Evaluation of the Overheight Vehicle Detection System (OVDS) Houston, Texas

Prepared by
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Evaluation of the Overheight Vehicle Detection System (OVDS)

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DISCLAIMER

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TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

Evaluation of the Overheight Vehicle Detection System (OVDS)

INTRODUCTION

Several of the Interstate Highways in the central part of Houston, Texas have lower bridge clearance heights, particularly on I-10 and I-45. Drivers carrying taller loads who are unfamiliar with the low clearance of certain bridges on I-10 and I-45 often fail to divert their route (via I-610). These drivers, typically in trucks, may strike bridges resulting in damage to the structures and cause major congestion and delays to traffic along these freeways. At the beginning of 2015, the TxDOT Houston district noticed a spike in bridge hits and deployed an Overheight Vehicle Detection System (OVDS) to detect and advise (via a roadside dynamic message sign, or DMS) overheight vehicles to use I-610 as an alternate route. This system is different than other similar systems deployed in Houston and in Texas as it is intended to provide warning for an overall stretch of 12-13 miles of urban freeway, as opposed to one or two isolated low-clearance bridges within a mile or two.

Goals/Objectives

The goal of the TxDOT Houston District for this pilot evaluation was to identify a system that will help eliminate or significantly reduce bridge hits due to overheight truck loads. In order to achieve this goal, an OVDS was selected and deployed at two locations with the following two objectives:

1. Evaluate the technical and operational capabilities of an active overheight detection and warning system via pilot deployment at two sites along I-10. These locations are:
   1) IH 10 East WB @ Mercury Drive (referred to as Mercury Site for this report); and
   2) IH 10 Katy EB @ Chimney Rock Road/Wirt Road (referred to as the Wirt Site for this report).
2. Evaluate the effectiveness of the warning system in rerouting over-height vehicles to use I-610 Loop instead of traveling into or thru downtown on I-10.

OVDS Overview

The OVDS system deployed for pilot demonstration in Houston, Texas consists of following components shown in Figure 1 thru Figure 3:

- an infrared-based overheight vehicle detection sensor;
- an integrated camera capable of capturing both images and video;
- wireless communications to send alerts via email and text messages, and
- an integrated and dedicated dynamic message sign located downstream from the sensor equipped with top mounted flashing beacons to display a warning and advisory message.

The overheight detection sensor is a Z-pattern red/infrared model. Two beams of infrared rays are set up across the freeway lanes in a Z-pattern at a pre-determined height. When a vehicle exceeding the threshold height travels under the sensor beam, it causes a break in the infrared beam and the system generates an alarm, logging the event (*1, 2*).

It should be noted that the OVDS does not have the capability to measure the actual height of a vehicle traveling under the sensor beam and thus all vehicles that meet or exceed the threshold height are considered overheight without any consideration for the actual height of the vehicle.

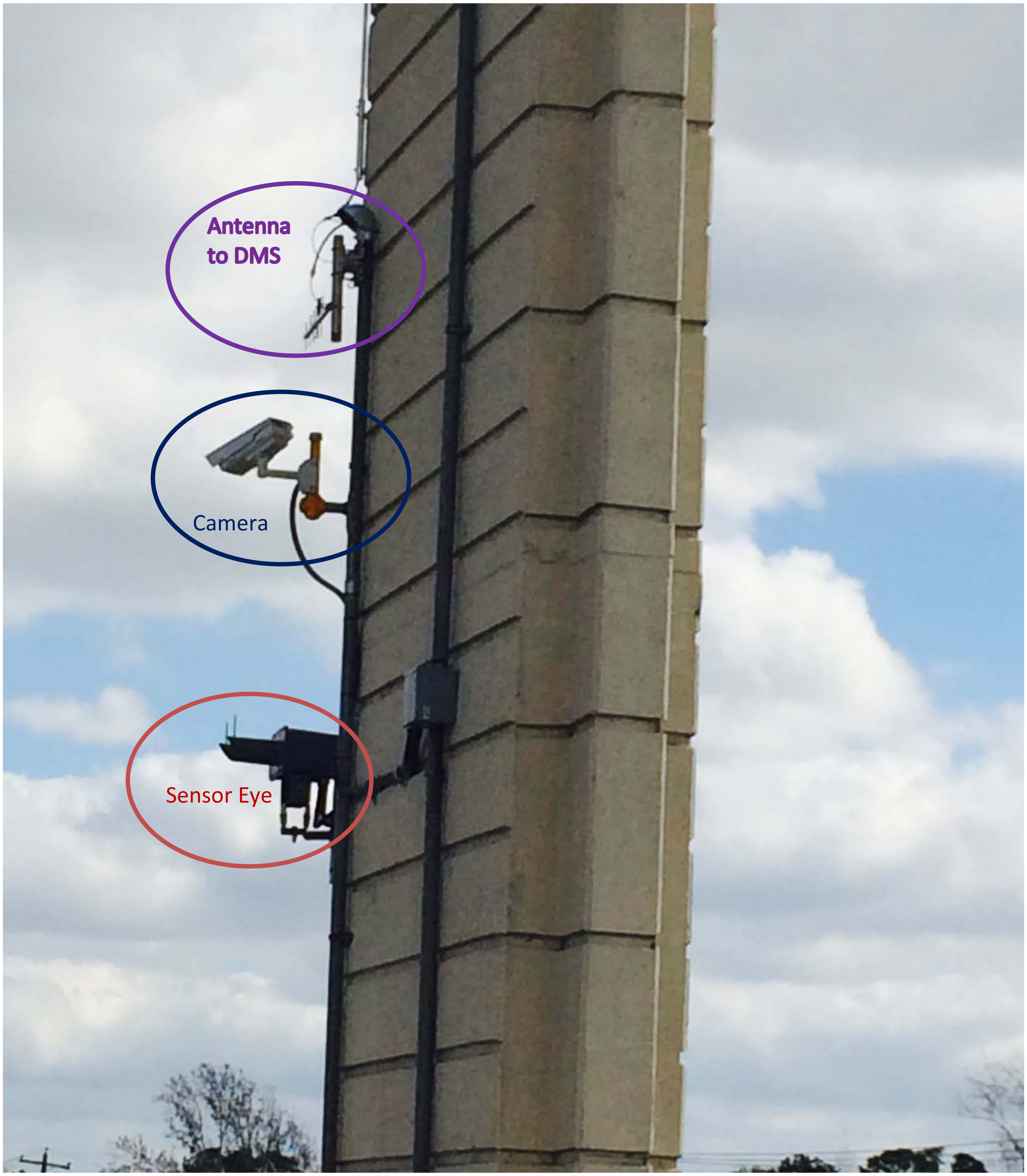

Figure 1. OVDS Components at Detection Location – to Roadside at Wirt Site shown.

Figure 2. OVDS Components at Wirt Site (on centerline of I-10).

Figure 3. DMS with Top Mounted Beacons Showing the Warning Message.

Once an overheight alarm is generated, the following three actions are taken (*2*, *3*, *4*):

1. The integrated camera takes a series of snap-shots (5 pictures taken one second apart) of the roadway downstream of the sensor (pre-set view) that are attached to the email alert sent to a pre-designated server or individuals if so configured. For this pilot demonstration, email alerts from the OVDS were sent to a server that in turn was configured to send these email alerts out to individual email addresses. Figure 4 shows an example of five pictures received in an email alert.
2. The cell modem sends a text message to pre-designated numbers with the warning message that an overheight alarm has been detected. The cell modem can be configured to send additional information messages such as 'OVDS Fault Detected' or 'No OVDS Alarm Detected' if desired during troubleshooting or for maintenance staff.
3. OVDS sends a contact closure signal to the radio receiver in DMS that stays active for the duration of a pre-set alarm time. The DMS controller displays the warning message for the amount of radio receiver alarm time. For the pilot project, the radio receiver alarm time in the DMS was set to 30 seconds and relay is programmed to retrigger the radio receiver alarm time. This means that if two overheight vehicles are detected within a 30 second period, the total duration of the message display does not get extended but stays 30 seconds. In other words, if a second overheight gets detected while the message has already been displayed for 25 seconds, the second vehicle will see the message only for 5 seconds.

Figure 4. Example of Pictures Received in the Email Alarm Alert

For the pilot project, a DMS with top-mounted flashing beacons was preconfigured with the message 'OVERHEIGHT MUST EXIT I-610' (see Figure 3) to be displayed for 30 seconds. The DMS operated so that the flashing beacons become active as soon the contact closure signal is received by the DMS assembly. The DMS board is always on with a blank message in order to shorten the start-up and activation time between communications from the overheight sensor system to when the message displays. The time between contact closure to the display of the warning message is less than 1.0 second. The displayed message is a single phase message with 2 units of information and meets the Texas Manual on Traffic Control Devices (TxMUTCD) legibility and visibility requirements for changeable message signs. The DMS board is photocell equipped to provide the correct brightness and visibility for both during daytime and nighttime operations.

Location Overview

The two pilot locations were strategically selected so as to:

- Provide warning for multiple bridges downstream of each site;
- Provide overheight vehicles with sufficient distance to exit to the alternative route on I-610;
- Have availability of overhead sign bridges to mount the sensor equipment and locate the equipment at a reasonable distance upstream of the I-610 exit signs; and
- Have availability of a suitable location for a DMS board that would on sufficient distance away from the sensor, but far enough in advance of the I-610 interchange;
- Provide a clear line of sight between overheight vehicles traveling in any lane on the facility to the DMS downstream from the sensor (no roadway geometry, other signs, or vegetation in the way).

The following subsections describe the general and geometric characteristics of each site.

1. ***Mercury Site: I-10 (East Freeway) Westbound at Mercury Drive***
   Figure 5 shows the sensor location near Mercury Drive, the downstream DMS location, and the I-610/I-10 interchange. I-10, in the westbound direction at this site, has four lanes at the sensor location and the entry ramp from Mercury Drive adds the fifth lane on the right. At the interchange, there are five lanes, out of which the two right lanes exit to I-610 and the three left lanes continue towards Downtown Houston. Overheight vehicles detected at the sensor location are alerted to their overheight status and advised to exit I-610 via a display on a portable dynamic message sign that is located approximately 1200 feet downstream of the sensor location. The painted gore of the interchange of I-610/I-10 is approximately one mile from the sensor location and 4000 feet downstream of the DMS location. At travel speeds of 60 mph, the system allows 13.4 seconds of message exposure time and in the worst case, an overheight vehicle traveling in the far left lane will have approximately 4000 feet (45 seconds when traveling at 60 mph) to complete the 3 lane changes required to use I-610 as advised.

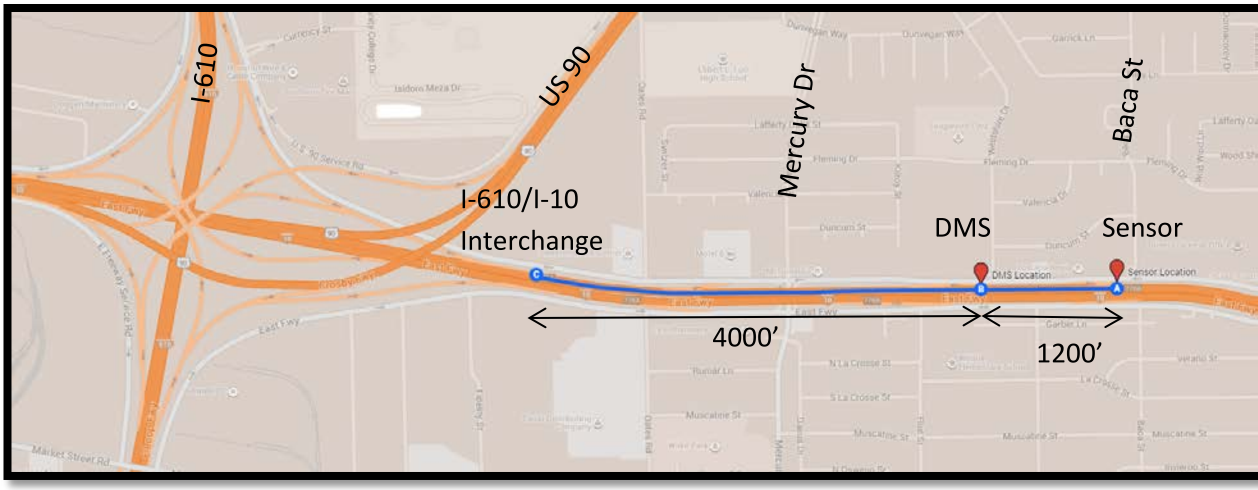

Figure 5. Sensor, DMS and I-610/I-10 Interchange Location for Mercury Site (Map Data: Google)

2. ***Wirt Site: I-10 (Katy Freeway) Eastbound at Chimney Rock Road/Wirt Road***

Figure 6 shows the sensor location, the downstream DMS location, and interchange of I-610/I-10 for this site. At the sensor location, I-10 eastbound has five freeway mainlanes, one exit only (auxiliary) lane to Wirt Road, and two eastbound managed lanes. Out of five freeway mainlanes, the three right lanes are ‘exit only’ to I-610 and the two left lanes continue thru as I-10 eastbound towards Downtown Houston. At the interchange location, I-10 eastbound has eight lanes, out of which the four rightmost lanes exit to I-610 and four left lanes continue as I-10 eastbound. The entry ramp from Voss Road adds one lane on the right that is forced to exit to I-610 and termination of managed lanes west of the I-610/I-10 interchange adds two lanes on the left that continue east as part of the I-10 mainlanes.

Overheight vehicles detected at the sensor location are alerted to their overheight status and advised to exit to I-610 via a DMS that is located approximately 1250 feet downstream of the sensor location. The painted gore of interchange of I-610/I-10 is approximately 1.96 miles downstream of the DMS location. At maximum travel speeds of 60 mph, the system allows 14 seconds of message exposure time (between sensor and DMS). An overheight vehicle traveling in the far left lane (of the freeway) will have approximately 117 seconds when traveling at 60 mph to complete the two lane changes required to use I-610 as advised.

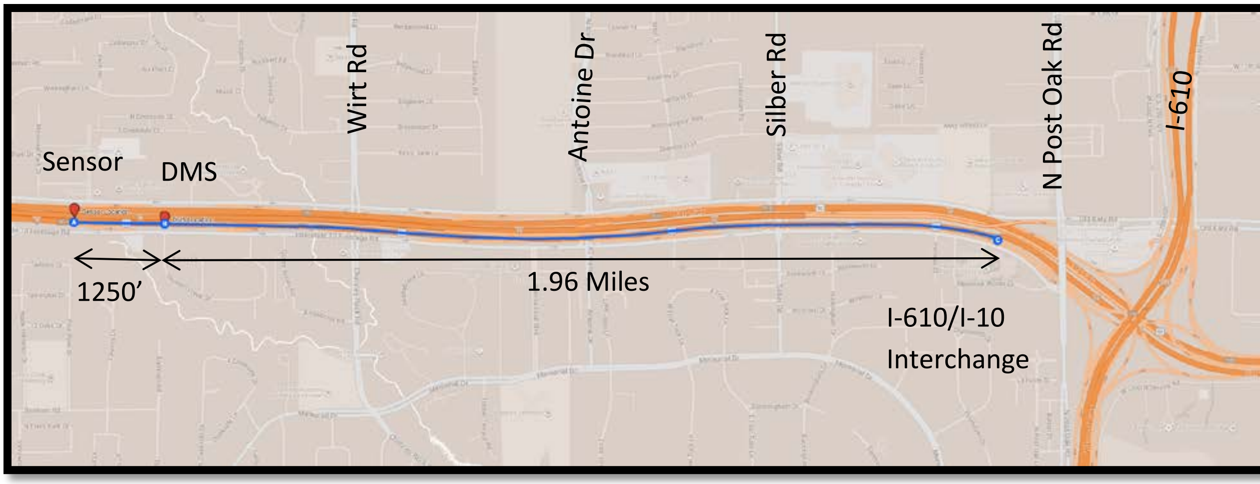

Figure 6. Sensor, DMS and I-610/I-10 Interchange Location for Wirt Site (Map Data: Google)

Implementation Schedule

For this pilot demonstration, the initial height was set to 13'10" and the system (excluding the DMS) was activated on February 14, 2015 at Mercury site and on February 15, 2015 at Wirt site. However after considering that: 1) the lowest bridge clearance in downtown Houston is 14'1" as designated on bridge placard, and 2) the Texas state requirement for overheight permit is 14'0" (*5*); threshold height was changed to 14'0" on February 28, 2015.

Table 1 shows key dates for the pilot demonstration.

Table 1. Key Deployment Dates for Pilot Demonstration (*6*)

Action	Mercury Site	Wirt Site
Sensor Active but No DMS with Threshold Height 13'-10"	February 14, 2015	February 15, 2015
Sensor Active but No DMS with Threshold Height 14'-0"	February 28, 2015	February 28, 2015
Sensor and DMS both Active with Threshold Height 14'-0"	April 7, 2015	April 15, 2015

During the evaluation period, the Z-patterned infrared detection sensors were set to detect vehicles that exceed 14'0" in height. However, a general examination of 1) overheight vehicle configurations at both locations, 2) the number of overheight alarms generated, and 3) the proportion of overheight vehicles by travel lane at sensor raised concerns about the accuracy of threshold height as being 14'0". This concern led TxDOT project personnel to verify the threshold height at both locations. Upon verification, threshold height at Wirt site was found to be 14'0" while the threshold height at Mercury site was 14'1" (*7*).

EVALUATION GOALS AND METHODOLOGY

Evaluation methodology was developed to determine if the pilot demonstration was effective in satisfying the project goals and performance measures were tailored for each goal.

Evaluation Goal 1: Document any technological and institutional issues that complicated deployment and operation of OVDS.

The evaluation methodology was to collect available log data from various components of the system to identify any technical and/or operational issues with individual components and in summary with the complete system. Specifically, log data from the sensor alarm event monitor, from the fault event monitor, from alarm alert emails, and from video files from the sensor camera were used to:

- Document any issues with normal operations of the system;
- Identify any discrepancies in overheight alarms detected and logged by the sensor modem and alarm alert emails received by designated individuals;
- Identify false event alerts (if any) by examining photos attached with the email alerts (for a sample set of email alerts) where no overheight vehicle was seen in the accompanying pictures; and
- Identify if the DMS contact closure is completed for every overheight vehicle detected. This was done by visually verifying DMS activation for a sample set of alarm alerts using the video files from sensor camera.

In addition to identifying any technical issues with the system operation, researchers interviewed TxDOT project personnel to document any institutional or technical issues encountered with procurement, deployment, and integration of the system.

Evaluation Goal 2: Determine if OVDS is effective in diverting overheight vehicles to I-610. Also determine proportion of over-height vehicles in the vehicle mix at the sensor location.

In order to identify the effectiveness of OVDS in diverting vehicles to I-610, evaluation was completed in a before-after study format. Researchers compared the overheight vehicles exiting to I-610 in the Before period (with OVDS sensor operational but no DMS activation) with that in the After period (both OVDS sensor and DMS active). To identify the overheight vehicles exiting I-610, researchers obtained OVDS alarm alert emails (showing overheight vehicle) and collected video data at the interchange of I-610/I-10. Overheight for this study was defined as any vehicle that is higher than the sensor threshold set for detection.

For the Mercury site, the Before period was from March 1, 2015 thru April 6, 2015 (37 days). The DMS was activated on April 7, 2015 at 9:14 AM and the After period data at this site were collected from May 8, 2015 thru June 2, 2015 (26 days). For the Wirt Site, the Before period was from March 1, 2015 thru April 14, 2015 (45 days). The DMS was activated on April 15th at 9:33 AM and the After period data at this site were collected from April 23, 2015 thru May 1, 2015 (9 days). Table 2 shows the dates for which alarm alert emails and video data were collected and analyzed to determine the effectiveness of OVDS in diverting overheight vehicles.

In order to determine the proportion of over-height vehicles in the vehicle mix, researchers obtained available smart sensor (radar) data from radars closest to the OVDS sensor location.

Table 2. Dates for Before and After Period Data Collection

Mercury Site		Wirt Site	
Before Period	**After Period**	**Before Period**	**After Period**
3/4/2015	5/8/2015	3/19/2015	4/23/2015
3/5/2015	5/9/2015	3/20/2015	4/24/2015
3/6/2015	5/10/2015	3/31/2015*	4/25/2015
3/7/2015	5/11/2015	4/1/2015	4/26/2015
3/8/2015	5/12/2015	4/2/2015	4/27/2015
3/9/2015	5/13/2015	4/3/2015	4/28/2015
3/10/2015	5/14/2015	4/4/2015*	4/29/2015
3/11/2015	5/15/2015*	4/12/2015	4/30/2015
3/12/2015	5/18/2015*	4/13/2015	5/1/2015
3/13/2013*	5/20/2015*		
3/16/2015	5/26/2015		
3/17/2015	5/27/2015		
3/18/2015	5/28/2015		
3/19/2015	5/29/2015		
3/20/2015	6/2/2015*		

*Researchers had planned to collect and analyze continuous video data at both sites, however due to several consecutive rainy and cloudy days, the solar-powered portable video equipment failed and video data from some days was unable to be recorded. The days included in the study periods may not be consecutive.

EVALUATION RESULTS

Data collected from system components, video data, and interviews with TxDOT Project personnel were analyzed and the results are presented in this section for following measures of effectiveness.

1. OVDS Operations – Normal versus Faulty Operations

The system includes two monitors for the infrared sensor – an alarm event monitor and a fault event monitor.

Alarm Monitor Log Analysis

The alarm event monitor logs the time stamp of its initialization, time stamp of its complete start (ready to detect overheight vehicles), a warning message when an overheight vehicle is detected, time stamp of SMS alert sent (if configured to send SMS alerts), sensor beam reset status check (approximately 10 to 12 seconds) after detecting the overheight vehicle, and counter update of overheight vehicle alarms detected since last initialization. Table 3 shows an example of data logged in an alarm event monitor.

Table 3. Example of Alarm Event Monitor Data Log.

INFO_02/14/2015_16:05:42_Alarm Monitor Initializing...
INFO_02/14/2015_16:06:42_Alarm Monitor Started.
INFO_02/14/2015_16:06:42_No OVDS Alarm detected.
INFO_02/14/2015_16:06:42_OVDS Alarms since reset on_02/14/2015_16:05:42_is_0
WARNING_02/14/2015_16:10:35_WARNING: OVDS Alarm detected!
INFO_02/14/2015_16:10:35_Sending SMS alert(s)...
INFO_02/14/2015_16:10:35_SMS alert(s) sent.
INFO_02/14/2015_16:10:46_No OVDS Alarm detected.
INFO_02/14/2015_16:10:46_OVDS Alarms since reset on_02/14/2015_16:05:42_is_1

Alarm Monitor Log Analysis Findings

- *An analysis of the alarm monitor logs suggests that it takes 10 to 12 seconds for the system to recover from its alarm state and be ready to detect a new alarm. However, as per vendor information, this time can be shortened to about 5 seconds if so desired (2).*
- *If two overheight vehicles were traveling side by side at the same time or an overheight vehicle is traveling right behind another overheight vehicle such that they pass the beam within 10 seconds of each other, it will be logged as only one alarm event.*
- *The alarm event monitor gets reinitialized after power failure or after any manual change in settings of the wireless modem.*

Fault Monitor Log Analysis

Table 4 shows an example of data logged in Fault Event monitor. The Fault Event monitor logs the time stamp of its initialization, time stamp of its complete start (ready to detect any faults with the sensor beam), an initial check for any faults, a warning message when fault is detected, time stamp of SMS alert and email alert sent (if configured to send SMS and email alerts), fault status check after detecting the fault, another SMS and email alert sent after reaching a 'No Fault' state, and counter update of fault events detected since last initialization.

Researchers analyzed the fault monitor logs from 2/14/2015 16:05:01 thru 5/27/2015 16:05:01 (a total of 102 full days) to assess the percent of time when the sensor beam was considered to be in fault (i.e. not functioning normally). Time stamps of following info and warning messages were used to quantify fault time for each pilot site:

i. Message 'OVDS Fault Detected' – time stamp of text alert sent for fault occurred
ii. Message 'No OVDS Fault Detected' which indicates end of fault – Time stamp of when the system recovered from fault.

Table 4. Example of Data Logged in Fault Event Monitor

```
INFO_02/14/2015_16:05:01_Fault Monitor Initializing...
INFO_02/14/2015_16:06:01_Fault Monitor Started.
INFO_02/14/2015_16:06:01_No OVDS Fault detected.
INFO_02/14/2015_16:06:01_Sending SMS alert(s). Please wait...
INFO_02/14/2015_16:06:01_SMS alert(s) sent.
INFO_02/14/2015_16:06:01_Sending email alert. Please wait...
WARNING_02/14/2015_16:06:01_Failed to send email alert. Socket Error.
INFO_02/14/2015_16:06:01_OVDS Faults since reset on_02/14/2015_16:05:01_is_0
WARNING_02/28/2015_08:28:14_WARNING: OVDS Fault detected!
INFO_02/28/2015_08:28:14_Sending SMS alert(s). Please wait...
INFO_02/28/2015_08:28:14_SMS alert(s) sent.
INFO_02/28/2015_08:28:14_Sending email alert. Please wait...
INFO_02/28/2015_08:28:19_Email alert sent.
INFO_02/28/2015_08:32:05_No OVDS Fault detected.
INFO_02/28/2015_08:32:05_Sending SMS alert(s). Please wait...
INFO_02/28/2015_08:32:05_SMS alert(s) sent.
INFO_02/28/2015_08:32:05_Sending email alert. Please wait...
INFO_02/28/2015_08:32:08_Email alert sent.
INFO_02/28/2015_08:32:08_OVDS Faults since reset on_02/14/2015_16:05:01_is_1
```

Fault Monitor Log Analysis Findings

Table 5 shows a summary of Fault Monitor Log data for the Mercury site and Table 6 shows a summary of Fault Monitor Log data for the Wirt site. Findings from the analysis of fault monitor log are summarized below.

- *Fault event monitors get reinitialized after power failure or after any manual change in settings of the wireless modem.*
- *At the Mercury site, the fault monitor was reinitialized six times over a period of 102 days, detected OVDS fault four times over a period of 102 days, and experienced a denial of service (DoS) attack on 3/11/2015.*
- *Fault Log analysis for the Wirt site shows no faults were detected for the evaluation period.*

Table 5. Summary of OVDS Fault Monitor at Mercury Site

	Fault Monitor Initialized	Fault Monitor Started	OVDS Fault detected	No OVDS Fault detected	Fault Time = F_{EA} - F_A
2/14/2015	16:05:01	16:06:01	-	16:06:01	-
2/28/2015	-	-	8:28:14	8:32:05	0:03:51
2/28/2015	-	-	9:10:11	9:12:00	0:01:49
2/28/2015	-	-	9:25:36	9:29:51	0:04:15
2/28/2015	-	-	9:50:37	9:52:39	0:02:02
3/11/2015	7:16:11	7:17:11	-	7:17:11	-
3/11/2015	Denial of Service attack occurred that resulted in 932 email alerts with the info 'No OVDS Fault Detected', out of which 310 experienced delivery failure due to socket error. This issue was resolved by tightening up security by changing password, changing the telnet port, disabling SSH, and cloaking pinging of modem.				
3/11/2015	7:38:09	7:39:09	-	7:39:09	-
3/11/2015	13:09:38	13:10:38	-	13:10:38	-
4/10/2015	22:59:23	23:00:23	-	23:00:23	-
5/26/2015	9:07:50	9:08:50	-	9:08:50	-
Total Fault Time					0:11:57

Table 6. Summary of OVDS Fault Monitor Log at Wirt Site

	Fault Monitor Initialized	Fault Monitor Started	OVDS Fault detected	No OVDS Fault detected	Fault Time = F_{EA} - F_A
02/14/2015	16:05:44	16:06:44	-	16:06:44	-
04/10/2015	22:59:43	23:00:43	-	23:00:43	-
04/20/2015	08:36:19	08:37:19	-	08:37:19	-

2. OVDS Operations – True versus False Alarms

This measure was included in the evaluation to identify if all alerts detected by the OVDS are initiated by an overheight vehicle. Here it should be noted that neither site provides a way to measure the actual height of the vehicle passing under the sensor, but only indicates that it is 14 feet or taller, so this measure is based on qualitative observations of the vehicle height and not on quantitative observations for actual vehicle height. For the purposes of this study, the following criteria were applied to determine if an alarm alert was true or false:

- Alarm alert true: when the accompanied video/picture shows a tall (taller than passenger vehicles and single unit trucks) vehicle; and
- Alarm alert false: when the accompanied video/picture does not show a tall vehicle.

The measure was quantified for email alerts received for the dates shown in Table 2.

A total of 748 alarm email alerts were analyzed for Mercury site and 858 alarm email alerts for analyzed for Wirt site. For every alarm alert email analyzed, there were accompanying pictures that showed a tall vehicle (taller than a passenger car and single unit trucks). Since researchers couldn't measure the actual height of the vehicle from a picture, it was assumed the tall vehicle in the pictures attached with the alert email met or exceeded the threshold height and thus was responsible for sensor break and triggering the alarm.

Findings

Based on this hypothesis for checking false alarms, no false alarms were found during the study period.

3. OVDS Operations - Monitor Logged Alarms versus Email Alerts Received

Researchers included this measure to determine if all the alarms logged by the sensor monitor were transmitted with attached pictures. Table 7 shows number of monitor logged alarms and number of email alerts received for that date for both pilot sites. This measure was analyzed for a period of 3 months starting from 3/1/2015 and ending on 5/31/2015.

Table 7. Number of OVDS Alarms Logged by Monitor vs. Received by Emails

Mercury Site			Wirt Site		
Monitor Logged Alarms	Email Alerts Received	Percent Difference	Monitor Logged Alarms	Email Alerts Received	Percent Difference
2154	2180	-1.2%	4633	4448	4.0%

Findings

As can be seen from Table 7, there are some inconsistencies between the number of alarms logged by the alarm monitor and the number of alarms received via email communication at both pilot locations. Since the number of email alerts received is more for Mercury site and less for Wirt site, researchers were unable to find a logical explanation for what might cause the inconsistencies or which source should be considered complete from an end user's perspective.

4. OVDS Operations – Sensor and DMS Communications

This measure quantifies any discrepancies in communication between the OVDS and DMS. The initial evaluation plan was to compare the contact closure signal data as sent by OVDS sensor (time stamp of OVDS alarm detection) with the DMS logs for the contact closure received (time stamp of event change log for message change) to identify if DMS message was displayed for every overheight vehicle detected. However, the DMS controller was not set up to log event change data at system setup.

After a considerable thought, it was decided to examine video from the sensor camera to visually confirm if the DMS was activated upon alarm transmittal. The sensor camera at both sites is aligned such that DMS sign activation is recognizable in the camera view. Figure 7 shows a screen capture of the alert video taken at the start of the video when DMS was not yet activated and Figure 8 shows a screen capture of the same alert video showing an activated DMS. Figure 7 and Figure 8 are meant to illustrate that the video from the sensor camera was able to show the DMS in its inactivated (dark) state and its activated state. The difference between time stamps of the two pictures is not meant to represent the actual time it takes to activate the DMS. The time between contact closure and DMS activation is less than 1.0 second.

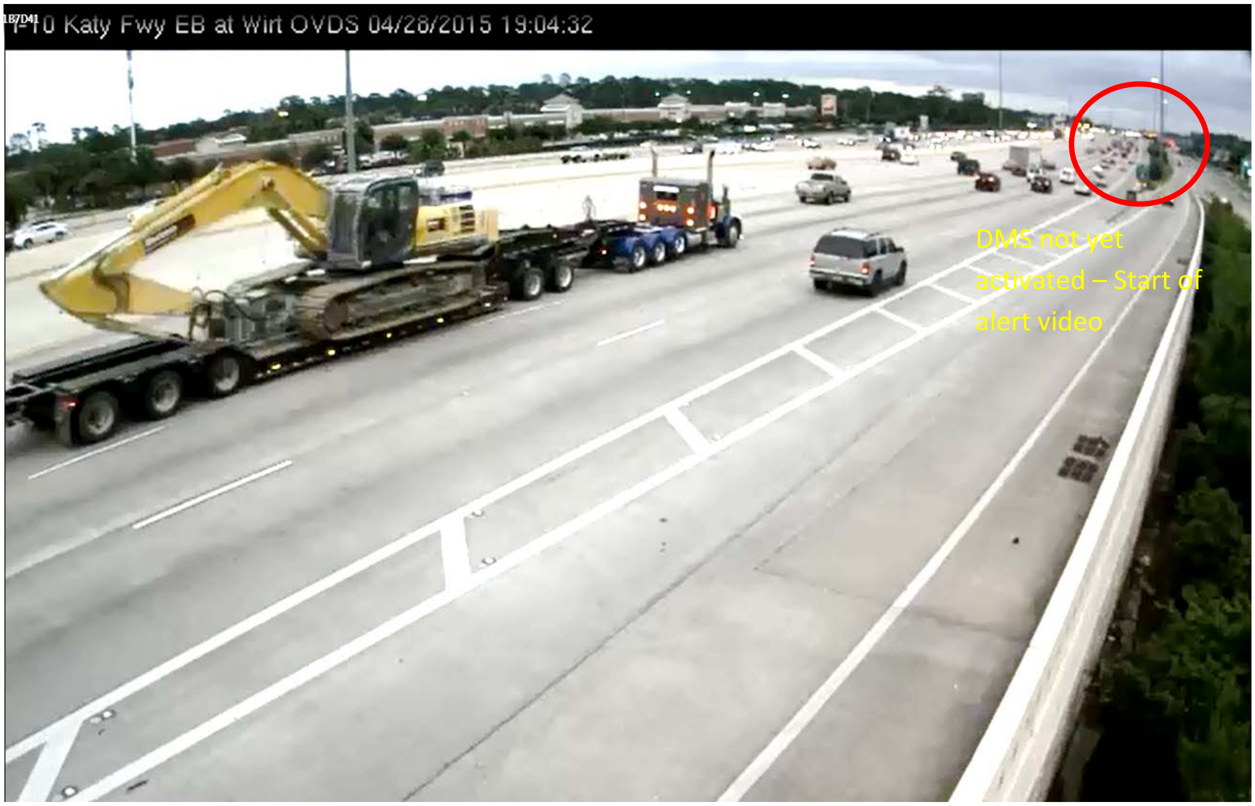

Figure 7. Screen Capture from Sensor Video Showing Dark DMS at the Time of Alarm.

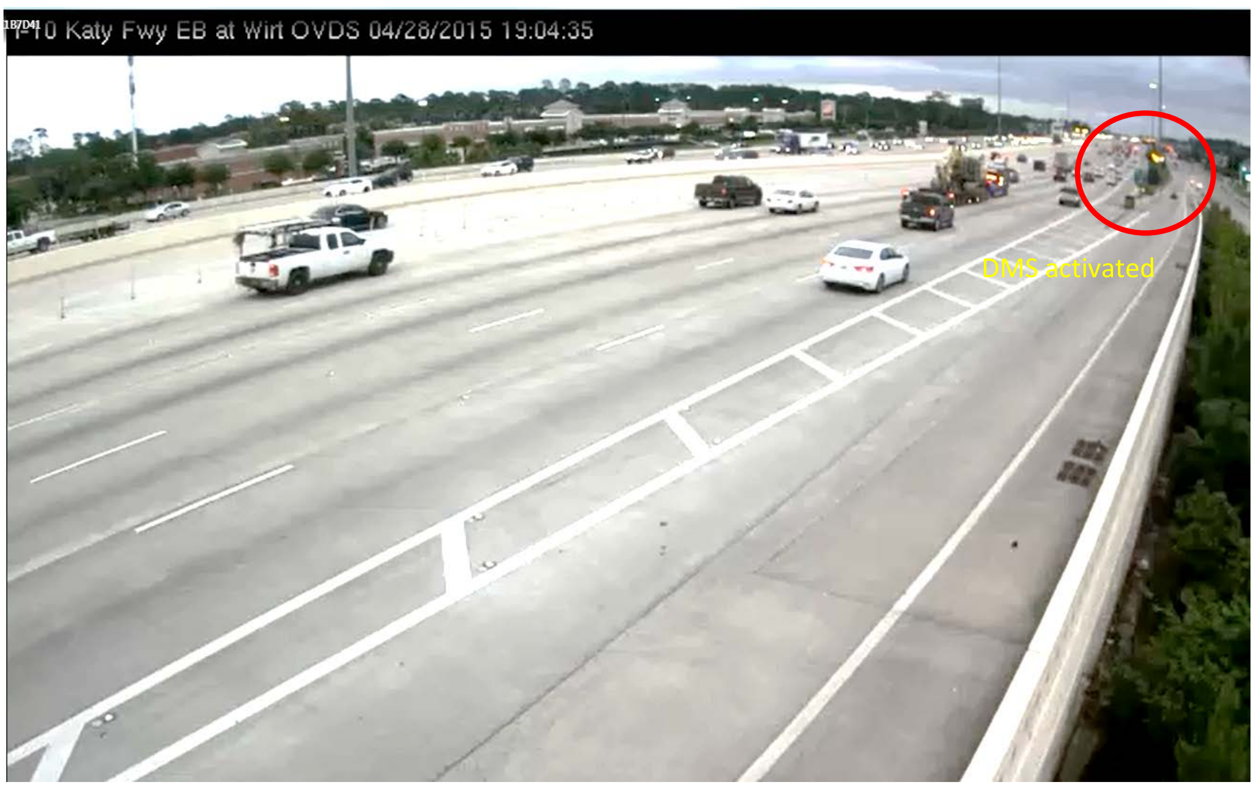

Figure 8. Screen Capture from Sensor Video Showing Active Downstream DMS.

Visual confirmation was completed for a sample set of alarm events from each site. Researchers examined 58 alarm videos (all alerts for two days - 5/11/2015 and 5/12/2015) from the Mercury site and 67 alarm videos (all alerts received on 4/28/2015) for the Wirt site.

Findings

- *Based on a visual examination of the alert videos, the downstream DMS was activated for each of the 125 alarms examined from both sites.*
- *No discrepancies between sensor and DMS communications were found for each of the 58 alarms examined at the Mercury site and each of the 67 alarms examined at the Wirt site.*

5. Document Technical and Institutional Issues

Researchers met with TxDOT project personnel to identify any institutional and technological issues encountered and lessons learned in implementing the demonstration OVDS system. Below is a summary of TxDOT project staff experience with this pilot implementation (*8*).

a. Technology Selection

The OVDS system selected is a proprietary system. TxDOT project personnel selected this system based on TxDOT's in-house market research to identify a system that will detect an overheight vehicle and provide warning to the detected vehicle. Other DOT experience, specifically NYDOT, with the selected system was also considered.

b. Procurement

At the beginning of project planning and procurement stage, TxDOT was in the process of implementing a new department-wide procurement process and the OVDS system procurement needed to be sole source because of the unique and proprietary nature of the system. Though three other TxDOT districts had purchased the system, but the product is not TxDOT's Qualified Products List (QPL) and there are no standard or special specifications for reference. Sole source justification for system procurement proved to be a challenge and caused delays of three to four months. Ultimately the system was procured through an existing maintenance contract resulting in additional costs and time.

Lesson learned –Plan for additional budget and time in the project if sole sourcing the system is the only or the most feasible option. There should be some consideration of expedited procurement process with more flexibility in procurement of materials and services for demonstration projects.

c. Deployment

For deployment, selecting a threshold detection height was very important as the OVDS does not measure the actual height of the vehicle, but only provides alert when a vehicle exceeds the threshold height. If an overheight vehicle driver is familiar with his vehicle height and has driven the same load/vehicle without hitting a bridge, he is likely to disregard the DMS alert advising him to exit to an alternate route. The project team wanted to minimize the disregard for DMS warning by determining the correct threshold height that will provide sufficient safety factor for the bridges and yet allow regular/everyday loads to continue on their route inside I-610.

In order to select the threshold height for the system, TxDOT personnel collected bridge clearance information inside I-610, particularly near Downtown Houston. This information was collected from two sources – signed bridge clearance on the bridges themselves and bridge clearance heights from the TxDOT Bridge Division in Austin. However, in many cases, the two readings were not the same and there was no clear relationship between them. As such, the project team was unable to determine the factor of safety for the signed bridge clearance.

The research team did not have the resources available to measure all the bridge clearances in the area prior to project deployment, so the threshold height was determined based on engineering judgement and permit rules for overheight vehicles. There are two different permit rules for the Downtown Houston area as the City of Houston requires permits for all vehicles that exceed 13'6" in height while State of Texas requires overheight permits for all vehicles that exceed 14'0" (*5*, *9*). Since the initial threshold height set at 13'10" resulted in large number of overheight alarms, project team decided to use lowest bridge clearance (14'1") as the criteria for selecting the threshold height of 14'0" for this pilot project.

Lesson learned – It is very important to know the actual bridge clearances in the area for which the system is being deployed.

It would also be very advantageous if future deployments of the OVDS could measure the actual height of the vehicle, either by deploying multiple sensor beams set at different heights or redesigning of the system to include this functionality. Being able to measure the actual height of the vehicle will help set an optimal threshold height as well as provide better chance of integration with the enforcement program.

d. Integration of the system

The OVDS is a standalone system that sends email alerts to TxDOT servers located at TranStar but any of its components are not integrated with the TxDOT's traffic management functions. The system camera and monitors can be accessed directly through the cell modem, however the DMS controller was accessible only via field connection as TxDOT decided not to use an additional cell modem for the DMS. The ultimate goal of the TxDOT project team is to integrate the system with enforcement while acknowledging the impediments.

e. Cell Communications

During the project evaluation period, cellular communications were quite reliable at both locations. There was one incident of a DoS attack at the Mercury site on 3/11/15 (discussed above in Section 1) and one incident of communication failure due to power issues at the Wirt site on 6/20/15.

Lesson learned – Cellular communications, particularly in urban areas, appear to be adequately reliable for the purpose of deploying the OVDS.

6. Proportion of Overheight Vehicles in Heavy Vehicles

The proportion of overheight vehicles was selected to understand if certain factors, including land-use (proximity to Ports, to shippers, heavy machinery industry, etc.) in the vicinity of the sensor location and the percent of heavy vehicles in the vehicle mix affect the proportion of overheight vehicles in heavy vehicles or the overall vehicle mix.

In order to identify the proportion of overheight vehicles in the vehicle mix, researchers obtained the volume and classification data from radar sensors located at I-10 westbound at Mercury Drive and I-10 eastbound at Voss Rd (just upstream of the sensor location for the Wirt site). Radar sensors classify vehicles based on vehicle length, and this is configurable for each sensor. The two radar sensors used in this evaluation were configured to classify vehicles in three classes so that a vehicle of length less than 25 feet is “small” (mostly passenger vehicles), vehicles of length between 25 feet and 40 feet are “medium” (mostly single unit trucks and buses), and vehicles having a length more than 40 feet are classified as “large” (tractor trailers). Classes medium and large were combined to represent heavy vehicles for computing the proportion of overheight vehicles since some overheight vehicles were shorter length dump trucks that would be automatically classified as “medium” by the radar systems.

The alarm email alerts were used as the source for calculating the number of overheight alarms detected at each pilot site. The proportion of overheight vehicles related to the total number of heavy vehicles was computed for two weeks – one week (from March 4th thru March 10th) for the Before study period and one week (April 16th thru April 22nd) for the After study period. The After study period dates for this measure are different than the video data collection dates as the radar data after April 23rd was not available for the Wirt site.

Table 8 shows the proportion of overheight vehicles for the Mercury site and Table 9 shows the proportion of overheight vehicles for the Wirt site from March 4th thru March 10th for the Before period and from April 16th thru April 22nd for the After period.

Table 8. Proportion of Overheight Vehicles by Day at Mercury Site - Before and After Periods.

Date/Period		Number of overheight vehicles detected (24 hours)	Number of heavy vehicles in traffic (24 hours)	Total number of vehicles (24 hours)	Percent of overheight vehicles in heavy vehicle class	Percent of heavy vehicles in overall vehicle mix	Percent of overheight vehicles in overall vehicle mix
Before Period	4-Mar	35	5417	73,915	0.65%	7.33%	0.047%
	5-Mar	24	7267	73,907	0.33%	9.83%	0.032%
	6-Mar	24	6359	80,885	0.38%	7.86%	0.030%
	7-Mar	20	3310	72,460	0.60%	4.57%	0.028%
	8-Mar	17	3158	55,198	0.54%	5.72%	0.031%
	9-Mar	23	5040	67,225	0.46%	7.50%	0.034%
	10-Mar	20	5376	73,449	0.37%	7.32%	0.027%
	Average	**23**	**5132**	**71,006**	**0.45%**	**7.23%**	**0.032%**
After Period	16-Apr	22	4536	69,353	0.49%	6.54%	0.032%
	17-Apr	15	4184	77,074	0.36%	5.43%	0.019%
	18-Apr	11	2002	66,758	0.55%	3.00%	0.016%
	19-Apr	8	1697	60,673	0.47%	2.80%	0.013%
	20-Apr	21	3929	71,898	0.53%	5.46%	0.029%
	21-Apr	21	4166	70,314	0.50%	5.92%	0.030%
	22-Apr	25	4377	71,786	0.57%	6.10%	0.035%
	Average	**18**	**3556**	**69,694**	**0.51%**	**5.10%**	**0.026%**
Difference: After-Before		**-5**	**-1576**	**-1312**	**+0.06%**	**-2.1%**	**-0.006%**

Table 9. Proportion of Overheight Vehicles at the Wirt Site for Before and After Periods.

Date/Period		Number of overheight vehicles detected (24 hours)	Number of heavy vehicles in traffic (24 hours)	Total number of vehicles (24 hours)	Percent of overheight vehicles in heavy vehicles	Percent of heavy vehicles in overall vehicle mix	Percent of overheight vehicles in overall vehicle mix
Before Period	4-Mar	63	9467	112,260	0.67%	8.43%	0.056%
	5-Mar	78	10,386	109,206	0.75%	9.51%	0.071%
	6-Mar	79	9863	118,136	0.80%	8.35%	0.067%
	7-Mar	26	5848	116,179	0.44%	5.03%	0.022%
	8-Mar	18	3763	82,240	0.48%	4.58%	0.022%
	9-Mar	47	9398	90,089	0.50%	10.43%	0.052%
	10-Mar	33	9558	110,594	0.35%	8.64%	0.030%
	Average	**49**	**8326**	**105,529**	**0.59%**	**7.89%**	**0.046%**
After Period	16-Apr	62	7331	108,597	0.85%	6.75%	0.057%
	17-Apr	52	6986	111,594	0.74%	6.26%	0.047%
	18-Apr	37	4548	105,283	0.81%	4.32%	0.035%
	19-Apr	21	3203	94,087	0.66%	3.40%	0.022%
	20-Apr	61	7254	110,995	0.84%	6.54%	0.055%
	21-Apr	84	8405	110,296	1.00%	7.62%	0.076%
	22-Apr	84	8384	110,945	1.00%	7.56%	0.076%
	Average	**57**	**6587**	**107,400**	**0.87%**	**6.13%**	**0.053%**
Difference: After-Before		**+8**	**-1739**	**+1871**	**+0.28%**	**-1.76%**	**+0.007%**

Findings

- The proportion of overheight vehicles in the heavy vehicle class is 1% or less for each of the 24 hour periods analyzed at both pilot sites and for both study periods.
- The average number of overheight vehicles per day as well as average heavy vehicle volumes per day at Mercury site decreased in the After period, while the proportion of overheight vehicles in heavy vehicle class increased slightly by 0.06%.
- At Wirt site, the average daily number of overheight vehicles increased while the average daily volumes for heavy vehicle class decreased in the After period. This means the percent of overheight vehicles in the heavy class increased by 0.28% for the After period as compared to that for the Before period.
- Proportion of overheight vehicles in heavy vehicle class was smaller at Mercury site as compared to that at Wirt site.

7. Overheight Vehicles – Most Common Configurations Identified

The project team was interested in identifying the type of vehicles that were over the threshold height of 14’0” and understanding if there was a certain type of load on these vehicles that results in an overheight status. Table 10 shows the distribution of the most common load or trailer types for overheight vehicles detected at each site. The percentages of these trailer types remained similar for both Before and After periods, but were somewhat different at each site.

Table 10. Most Common Overheight Vehicle Load/Cargo Types.

Type of Vehicle	Wirt Site	Mercury Site
Car Carriers	45%	25%
Designated Oversize Loads	15%	33%
Closed Cargo Trucks	15%	5%
Other	25%	37%

Figure 9 thru Figure 11 present pictures of overheight vehicle types that were seen more often in the email alerts than any other type of overheight vehicles.

Figure 9. Car Carrier Detected as Overheight at the Wirt Site.

Figure 10. Designated Oversize Load Detected as Overheight at the Wirt Site.

Figure 11. Closed Cargo Truck Detected as Overheight at the Wirt Site.

The rest of the overheight vehicles detected were a miscellaneous mixture of loaded flatbed, lowboy, cargo covered with tarp, garbage trucks, mobile homes, and pallets trucks.

Table 11 presents a distribution of type of overheight vehicles that were continuing along I-10 in the Before and After period at each site. Figure 12 shows a flatbed carrying an overheight load at Mercury site that continued on I-10.

Table 11. Most Common Overheight Vehicle Types Staying on I-10

Type of Vehicle	Wirt Site		Mercury Site	
Study Period	Before	After	Before	After
Car Carriers	29%	25%	38%	38%
Designated Oversize Loads	3%	2%	3%	8%
Trailers, Flatbeds and Lowboys carrying miscellaneous loads	44%	35%	45%	27%
Closed Cargo Trucks	24%	37%	5%	17%
Wooden Pallets	-	1%	5%	10%

Figure 12. Lowboy Overheight Load at the Mercury Site (continued on I-10 Inside of I-610).

Findings

- Car carriers, designated oversize loads, and closed cargo trucks were the most common type of overheight vehicles detected at both sites.
- At Mercury site, 96% or more of the designated oversize vehicles exited I-610 for both study periods. At Wirt site, percent of designated oversize vehicles exiting to I-610 increased to 97% in the After period as compared to 90% for the Before period.
- Of all the overheight vehicles continuing on I-10 at the Wirt site, 25% to 29% were car carriers. Similarly at the Mercury site, car carriers accounted for 38% of the vehicles continuing on I-10 in both Before and After periods.
- At the Wirt site, closed cargo trucks accounted for 37% of the overheight vehicles that continue to travel on I-10 despite detection and a warning message to exit I-610. However at Mercury site, closed cargo trucks represented only 17% of the overheight vehicles continuing on I-10 in the After period.
- At both sites, a higher percentage of closed cargo trucks continued to travel on I-10 towards Downtown Houston in the After period as compared to the Before period.

8. OVDS Effectiveness in Diverting Overheight Vehicles

In order to identify the effectiveness of OVDS in diverting vehicles to I-610, the evaluation was completed in a before-after study format. Overheight for this study was defined as any vehicle that is higher than the sensor threshold set for detection. Data for this measure was analyzed and compared for the Before and After periods from following perspectives:

Proportion of overheight vehicles exiting to I-610 (total number and by day of week)

Researchers compared the overheight vehicles exiting to I-610 in the Before period (OVDS Sensor operational but no DMS activation) with that in the After period (both OVDS sensor and DMS active). To identify the overheight vehicles exiting to I-610, researchers viewed the OVDS alarm alert emails identifying the overheight vehicle at the sensor location and then viewing the video at the interchange of I-610/I-10 to determine if the overheight vehicle identified from the alert email exited to I-610 or continued on I-10.

Findings for the Mercury Site

Figure 13 presents the percent of overheight vehicles exiting to I-610 by day of the week (and total for all days) analyzed at Mercury site.

Table 12 shows the number of overheight vehicles at Mercury site by route for each of the dates for which video data were analyzed. The percentage of overheight vehicles exiting to I-610 increased or stayed the same for every day of the week except Sunday. The overall proportion of overheight vehicles exiting to I-610 increased in the After period by approximately 5%. Using the Z-test on the proportions, researchers found that increase in proportions of overheight vehicles exiting to I-610 in the After period was not statistically significant at a 95% confidence level, but was statistically significant at a 90% confidence level.

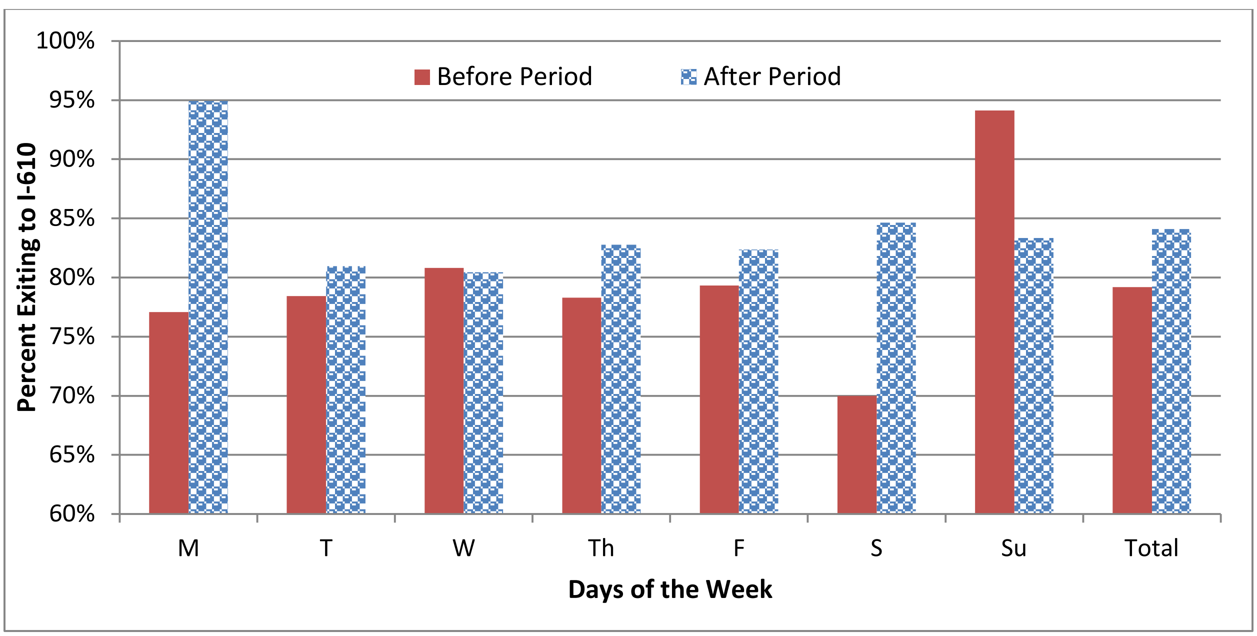

Figure 13. Percent of Overheight Vehicles Exiting to I-610 by Day of the Week at Mercury Site

Table 12. Number of Overheight Vehicles by Route at the Mercury Site for Before and After Periods.

Before Period				After Period			
Date	**Day of Week**	**# Exiting to I-610**	**# Staying on I-10**	**Date**	**Day of Week**	**# Exiting to I-610**	**# Staying on I-10**
3/4/2015	Wednesday	26	8	5/8/2015	Friday	8	3
3/5/2015	Thursday	15	7	5/9/2015	Saturday	11	2
3/6/2015	Friday	16	4	5/10/2015	Sunday	10	2
3/7/2015	Saturday	14	6	5/11/2015	Monday	30	1
3/8/2015	Sunday	16	1	5/12/2015	Tuesday	23	2
3/9/2015	Monday	14	9	5/13/2015	Wednesday	20	7
3/10/2015	Tuesday	12	8	5/14/2015	Thursday	22	3
3/11/2015	Wednesday	31	2	5/15/2015	Friday	13	3
3/12/2015	Thursday	28	8	5/18/2015	Monday	26	2
3/13/2013	Friday	27	7	5/20/2015	Wednesday	25	4
3/16/2015	Monday	23	2	5/26/2015	Tuesday	3	1
3/17/2015	Tuesday	28	3	5/27/2015	Wednesday	29	7
3/18/2015	Wednesday	23	9	5/28/2015	Thursday	26	7
3/19/2015	Thursday	40	8	5/29/2015	Friday	21	3
3/20/2015	Friday	3	1	6/2/2015	Tuesday	8	5
Total Number		316	83	Total Number		275	52
Percent		79.2%	20.8%	Percent		84.1%	15.9%
Difference in proportions from Before to After						4.9%	-4.9%
Difference in proportions from Before to After statically significant (Z-test)						No at 95% Confidence	
						Yes at 90% Confidence	

Findings for the Wirt Site

Figure 14 presents percentage of overheight vehicles exiting to I-610 by day of the week (and total for all days) analyzed at the Wirt site. Table 13 shows the number of overheight vehicles at Wirt site by route for each of the dates for which video data were analyzed. The percentage of overheight vehicles exiting to I-610 increased or stayed the same for every day of the week except for Sunday and Tuesday.

The overall proportion of overheight vehicles exiting to I-610 increased in the After period by 4.5%. Using the Z-test of proportions, researchers found that the increase in proportion of overheight vehicles exiting to I-610 in the After period was not statistically significant at a 95% confidence level, but was statistically significant at a 90% confidence level.

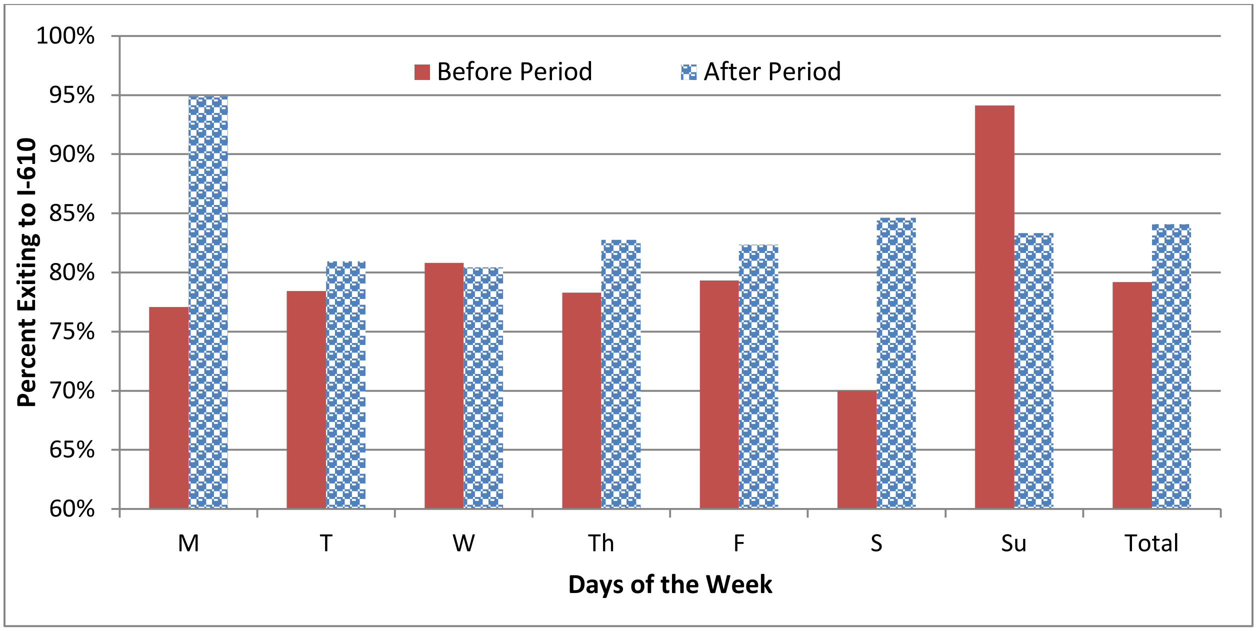

Figure 14. Percent of Overheight Vehicles Exiting to I-610 by Day of the Week at Wirt Site

Table 13. Number of Overheight Vehicles by Route at Wirt Site for Before and After Periods

Before Period				After Period			
Date	Day of Week	# Exiting to I-610	# Staying on I-10	Date	Day of Week	# Exiting to I-610	# Staying on I-10
3/19/2015	Thursday	48	26	4/23/2015	Thursday	42	18
3/20/2015	Friday	36	18	4/24/2015	Friday	35	25
3/31/2015	Tuesday	54	17	4/25/2015	Saturday	30	10
4/1/2015	Wednesday	28	18	4/26/2015	Sunday	12	6
4/2/2015	Thursday	55	16	4/27/2015	Monday	37	13
4/3/2015	Friday	29	19	4/28/2015	Tuesday	48	18
4/4/2015	Saturday	13	6	4/29/2015	Wednesday	43	10
4/12/2015	Sunday	15	6	4/30/2015	Thursday	47	16
4/13/2015	Monday	6	12	5/1/2015	Friday	20	6
Total Number		284	138	Total Number		314	122
Percent		67.3%	32.7%	Percent		71.8%	28.2%
Difference in proportions from Before to After						4.5%	-4.5%
Difference in proportions from Before to After statically significant (Z-test)						**No, 95% Confidence**	
						Yes, 90% Confidence	

Researchers hypothesize that the following factors may have contributed to overheight vehicle driver's decisions for not exiting to I-610 in the After period:

- The OVDS sensor currently available does not have the capability to measure the actual height of a vehicle thus, it is not possible to identify whether vehicles that are 14'2" are continuing along I-10 or vehicles that are 14' 8" are continuing along I-10. Thereby it is possible that overheight vehicle drivers are familiar with the low clearance bridges (lowest marked clearance is 14’1”) along I-10 and their vehicle heights, thus don’t feel the need to comply with the DMS message shown. Another reason could be that the destination of the overheight vehicle is prior to the lowest bridge clearance and thus the message is not applicable for his destination.

- The overheight vehicle driver continuing along I-10 did not think the message was for him/her if there is another truck traveling close by.
- The overheight vehicle driver continuing along I-10 did not see the DMS message.

9. Overheight Vehicles – Travel Patterns by Travel Lane

The project team was also interested in identifying travel patterns of overheight vehicles by travel lane at the OVDS sensor and again at the I-610/I-10 interchange. Researchers used photos from the email alarm alerts to identify the travel lane of overheight vehicles at the sensor location, video data collected at the interchange to identify the travel lane of the overheight vehicle at the interchange, and radar data to determine the number of heavy vehicles by travel lane. This allowed researchers to:

- Compare travel patterns of overheight vehicles and heavy vehicles to identify if there could be issues with sensor beam identifying overheight vehicles in the left lanes.
- Identify if multiple lane changes could be a factor for overheight vehicles in complying with the DMS message.
- Identify if the amount of increase in lane changes could result in unintended safety concerns between the DMS and interchange location.

Results and Findings for the Mercury Site

Table 14 shows the number and percent of overheight vehicles by travel lane at OVDS sensor and also the number and percent of heavy vehicles by travel lane at the radar location for the Mercury site. There is a regulatory truck lane restriction at the Mercury site, no trucks in inside lane.

Table 14. Overheight and Heavy Vehicles by Travel Lane at Sensor for Mercury Site

Study Period	Travel Lane @ Sensor	Overheight Vehicles		Heavy Vehicles	
		Number	Percent	Number	Percent
Before	1 (outside)	235	58.9%	1793	36.1%
	2	111	27.8%	1317	26.5%
	3	52	13.0%	1548	31.2%
	4 (inside)	1	0.3%	311	6.3%
	Total	399	100.0%	4970	100.0%
After	1 (outside)	201	61.5%	1433	38.5%
	2	84	25.7%	1012	27.2%
	3	41	12.5%	1152	31.0%
	4 (inside)	1	0.3%	125	3.4%
	Total	327	100.0%	3723	100.0%

Figure 15 shows lane alignment between sensor location and interchange, and the corresponding lane numbers at this site. Table 15 shows the number of overheight vehicles by route (I-610 or I-10) and their travel lane at OVDS sensor, travel lane at I-610/I-10 interchange, and the number of minimum lane changes completed between the DMS and the I-610/I-10 interchange at Mercury site. To compute the average number of lane changes completed by an overheight vehicle between the sensor and interchange, it was assumed that an overheight vehicle will complete the least amount of lane changes in order to reach its destination.

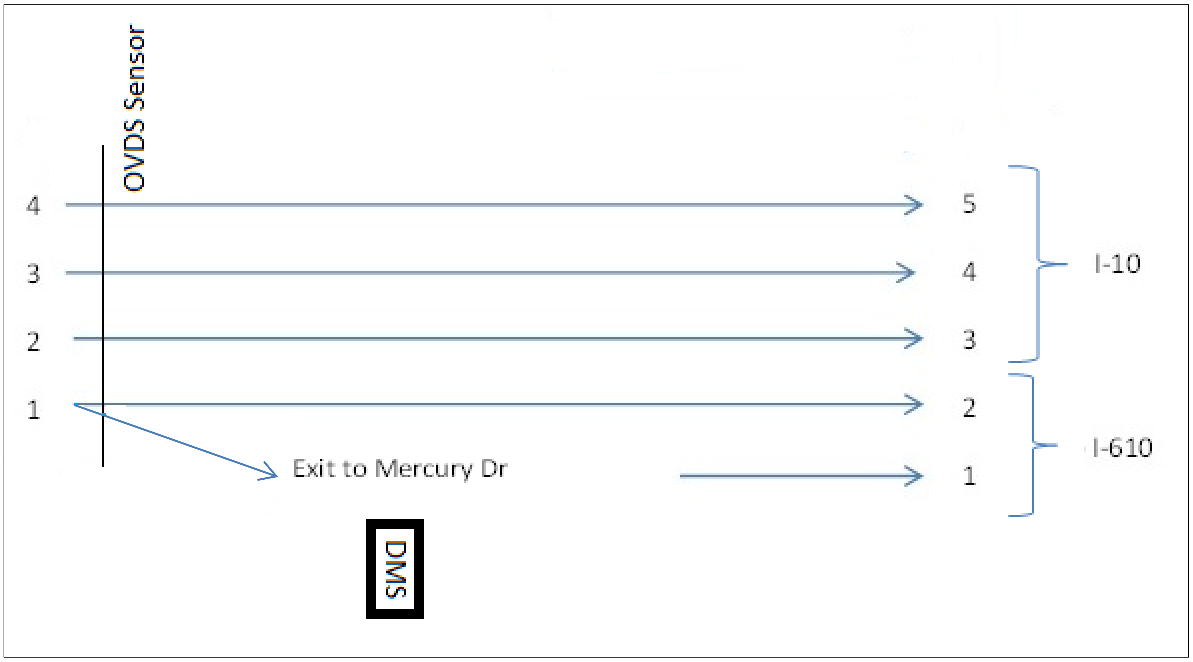

Figure 15. Lane Alignment with Lane Numbers from OVDS Sensor to Interchange at Mercury Site

Table 15. Number of Overheight Vehicles by Travel Lane and Lane Changes at Mercury Site

Travel Lane @ Sensor	Travel Lane @ Interchange	Before Period				After Period			
		To I-610		To I-10		To I-610		To I-10	
		# of vehicles	Minimum # of lane changes completed*	# of vehicles	Minimum # of lane changes completed*	# of vehicles	Minimum # of lane changes completed*	# of vehicles	Minimum # of lane changes completed*
1 (outside)	1 (outside)	111	0	-		67	0	-	-
	2	114	114	-		131	131	-	-
	3	-	-	7	14	-	-	3	6
	4	-	-	3	9	-	-	-	-
2	1	25	25	-	-	28	28	-	-
	2	52	0	-	-	39	0	-	-
	3	1	1	24	24	-	-	12	12
	4	-	-	9	18	-	-	5	10
3	1	5	10	-	-	1	2	-	-
	2	8	8	-	-	8	8	-	-
	3	-	0	1	0	-	-	3	0
	4	-	-	35	35	-	-	29	29
	5 (inside)	-	-	3	6	-	-	-	-
4 (inside)	1	-	-	-	-	1	3	-	-
	5 (inside)	-	-	1	1	-	-	-	-
Total number of lane changes			158		107		172		57
Total number of overheight vehicles		316		83		275		52	
Number of lane changes/vehicle		**0.50**		**1.29**		**0.62**		**1.09**	

Figure 16 shows the percent of overheight vehicles exiting to I-610 by travel lane at sensor in the Before and After period for Mercury site.

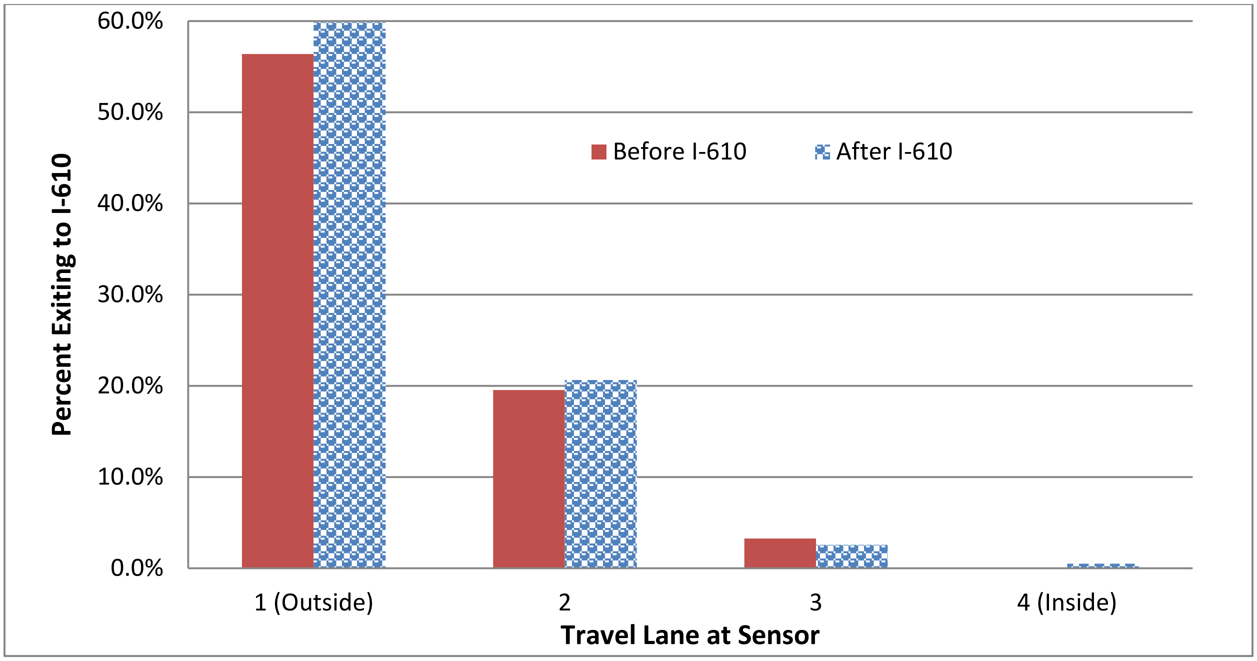

Figure 16. Percent of Overheight Vehicles by Travel Lane at Sensor and Exiting to I-610 at Mercury Site

- Approximately 87% of overheight vehicles were traveling in the two right lanes at the sensor location both in the Before and After period. For this particular location, heavy vehicles traveling in the 2 right most lanes accounted for approximately 63% in the Before period and 66% in the After period of all heavy vehicles. The analysis suggests majority of overheight vehicles travel in the two right most lanes at this site which Is not surprising considering Left lane at this location is restricted to truck traffic.
- In the Before period, 79% of overheight vehicles exited to I-610 and 21% went west on I-10. Out of the 79% that exited to I-610, 76% were traveling in the two right lanes and the other 3% were traveling in the 3rd lane from right. In the After period, 84% of overheight vehicles exited to I-610 and 16% stayed on I-10. Out of the 84% that exited to I-610, 81% were traveling in the two right lanes and the other 3% were traveling in the two left lanes. The analysis for travel patterns by travel lane at sensor and travel lane at interchange also suggests that most overheight vehicles were traveling in the two right most lanes and had aligned themselves to exit I-610 without having to complete multiple lane changes.
- The average number of lane changes per overheight vehicle exiting to I-610 in the After period increased to 0.62 as compared to 0.5 for the Before period. Based on the available data about number and travel patterns of overheight vehicles, DMS message compliance resulted in approximately three additional lane changes per day (23 overheight vehicles per day * 0.12 additional lane changes/overheight vehicle = 2.8 lane changes per day). Researchers are of the opinion that three additional lane changes per day are not likely to cause any unintended safety concerns in the area between the sensor and interchange.

Results and Findings for Wirt Site

Table 16 shows the number and percent of overheight vehicles by travel lane at OVDS sensor and also the number and percent of heavy vehicles by travel lane at the radar location for Wirt site. For this site, there are six lanes at the OVDS sensor location and five lanes at the radar sensor location that was used to obtain heavy vehicle data. Number 1 lane represents the right most lane and Number 6 lane represents the left most freeway lane. Lanes 2, 3, and 4 continue to I-610 whereas Lanes 5 and 6 continue east at I-10 at the interchange.

Table 16. Overheight and Heavy Vehicles by Travel Lane at Sensor for Wirt Site

Study Period	Travel Lane @ Sensor	Overheight Vehicles		Heavy Vehicles	
		Number	Percent	Number	Percent
Before	1 (Auxiliary lane)	12	2.8%	NA	NA
	2	97	23.0%	847	13.7%
	3	164	38.9%	1336	21.5%
	4	112	26.5%	1713	27.6%
	5	35	8.3%	1594	25.7%
	6 (inside)	2	0.5%	710	11.5%
	Total	422	100%	6199	100%
After	1 (Auxiliary lane)	15	3.4%	NA	NA
	2	112	25.7%	934	14.9%
	3	173	39.7%	1257	20.1%
	4	115	26.4%	1656	26.5%
	5	20	4.6%	1678	26.8%
	6 (inside)	1	0.2%	732	11.7%
	Total	436	100%	6256	100%

Figure 17 shows lane alignment between sensor location and interchange, and the corresponding lane numbers. Table 17 shows the number of overheight vehicles by route (I-610 or I-10) and their travel lane at OVDS sensor, travel lane at I-610/I-10 interchange, and the number of minimum lane changes completed between the DMS and the I-610/I-10 interchange at Wirt site. To compute the average number of lane changes completed by an overheight vehicle between the sensor and interchange, it was assumed that an overheight vehicle will complete the least amount of lane changes in order to reach its destination.

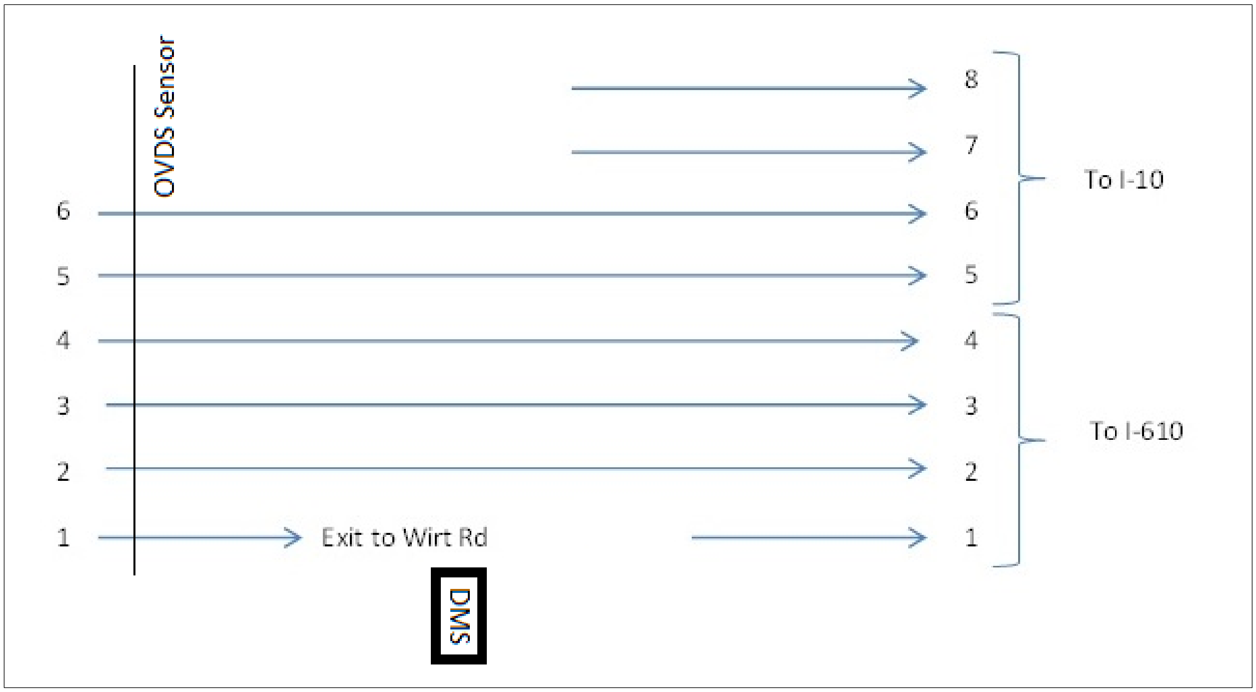

Figure 17. Lane Alignment with Lane Numbers from OVDS Sensor to Interchange at Wirt Site

Table 17. Number of Overheight Vehicles by Travel Lane and Lane Changes at Wirt Site.

Travel Lane @ Sensor	Travel Lane @ Interchange	Before Period				After Period			
		To I-610		To I-10		To I-610		To I-10	
		# of vehicles	Minimum # of lane changes completed*	# of vehicles	Minimum # of lane changes completed*	# of vehicles	Minimum # of lane changes completed*	# of vehicles	Minimum # of lane changes completed*
1 (outside)	1 (outside)	3	6	-	-	1	2	-	-
	2	4	4	-	-	9	9	-	-
	3	5	10	-	-	4	8	-	-
	5	-	-	-	-	-	-	1	4
2	1 (outside)	2	2	-	-	6	6	-	-
	2	11	0	-	-	19	0	-	-
	3	67	67	-	-	65	65	-	-
	4	10	20	-	-	15	30	-	-
	5	-	-	6	18	-	-	6	18
	6	-	-	1	4	-	-	-	-
	7 (inside)	-	-	-	-	-	-	1	5
3	1 (outside)	1	2	-	-	4	8	-	-
	2	11	11	-	-	10	10	-	-
	3	46	0	-	-	45	0	-	-
	4	73	73	-	-	87	87	-	-
	5	-	-	21	42	-	-	21	42
	6	-	-	12	36	-	-	5	15
	7 (inside)	-	-	-	-	-	-	1	4
4	1 (outside)	1	3	-	-	2	6	-	-
	2	3	6	-	-	3	6	-	-
	3	12	12	-	-	9	9	-	-
	4	30	0	-	1	29	0	-	-
	5	-	-	23	23	-	-	22	22
	6	-	-	32	64	-	-	38	76
	7 (inside)	-	-	11	33	-	-	12	36
5	1 (outside)	2	8	-	-	1	4	-	-
	2	-	-	-	-	2	6		-
	3	1	2	-	-	1	2	-	-
	4	2	2	-	-	-	-	-	-
	5	-	-	5	0	-	-	-	-
	6	-	-	13	13	-	-	8	8
	7 (inside)	-	-	12	24	-	-	8	16
6 (inside)	1 (outside)	-	-	-	-	1	5	-	-
	6	-	-	1	0	-	-	-	-
	7 (inside)	-	-	1	1	-	-	-	-
Total number of lane changes			228		259		263		246
Total number of overheight vehicles		284		138		313		123	
Number of lane changes/vehicle		**0.80**		**1.88**		**0.84**		**2.00**	

Figure 18 shows the percent of overheight vehicles exiting to I-610 by travel lane at sensor in the Before and After period for Wirt site.

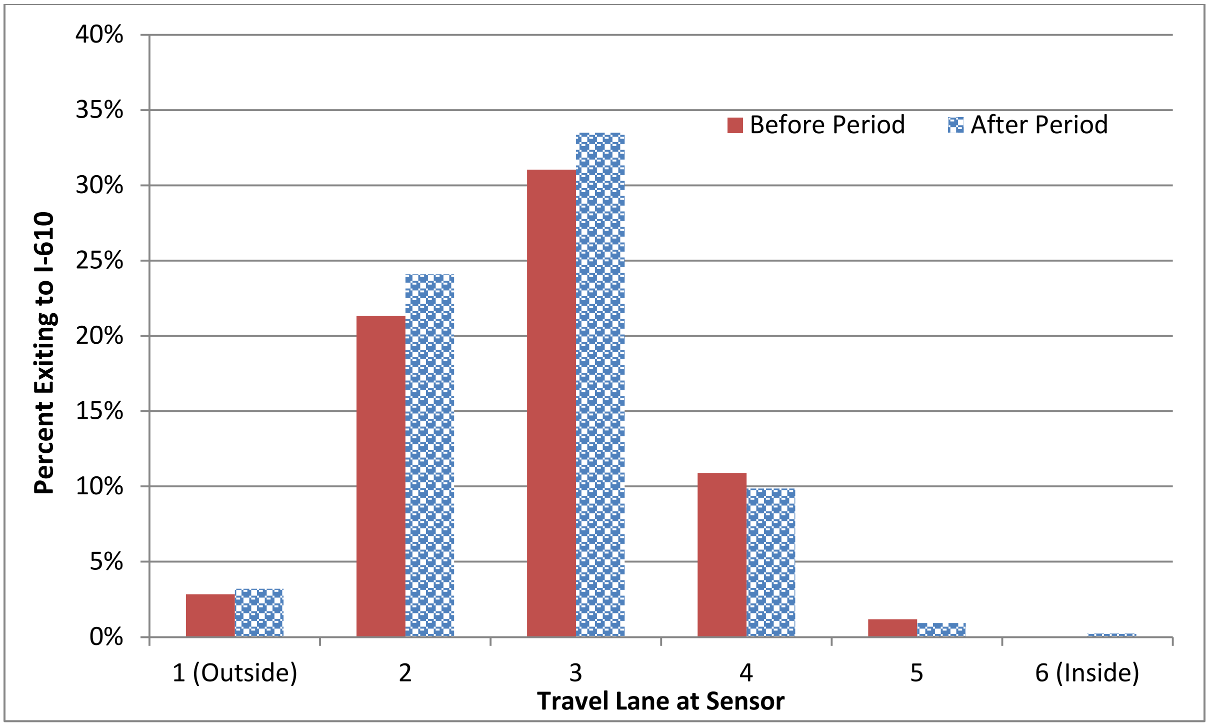

Figure 18. Percent of Overheight Vehicles by Travel Lane at Sensor and Exiting to I-610 at Wirt Site

- The percentage of overheight vehicles traveling in the three right lanes that continue to I-610 and in the auxiliary lane was approximately 91% in the Before period and 95% in the After period. For this particular location, heavy vehicles traveling in the 3 right most lanes accounted for approximately 63% in the Before period and 62% in the After period of all heavy vehicles.
- In the Before period, 67% of overheight vehicles exited to I-610 and 33% remained on I-10. Out of the 67% that exited to I-610, 66% were traveling in the right lanes that continue to I-610 and the other 1% were traveling in the 5th lane from right. In the After period – 72% overheight vehicles exited to I-610 and 28% stayed on I-10. Out of the 72% that exited to I-610, 71% were traveling in the right lanes that continue to I-610 and the other 1% were traveling in the 5th lane from right. The analysis for travel patterns by travel lane at sensor and travel lane at interchange also suggests that most overheight vehicles were traveling in the right most lanes and had aligned themselves to exit I-610 without having to complete multiple lane changes.
- Average number of lane changes per overheight vehicle exiting to I-610 in the After period increased to 0.84 as compared to 0.80 for the Before period. Based on the available data about number and travel patterns of overheight vehicles, DMS message compliance resulted in approximately 3 additional lane changes per day (57 overheight vehicles per day *0.04 additional lane changes/overheight vehicle = 2.28 lane changes per day). Researchers

believe that 3 additional lane changes per day are not likely to cause any unintended safety concerns in the study area.

10. Document Bridge Hits in the Before and After Period.

This section documents the bridge hit information for bridge locations that are downstream of the two pilot locations and based on the routes it is possible that these overheight vehicles responsible for bridge hits could have traveled through the sensors and were presented DMS messages. The pilot OVDS system is strategically deployed to provide warning for multiple bridges downstream of each site, however this strategical placement also includes the possibility that an overheight vehicle could have entered the freeway corridor at entry points downstream of the sensor location and will travel undetected and unwarned. Another possibility with this strategic placement of OVDS is that overheight vehicles detected and warned by the system have destinations downstream of the I-610 loop but upstream of the low clearance bridges and these overheight vehicles are aware of both the low clearances and their vehicle heights thus not causing a bridge hit without complying with the warning to exit I-610.

Table 18 presents the dates and time of each bridge hit along with the bridge location information and potential that the overheight vehicle could have been detected at one of the pilot locations if the system was active (*10*). A total of 38 bridge hits occurred in the Before period out of which 4 had possibility of detection at the Wirt location and 12 had possibility of detection at the Mercury site. One overheight truck was detected at Mercury site on 3/31/15, however the DMS was not active at the time so no warning message was displayed on the DMS. In the After period that started on April 7, 2015 at the Mercury location and on April 15, 2015 at the Wirt location, there have been two bridge hits out of which the one that occurred on 4/21/15 had the possibility of detection at Wirt location.

Findings from Bridge Hits Documentation

Comparing the number of bridge hits for the After period (April 7, 2015 thru July 28, 2015) with the same duration Before period from last year (April 7th thru July 28, 2014), there were a total of 4 bridge hits in the Before period and no bridge hit in the After period that presented the possibility of detection at Mercury site. Similarly comparing the number of bridge hits for the After period (April 15, 2015 thru July 28, 2015) with the same duration Before period from last year (April 15, 2014 thru July 28, 2014), there were a total of 2 bridge hits in the Before period and one bridge hit in the After period that presented the possibility of detection at Wirt site. This comparison suggests a positive effect of OVDS in reducing bridge hits in the After period, however there has been an overall decrease in bridge hits in the After period (only 2 hits) as compared to the same duration Before period (13 hits) from last year, thus it is difficult to attribute the benefit to OVDS system alone. Overall traffic levels of trucks may have reduced as the Houston economy has cooled somewhat in 2015, but it may also be likely that overheight vehicle drivers have learned of the presence of OVDS and possibility of enforcement, therefore these vehicle drivers are paying more attention to their vehicle heights and bridge clearances altogether. Either way, this is a positive trend for reduction in bridge hits.

Table 18. Bridge Hits (1/1/14 thru 7/28/15) and Potential for Detection at Pilot Locations (*10*)

Date/Time of Bridge Hit	Bridge Location	Marked Bridge Clearance	Potential for Detection	
			At Wirt	At Mercury
1/12/2014 10:18 AM	I-10 WB @ Waco St.	14’-5”	No	**Yes**
1/23/2014 4:13 PM	I-610 South EB @ Broadway	14’-3”	No	No
1/31/2014 11:25 PM	I-10 EB @ Houston Ave.	14’-7”	**Yes**	No
2/7/2014 6:29 PM	I-45 NB @ Hogan/Crockett	14’-3”	No	No
2/20/2014 3:51 PM	I-10 WB @ Lockwood Dr.	15’-2”	No	**Yes**
2/21/2014 8:13 PM	I-45 NB @ McKinney	14’-5”	No	No
2/26/2014 2:42 PM	US 59 NB @ I-610 West Loop NB	14’-4”	No	No
3/12/2014 5:01 PM	I-45 SB @ North St.	14’-10”	No	No
3/20/2014 11:34 PM	I-10 EB @ I-45	14’-1”	**Yes**	No
3/24/2014 2:38 PM	I-10 WB @ McCarty/US 90 Alt.	14’-6”	No	**Yes**
3/28/2014 9:20 PM	I-45 SB @ Dallas St.	14’-9”	No	No
3/31/2014 3:37 PM	I-45 SB HOV entry @ FM 1960	16’-10”	No	No
4/10/2014 7:12 PM	I-45 NB @ Reveille St. Entry	N/A	No	No
4/15/2014 12:42 PM	I-10 EB @ Houston Ave.	14’-7”	**Yes**	No
4/16/2014 4:02 PM	I-610 East SB @ SH 225	14’-3”	No	No
4/17/2014 3:11 PM	I-610 East NB @ Clinton Dr.	N/A	No	No
4/22/2014 8:26 AM	US 59 NB @ 610 West Loop NB	14’-4”	No	No
4/30/2014 7:37 PM	I-45 NB @ Hogan/Crockett	14’-3”	No	**Yes**
5/7/2014 4:09 PM	I-10 EB @ Houston Ave. bridge	14’-7”	**Yes**	No
5/12/2014 9:33 AM	I-10 WB @Meadow St	14’-3”	No	**Yes**
5/13/2014 9:42 AM	Spur 5 SB @ Cullen	N/A	No	No
5/20/2014 9:39 AM	SH 249 NB @ W. Greens Road	N/A	No	No
5/29/2014 11:05 AM	I-10 EB @ US 59	14’-3”	No	**Yes**
5/30/2014 3:46 PM	I-10 WB @ US 59	14’-3”	No	**Yes**
6/23/2014 3:17 PM	US 59 NB @ I-610 West Loop NB	14’-4”	No	No
8/13/2014 1:50 PM	US 59 NB @ I-610 West Loop NB	14’-4”	No	No
8/25/2014 4:57 AM	I-10 WB @ Waco St.	14’-5”	No	**Yes**
10/9/2014 9:04 AM	US 59 NB @ 610 West Loop NB	14’-4”	No	No
10/9/2014 2:32 PM	US 59 NB @ 610 West Loop NB	14’-4”	No	No
11/10/2014 12:34 PM	I-10 WB @ Wayside	N/A	No	**Yes**
11/14/2014 9:17 AM	I-45 NB @ Hogan/Crockett	14’-3”	No	**Yes**
12/18/2014 1:56 PM	US 59 NB @ I-610 SB	14’-5”	No	No
12/21/2014 10:22 PM	I-45 SB @ Dallas St.	14’-9”	No	No
12/22/2014 3:20 PM	I-10 WB @ Waco St.	14’-5”	No	**Yes**
12/31/2014 1:21 PM	US 59 NB @ McClennan	16’-2”	No	No
2/6/2015 3:05 PM	FM 1960 WB @ US 290	N/A	No	No
3/30/2015 9:28 AM	I-10 WB @ Wayside	N/A	No	**Yes**
3/31/15 10:07 AM*	I-10 WB @ Waco St	14’5”	No	**Yes***
4/21/2015 11:28 AM	I-10 EB @ Houston Ave	14’7”	**Yes**	No
7/28/2015 5:18 AM	US 59 NB @ 610 West Loop NB	14'-4"	No	No

*- Detected by OVDS at Mercury Site, However the DMS was not active at the time this hit occurred, so no warning message was displayed on the DMS.

11. Document Cost Effectiveness of the OVDS.

Cost of OVDS

The total cost of the OVDS deployment to furnish, install and test for each demo site was $135,000. However, demo sites were chosen so that overhead sign bridges were available for mounting the system components, and while a roadside structure was available for mounting the DMS at the Wirt site, the Mercury site used a portable trailer-mounted DMS located roadside. There was existing power supply at both locations (*10*).

Costs of Bridge Hits

TxDOT personnel estimate the average cost of a bridge hit to be between $200 to $300k excluding the costs of user delays due to lane closures both at the time of bridge hit (to back up the truck and escort it to a safe place) and at the time bridge repair (*10*).

Findings

- Based on above described cost of OVDS and average cost of a bridge hit, a reduction of one bridge hit due to OVDS at one site will result in savings of approximately $65,000 (using a lower estimate) to TxDOT. Such a reduction in bridge hits will also result in additional delay savings for the motorists in the area.
- Documentation of bridge hits that could possibly have been detected and avoided at one of the two pilot locations shows a decrease of 5 bridge hits for the After period when compared with the same duration Before period from last year. If this reduction could be solely attributed to the deployment of OVDS, then the system has provided a benefit-cost ratio of 3.7 (using low estimate for bridge repair) in little over three months it has been active.

FINDINGS AND RECOMMENDATIONS

Summary of Findings

Researchers completed this pilot evaluation for six measures 1) to identify any concerns with OVDS operations, 2) document institutional lessons learned, 3) determine the general characteristics of overheight vehicles detected such as proportion in vehicle mix, type of loads, travel patterns by travel lane, 4) determine effectiveness of OVDS in diverting overheight vehicles, 5) documenting bridge hits for the Before and After period, and 6) cost effectiveness of the system. The following subsections list the findings for each of the above measures. The last subsection under findings summarizes remaining or outstanding issues.

As an overall finding, the OVDS appear to influence through trips on the freeway and divert an additional incremental number of trucks to the alternate route (I-610). There appears to be no adverse or unexpected consequences of providing this warning to truck drivers of an overheight status.

OVDS Operations

- Under normal operations, it takes 10 to 12 seconds for the infrared sensor to recover from its alarm state and be ready to detect a new alarm.
- If an overheight vehicle is traveling right behind another overheight vehicle such that they pass the beam within 10 seconds of each other, the second vehicle will not be detected by the system separately.
- If two overheight vehicles were traveling side by side at the same time, it will be detected as only one alarm event.
- Upon receiving an overheight alarm, OVDS sends a contact closure signal to the radio receiver in DMS that stays active for the duration of a pre-set alarm time. The DMS message gets displayed for the amount of alarm time set for the radio receiver. For the pilot project, the radio receiver alarm time in the DMS was set to 30 seconds. If two overheight vehicles are detected within a 30 second period, the total duration of the message display does not get extended but stays 30 seconds. This means that if a second overheight gets detected while the message has already been displayed for 25 seconds, the second vehicle will see the message only for 5 seconds.
- Alarm event and fault event monitors automatically get reinitialized after power failure or after any manual change in settings of the wireless modem.
- At the Mercury site, the fault monitor was reinitialized six times, detected OVDS fault four times, and experienced a denial of service (DoS) attack on 3/11/2015 during a period of 102 days for which fault event monitor log were examined.
- At the Wirt site, no sensor faults were detected for a period of 102 days for which fault event monitor log were examined.

- Every alert email examined had accompanying pictures showing a tall vehicle which was not a passenger car or pick-up truck. Since OVDS doesn't measure the actual vehicle height and researchers had no way of measuring the vehicle height from pictures, tall vehicle was assumed to have met or exceeded the threshold height. Based on this assumption, all overheight alarms detected were true alarms at both sites.
- There are some inconsistencies between the number of alarms logged by the alarm monitor and the number of alarms received via email communication at both pilot locations. If the system were to be integrated with an enforcement program, the discrepancies make it difficult to decide which source is complete and thus should be used.
- The sensor camera at both sites is aligned so that DMS is in direct line of sight of the camera. A sample set of alarm videos from each site were visually examined to identify if DMS gets activated for every overheight alarm generated. Based on a visual examination of the 58 alarm videos examined at the Mercury site and 67 alarm videos examined at the Wirt site, DMS was activated for each of the 125 alarms examined from both sites.

Institutional Lessons Learned

- Plan additional time and budget for procurement when procurement needs to be sole source, particularly when the product does not have standard/special specifications for reference and is not on the TxDOT QPL. TxDOT staff indicated that it would be optimal to have an expedited procurement process with more flexibility in accessing materials and services for demonstration projects.
- It is very important to know actual bridge clearance versus marked bridge clearance so that a reasonable threshold height can be selected.
- If the system were to be integrated with an enforcement program, it is important to set a reasonable threshold height and develop a plan to calibrate and validate the OVDS setting for threshold height at regular intervals.
- Cellular communications, particularly in the urban areas, have been found to be quite reliable and provide a convenient and less expensive way to deploy similar systems.

Characteristics of Overheight Vehicles Detected

- The proportion of overheight vehicles in the heavy vehicle class is 1% or less for each of the 24 hour periods analyzed at both pilot sites and for both study periods.
- The average number of overheight vehicles per day as well as average heavy vehicle volumes per day at Mercury site decreased in the After period, while the proportion of overheight vehicles in heavy vehicle class increased slightly by 0.06%.
- At Wirt site, the average daily number of overheight vehicles increased while the average daily volumes for heavy vehicle class decreased in the After period. This means the percent of overheight vehicles in the heavy class increased by 0.28% for the After period as compared to that for the Before period.

- Proportion of overheight vehicles in heavy vehicle class was smaller at Mercury site as compared to that at Wirt site.
- Car carriers, designated oversize loads, and closed cargo trucks were the most common type of overheight vehicles detected at both sites.
- The majority of the designated oversize vehicles exited I-610 at both sites for both study periods.
- Of all the overheight vehicles continuing on I-10 at the Wirt site, 25% to 29% were car carriers. Similarly at the Mercury site, car carriers accounted for 38% of the vehicles continuing on I-10 in the both Before and After periods.
- At the Wirt site, closed cargo trucks accounted for 37% of the overheight vehicles that continue to travel on I-10 despite detection and a warning message to exit I-610. However at the Mercury site, closed cargo trucks represented only 17% of the overheight vehicles continuing on I-10 in the After period.
- At both sites, a higher percentage of closed cargo trucks continued to travel on I-10 in the After period as compared to the Before period.

OVDS Effectiveness in Diverting Overheight Vehicles

- At the Mercury site, the proportion of overheight vehicles exiting to I-610 increased in the After period by approximately 5%. Using the z-test on those proportions, researchers found that the increase in proportions of overheight vehicles exiting to I-610 in the After period is statistically significant at 90% confidence level, but not at 95% confidence level.
- At the Wirt site, the overall proportion of overheight vehicles exiting to I-610 increased in the After period by 4.5%. Using the z-test on those two proportions, researchers found that the increase in proportions of overheight vehicles exiting to I-610 in the After period is statistically significant at 90% confidence level, but not at 95% confidence level.

Overheight Vehicles – Travel Patterns by Travel Lane

Findings for Mercury Site

- Approximately 87% of overheight vehicles were traveling in the two right lanes at the sensor location both in the Before and After period
- In the Before period, 79% overheight vehicles exited to I-610 and 21% stayed on I-10. Out of the 79% that exited to I-610, 76% were traveling in the two right lanes and the other 3% were traveling in the third lane from the right. In the After period, 84% of overheight vehicles exited to I-610 and 16% stayed on I-10. Out of the 84% that exited to I-610, 81% were traveling in the two right lanes and the other 3% were traveling in the two left lanes. The analysis for travel patterns by travel lane at sensor and travel lane at interchange also suggests that most overheight vehicles were traveling in the two right most lanes and had aligned themselves to exit I-610 without having to complete multiple lane changes.
- The average number of lane changes per overheight vehicle exiting to I-610 in the After period increased to 0.62 as compared to 0.50 for the Before period. Based on the available data about number and travel patterns of overheight vehicles, DMS message compliance

resulted in approximately three additional lane changes per day (23 overheight vehicles per day * 0.12 additional lane changes/overheight vehicle = 2.8 lane changes per day). Researchers believe that three additional lane changes per day are not likely to cause any unintended safety concerns in the study area.

Findings for Wirt Site

- The percentage of overheight vehicles traveling in the three right lanes that continue to I-610 and in the auxiliary lane was approximately 91% in the Before period and 95% in the After period.
- In the Before period, 67% of overheight vehicles exited to I-610 and 33% stayed on I-10. Out of the 67% that exited to I-610, 66% were traveling in the right lanes that continue to I-610 and the other 1% were traveling in the 5th lane from right. In the After period, 72% overheight vehicles exited to I-610 and 28% stayed on I-10. Out of the 72% that exited to I-610, 71% were traveling in the right lanes that continue to I-610 and the other 1% were traveling in the fifth lane from right. The analysis for travel patterns by travel lane at sensor and travel lane at interchange also suggests that most overheight vehicles were traveling in the right most lanes and had aligned themselves to exit I-610 without having to complete multiple lane changes.
- Average number of lane changes per overheight vehicle exiting to I-610 in the After period increased to 0.84 as compared to 0.80 for the Before period. Based on the available data about number and travel patterns of overheight vehicles, DMS message compliance resulted in approximately three additional lane changes per day (57 overheight vehicles per day * 0.04 additional lane changes/overheight vehicle = 2.28 lane changes per day). Researchers believe that the three additional lane changes per day are not likely to cause any unintended safety concerns in the study area.

Bridge Hits in the Before and After Period

- Bridge hits that could possibly be detected at Mercury site decreased to none in the After period (April 7, 2015 thru July 28, 2015) as compared to four in the same duration Before period from last year. Similarly, bridge hits that could possibly be detected at Wirt site decreased to one in the After period (April 15, 2015 thru July 28, 2015) as compared to two in the same duration Before period from last year. However there has been an overall decrease in bridge hits (for the entire Houston region) from thirteen hits in the Before period to two hits in the After period.
- It is likely that overheight vehicle drivers have learned of the presence of OVDS and possibility of enforcement, therefore are paying more attention to their vehicle heights and bridge clearances resulting in fewer bridge hits in the After period.

Cost Effectiveness of OVDS

- An analysis of costs of OVDS ($135k per demo site) and bridge hits ($200k per bridge hit) suggests that a reduction of one bridge hit due to OVDS deployment at one site will result in approximate savings of $65,000 (using a lower estimate) to TxDOT. Such a reduction in bridge hits will also result in additional delay savings for the motorists in the area.

- Documentation of bridge hits that could possibly have been detected and avoided at one of the two pilot locations shows a decrease of 5 bridge hits for the After period when compared with the same duration Before period from last year. If this reduction could be solely attributed to the deployment of OVDS, then the system has provided a benefit-cost ratio of 3.7 in little over three months it has been active.

Outstanding Concerns

- If the OVDS were to be integrated with an enforcement program, the project team would need to:
    - Know if sensor beam maintains the accuracy of the threshold height overtime or recalibration is needed.
    - Verify the reliability of the OVDS in detecting overheight vehicles.
- If there is a desire to set threshold heights that more closely reflect the bridge clearance heights, then the project team requires an updated and accurate bridge clearance inventory. For the Pilot project, TxDOT personnel collected bridge clearance information inside I-610, particularly near Downtown Houston from two sources – signed bridge clearance on the bridges themselves and bridge clearance heights from the TxDOT Bridge Division in Austin. However, in many cases, the two readings were not the same and there was no clear relationship between them or any explanation for the differences. As such, the project team was unable to determine: 1) if there was a factor of safety included for signed bridge clearance values; 2) if yes, what was that factor of safety; and 3) when were these clearance heights established?

Recommendations

- There is a need to develop an updated and accurate bridge clearance inventory that clearly lists the measured bridge clearances, dates of measurement, location of measurement (center of roadway, shoulder lane, center of left lane etc.), and clearance value marked on the bridge itself. This inventory should be updated at regular time periods and especially after a construction or rehabilitation project for a given location.
- Since the OVDS system appears to be effective in redirecting overheight loads to a route that does not have lower clearance bridges, the District should conduct a study to determine if OVDS should be deployed at other locations.
- Develop a plan to integrate the OVDS system with an enforcement program including identification of any technical, funding, and legal impediments to the integration. This plan should address concerns identified under outstanding concerns in addition to any additional impediments identified as part of the plan development.
- Findings on the number of bridge hits show a reduction in bridge hits after the deployment of OVDS. However the entire TxDOT Houston District has experienced a lower number of bridge hits since the beginning of 2015, thus making it difficult to attribute the full benefits of reduced bridge hits to OVDS. Thus, it would be prudent to continue monitoring bridge hits in order to better document the benefits of the OVDS.
- Develop a plan to integrate OVDS with any connected vehicle projects.

- Upon receiving an overheight alarm, OVDS sends a contact closure signal to the radio receiver in DMS that stays active for the duration of a pre-set alarm time. The DMS message gets displayed for the amount of alarm time set for the radio receiver. For the pilot project, the radio receiver alarm time in the DMS was set to 30 seconds. If two overheight vehicles are detected within a 30 second period, the total duration of the message display does not get extended but stays 30 seconds. This means that if a second overheight gets detected while the message has already been displayed for 25 seconds, the second vehicle will see the message only for 5 seconds. ***For future deployments, ensure that DMS radio receiver is programmed in a way that ensures DMS message display is of the same duration for each overheight vehicle detected.***
- The demonstration OVDS deployed in Houston is specified to operate for speeds between 1 and 75 mph. A future deployment of OVDS for a roadway segment (especially one with posted speed limit of 75 mph or over) should consider the operating speeds of heavy vehicles in the segment and the capabilities of the OVDS system being considered.

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APPENDIX (OVDS SPECIFICATON SHEET)

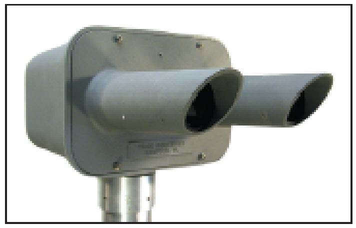
OVERHEIGHT VEHICLE DETECTION AND WARNING SYSTEMS

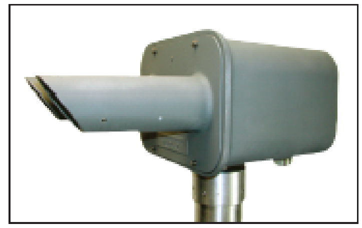
TRIGG industries

Specifications

Model # 3403-Z
Double Eye Z-Pattern®*
Visible Red / Infrared
Overheight Vehicle Detection System

* PATENTED
Z-Pattern® CE


Remote


Master

INPUT POWER	115 VAC, +/- 20%, 50/60 Hz. Other options include 24 VDC solar or 230 VAC, +/- 10%, 50/60 Hz operation.
OUTPUT...............................	Two Form C, dry relay contact closures for Overheight Alarm Functions. One Form C, dry relay contact closure for Fault Reporting. Contacts rated 240 VAC 10A, protected by 8A circuit breakers.
CERTIFICATIONS	CE Marking.
FAULT REPORTING	Factory configuration per customer selection of operational mode, loss of source/ detector/power or total failure. See Options and Accessories section.
ALARM TIME	Adjustable by customer from 5 to 60 seconds.
ELECTRONICS	Sensors are NEMA 6P enclosure rated.
EFFECT OF AMBIENT .... LIGHT	Use of Dual Beam RED/IR Z-Pattern® provides automatic switch to Single Beam Detection Mode of Overheight Protection if the sun or other interference saturates one detector.
MAXIMUM RANGE	700 feet (213 m). Suggested maximum range 200 feet (61 m) to allow for bad weather and lens contamination.
DIRECTION SELECTION	Selection switch. No tools or adjustment required.
ALIGNMENT	Four LEDs and meter (GO-NOGO functions) provided for ease of alignment and testing.
REACTION SPEED	1 to 75 MPH (1 to 121 km/h) for a 2.5 inch (6.25 cm) diameter object 1 inch (2.5 cm) above the detection height. Custom speed/size available.
TEMPERATURE RANGE	-40° to +135° F (-40° to +57° C).
ENVIRONMENTAL .... CONTROL	Internal thermostat with heater and fan controls air flow which reduces moisture and maintains internal temperature during cold weather.
HOUSINGS	External housing is heavy ALMAG casting and sheet aluminum (not less than 1/8 inch or .318 cm thickness) for rugged durability and extended life. Cabinet design minimizes effects of vandalism and provides rigid mounting. NEMA 3R Certified.
MOUNTING	The pole cap serves as a mounting bracket and sighting base with our poles, or a three-Axis mount is available. See Options and Accessories section.
DIMENSIONS	Remote Cabinet: 12¾ x 16½ x 8½ inches (32 x 42 x 22 cm). Master Cabinet: 12¾ x 18¾ x 8½ inches (32 x 48 x 22 cm).
SHIPPING WEIGHT	60 lbs (27 kg).

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