TOLL EQUIPMENT AND TECHNOLOGY AND RELATED IMPACTS TO HOT LANES OPERATIONS

Submitted as Part of the
HOUSTON HOT LANE NETWORK
Value Pricing Project 126XXIA005

Prepared for the
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Houston District

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Revised, August 2009

Toll Equipment and Technology and Related Impacts to HOT Lanes Operations

The purpose of this investigation was to provide guidance on the typical equipment and technologies in use for HOT lanes and discuss their related impacts for the proposed operations of the lanes. This investigation focused on the equipment and technologies outlined in the Detailed Concept of Operations (Attachment A), as part of MTRO Request for Proposal No RP0700007 and subsequent modifications.

Background

HOT lanes are limited-access highway lanes that provide free or reduced cost access to qualifying high occupancy vehicles (HOV) and also provide access, for a fee, to other paying vehicles not meeting passenger occupancy requirements. HOT lanes utilize sophisticated electronic toll collection and traffic information systems.

In general, the process of tolling and congestion pricing can incorporate up to nine functional areas, as listed below:

- Informing – Provide adequate information to users and potential users,
- Detection – Detecting, and in some cases measuring, each individual instance of use,
- Identification – Identifying the user, vehicle, or in some cases, numbered account,
- Classification – Measuring the vehicle to confirm its class,
- Verification – Processes to assist in confirming transactions and/or potential enforcement,
- Payment – Methods of collect payment,
- Enforcement – Identifying violators and pursuing charges and/or fines,
- Exemptions – Managing exceptions to the established rules, within the capabilities of the system, and,
- System Reliability – Provision of cost-effective systems that can meet desired reliability levels.

While the above areas are a general overview of the tolling process from start to finish, the algorithms, equipment, and procedures employed to complete a transaction may differ by facility. As an example, some facilities require a tag for every vehicle, while others do not. In some cases, video detection is utilized for toll collection and enforcement, while in other cases; it is employed solely for enforcement practices. Some facilities do not even incorporate a classification procedure.

Scope of this technical memorandum

The functional areas listed above all require the use of significant amounts of equipment and technology. The list blow identifies the equipment and technologies pertinent to the METRO HOT lanes modification project which will be discussed in this technical memorandum. These items include:

- Toll tags,
- Toll tag readers,
- Camera systems,
- Communications,
- Data collection equipment for pricing algorithm, and
- Pricing displays.

Additional technology and equipment, such as those items related to enforcement and operations (such as incident management) of the HOT lanes, are not covered under the scope of this technical memorandum.

As a methodology for examining the impacts to TxDOT of each of these technology items, the concept of operations (COO) from the RFP is first presented. Following the COO summary is a section relating to each technology item, where a brief description is provided along with an assessment of impacts to TxDOT. Primarily, these assessments look at the potential impacts to TxDOT for assuming operations of the HOT lanes or by changing the COO.

Concept of Operations

In broad terms, the concept of operations describes a reconfiguration of five existing HOV facilities to HOT lanes. The HOV lanes are stated to be generally 20 feet wide, with a 12 foot lane and a 4 foot shoulder on either side. The HOV facilities are 1-way and get closed for reversal operations for a 3-hour period while all systems are manually reversed and checked. Each HOV facility has numerous access points, at various transit centers, park and rides, or direct connections, throughout the length of the corridor. With the exception of the entry points, much of the geometrics are expected to remain the same.

The entry points to the HOT lanes will utilize a declaration lane style access. These entry points will be two lanes, one for tolled trips and one for free trips. An observation booth that is either between the lanes or to the side will be utilized by personnel for observation of the access to the lanes and spotting potential violators. It is unclear if there will be a continual booth presence at each location.

The COO details a HOT lane network that requires all vehicles to have a passive transponder sticker-tag, compatible with all other Texas toll authorities. The hardware and software in the system will be compatible with all of the protocols and standards in use throughout the state of Texas. Vehicles without a transponder and in the tolled lane will be considered a toll violator.

The toll rate will variable, based upon the average speed in the HOT lanes. A threshold of 50 mph will be used, with the toll increasing as the speed drops, to regulate the amount of SOVs entering the facility. There is no comparison to the general purpose lanes in the pricing algorithm. Pricing will be calculated for two segments per facility. Pricing will be the same for each entry and exit point within the segment. It is anticipated that pricing will not change more frequently than once every 5 minutes.

Speed data collection is planned for the entire system and will be independent of the existing data collection equipment. Camera coverage is planned for the entire length of every facility, for both daily operations and verification of gate closures prior to switching operations. All cameras, data collection, toll equipment and communications will be accomplished via a high-speed wireless communications network, with data, including camera and gate operation information being available in the TranStar traffic management center in addition to the toll data being sent to the toll collection processing facility.

<u>Toll Tags</u>

Toll tags are an integral portion of the tolling system. Modern toll tags have the ability to not only provide information for the collection of tolls, but can also be used to receive information and / or send data in support of items such as performance measurement. In general, toll tags come in both passive and active versions. An active tag emits radio frequency (RF) energy at set intervals and can be interrogated by readers at distances that far exceed passive tags. However, a battery is required for active tags and generally imparts a higher cost of ownership for each tag.

Passive tags reflect radio energy and do not require a battery. The tag is ‘powered’ up when a beam from the toll tag reader is emitted. The main disadvantage of passive tags is the short distances that can be achieved between tags and readers, however in the case of overhead gantry readers, this is rarely a problem. In some cases, interference from other RF sources may interfere with tag reads, but in a passive system, the readers can be tuned to a different frequency and the tags will respond. This reconfiguration is not possible in an active tag system.

Newer generations of toll tags have also used different protocols, or data communication handshakes, between the readers. Generally, these protocols have increased both the speed of the data transaction, and the amount of information that can be exchanged. When a new protocol is employed, users do not have to get a new tag, as the readers are backwards compatible with the older protocols.

In Houston, there are approximately 1.7 million tags already in use. These tags are used in conjunction with HOV facilities, but are also interrogated by readers placed on the main lanes. These additional readers are not connected to any toll collection databases or system. Tag reads at successive reader locations are matched to obtain travel times, which TranStar uses to populate the Houston real-time traffic map.

Considerations for TxDOT

In the COO, it was stated that all users of the HOT lanes would require a tag. Currently, users of the HOV facilities are not required to have a toll tag. While the requirement to obtain a toll tag would not fundamentally affect the operations of the systems employed for electronic toll collection, a significant user backlash could occur by forcing a registration process on users that have been utilizing the HOV facilities for many years.

While passive and active each have advantages, the use of passive should be considered more advantageous for the Houston HOT lanes, due to the zero cost of ownership for drivers (no batteries) and the ability to tune the ETC equipment to use whatever frequencies work best for the roadway environment.

An option being discussed is to remove this requirement and allow existing HOV users to continue to utilize the system as they do today. Removing this requirement could lead to a better public acceptance of the project and help to reduce the concerns of existing HOV users.

Toll Tag Readers

The partner to the toll tag is the toll tag reader. Typically mounted on overhead gantries, in a passive system, the toll tag interrogates the toll tag and receives information specific to the tag. The reader then sends that information to the toll collection system, where it is transmitted to the processing center for review and assignment of fees, if any apply.

As stated in the previous section, the COO and supporting deployment information identify a requirement to equipment each lane of the declaration area the same. The equipment for each lane includes a toll tag reader as well as a camera system for performing license plate recognition (LRP).

Considerations for TxDOT

Because of the price of each individual unit, toll tag readers are a substantial cost component of any deployment. In addition, while highly reliable, there is an associated maintenance cost for every piece of equipment deployed in a project. Because the COO and deployment plan specifies that each lane of the declaration areas will be equipped with the same equipment (both readers and cameras), the removal of this registration requirement ***could*** be used to justify a corresponding reduction in equipment, by removing the readers in the lanes designated for HOV readers.

A typical cost value for the equipment at an overhead reader deployment site is in the range of $50K to $60K. This number was obtained from sample installations in Houston using the Transcore 1301 reader. Additional costs would be necessary for any site work. Depending on final number of entrance points, the reduction of entry locations could have a significant impact on not only the initial equipment cost but the corresponding maintenance costs throughout the life of the project. The communications cost will likely not be significantly affected, as communications to the reader in the adjacent declaration lane will still have to be provided.

Camera Systems

Cameras can be employed in multiple roles in any tolling implementation. A primary role is for enforcement. In one situation, camera images from an upstream location (typically the entry point) are examined in real-time and information on potential violations is relayed to an officer downstream. The officer can stop the vehicle, verify occupancy requirements and complete the enforcement operation.

In another usage, camera images are used in license plate recognition systems (LRP). As a brief overview, license plate recognition systems snap an image of the front and/or rear license plate on the vehicle and uses computer algorithms to detect and recognize the letters of the alphabet and numbers. License plate recognition is also referred to by several other names, including Automatic Vehicle Identification (AVI), Automatic Plate Number Recognition (ANPR, Optical Character Recognition (OCR), and less commonly, Car Plate Recognition. Because different countries and states use different fonts, colors, backgrounds, and patterns, the systems must be adept at distinguishing many different styles and patterns accurately. For tolling systems, this poses an additional challenge as these facilities may be more likely to receive a higher percentage of vehicles from out of state than say a parking garage.

LPR deployments can be used in two different manners. The first is to support enforcement procedures only, by taking pictures of vehicles that do not register a toll tag read. The images are then processed through the back-office operations and fines are assessed through the established business procedures.

The second LPR usage is for full toll collection procedures, which takes pictures of all vehicles. The topic of LPR for toll and its associated usage and performance characteristics for video tolling was the focus of an earlier technical memorandum on this project.

Cameras are an integral part of the proposed system. In the declaration lane operating as a toll lane, the detection equipment will look for a vehicle. If it detects a vehicle, the toll tag reader will look for a tag read. If there is no read, the camera system will be employed to snap a picture, which will be process as a violation in accordance with business policies.

In the declaration lane operating as an HOV lane, the observation booth staff will be watching HOV lane looking for suspect vehicles. The camera systems will take photos of the vehicles that can be relayed downstream to an officer.

Another role of cameras, particularly on this project is for daily operations. The deployment plan calls for continuous camera coverage on every corridor. These streams could be used for incident detection and management, as well as for verification of an empty corridor prior to switching operations to the opposite direction.

Considerations for TxDOT

The implications to TxDOT for the camera systems on the HOT lane modification project do not pertain to the physical deployments of the equipment. Because the equipment is integral to the concept of operations and the tolling mechanisms, there is little reduction in costs that could be achieved, without sacrificing significant functionality or flexibility. Options being discussed however include the closure of some entry points to the HOT lane system. Each point of closure would have a corresponding decrease in cost from equipment not deployed.

Figure 1 shows an illustration of camera locations along the Northwest Freeway HOT lane corridor, based on considerations of 1-mile spacing as well as coverage of each access point. The cameras are assumed to be full Pan-Tilt-Zoom (PTZ) capable with a 360 degree field of view. At a planning level analysis, 10 camera installations would be necessary to cover the corridor. This is based on an average spacing of approximately a mile, allowing each camera to have a field of view of 0.5 miles in each direction. Additional cameras may be necessary after a detailed site survey if geometric features block the camera view. At $5K to $10K per camera installation, covering the 290 corridor could require $100K or more, as an example.

One implication that TxDOT may need to consider and plan for is the integration of the addition camera feeds into TranStar. Aside from performing advance planning for the physical connection points, video codecs, cabling, and switching requirements, the additional cameras may affect the timing sequence of the camera rotations employed to visually detect incidents. Additional staff or a change in the rotations may be necessary to achieve the same performance and detection levels of current operations.

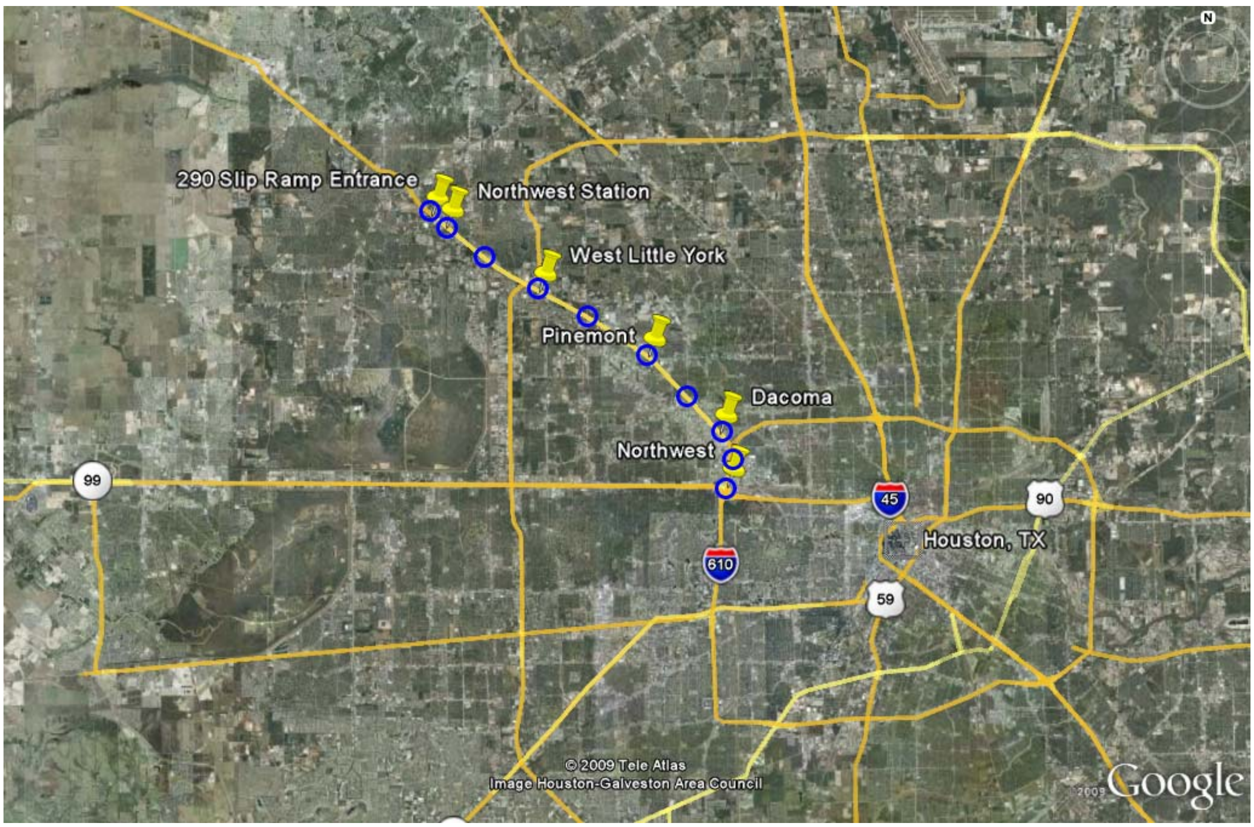

Figure 1. Northwest Freeway-Potential Camera Locations.

Camera installations will require field infrastructure, such as power, communications, and a support structure. In many cases, these practicalities may dictate the actual locations more than coverage considerations. One item to keep in mind for deployment is that one aspect of the surveillance infrastructure is to provide positive visual confirmation that gates are closed prior to reversing operations. This surveillance will serve as a critical backup to the ARGO gate operation system specified in the COO.

Communications

In virtually any deployment, the provision of communications is a critical consideration. The COO for this project specifies a "high-speed, secure telecommunications network…." The communications system is specified to be designed by the successful bidder. Given that METRO has minimal fiber communications infrastructure in the HOT lane corridors, the resulting solution is presumed to be at least partially wireless.

The design of wireless communication systems is not a science, but rather an art based on scientific principles. Substantially different designs can achieve the same end results. Multiple influences must be considered, including items such as range, bandwidth, quality, response time, interference, security, cost, environmental conditions, power, available locations, redundancy, features, and more.

Of all the items in that list, reliability is a critical element. This network will be part of an on-going business operation, carrying customer information, as well as systems to maintain the integrity of the traffic flow in the HOT lanes and assist in the response to incidents. While the COO did not specify a reliability figure, 99.99 percent would translate to an acceptable downtime of 1-minute per week. Many organizations require 99.999 percent reliability, which is equivalent to six seconds of downtime per week, on average.

Considerations for TxDOT

Most of the sensors, camera equipment, and communications equipment on the market today utilize an Ethernet interface and run Transmission Control Protocol/Internet Protocol (TCP/IP). Because Ethernet and TCP/IP are so widely supported, this capability provides a standard communications pathway for virtually any device on the market, despite the actual protocols used for the long-range transmission of the data.

There is an entire set of communications equipment that is designed to run wireless Ethernet standards, such as 802.11a, b, g, or n. While the use of these systems provides a standard interface, significant constraints would be faced adapting these systems to a long-haul corridor type of application.

As an example, Table 1 shows just a few of the typical parameters associated with the various levels of wireless Ethernet systems on the market today. Of particular note is the range information. While these ranges can be extended using directional antennas, repeaters, and ensuring good site conditions such as line-of-sight and no foliage, these systems were not designed for back-haul applications such as the transmission of data down a corridor. Some vendors have environmentally hardened equipment using these standards and can create solutions that carry data significantly longer distances but these are generally using departures from the standards.

Table 1. Typical Parameters for Wireless Ethernet Systems.

Standard	*802.11a*	*802.11b*	*802.11g*	*802.11n*
Max Rate	54 Mbps	11 Mbps	54 Mbps	600 Mbps
Typical Throughput	27 Mbps	5 Mbps	22 Mbps	144 Mbps
Range (outdoors)	100 feet	300 feet	300 feet	600 feet

Source: "IEEE 802.11" http://en.wikipedia.org/wiki/IEEE_802.11. Accessed August 19, 2009

As a comparison, the 5 Mbps stated as typical throughput for 802.11b is the typical bandwidth consumed to send 1-2 camera streams. Just the surveillance cameras alone identified in Figure 1, could easily consume 20-50 Mbps, which does not include data from the tolling system, the gate closure system, enforcement actions, and the pricing algorithm.

A typical equipment cost for an outdoor site is $4K to $6K, depending on the standard, the antennas in use, the cabling lengths and more. This cost assumes a readily available structure such as a light or sign support. As with other site deployments discussed in this memo, the availability of power and support structures is critical and may be a significant factor in where equipment is located. This may lead to equipment being placed at less than optimal locations for throughput. A significant trade-off of these systems is that the throughput dramatically decreases as the distance between nodes on the network increases. While the communications equipment for each site is relatively inexpensive, the number of sites required may be significant to carry data down the entire corridor in order to achieve usable bandwidth.

Given the constraints of the typical lower cost widely available wireless Ethernet systems, the use of proprietary communication systems should be investigated. While generally more expensive per site, the throughput that can be achieved in conjunction with much longer distances, generally offers a significant cost offset by reducing the number of intermediate sites necessary to travel the corridor. These systems typically offer greatly increase reliability and security in addition to substantially increased bandwidth.

Prior to any decisions pertaining to the type of wireless system that should be employed, at minimum, a careful accounting of data sources and their bandwidth must be performed. Additionally, surveys to determine potential sites and the spacing between them is an input that is important in the decision process.

An option being considered is developing an agreement with TxDOT to utilize the fiber infrastructure in the corridor owned by TxDOT. The cost implications of this are not well known at this point in time. Wired, vs. wireless equipment has different components, but each deployment site often winds up with comparable costs. An estimation of the financial impact is not possible without significant additional information.

Another impact however is the potential improvements in quality and decrease in interference. Having the camera systems on a fiber communication system would substantially improve the response time, resulting in smoother operations, faster switching, higher quality pictures, and a higher bandwidth capability.

Data Collection Equipment for Pricing Algorithm

The COO states that the pricing algorithm will be supported by an independent vehicle detection system, capable of speed and volume data collection. No further details are provided as to the type of equipment and spacing, other than it is to be independent of the existing TTI traffic monitoring system.

Considerations for TxDOT

Some type of data collection is necessary to provide this input. If sensor type equipment is not used, the other alternative would be a set of supplemental toll tag readers to perform as the existing tag reader on the freeway lanes do. While this system is a known commodity, the cost would appear to be substantially higher using tag readers. A sensor type of equipment, such as the Wavetronix, is a more cost-effective solution.

In order to provide input into a pricing algorithm dependant on speeds, the collection points should be well outside the influence area of entry / exit point operations and any enforcement operations. As a general rule of thumb, this would typically ½ to 1-mile downstream of the entry point, although it also depends on the entering volume at the location. If a length of 1-mile from an entry or exit point is assumed as an area of influence, a roadway spacing of 2-miles or more would form the basis for speed measurements free from interference. The additional 1-mile comes from the lanes are bi-directional, so candidate locations should have the spacing available in both directions. This also conforms to the general spacing used in the Houston AVI system.

An option under consideration is to utilize Wavetronix data collection stations at a spacing of approximately 2-miles in the HOT lanes. This would provide the speed collection necessary to for the pricing algorithm.

The use of this 2-mile spacing allows the following road segments to be considered for a speed data collection stations.

- North Freeway (locations illustrated in Figure 2)
    - Between Quitman and Airline/Crosstimbers
    - Between Airline/Crosstimbers and Veterans Memorial
    - Between Veterans Memorial and Aldene-Bender
    - Between Aldene-Bender and Rankin
    - Between Kuykendahl and FM 1960
- Eastex Freeway (locations illustrated in Figure 3)
    - Between Kelley and Tidwell Transit Center
    - Between Tidwell Transit Center and Eastex Park and Ride
    - Between Eastex Park and Ride and McKay Drive
    - Between McKay Drive and Townsen Park and Ride
- Gulf Freeway (locations illustrated in Figure 4)
    - Eastwood Transit Center to IH-610
    - IH-610 to Monroe Park and Ride
    - Monroe Park and Ride to Fuqua Park and Ride

- Southwest Freeway (locations illustrated in Figure 5)
    - Milam to Dunlavey
    - Westpark Park and Ride to Hillcroft Transit Center
    - Hillcroft Transit Center to Westwood Park and Ride
    - Westwood Park and Ride to West Bellfort Park and Ride
- Northwest Freeway (locations illustrated in Figure 6)
    - Northwest Transit Center to Dacoma
    - Dacoma to Pinemont Park and Ride
    - Pinemont Park and Ride to West Little York Park and Ride
    - West Little York Park and Ride to Northwest Station Park and Ride

The number of sensors required on each facility depends primarily on the formulation of the pricing algorithm and the input requirements. If multiple pricing segments are used per facility, a minimum of one sensor would be required for each pricing segment. Sensors such as Wavetronix are bi-directional and so only one sensor would be required at a location. All the HOT lanes except the Gulf Freeway have a minimum of 4 locations with the suggested spacing. It is likely that 3-4 locations would be better suited to provide representative data on the speed conditions on the facilities, along the entire length. Sensors such as supplementary AVI readers could be used to computer actual average trip times and also provide the necessary input into the pricing algorithm.

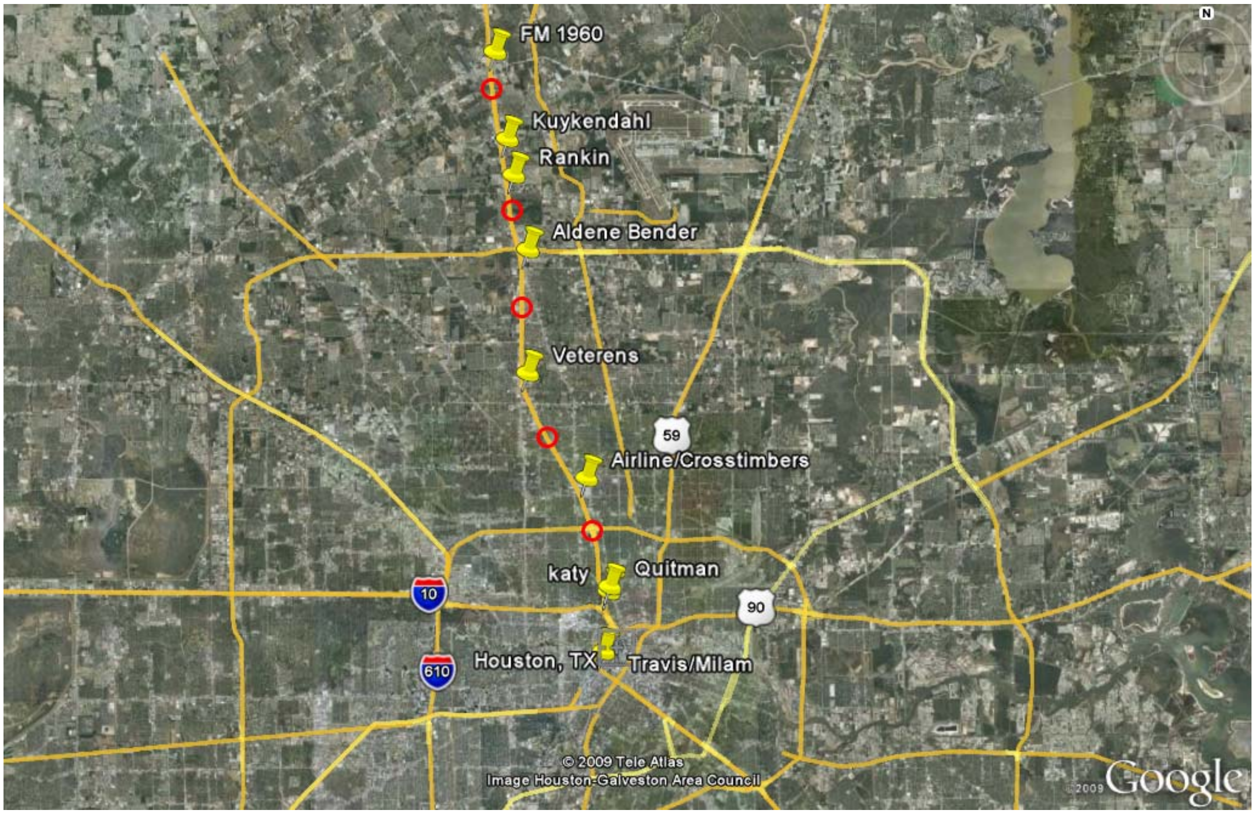

Figure 2. North Freeway-Potential Data Collection Locations.

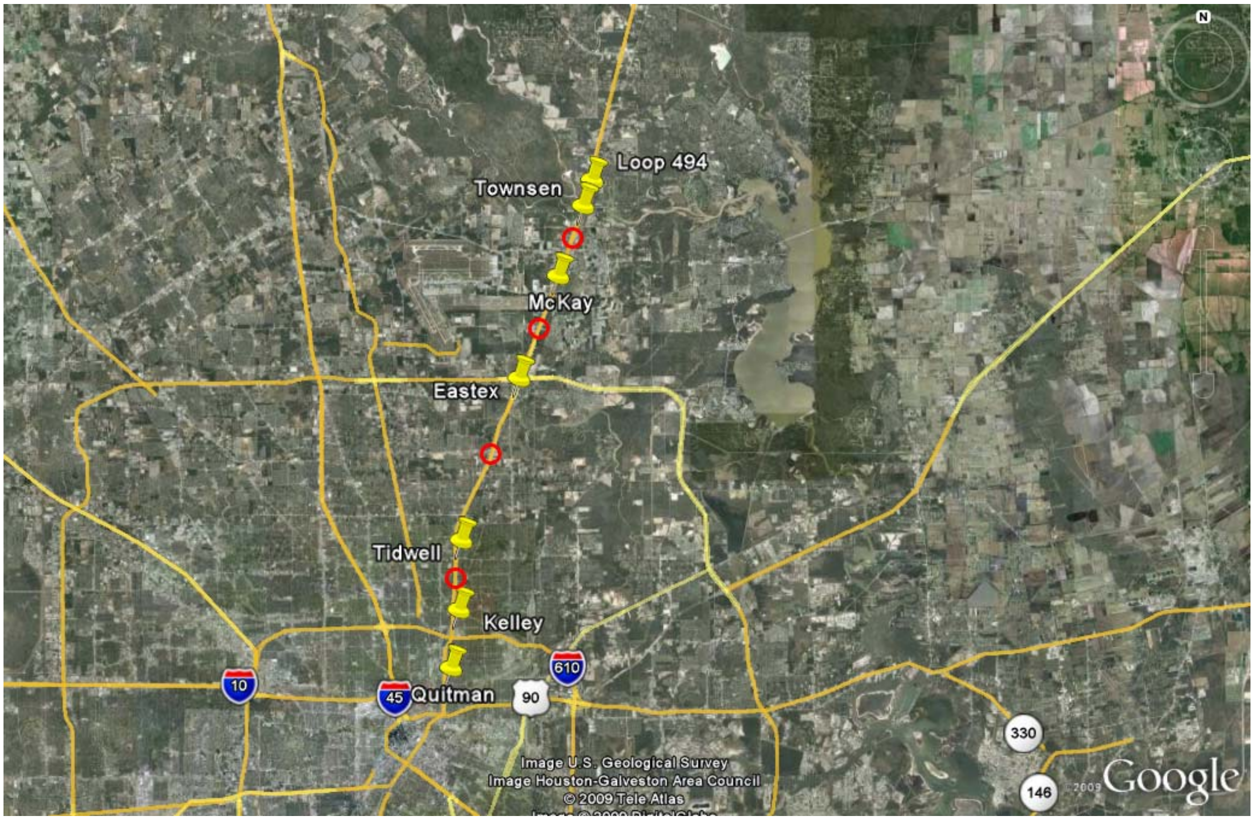

Figure 3. Eastex Freeway-Potential Data Collection Locations.

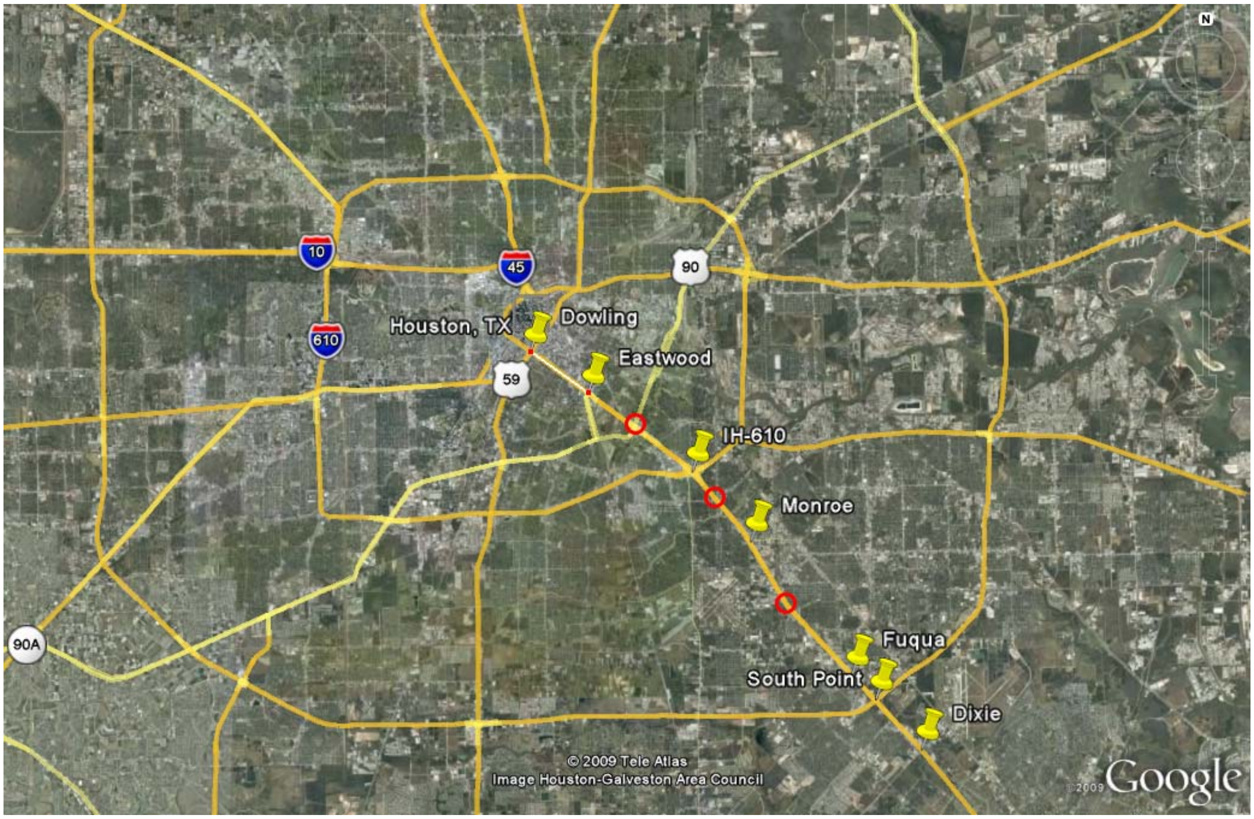

Figure 4. Gulf Freeway-Potential Data Collection Locations.

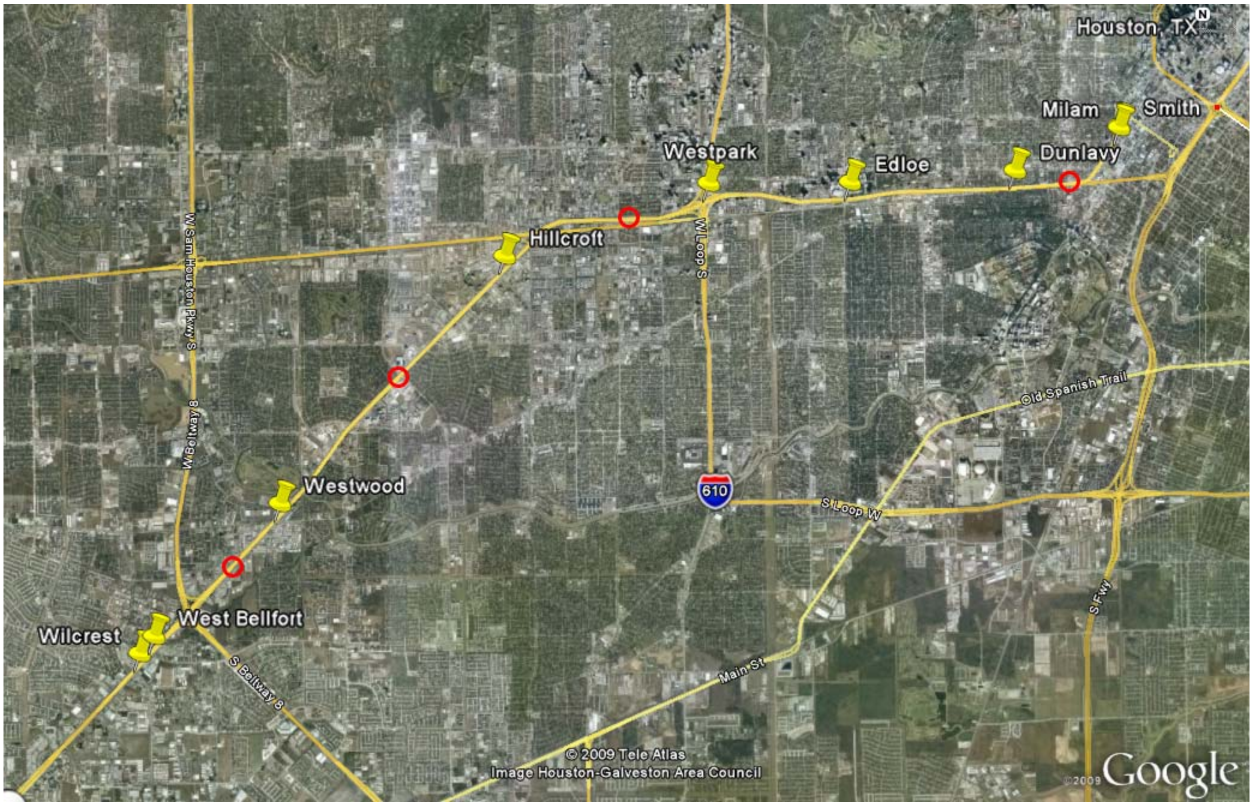

Figure 5. Southwest Freeway-Potential Data Collection Locations.

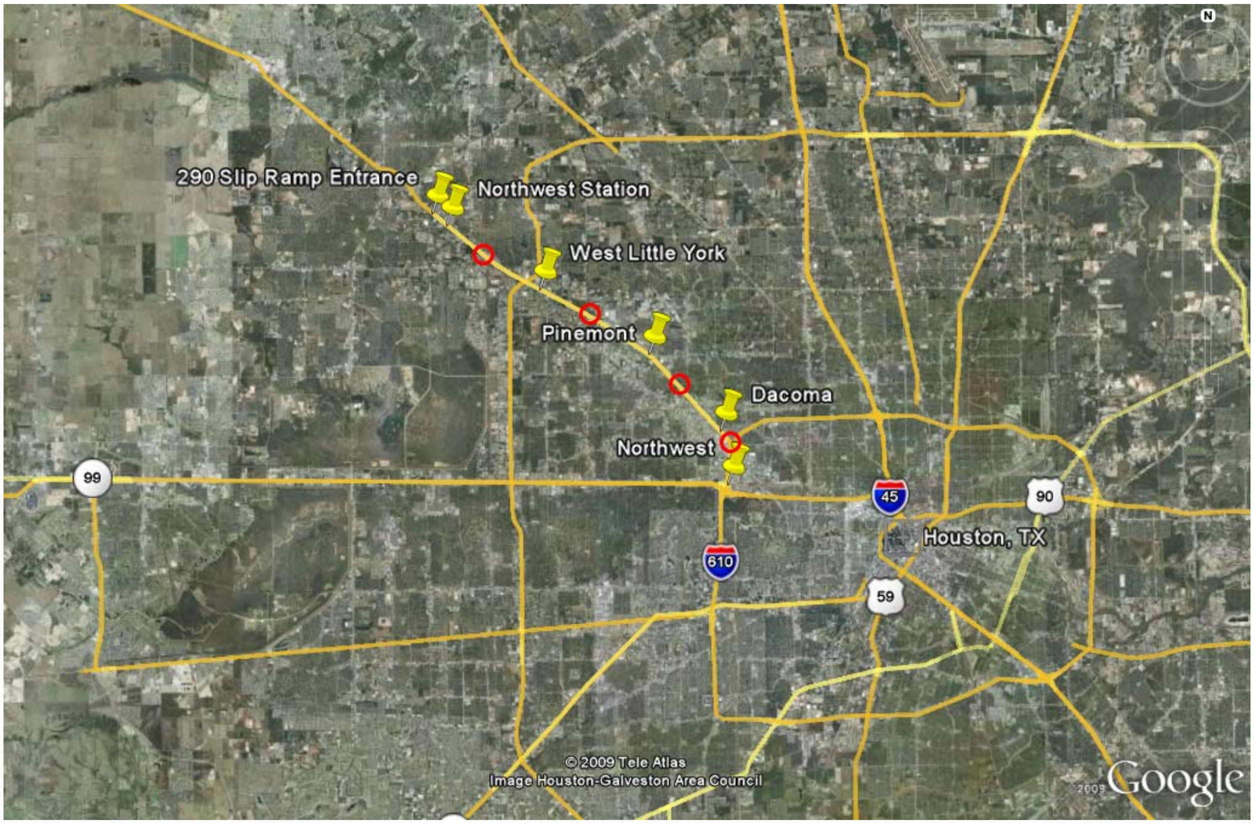

Figure 6. Northwest Freeway-Potential Data Collection Locations.

An option under discussion is to reduce the number of pricing segments to one for the entire facility. While this theoretically could reduce the need to one sensor per facility, a single spot speed location is not going to be very response to traffic throughout the facility.

The use of additional sensors also has a side benefit of providing data for incident detection, by detecting a slow-down in speeds on the facilities. Incidents could then be verified using the cameras on the facilities.

Wavetronix units can typically be purchased for approximately $8K, with a typical site installation requiring an addition $7K, for a total estimated cost of $15K per deployment site. Establishing three to four sites per facility would cost 445K to $60K.

In terms of choosing locations for sensor deployments, the following factors should be considered.

- Power – available power is optimum, although sites can be configured for solar operation at additional cost. Longer term maintenance issues may also arise from solar operations.
- Communications – if wireline communications will be used, reducing the distance from available termination points may be an important consideration. If wireless communications will be employed, site surveys should be performed to examine for interference, and line-of-sight, if necessary.
- Structures – both the sensors and any associated wireless communications equipment will need an adequate mounting structure. Sensors such as Wavetronix have both lateral distance and height requirements for placements, depending on the mode of operation (sidefire vs. frontfire).
- Absence of any geometric features – optimum locations would be areas of the roadway where significant geometric features such as curves or grades do not exist. A site survey should watch for a preponderance of braking maneuvers to ensure drivers do not sense a restriction that is not immediately obvious to a site survey team. The absence of any features would also rule out locations where the number of lanes changes or there are merge/diverge areas, although the previous guidance of placing sensors in areas free of entry/exit operations should cover that concern.

Finally, it is important to remember that proper validation of each sensor location should take place after installation and prior to use in any pricing algorithm.

<u>Pricing Displays</u>

The information displays that display pricing for the HOT lanes are relatively simple pieces of equipment. Consideration of the deployment impacts of these displays is more a function of their type and size, their location, and the availability of power and communications. The COO does not provide detail on the specific locations and deployment needs for each location.

Considerations for TxDOT

An option being considered is developing an agreement with TxDOT to incorporate the pricing displays on existing sign bridges, where possible. This agreement, while obviously a function of the available real-estate space on the sign bridges, could significantly reduce the deployment costs for displaying pricing information.

If supplemental sign supports are necessary, the selection of installation locations depends on a number of factors. Items such as power, and communications were discussed in previous areas. Additional items to consider would include sight distance and decision sight distance. The distance necessary for decision-making after viewing the sign depends on speed. On a high-speed approach to the HOT lanes, the sign will need to be sufficiently far upstream to allow the driver to make an entrance decision. On lower speed approaches, this distance can be reduced. On some entrances to the existing park and ride lots, this may require the displays to be on the arterial streets.

Detailed guidance on the information that should be displayed on the signs is contained in the technical memorandum for Task 7.

<u>In-Pavement Lighting Displays</u>

The application of in-pavement devices, specifically in-pavement lighting devices, has potential in supplementing traditional traffic control and or safety devices in a HOV/HOT lane access control system. These innovative devices, which METRO has experience with on the existing Red Line LRT, could supplement automatically closed gates, reinforce the meaning of traffic signal indications or different types of signs, or provide wrong way indications on the pavement, for example. However, they are subject to experimentation procedures and should be thoroughly vetted as to their cost effectiveness before widespread inclusion in conceptual or final design.

Considerations for TxDOT

The use of any in-pavement devices would require substantial planning prior to deployment, both in terms of obtaining permission and in terms of defining the exact infrastructure and communication needs to incorporate into the civil construction aspect of the HOT lanes modification. If desired, a recommendation would be to experiment with the devices on one facility and perform a thorough evaluation of their effectiveness, prior to implementing across all facilities.

<u>Conclusions</u>

This technical memorandum has examined several equipment or technology areas necessary to support tolling operations on the HOT lanes modification project. Because the final design aspects of many areas of the project are not yet known, this memorandum focused on broad-scale technology areas, as opposed to a specific location or installation. In each instance, the assessment of the impacts to TxDOT examined if changes were possible to reduce the costs of the deployments, without substantially reducing the capabilities of the design.

In a number of areas, changes could be made that are thought to have an overall reduction in costs for the project. These are not recommendations to proceed with those changes, merely an assessment of the cost implications. In all cases, a more detailed evaluation would have to be performed to determine the best path.