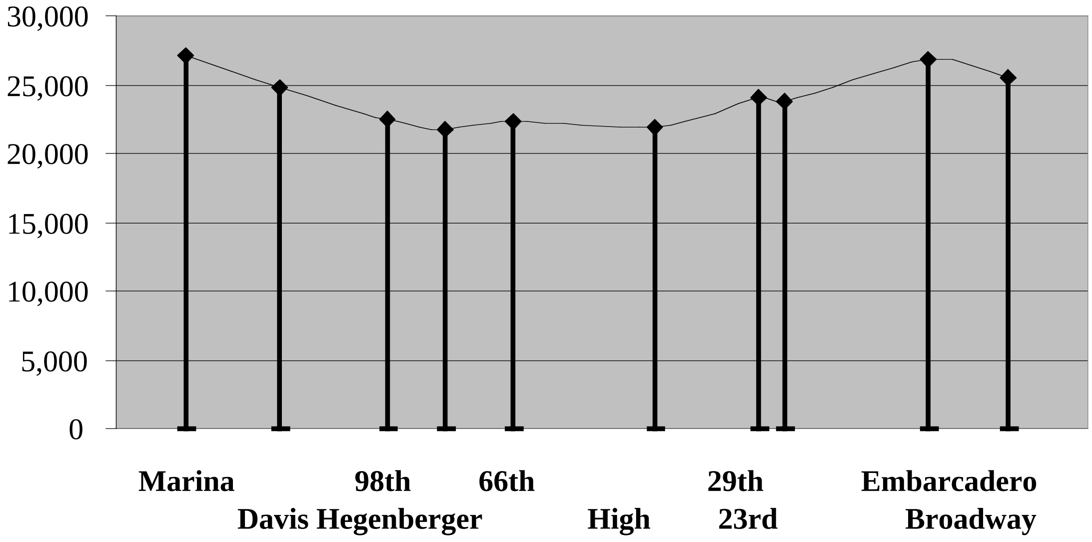


Figure 2.2: Estimated Daily Volume of Travelers on I-880 Who Al
Crossed a Bridge

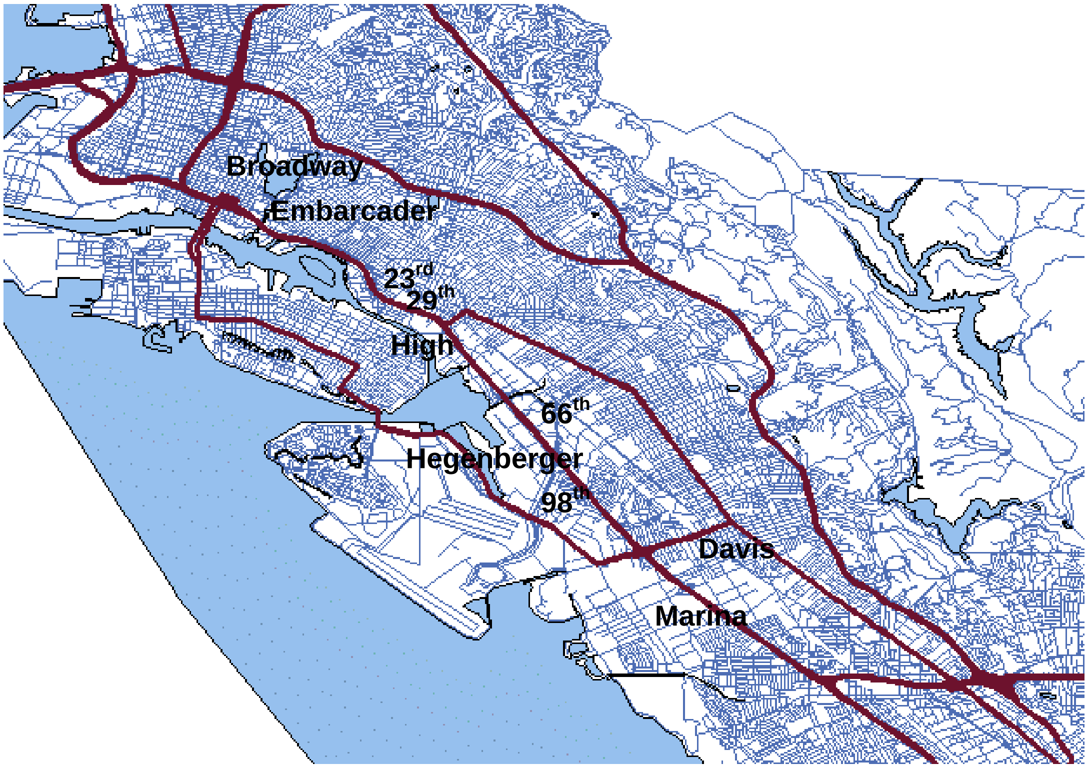
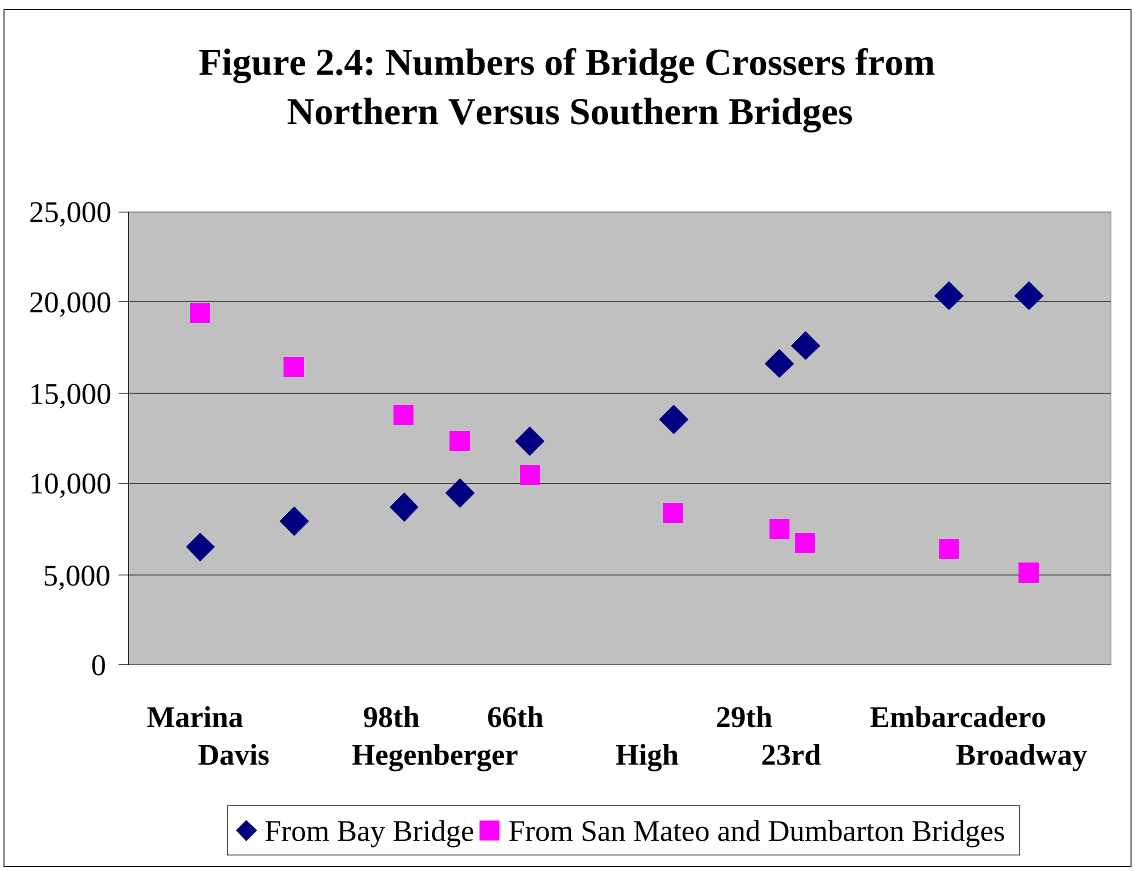


Figure 2.3: Locations of Data Sites from Figure 2.2



2.3 Proportion of Bridge Travelers Equipped with Toll Tags

Because electronic toll collection has been operating in the Bay Area for only a short time, the proportion of bridge users having transponders was estimated based on toll tag usage rates on the TRANSMIT system in New York.

The proportion of toll tag users at existing toll facilities across the country vary widely, depending upon the system and the incentives offered. The TRANSMIT system in New York/New Jersey expected penetration levels up to 65% by the end of 2000, as toll rates went up. The electronic toll users will be receiving a discount on the toll. We based our analysis on the proportions of toll tag users on two of the TRANSMIT system bridges in 1996 (shown in Figure 1.2), assuming that initial markets in the Bay Area would be similar. These rates varied 5 to 30% depending on the time of day. The low percentage of transponder users during off-peak hours may not be a hindrance to travel time calculations, since congestion is also likely to be low during these times.

We applied the TRANSMIT hourly rates of toll tag use to estimated hourly volumes of bridge crossers at 66th Avenue on I-880, assuming that the proportion of bridge crossers at that location was the same throughout the day. The results are shown in Table 2.1 and Figure 2.5. As can be seen in Table 2.1, between 6 AM and 10 PM the number of toll tags never drops below 30 per 15-minute period; 15 vehicles per a 15-minute period (in each direction) is a conservatively high estimate of how many probe vehicles are needed for reasonably accurate travel time estimates.

This methodology results in an assumption that 15.7% of bridge users on I-880 have transponders in their vehicles. Experience with toll tags on the Golden Gate Bridge, suggests that our assumptions regarding the proportion of bridge travelers using toll tags may have been lower than will actually be the case. After 3 months of FasTrak operation, 34% of Golden Gate Bridge users use toll tags, 59% in the morning peak.

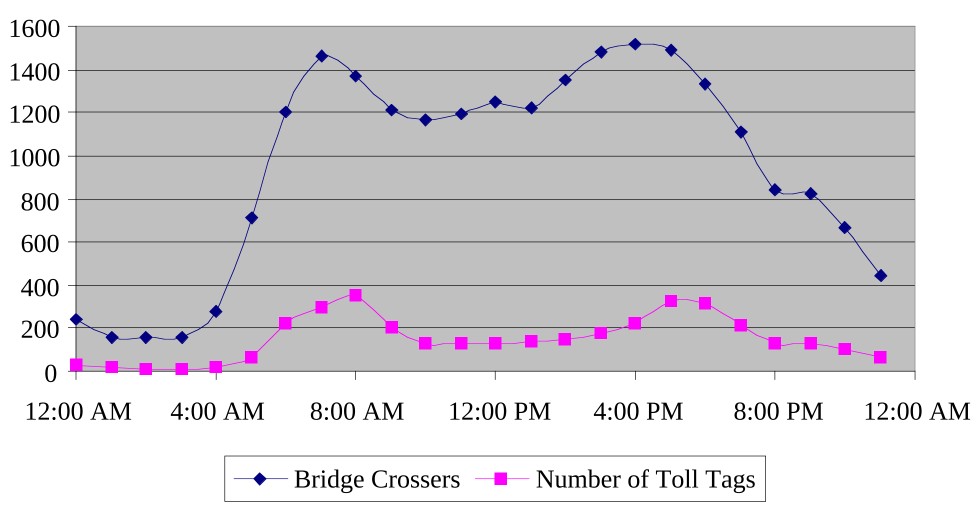
2.4 Location of Detection Sites

Ten detection sites are identified for this section of I-880. They are approximately one mile apart, serve the major activity centers (e.g., airport), and make use of existing overhead structures (overpasses), wherever possible. These locations are shown in Figure 2.6 and are listed below in order from south to north. Except where noted all sites have one antenna for each direction of traffic.

1. **Floresta Boulevard Overpass (Postmile 21.69)**: Floresta Boulevard crosses I-880 in San Leandro, approximately one and half miles north of I-238. It is the first overpass north of I-238 and has no on- or off-ramps connecting it with I-880.
2. **Williams Street Overpass (Postmile 23.23)**: This is one and a half miles north of the Floresta Overpass, and is just north of the on/off ramps at Marina Boulevard.

Table 2.1 Estimated Number of Transponders at 66th Avenue (both directions)				
Time	**Recorded Overall Volume**	**Bridge Crossers**	**Number of Toll Tags**	**Number Per 15 Minutes**
12:00 AM	2,427	244	28	7
1:00 AM	1,607	161	14	3
2:00 AM	1,544	155	11	3
3:00 AM	1,536	154	11	3
4:00 AM	2,732	274	17	4
5:00 AM	7,130	716	67	17
6:00 AM	11,925	1198	221	55
7:00 AM	14,526	1459	300	75
8:00 AM	13,623	1368	349	87
9:00 AM	12,075	1213	207	52
10:00 AM	11,614	1167	130	33
11:00 AM	11,903	1196	128	32
12:00 PM	12,428	1248	134	33
1:00 PM	12,163	1222	135	34
2:00 PM	13,483	1354	146	37
3:00 PM	14,740	1481	177	44
4:00 PM	15,132	1520	224	56
5:00 PM	14,835	1490	324	81
6:00 PM	13,251	1331	318	79
7:00 PM	11,085	1113	216	54
8:00 PM	8,377	841	133	33
9:00 PM	8,233	827	129	32
10:00 PM	6,612	664	99	25
11:00 PM	4,433	445	62	15

Figure 2.5: Number of Possible and Likely Toll Tag-Equipped Vehicles at 66th Avenue



3. **98th Avenue Overpass (Postmile 24.72)**: This is the first exit in Oakland for vehicles traveling north. It is also the southern exit for travelers going to the Oakland International Airport. It is north of the Davis Street interchange.
4. **Airport Drive/Neil Armstrong Way (off I-880 at Oakland International Airport)**: This detection site is approximately two miles west of I-880, at the entrance to the Oakland Airport. It will utilize a sidefire antenna attached to existing poles. This site will assist air travelers by determining the travel time to the airport entrance from various points along I-880. As air travel is very time-driven, this will enable travelers to better plan their schedules, particularly infrequent fliers who may not know exactly how far the airport is. Because knowing the travel times *from* the airport is generally less important than times *to* the airport, the reader for the outbound direction could be eliminated to reduce costs (although it is quite feasible to have one reader for both directions, depending upon placement).
5. **Hegenberger Road Overpass (Postmile 25.43)**: This is the northern exit for the Oakland International Airport and the southern exit for the Oakland Alameda County Coliseum Complex. This complex hosts Oakland Athletics, Oakland Raiders, and Golden State Warriors games, as well as concerts and other events. Thus, like the airport, there may be many people driving to this point who are unfamiliar with it and could use travel times to schedule their time better.
6. **66th Avenue Overpass (Postmile 26.56)**: This is the northern exit for the Oakland Alameda County Coliseum Complex.
7. **High Street Signs (Postmile 27.54)**: High Street is the most southern access point for island of Alameda. There is no structure bridging the entire highway at this point, so antennas will be mounted on signs that are over hanging a single lane on each side. While this will not affect transponder detection, it will increase costs somewhat, since many components will have to be duplicated one each side (e.g., radio modems).
8. **23rd Avenue Overpass (Postmile 28.97)**: This is just north of the 29th Avenue interchange, which has no highway-width overhead structure.
9. **16th Avenue Overpass (Postmile 29.35)**: 16th Avenue provides access to Oakland.
10. **Broadway Avenue Sign (Postmile 31.96)**: This is the final detection site before I-980 splits from I-880. This site has an overhead sign spanning the northbound direction of I-880; therefore, the southbound direction will require a sidefire antenna attached to the center of the overhead sign.

Other possible detector locations in this particular section of I-880 are:

11. **I-880, South of I-238** and
12. **I-238, East of I-880**: An average of 29,000 vehicles travel northbound on I-880 from I-238 each day. Putting detection sites upstream of the interchange would provide information on the flow of traffic through the interchange and greatly increase available data for origin-destination studies.
13. **I-980, North of I-880** and

14. **1-880 (Cypress Freewat), North if I-980:** These sites would provide the same type of information as 11 and 12 at the north end of this section of I-880.
15. **I-880 (Cypress Freeway), North of I-980**: These sites would provide the same type of information as 11 and 12 at the northern end of this section of I-880 under investigation.

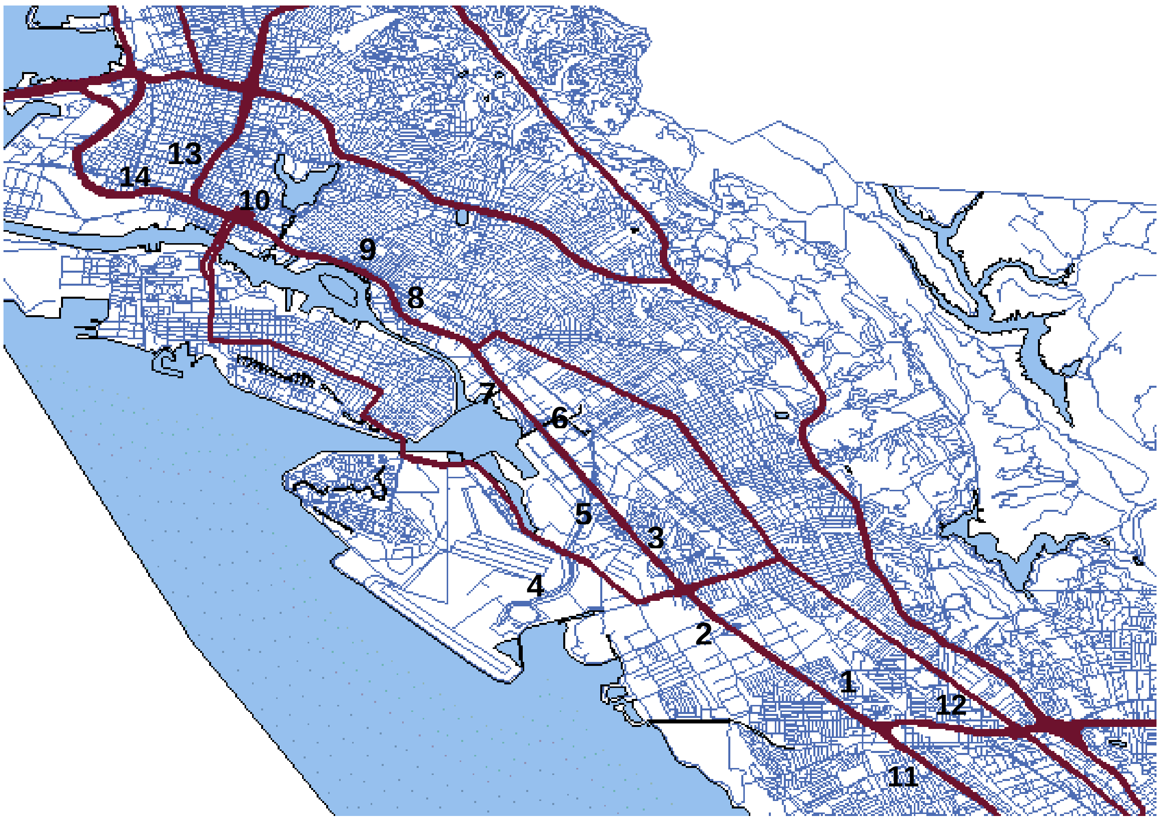


Figure 2.6: Location of Detector Sites

Of course, the toll facilities themselves will be part of the travel time analysis system. These sites are several miles away from their nearest neighbor (e.g., the Dumbarton Bridge toll facility and the Floresta Boulevard site) and therefore will be unable to detect particularly slow highway sections. However, they will still provide valuable data for cumulative travel time.

2.5 Operations Center

The Caltrans traffic operations center would be a logical location for processing the data from the toll tags, because it is already set up to receive traffic data and to provide information to the public via TravInfo. The system would require the following new hardware: 4 modems[5] to receive calls from the field; a central computer, and an Internet link to TravInfo. A staff person or consultant would be needed to customize software to analyze incoming data, compute travel times, and feed information to the server. An additional staff person would be needed to oversee the system and perform further analyses.

2.6 Costs

The figures in this section represent only rough estimates, because many technology costs are declining and because there may be unknown infrastructure requirements. Furthermore, these numbers are "typical" and are not intended to show the range of possible costs (see Section 1.6.4)

- *Transponders*: $0. Already paid for as part of the ETC program on Bay Area bridges.
- *Antennas, Roadside Readers, and Modems*: $205,000. This figure assumes two reader/antenna configurations (one for each direction), at the ten detection sites, with an estimate of $5,000 extra dollars being required for the High Street site. To implement the additional four sites on the feeder freeways would require another $80,000.
- *Telephone Connection*: $350. This assumes one modem is needed per site.
- *Operations Center Computer*: $3,000.
- *Operations Center Modem*: $400.
- *Computer Data Storage*: $100 per year.
- *Analysis Software*: $200.
- *Software customization and Support*: $12,000.
- *Channel/Digital Service Units:* $2,000.
- *Server:* $10,000. This assumes that TravInfo will be required to add one server.
- *Installation*: $150,000. This assumes an overall installation cost of $6,000 per reader/antenna, plus $3,000 per site for traffic protection.
- *Maintenance Costs*: $30,000 per year. This assumes $3,000 of maintenance is needed per detection site per year, which is conservatively high.
- *On-Site Electricity*: $5,000 per year. This assumes $500 per individual reader/antenna.
- *Telephone Communications*: $20,000 per year. This assumes $2,000 per site.
- *Operations Center Equipment Maintenance*: $12,000
- *Additional Staff*: $100,000 per year. This assumes one person is brought in full-time to oversee and maintain probe vehicles program.
- **Capital Costs**: $378,000
- **Annual Operating Costs**: $117,000

[5] With ten detection sites dialing up every 15 minutes, four modems should be sufficient, if the calls are intentionally staggered.

CHAPTER 3

POTENTIAL SITES FOR TOLL TAG PROBES IN THE BAY AREA

3.1 Introduction

There are many Bay Area locations where toll tag probe vehicles could provide useful information. This section examines potential sites for installing tag readers. These are divided into four groups: bridges, freeways, other roads and arterials, and trip-generating sites such as the Oakland International Airport.

Each additional detection site would reduce average costs, because the operations center infrastructure would already be in place and there might be volume discounts for equipment. Even one or two sites along a freeway would be useful. For instance, a single site at the I-580/I-80 interchange in Albany could potentially provide travel times from Albany to the test section of I-880, as well as to the Carquinez, Richmond, and Oakland-San Francisco Bay Bridges

3.2 Ranking Sites in Terms of Numbers of Toll Tags

In order to roughly approximate the number of toll tags on other Bay Area highways, the methodology used in the case study was used to determine the number of bridge users entering each highway. Given the proportion of these vehicles that remained on the road in the case study area, assuming that the proportion remaining was inversely proportional to the distance from the bridge, and assuming that this proportion would be the same for all Bay Area bridges, the number of toll tag equipped vehicles was estimated for each congested road. The roads were then ranked from A to D based on these numbers, with A indicating the highest number of toll tags.

3.3 Toll Tag Potential for Bay Area Roadways

3.3.1 Bay Area Bridges

The Bay Area toll bridges are logical locations to begin implementation of a toll tag-based probe vehicle for the following reasons:

- *Large number of toll tag- equipped vehicles*

- *High volumes:* The toll bridges have some of the highest volumes of users of any roadways in the Bay Area, so the information will be useful to a large number of people.

- *Long delays and high variation in travel times:* The bridges are among the most congested sites, and on several of them travel times vary greatly throughout the day and between days.

- *Lower costs:* The bridges will already have tag readers at the toll booths, and if only the bridge or the toll booth is the bottleneck, only one other reader would be required to measure traffic in the toll booth direction. If both are bottlenecks during some part of the day, then two additional readers would be required.

Five bridges are prime candidates for a travel time measurement system because they cause significant delay.

3.3.2 Bay Area Freeways

Table 3.1 lists the congested freeways and bridges in the Bay Area and the resources needed to implement a travel time detection infrastructure once ETC is in place. For each section and direction it shows the average daily delay, existence of time critical destinations (e.g., airports), the availability of alternate routes, how its delay is ranked compared to all the others, and its ranking in terms of the number of toll tags. This gives an indication of the benefit of instituting a reader system in each section. The last five columns indicate the costs against which these benefits would be weighed. They give the length of the section, the number of readers needed and their cost if they were placed every mile and if they were placed every two miles. The first cost scenario presented in Table 3.1 assumes that reader locations are spaced approximately one mile apart. However, readers spaced every two or three miles would still provide useful, though less precise, travel time information, at roughly a half or third of the cost. Houston's TranStar system has been able to obtain good data with two to three mile spacings, although they would like to add additional sites. A rough estimate of the cost of purchasing and installing the readers at one-mile intervals is $7,304,829, while the costs for readers at two-mile intervals is $3,608,642.

3.3.3 Trip-Generating Centers

Travel time information would be especially useful near major activity centers, especially those at which arrival time is important, such as airports, sports arenas, or concert locations. People could use historical travel time information to determine when they should depart for these destinations and could use real time travel time information as they approach the destination to determine the best route. Information about travel times to popular beaches, for example, would help people decide when, and perhaps where, to go

Table 3.2 lists major activity centers in the Bay Area, their location, and whether the prospects are good, fair, or poor for obtaining adequate travel time information from toll tags. Of course, the prospects will improve everywhere as toll tags become more ubiquitous.

Table 3.1: Congested Area Freeways with Priority Rankings														
Location	Route	Dir.	Delay (hours)			Time Crit.	Alt Rt	Delay Rank	Tag Ranking	Length	One Mile		Two Mile	
			AM	PM	Total						Readers	Cost	Readers	Cost
SR 4														
Route 242 to Port Chicago Highway	4	E		620	620			54	B	0.8	1	$17,518	0	
Bailey Rd to Willow Rd	4	W	380		380			79	B	3.3	3	$52,553	2	$35,035
Bailey Rd to Loveridge Rd	4	E		1120	1120			31	A	4.2	4	$70,070	2	$35,035
Lone Tree Way to Railroad Rd	4	W	1020		1020			37	C	14.0	14	$245,245	7	$122,623
Lark Ave to Camden Ave	17	N	310		310			85	D	1.6	2	$35,035	1	$17,518
At Lark Ave	17	S		70	70			130	D	0.0	0		0	
SR 24														
Broadway to Caldecott Tunnel	24	E	770	1590	2360			11	A	1.5	2	$35,035	1	$17,518
Broadway to Route 580	24	W	610		610			55	A	3.8	4	$70,070	2	$35,035
Gateway Blvd to Fish Ranch Rd	24	W		380	380			79	A	1.2	1	$17,518	1	$17,518
Camino Pablo to Fish Ranch Rd	24	W	510		510			66	A	2.3	2	$35,035	1	$17,518
First St to Route 680	24	E		530	530			63	A	2.6	3	$52,553	1	$17,518
I-80														
Route 101 to Sterling St	80	E	260	2230	2490			9	A	++	1	$17,518	1	$17,518
Fremont St to Route 101	80	W		190	190			106	A	1.5	2	$35,035	1	$17,518
San Francisco-Oakland Bay Bridge											4	$70,070		
At Bay Bridge Toll Plaza	80	W		490	490			69	A	0.0	0		0	
At Route 580	80	E		840	840			42	A	0.0	0		0	
Route 580 to Gilman St	80	E		1840	1840			12	A	3.8	4	$70,070	2	$35,035
University to Route 580/880 interchange	80	W		400	400			76	A	3.0	3	$52,553	2	$35,035
Route 4 to Ala/SF County Line	80	W	5840		5840		++	2	A	18.1	18	$315,315	9	$157,658
Central Ave to Route 4	80	E		740	740		++	49	A	10.1	10	$175,175	5	$87,588
Carquinez Bridge											1	$17,518		
At Carquinez Bridge Toll Plaza	80	E		270	270			96	A	0.0	0		0	

Table 3.1: Congested Area Freeways with Priority Rankings														
Location	Route	Dir.	Delay (hours)			Time Crit.	Alt Rt	Delay Rank	Tag Ranking	Length	One Mile		Two Mile	
			AM	PM	Total						Readers	Cost	Readers	Cost
SR 84														
Newark Blvd to Dumbarton Bridge Toll Plaza	84	S	2920		2920			6	A	1.7	2	$35,035	1	$17,518
Dumbarton Bridge											4	$70,070		
At Route 880	84	N		90	90			126	A	0.0	0		0	
SR 85														
At Bernal Rd (metered connector from NB 101)	85	N	270		270		++	96	D	0.0	0		0	
At Union Ave	85	S		110	110		++	121	D	0.0	0		0	
Saratoga Ave to Winchester Blvd	85	S		110	110		++	121	C	2.7	3	$52,553	1	$17,518
Stevens Creek Blvd to De Anza Blvd	85	S		590	590		++	58	B	1.8	2	$35,035	1	$17,518
Route 280 to Fremont Ave & at Route 101	85	N	1700		1700		++	13	A	1.4	1	$17,518	1	$17,518
Evelyn Ave to Fremont Ave	85	S		1050	1050			33	A	2.8	3	$52,553	1	$17,518
SR 87														
Route 280 to Alma Ave & at Curtner Ave	87	S		1290	1290			19	C	2.3	2	$35,035	1	$17,518
SR 92														
Route 101 to Hilldale Blvd & at Ralston Ave	92	W		290	290			92	A	2.8	3	$52,553	1	$17,518
Route 101 & at Alameda De Las Pulgas	92	W	40		40			136	A	1.6	2	$35,035	1	$17,518
Foster City Blvd to Route 880	92	E		3730	3730			3	A	11.6	12	$210,210	6	$105,105
San Mateo Bridge											4	$70,070		
Route 880 to Industrial Blvd & at Toll Plaza	92	W	1540		1540			15	A	3.8	4	$70,070	2	$35,035
US 101														
Cochrane Rd to Burnett Ave	101	N	420		420			73	D	++	1	$17,518	1	$17,518
Route 85 to Scheller Rd	101	S		1030	1030			36	D	8.9	9	$157,658	4	$70,070
At Tully Road	101	N	140		140			119	D	0.0	0		0	
Route 280/680 to Tully Rd	101	S		700	700			51	C	1.8	2	$35,035	1	$17,518
Route 280 to Route 880	101	N	1250		1250			21	C	3.4	3	$52,553	2	$35,035
Guadalupe Pkwy to Montague Expwy	101	N	550		550		++	62	B	2.1	2	$35,035	1	$17,518

Table 3.1: Congested Area Freeways with Priority Rankings

Location	Route	Dir.	Delay (hours)			Time Crit.	Alt Rt	Delay Rank	Tag Ranking	Length	One Mile		Two Mile	
			AM	PM	Total						Readers	Cost	Readers	Cost
US 101 (continued)														
Montague Expwy to Great America Pkwy	101	N		190	190	++	++	106	B	0.8	1	$17,518	0	
Great America Pkwy to 13th St	101	S		2880	2880	++	++	7	B	5.0	5	$87,588	3	$52,553
Route 237 to Route 85	101	N		370	370		++	81	B	2.0	2	$35,035	1	$17,518
Ellis St to Lawrence Expwy	101	S	230		230		++	102	B	3.2	3	$52,553	2	$35,035
Ellis St to Rte 85	101	N	160		160		++	111	B	1.1	1	$17,518	1	$17,518
San Antonio Rd to Route 85	101	S		1270	1270		++	20	B	2.2	2	$35,035	1	$17,518
Middlefield Way to University Ave	101	N		1140	1140			28	B	3.6	4	$70,070	2	$35,035
Woodside Rd to Route 85	101	S	1050		1050			33	B	9.8	10	$175,175	5	$87,588
Woodside Rd to Marsh Rd & at Willow Rd	101	S		150	150			114	A	3.5	4	$70,070	2	$35,035
Whipple Ave to Ralston Ave	101	N		780	780			46	A	2.9	3	$52,553	1	$17,518
Route 92 to Hillsdale Blvd	101	S	520		520			65	A	0.8	1	$17,518	0	
Route 92 to Third Ave	101	N	480	930	1410	++		17	A	1.6	2	$35,035	1	$17,518
At Poplar Ave	101	S	220	90	310			85	A	0.0	0		0	
At Broadway	101	N		260	260	++		98	A	0.0	0		0	
Millbrae Ave to Broadway	101	S		510	510	++		66	A	1.4	1	$17,518	1	$17,518
San Bruno Ave to Millbrae Ave	101	S	450		450	++		72	A	2.4	2	$35,035	1	$17,518
At Old Bayshore Blvd	101	S	150		150	++		114	A	0.0	0		0	
From Alemany to Army St	101	N	800		800		++	44	A	0.9	1	$17,518	0	
Route 280 to Route 80	101	N		970	970		++	39	A	2.3	2	$35,035	1	$17,518
Army St to Harney Way	101	S	690		690		++	52	A	0.4	0		0	
Route 80 to Fell St	101	N		60	60		++	132	A	1.1	1	$17,518	1	$17,518
South Van Ness to Fell St	101	N	40		40		++	136	A	0.3	0		0	
South Van Ness to Route 80	101	S		80	80		++	127	A	1.1	1	$17,518	1	$17,518
Golden Gate Bridge											3	$52,554		
Sausalito to Golden Gate Bridge Toll Plaza	101	S	1360		1360			18	A	2.3	2	$35,035	1	$17,518
Paradise Drive to Villa/Lincoln Ave	101	N		1130	1130			29	A	4.8	5	$87,588	2	$35,035

Table 3.1: Congested Area Freeways with Priority Rankings														
Location	Route	Dir.	Delay (hours)			Time Crit.	Alt Rt	Delay Rank	Tag Ranking	Length	One Mile		Two Mile	
			AM	PM	Total						Readers	Cost	Readers	Cost
US 101 (continued)														
At Sir Francis Drake Blvd	101	S	80		80			127	A	0.0	0		0	
South Novato Blvd to Route 580	101	S	3240		3240			4	A	9.1	9	$157,658	5	$87,588
De Long Ave to Redwood Sanitary Rd	101	N		750	750			47	A	3.9	4	$70,070	2	$35,035
Old Redwood Hwy to South Petaluma Blvd	101	S	1240		1240			22	B	4.7	5	$87,588	2	$35,035
Santa Rosa Ave to College Ave	101	N		510	510			66	D	5.2	5	$87,588	3	$52,553
Todd Rd to Route 12	101	N	190		190			106	D	3.1	3	$52,553	2	$35,035
College Ave to Route 12	101	S	260		260			98	D	1.1	1	$17,518	1	$17,518
Mendocino Ave to Corby Ave	101	S		560	560			61	D	4.4	4	$70,070	2	$35,035
SR 160														
Antioch Bridge											1	$17,518		
SR 237														
At Mathilda Ave & at North First St	237	E	170		170			110	C	0.0	0		0	
Lawrence Expwy to Route 101 & at Zanker Rd	237	W		310	310			85	C	10.1	10	$175,175	5	$87,588
North First St to Route 880	237	E		2570	2570			8	C	2.4	2	$35,035	1	$17,518
Route 880 to Zanker Ave	237	W	530		530			63	C	1.4	1	$17,518	1	$17,518
SR 238														
Route 580 to Route 185	238	N	150		150			114	B	1.9	2	$35,035	1	$17,518
At Route 580/238 interchange	238	N		150	150			114	A	0.0	0		0	
Route 880 to Hesperian Blvd	238	S		310	310			85	A	0.4	0		0	
SR 242														
Concord Ave to Route 680	242	S	1180		1180			27	C	1.5	1	$17,518	1	$17,518
I-280														
At Route 101	280	N	60		60		+	132	C	0.0	0		0	
11th St to Route 87	280	N		290	290		+	92	C	1.3	1	$17,518	1	$17,518
Route 87 to 11th St	280	S		80	80		+	127	C	0.8	1	$17,518	0	
Route 87 to Route 880	280	N	400		400		+	76	C	2.9	3	$52,553	1	$17,518

Table 3.1: Congested Area Freeways with Priority Rankings														
Location	Route	Dir.	Delay (hours)			Time Crit.	Alt Rt	Delay Rank	Tag Ranking	Length	One Mile		Two Mile	
			AM	PM	Total						Readers	Cost	Readers	Cost
I-280 (continued)														
Meridian Ave to Route 880	280	N		600	600		+	57	C	1.4	1	$17,518	1	$17,518
Moorpark Ave to Southwest Expwy	280	S		390	390		+	78	C	0.4	0		0	
Saratoga Ave to Foothill Expwy	280	N	680		680		+	53	C	5.5	6	$105,105	3	$52,553
At Saratoga Ave	280	S	60		60		+	132	C	0.0	0		0	
Route 85 to De Anza Blvd	280	S		110	110		+	121	B	1.3	1	$17,518	1	$17,518
Page Mill Expwy to Magdalena Ave	280	S		790	790		++	45	B	4.3	4	$70,070	2	$35,035
Sandhill Rd to Woodside Rd	280	N		180	180			109	B	3.3	3	$52,553	2	$35,035
Farm Hill Blvd to Woodside Rd	280	S	70		70			130	A	1.3	1	$17,518	1	$17,518
Crystal Springs Ave to Westborough Blvd	280	N		460	460			71	A	9.1	9	$157,658	5	$87,588
John Daly Blvd to Route 380	280	S	750		750			47	A	4.3	4	$70,070	2	$35,035
Geneva Ave to Route 101	280	N	160		160			111	A	2.6	3	$52,553	1	$17,518
Route 101 to Monterey	280	S		290	290		++	92	B	1.6	2	$35,035	1	$17,518
At Route 101 and at 4th St and 6th St off-ramps	280	N	110		110		++	121	B	0.0	0		0	
6th St to Pennsylvania Ave	280	S		160	160		++	111	B	++	1	$17,518	1	$17,518
I-380														
Route 101 to Route 280	380	W		110	110			121	A	2.0	2	$35,035	1	$17,518
I-580														
Vasco to Route 84 & Livermore to El Charro	580	W	1200		1200			26	C	8.2	8	$140,140	4	$70,070
Redwood Rd to Route 238	580	W	250		250			100	B	1.4	1	$17,518	1	$17,518
Strobridge to Route 238	580	W		220	220		+	103	B	+	0		0	
Foothill to El Charro Rd	580	E		1700	1700		+	13	B	18.4	18	$315,315	9	$157,658
MacArthur to Fruitvale	580	W	290		290		+	92	A	1.5	2	$35,035	1	$17,518
Oakland Rd to Coolidge Ave	580	E		210	210		+	104	A	3.1	3	$52,553	2	$35,035
Route 24 to Route 80	580	W	350		350		+	82	A	1.3	1	$17,518	1	$17,518
Richmond-San Rafael Bridge											4	$70,070		
At Route 101	580	W		590	590			58	A	0.0	0		0	

Table 3.1: Congested Area Freeways with Priority Rankings														
Location	Route	Dir.	Delay (hours)			Time Crit.	Alt Rt	Delay Rank	Tag Ranking	Length	One Mile		Two Mile	
			AM	PM	Total						Readers	Cost	Readers	Cost
I-680														
King Rd to McKee Rd	680	N	300		300		++	89	D	2.0	2	$35,035	1	$17,518
Landess Ave to Scott Creek Rd	680	N		1230	1230		++	23	D	3.9	4	$70,070	2	$35,035
Route 237 to McKee Rd	680	S		1100	1100		++	32	D	5.3	5	$87,588	3	$52,553
At Scott Creek & at Durham	680	N		480	480		++	70	D	0.0	0		0	
Sunol Rd to south of Route 262	680	S	7240		7240			1	C	10.1	10	$175,175	5	$87,588
Bollinger Canyon Rd to Sycamore Rd	680	N		210	210			104	B	3.9	4	$70,070	2	$35,035
At Rudgear Rd	680	N	30		30			138	B	0.0	0		0	
Rudgear Rd to Sycamore Rd	680	S	1020		1020			37	B	5.7	6	$105,105	3	$52,553
Rudgear Rd to Route 24	680	N		50	50			135	B	2.0	2	$35,035	1	$17,518
Route 24 to Treat Blvd	680	N		150	150			114	A	2.0	2	$35,035	1	$17,518
No. Main St. to Route 24	680	S		300	300			89	A	1.2	1	$17,518	1	$17,518
Geary Rd to Route 24	680	S	2390		2390			10	A	2.0	2	$35,035	1	$17,518
Concord/Contra Costa Blvd to Route 242	680	S	1540		1540			15	A	1.4	1	$17,518	1	$17,518
Benicia Bridge											1	$17,518		
Arthur Rd to Benicia-Martinez Bridge Toll Plaza	680	N		1130	1130			29	A	2.8	3	$52,553	1	$17,518
Cordelia Rd to Route 80	680	N		120	120			120	A	0.0	0		0	
I-880														
Bascom Ave to Brokaw Rd	880	N	1040		1040		++	35	D	2.3	2	$35,035	1	$17,518
Route 101 to Bascom Ave	880	S		340	340		++	83	D	2.8	3	$52,553	1	$17,518
Montague Expwy to Dixon Landing & at Route 101	880	N		950	950		++	41	D	3.7	4	$70,070	2	$35,035
Great Mall Pkwy to Brokaw Rd	880	S		1230	1230		++	23	D	4.1	4	$70,070	2	$35,035
Route 262 to Auto Mall Parkway	880	N		820	820		++	43	C	2.3	2	$35,035	1	$17,518
Auto Mall Parkway to Dixon Landing	880	S	3030		3030		++	5	B	4.8	5	$87,588	2	$35,035
At Stevenson & Thornton to Fremont	880	N		590	590			58	A	5.2	5	$87,588	3	$52,553
Decoto/Rte 84 to Mowry	880	S	420		420			73	A	3.1	3	$52,553	2	$35,035

Table 3.1: Congested Area Freeways with Priority Rankings

Location	Route	Dir.	Delay (hours)			Time Crit.	Alt Rt	Delay Rank	Tag Ranking	Length	One Mile		Two Mile	
			AM	PM	Total						Readers	Cost	Readers	Cost
I-880 (continued)														
Fremont to Decoto	880	S		420	420			73	A	1.1	1	$17,518	1	$17,518
Whipple to Alvarado	880	S	250		250			100	A	0.7	1	$17,518	0	
Alvarado to Tennyson	880	N		1220	1220			25	A	2.6	3	$52,553	1	$17,518
Alvarado to Route 92	880	N	610		610			55	A	3.6	4	$70,070	2	$35,035
Route 92 to Hesperian Blvd	880	N		720	720	++	++	50	A	1.7	2	$35,035	1	$17,518
Route 238 to Route 92	880	S	960		960			40	A	4.0	4	$70,070	2	$35,035
Hegenberger Road to Hesperian Blvd	880	S		300	300	++	++	89	A	7.2	7	$122,623	4	$70,070
High St to Oak St	880	N	340		340		++	83	A	3.4	3	$52,553	2	$35,035

Table 3.2: Trip-Generating Centers			
Location	**Type of Facility**	**City**	**Prospects for Accurate travel times from toll tags**
UC Berkeley	University/Entertainment/ Sports Complex	Berkeley	Good
Cow Palace	Entertainment / Sports Complex	Brisbane	Good
Concord	Shopping Center	Concord	Fair
Mt. Diablo	Park	Contra Costa County	Poor
Half Moon Bay State Beach	Park	Half Moon Bay	Poor
Lawrence Livermore National Laboratory	Employment Center	Livermore	Poor
Muir Woods	Park	Marin County	Fair
Stinson Beach	Park	Marin County	Fair
Oakland Coliseum and Sports Arena	Entertainment / Sports Complex	Oakland	Good
Oakland International Airport	Airport	Oakland	Good
Jack London Square	Entertainment Complex	Oakland	Good
Stanford Shopping Center	Shopping Center	Palo Alto	Poor
Stanford University	University/Entertainment/ Sports Complex	Palo Alto	Poor
Stoneridge Mall	Shopping Center	Pleasanton	Poor
San Francisco International Airport	Airport	San Bruno	Good
Candlestick Point	Sports Complex	San Francisco	Good
PacBell Park	Sports Complex	San Francisco	Good
San Francisco Zoo	Entertainment Complex	San Francisco	Fair
Golden Gate Park	Park	San Francisco	Good
Fisherman's Wharf	Entertainment Complex	San Francisco	Good
San Jose Arena	Sports Complex	San Jose	Poor
San Jose State University	University	San Jose	Poor
San Jose International Airport	Airport	San Jose	Poor
Great America	Amusement Park	San Jose	Poor
Bishop Ranch	Employment Center	San Ramon	Poor
Santa Cruz Boardwalk	Amusement Park	Santa Cruz	Poor
Marine World	Amusement Center	Vallejo	Good
Walnut Creek	Shopping Center	Walnut Creek	Poor

The value of information for these sites will depend on the time sensitivity of the activities, the variability in travel times, and the familiarity of people traveling to these locations with local traffic conditions. For this reason, the airports are better candidates than all-year activity centers such as shopping malls or the San Francisco Zoo.

Once there is an existing infrastructure on the Bay Area highways, activity centers may wish to negotiate with Caltrans to install readers. San Francisco Airport, for example, may wish to have a reader on site so that they can inform travelers over the Internet or via telephones of current travel times from around the Bay Area. This could potentially reduce costs for Caltrans and increase exposure.

3.3.4 Other Roads and Arterials

Table 3.3 lists additional roadway segments in the Bay Area where coverage is desired; these are based on the functional requirements listed in the November 23, 1999 TravInfo Contractor RFP. We did not investigate the travel patterns of vehicles on these arterials, but we suspect that the distances traveled are shorter than on the freeways. If this is true, there would be a smaller proportion of the traffic passing between two readers, unless they are more closely spaced than on the freeway. And there are fewer vehicles than on the freeways. Also, vehicles are more likely to have stopped as they travel between two readers. All of these factors combine to make implementation of a tag reader system on arterials less promising than on most freeways. However arterials located near bridges may be good candidates if a high proportion of travelers stay on the arterial for more than mile or two. As the number of bridge travelers using toll tags increases, other arterials may also be good candidates.

The rankings in Table 3.3 are subjective judgements based on traffic volumes and proximity to toll bridges.

Table 3.3: Roads for Which TravInfo Requires Travel Times

Roadway	**Ranking (Poor, Fair, Good)**
Highway 29: Vallejo to Napa	Poor
Highway 37: I-80 to US101 Vallejo to Marin	Poor
Route 12: Sebastopol to Sonoma	Poor
Route 1: Mendocino to Santa Cruz	Poor
Route 82 El Camino Real from Daly City to Palo Alto	Good
Route 82 El Camino Real/Monterey Road from Palo Alto to Gilroy	Poor
Route 238/185 (Mission Blvd./ East 14th): I-880 to 42nd	Fair
Route 84: Livermore to I-880	Fair
Route 109: US101 to Dumbarton Bridge (Route 84)	Good
Route 13: I-580 to I-24	Poor
San Pablo Avenue (SR 123): 17th Street to Highway 4	Poor
Hesperian Blvd.: Alvarado Niles to I-880	Poor
Ygnacio Valley Road/Kirker Pass Road: I-680 to Highway 4	Poor
Treat Blvd.: Clayton to I-680	Poor
Sir Francis Drake Blvd.: Fairfax to US101	Good
19th Avenue (San Francisco): Route 1 to US101	Good
San Francisco: Van Ness, Market, Howard, Folsom, and Harrison	Good
Almaden Expressway: McKean to SR 87	Poor
Tully Road: SR 87 to US101	Poor
Capitol Expressway: Almaden to I-680	Poor
Central Expressway: San Antonio to Trimble	Poor
Lawrence Expressway: Saratoga Ave. to SR 237	Poor
San Thomas Expressway: SR17 to US101	Poor
Montague Expressway: US101 to I-680	Poor
Foothill Expressway: Page Mill to I-280	Fair
Page Mill/Oregon Expressway: I-280 to US101	Fair
Regional routes connecting Bay Area to other counties	Poor

Table 3.3 shows that a toll tag-based probe vehicle system is currently promising only on arterials in San Francisco, on Sir Francis Drake Boulevard in Marin and on El Camino Real and Route 109 on the Peninsula. Once experience has been gained on the use of toll tags for measuring travel times on freeways, providing a better idea of the number of vehicles using toll tags and their dispersion throughout the Bay Area, the prospects for using them on arterials can be reexamined in the light of this new information.

CHAPTER 4

CONCLUSIONS

The advantage of a toll-tag based travel time estimating system is that it could be implemented in the San Francisco Bay immediately at relatively little cost. Electronic toll collection has now been implemented on all of the Bay Area bridges, and shows promise of being well utilized. In December 2000, after 3 months of operation, 39% of vehicles crossing the Golden Gate Bridge were using toll tags, 59% during the peak commute period. FasTrak staff estimate that 60,000 toll tags have been sold for Golden Gate Bridge use. Furthermore, the Golden Gate Bridge and Caltrans can increase the cash toll relative to the automated toll to provide a greater incentive for people to use toll tags.

Caltrans already owns the overhead structures on which the readers would be mounted. Such a system is already operating well in Houston, so software for calculating travel times has already been developed. Because the toll tag information is used for billing, the transponders will be well maintained, and the information they provide will be very accurate.

Our analysis of the I-880 test section in Oakland, suggests that there will be a sufficient number of transponder-equipped vehicles to provide accurate travel time information during congested periods for an estimated cost of $377,950. This would assist travelers and truckers on this section of I-880 and would be especially valuable for people traveling to the Oakland Airport or to events at the Oakland Coliseum. Table 3.1 showed that prospects for a similar system are good for other sections of the Bay Area road system. The best prospects are described below. They were selected on the basis of their traffic volumes, level of congestion, proximity to toll facilities, and the usefulness of data.

1) **The eight Bay Area toll bridges**

The bridges are already equipped with some of the necessary infrastructure and will necessarily have high volumes of transponder-equipped vehicles, even in the initial stages of the program. Most of the bridges have high traffic volumes or significant delay. They are popular links for radio traffic reports, even when they are uncongested.

2) **Freeways**
   a) **I-80:** Between San Francisco and Vallejo, I-80 is often highly congested. Furthermore, this section should have large number of vehicles with transponders, receiving traffic from the Oakland-San Francisco Bridge and the Carquinez Bridge (and in Berkeley and Emeryville from the San Rafael-Richmond Bridge as well).

   b) **I-101:** I-101 has numerous areas of high delay from San Jose to Santa Rosa. Near these two cities, however, there may be insufficient toll tag-equipped vehicles. Therefore, the system should be installed first between SR85 in Mountain View and the Sonoma County line. It can be extended at either end if the use of toll tags increases enough to allow accurate travel time estimate.

c) **I-880 (Oakland to Hayward):** The section from the Bay Bridge to San Lorenzo was shown in the case study to be a good site. It is even more congested south of San Lorenzo but south of Fremont there may not be sufficient vehicles with toll tags.

d) I-580: The section of I-580 running through Oakland has significant delay and receives bridge traffic from San Francisco. There is also delay and large numbers of toll tag-equipped vehicles on the approaches to the Richmond-San Rafael Bridge and at the intersection with US 101. There is congestion between I-238 in Hayward and Pleasanton, but there may not be sufficient vehicles with toll tags in this section.

3) Other Links and Activity Centers

a) **Route 109:** This route serves a necessary link between the Dumbarton Bridge and I-101, is congested, and will have a high volume of toll tags.

b) **Sir Francis Drake:** From I-101, this is a congested roadway stretching into San Anselmo. Because it receives traffic from both the Golden Gate and San Rafael-Richmond bridges, there will be sufficient toll tag-equipped vehicles.

c) **19th Avenue:** As the Golden Gate Bridge supplies congested traffic onto this road in San Francisco, there should be adequate coverage. This will allow continuous travel time analysis from the North Bay into the Peninsula.

d) **Airports (e.g., Oakland and San Francisco):** Airport travelers would appreciate knowing current travel times in order to schedule their trip, as they have to be somewhere at a certain time and may not know how long it takes. The airports or airlines may even be interested in subsidizing the costs of on-site equipment and installation, in order to better serve their customers. While the majority of airport visitors may not have crossed a toll bridge, enough of them probably use bridges as part of their usual commute (i.e., on other days) that there will be sufficient toll tags. The number of usable vehicles would also increase if the airports or taxi companies decide to outfit their vehicles to keep better track of their operations. The system could also be constructed to allow visitors to pay for their parking with their toll tags.

e) **Sports Stadiums (e.g., Oakland Coliseum, UC Berkeley, PacBell Park, and ThreeCom Park):** Sporting events are another situation where people wish to arrive at a specific time and could utilize accurate travel time information. Some locations, such as the Oakland Coliseum, may be near enough to a freeway that a detector there will suffice. However, since for popular events there may be a long queue from the freeway off-ramp to the parking facility, an on-site detector may still be desired. As with airports it might be possible that these facilities would be interested in subsidizing the system.

f) **Entertainment Complexes and Venues (e.g., Marine World, Cow Palace, Jack London Square, and UC Berkeley):** Events at these facilities often have pre-determined starting times and the usual travel time may be unknown to many people.

Once implementation of a toll tag-based travel time information system has been implemented in some locations, it will be possible to refine estimates of where else such a system would be effective. Information on mailing addresses of FasTrak customers will provide some idea of where users live or work. It would also be possible to mail a questionnaire to FasTrak customers asking them about their frequency of use of the congested freeways. One advantage of this system is that it can be continually expanded, based on changing needs and growth in the use of toll tags. If high-occupancy toll lanes are implemented in the Bay Area, for example on I-680 on the Sunol Grade or US 101 between Novato and Petaluma, this would provide an additional source of toll tags in the North and South Bay regions.

In implementing a toll tag-based travel time information system, two different strategies could be used, or they could be mixed. One strategy would be to install an intensive system, with readers on every link, on one or a few highways. A different strategy would be to install an extensive system, with longer distances between readers, on a larger number of highways. In the first case, the system could be made more extensive as more resources became available. In the second case, readers would be added between existing readers, making the system more intensive. The best strategy might be a combination of these two, installing an intensive system where delay varies significantly from segment to segment and there are high off-ramp volumes, and another less intensive system where ramp volumes are relatively low. The costs, accuracy, and value of the information from each system could be evaluated to determine the effectiveness of each in the circumstances in which they were implemented and to guide further implementation.

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