GEORGIA DOT RESEARCH PROJECT 15-21
FINAL REPORT

Warning Systems Evaluation for Overhead Clearance Detection

Georgia Department of Transportation

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16. Abstract:
This study reports on off-the-shelf systems designed to detect the heights of vehicles to minimize or eliminate collisions with roadway bridges. Implemented systems were identified, reviewed, and compared and relatively inexpensive options recommended. Systems for the Georgia Department of Transportation (GDOT) should be able to effectively detect vehicle heights to prevent collisions with low-clearance bridges. Systems were classified in three main categories: passive (rigid or nonrigid), active, or combined. Each system had its own advantages and disadvantages. Since user needs and desired classification results may differ, the authors focused on advantages that specifically serve the interests of GDOT. Some systems have extra functionalities, such as vehicle-type classification, detection of the vehicle's height *and* length, and photographic acquisition of license plate information. However, some of the implemented solutions are costly and may not target GDOT's particular needs. Therefore, the study identifies the few adequate, cost-effective, and efficient systems that clearly meet those needs.

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Final Report

WARNING SYSTEMS EVALUATION FOR OVERHEAD CLEARANCE DETECTION

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EXECUTIVE SUMMARY

Currently, the Georgia Department of Transportation (GDOT) has an immediate need to minimize the number of collisions of tall vehicles against low-clearance bridges in Georgia. GDOT is interested in adopting warning systems that can accurately detect the height of tall vehicles and warn their drivers about the threat of imminent collision with a low overhead structure or bridge. A recent inspection report on the Houlihan Bridge near Savannah (Chatham County, GDOT District 5) demonstrates this need. It indicated an average of about 50 collisions by overheight vehicles per year. These collisions caused structural damage to the bridge and, in several instances, it had to be closed temporarily for repairs.

To prevent the constant outflow of resources for repairs and traffic control, the GDOT Office of Bridge Design (GDOT-OBD) is interested in finding the most cost-effective, efficient detection system to warn against such collisions. The project team identified, evaluated, and recommended existing systems that detect overheight vehicles and warn their drivers that they are approaching low-clearance bridges. GDOT also expressed interest in simultaneously capturing other parameters; for example, license plate information, approaching speeds, and/or pictures of the overheight vehicles. Therefore, a second objective of this investigation was to explore devices and/or systems that include these additional parameters.

The study consists of a comprehensive search and review of available, off-the-shelf systems. It describes the systems and their attributes. Articles, reports, and case studies on existing detection devices and low-clearance bridges/structures hit by overheight vehicles were considered. The search for off-the-shelf systems was not limited to the United States but extended to solutions implemented overseas. Additionally, the investigators deployed short surveys on existing detection systems, ranging from simple signage displaying vertical clearances to more complex remote sensing devices, to DOTs across the nation and compared the results to similar surveys completed by other state DOTs. After examining state-of-the-practice technologies and

automated devices implemented in the United States and overseas, the corresponding vendors/manufacturers were contacted to gather technical data and capabilities. Communication with numerous parties resulted in valuable information and enabled the research team to arrive at recommendations that can assist GDOT personnel in their final selection. Certain developers/ vendors of proprietary systems were asked for further information about initial acquisition expenditures, installation, operation, and required maintenance. Extended queries explored the systems' capability under normal conditions and special circumstances, such as inclement weather and/or low visibility.

This study presents useful information to assist GDOT in making appropriate decisions on the adoption of one or more sensor-based, camera-based, passive strategy systems or combined systems. The expected result of adopting adequate detection and warning systems is substantial reduction in the number of bridge collisions by overheight vehicles in Georgia and funds annually dedicated to repair bridges affected by these collisions.

The team also recommends that GDOT select one or two of the proposed systems, install them at the most critically affected sites, and monitor their performances for at least one year. The information on the effectiveness of the installed devices collected from such a pilot study will be crucial in achieving a final adoption decision to be implemented at other accident-prone, low-clearance bridges across Georgia.

ACKNOWLEDGMENTS

The authors thank GDOT for its strong support and valuable input. The work conducted was sponsored by the GDOT Office of Research. The authors particularly acknowledge the contributions and support of Jesse “Andy” Doyle, P.E., State Bridge Maintenance Engineer; Yusuf H. Ahmed, Transportation Engineering Associate; and David Jared, Assistant State Research Engineer. The research team would also like to acknowledge the kindness and helpfulness of Edward Welch, P.E, Bridge Preservation Engineer at the National Center for Pavement Preservation, who promoted this investigation during the 2016 Southeast Bridge Preservation Partnership conference in San Antonio, TX, and provided many personal contacts at Bridge Maintenance Units at other state Departments of Transportation to the Principal Investigator. Civil engineering students Mariah Peart, Jacob McCranie, Clayton Rogers and Dylan Mesta have contributed in gathering valuable data for this research under direct supervision of Principal Investigator.

CHAPTER 1. INTRODUCTION AND RESEARCH APPROACH

Departments of transportation (DOTs) across the nation need a way to accurately detect road vehicle heights. It is required for traffic planning, to determine minimum clearances under bridge structures, to estimate truck volumes, to establish roadway tolls, to use movable bridges, and many other purposes. In particular, many bridges in the state of Georgia are continuously affected when tall vehicles crash into their structural elements. For example, a recent inspection report on the Houlihan Bridge over the Savannah River (Chatham County, GDOT District 5) documents damages resulting from approximately fifty hits per year by overheight vehicles. This case emphasizes the urgent need to implement preventive detection measures.

A number of solutions have been investigated. The known methods of vehicle height detection are based on different approaches employing various types of sensors, such as inductive loops, magnetic sensors, piezoelectric sensors, video cameras, and infrared laser sensors. Each approach provides a specific mechanism for detecting and classifying vehicles based on their height, and each has its own advantages and disadvantages. Some off-the-shelf systems have such extra functionalities as vehicle-type classification, detection of both height and length of a vehicle's profile, and photographic acquisition of license plate information.

Since user needs and desired classification results may differ, investigating the specific advantages of existing detection techniques and systems is of great interest for GDOT. Currently, a few identified highway projects focus on early warning systems for tall load vehicles; they are noted in Transportation Research Board (TRB) databases and/or can be identified from other sources. However, some of the implemented solutions are costly and may not target GDOT's particular needs. Therefore, this work aims to identify adequate, cost-effective, and efficient systems for GDOT.

The project focused on designed, tested, and commercially available systems that enable early detection of vehicle heights to minimize collisions against structural elements of roadway bridges or overpasses. The main goals were to identify, review, and compare already implemented systems and to recommend relatively inexpensive ones. The research approach was to achieve five tasks aligned with the objectives stated in the corresponding needs statement.

Task 1 was a comprehensive literature review on the proposed topic, collecting findings from various case studies, reports on bridges or other low-clearance structures hit by overheight vehicles, and lessons learned from those events, including, when available, damage assessments in terms of costs and/or durations of repairs. This review focused on not only the United States, but other locations abroad that were relevant to our purpose.

Task 2 compared existing strategies to reduce bridge collisions. Different schemes were investigated through a short survey distributed to state DOTs across the nation. Passive devices (rigid and nonrigid) and active detection and warning systems were considered overhead clearance detection methods. Families of signage elements with passive or active strategies were taken into account. Signs can provide simple information, such as vertical clearance warnings, vertical heights, or arrows indicating low clearance. Height restrictors, such as long hanging tubes and/or chains that produce noise when they rub against the top of the vehicle, were also evaluated for efficiency.

Task 3 explored the available, state-of-the-practice technologies and automated devices across the US and abroad for mitigating overheight vehicle collisions with bridges. Foreign vendors were contacted to confirm technical data and capabilities of their respective devices. These systems were documented as much as possible, including those triggered by laser-activated early warning detection systems (EWDS). Other devices, such as those using infrared beams, audible bells, and warning signs with flashing beacons to warn drivers that their vehicles exceed the height of an upcoming bridge, were investigated. Optical systems with height detectors, laser modules with laser beams and scanning sensors, and infrared sensors that trigger electronic messaging signs were explored. Combinations of laser or infrared systems with an active sign and/or warning system were also considered along with GIS-based network routing procedures for oversized vehicles. Furthermore, we explored newly developed systems using video imaging and object tracking to record vehicle information and operator behavior to protect the bridge and to lead the driver to alternate routes. Systems for vehicle identification, such as license plate readers (LPR), were surveyed to inform GDOT about the possibility of installing them in certain locations based on specific needs. We requested documentation from domestic and foreign manufacturers and vendors on instances when false alarms were triggered. Our overall analysis of the various technologies and devices is presented in technical terms.

Task 4 consisted of compiling data from vendors on existing warning systems' costs and effectiveness to gain insight on prevention and detection alternatives. To correlate the data obtained from the DOT surveys administered in Task 2, the researchers continued to contact selected state DOTs and manufacturers for more in-depth technical and economic information on overhead clearance warning systems. We asked manufacturers about these systems' capacity to detect objects moving at speeds between 1 and 100 miles per hour and under specific temperature, humidity, fog, rain, snow, or other local conditions (flying birds, insects). Vendor inquiries were directed via a short questionnaire on how such conditions might interfere with the normal operation and response of their units. We focused on material costs in this task. Depending on the availability of pertinent information for each system, reported data include such implementation results as the number of hits per year (efficiency), checkup frequency (maintenance), cost of maintenance, and field test statistics. Similarly, we report installation costs, either by in-house labor or a subcontracted third-party, for some products based on information exchanges with vendors.

Task 5 focused on recommending current, on-the-market warning systems based on their capital, operating, and maintenance costs and potential success rate, if available from market sources. This final report formally presents our results based on current information from the market at the time of submission to GDOT. Our recommendations resulted from an analysis of several technologies: sensor-based, camera-based, or passive strategies associated with active ones. They were assessed for feasibility, immediate costs, and life-cycle cost, if enough information was obtained. We report their capacity to resist adverse weather and performance under different light/fog conditions and various types of vibrations. The final chapter tabulates our findings, so GDOT can use them to develop a strategy for reducing the number of oversize vehicle collisions with bridges based on their location. GDOT-OBD can consider site selection based on the needs at specific locations and the geometry of the bridges or other low-clearance structures.

The primary objectives of this study were finding appropriate vehicle height-detection and warning systems and evaluating their technical data to assess their probable performance at bridges, overpasses, tunnels, and other structures often struck by unpermitted and/or permitted vehicles with heights that exceed the physical clearance. On a regular basis, overheight vehicles significantly damage GDOT structures, which require frequent, extensive, and expensive repairs depending on their type and configuration. GDOT has many strategies to consider to mitigate these unfortunate events, including effective routing strategies for permitted vehicles.

We developed and delivered a survey involving other state DOTs as a quantitative research tool, and the report reflects on our findings about systems that other state DOTs are using. The study examines these agencies' strategies for using warnings and overheight detection as well as routing procedures under conditions noted in specific case studies. The report presents several technologies and their current costs, if they were voluntary provided by vendors, and summarizes the survey responses of domestic and foreign manufacturers (vendors).

1.1 PROBLEM DESCRIPTION AND RELATED ACCIDENTS

Collisions of tall vehicles against low-clearance bridges are a safety and economic problem experienced by most of the United States and many countries around the world. The news media continually report numerous nonfatal and, unfortunately, some fatal accidents. Some transportation agencies have been proactive and are adopting preventive measures to minimize these costly incidents and simultaneously increase the overall safety of their streets and roads. For this purpose, several are implementing the use of Overheight Vehicle Detection and Warning (OVD&W) systems.

A five-year-old report (Agrawal et al., 2011) presented a map showing the total number of bridge hits from 2005 to 2008 in different states across the nation (Fig. 1.1). Color represents the seriousness of the bridge hit problem; red = serious; green = not serious; yellow = no response.

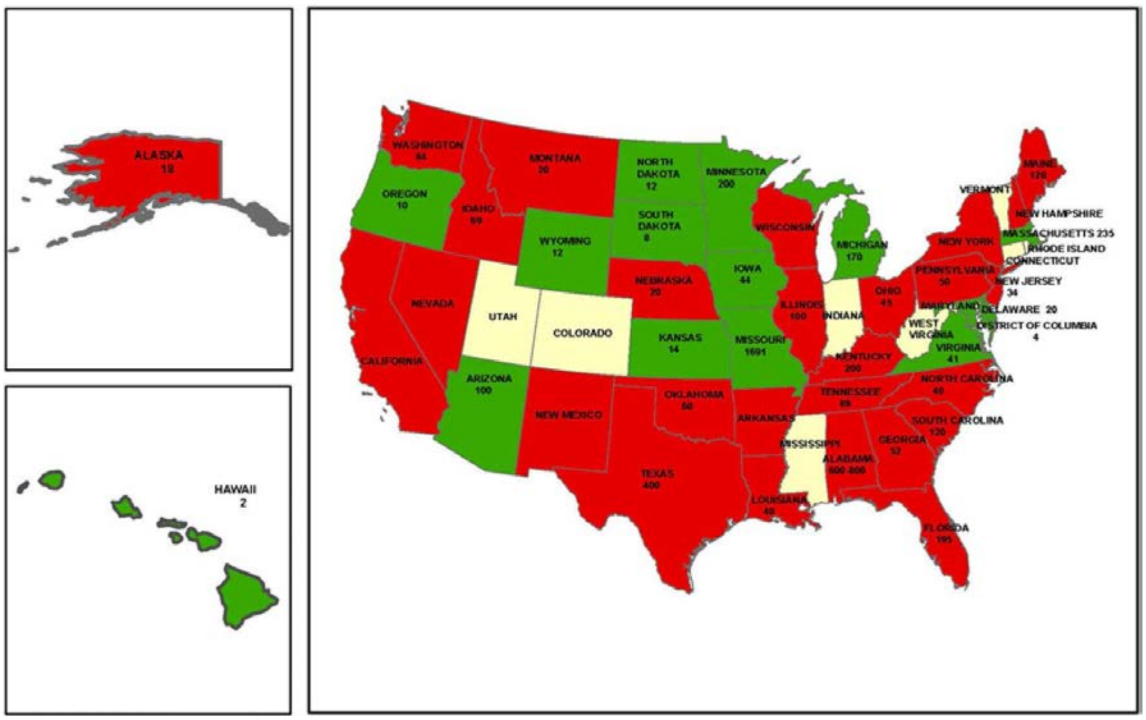

Figure 1.1

Number of bridge hits from 2005 to 2008 (Agrawal et al., 2011)

Since the numbers in Figure 1.1 are difficult to read, they are repeated here: Alabama, 600-800; Alaska, 18; Arizona, 100; Arkansas (no data); California (no data); Colorado (no response); Connecticut (no data); Delaware, 20; District of Columbia, 4; Florida, 195; Georgia, 52; Hawaii, 2; Idaho, 69; Illinois, 100; Indiana (no response); Iowa, 44; Kansas, 14; Kentucky, 200; Louisiana, 40; Maine, 120; Maryland (no data); Massachusetts, 235; Michigan, 170; Minnesota, 200; Mississippi (no response); Missouri, 1,691; Montana, 20; Nebraska, 20; Nevada (no data); New Hampshire (no data); New Jersey, 34; New Mexico (no data); New York, 755; North

Carolina, 40; North Dakota, 12; Ohio, 45; Oklahoma, 60; Oregon, 10; Pennsylvania, 50; Rhode Island, 5 [this number was extracted from a similar map (Singhal, 2015)]; South Carolina, 120; South Dakota, 8; Tennessee, 89; Texas, 400; Utah (no response); Vermont (no response); Virginia, 41; Washington, 84; West Virginia (no response); Wisconsin (no data); Wyoming, 12. Figure 1.2 shows a railroad bridge in Durham, North Carolina. It has been the focus of local, national, and international media attention because of the numerous toll vehicle collisions against it. The Norfolk Southern-Gregson Street overpass runs across S. Gregson Street near the intersection with W. Peabody Street. It is continually hit by tall box trucks and other oversized vehicles attempting to travel under it, in many cases, rental vehicles whose occasional drivers are not fully aware of their dimensions. The S. Gregson Street overpass presents a low, 11’-8” vertical clearance under its deck.

Figure 1.2

March 2016 view of the railroad bridge at S. Gregson Street, Durham, NC. A warning sign and corresponding flashing lights are observed (© 2016 Google Maps)

In most of the accidents at this bridge, the roofs of the involved vehicles have been shaved or torn off, prompting the public to refer to it as the “can opener”. Actually, what acts as a can opener is a steel portal-frame structure with a strong horizontal crash beam placed in front of the overpass to protect it against incoming overheight vehicles (see Figs. 1.3 and 1.4). This bridge is also popularly known as “11foot8”. The website 11foot8.com (© Jürgen Henn), presents video footage of several collisions, from two different angles, using two cameras. Numerous videos from that site can be found at https://www.youtube.com/user/yovo68/videos.

Figure 1.3

March 2016 view of the railroad overpass at S. Gregson Street, Durham, NC. The steel frame (“can opener”) employed to protect the bridge against crashes is on the left (© 2016 Google Maps)

Figure 1.4

Truck after smashing into the crash beam of the S. Gregson St. Bridge on February 13, 2009

(11foot8.com, © Jürgen Henn)

On April 12, 2013, Fox31 KDVR, a Fox-affiliated television station in Denver, CO, broadcast information on the many accidents occurring at this bridge (Mitchell, 2013). The corresponding video clip (http://kdvr.com/2013/04/12/video-trucks-smash-into-bridge-time-after-time-after-time/) was posted online by KDVR. A recent video, recorded and uploaded onto the YouTube site on April 29, 2016 (https://www.youtube.com/watch?v=Wy7nlA7zlDM), shows what is indicated as "Crash #106"; that is, the 106th incident since the camera was installed. Another video, uploaded on May 12, 2016 (https://www.youtube.com/watch?v=1LNEQxJM9ZE), informs viewers that "Yesterday, the Dept. of Transportation activated the traffic signal and the new warning signage at the 11foot8 bridge. Let's see how that worked out so far." In this video, no accidents are observed. However, two months later, another video, uploaded on July 7, 2016, shows "Crash #108" (https://www.youtube.com/watch?v=iQfSvIgIs_M). An additional video compiles several accidents (https://www.youtube.com/watch?v=xzkWTcDZFH0), from 2008 to 2013. The Wikipedia entry for "11 foot 8 Bridge" indicates:

> The 76-year-old bridge cannot be raised, because nearby railroad crossings would also have to be raised. The street cannot be lowered, because a major sewer line runs only four feet (1.2 m) under Gregson Street. … The Transportation Department of the City of Durham maintains Gregson Street, which runs under the bridge. The city installed height detectors on Gregson a block before the bridge. When an over-height truck passes by the detector, yellow warning lights flash to alert the drivers of trucks that will not clear the low underpass. Unfortunately, many drivers fail to heed the warnings, and crash into the bridge.

On July 18, 2014, WTVD, an ABC-owned television channel (11) serving Durham, Raleigh, and Chapel Hill (http://abc11.com/traffic/i-team-trucks-vs-bridges-/199091/), informed viewers that a large semi-tractor trailer had been recently stopped cold after its roof was sheared off by a low-clearance (12'-4") overpass across Peace Street in Raleigh, NC (Camp, 2014; see Fig. 1.5).

Figure 1.5

Accident at Peace Street overpass, Raleigh, NC (published July 18, 2012 by Jon Camp, Channel 11, ABC WTVD)

The report indicated that similar incidents happened in May 2014 and at the end of 2013 in spite of four warning signs and two sets of flashing yellow lights on either side of the bridge. Mr. Wink Montague, owner of the store nearest to the bridge, who started working there in the 1960s, said he had witnessed numerous crashes against the girders of this overpass and added, “Almost any kind of truck loaded with anything you can think of has hit the bridge.” He has seen light materials, such as toilet paper, strewn everywhere, and heavy loads, such as concrete pipes tied by chains, rolling off the side after the chains were cut by the impact. Once, he said, the overpass was hit by a Ready-Mix truck, and the impact threw the concrete hopper off the back of the truck. On August 31, 2014, the *Quad-City Times*, an Iowa newspaper, reported on the collision of a semi-tractor trailer with the railroad bridge running across Harrison and Brady Streets (at 5th Street) in Davenport, Iowa (Geyer, 2014; http://qctimes.com/traffic/low-truck-eating-bridge-snares-semitrailers/article_6301f82d-d399-5a91-9c21-d4db3180cf26.html; see Fig. 1.6). The bridge has a low vertical clearance of 11’-8” and for many years has been notorious for the large number of crashes against its superstructure. The article indicated the number of hits diminished after 2001, when the Iowa Department of Transportation installed a height-detection system with electric warning signs on Harrison Street. Now, on average, the number of hits is about one per month. In the first eight months of 2014, the bridge was hit five times.

Figure 1.6

Accident at Harrison and Brady Streets railroad bridge, Davenport, Iowa (published August 31, 2014, by Thomas Geyer; photograph, Larry Fisher, Quad-City Times file photo)

In South Melbourne, Australia, an infamous, crash-prone, low-clearance (3.0 m = 9'-11") light-rail bridge crosses Montague Street. The *Herald Sun* (Korssen, 2016), an Australian newspaper (http://www.heraldsun.com.au/news/victoria/montague-street-bridge-warning-gantry-installed-after-it-was-hit-more-than-100-times/news-story/0645bf542c8c2805e83048b628e84b0c), reported that as of May 26, 2016, there had been 102 collisions in the past six years at this bridge. *The Age*, another Australian newspaper, reported on Monday, February 22, 2016 (Bucci et al., 2016) that a bus with 14 passengers and a driver crashed into the Montague St. Bridge. Fortunately, no one was significantly injured, but four passengers were temporarily trapped and had to be rescued by emergency crews, and eleven were taken to a hospital for treatment and observation (http://www.theage.com.au/victoria/bus-crashes-in-south-melbourne-trapping-commuters-20160221-gmzyko.html; see Fig. 1.7). On April 2016, two trucks hit the bridge within a time window of five hours. To minimize these crashes, in May 2016, two warning gantries were installed on Montague Street, one on each approach to the bridge (see Fig. 1.8). Due to the large number of crashes at this bridge, the public has opened social media, Twitter, and Facebook accounts to discuss events related to it. It has a dedicated website: [http://howmanydayssincemontaguestreetbridgehasbeenhit.com/.](http://howmanydayssincemontaguestreetbridgehasbeenhit.com/)

Figure 1.7

Accident at the Montague St. Bridge in South Melbourne, Australia, February 22, 2016

(Huffington Post, Australia, published on March 30, 2016)

Figure 1.8

One of two warning gantries installed near the Montague St. Bridge, Melbourne, Australia (photograph, Hamish Blair, Herald Sun, Australia, published on May 26, 2016)

On September 22, 2011, the *Daily Mail*, a UK newspaper, indicated that at about 8:45 A.M., a double-decker school bus carrying approximately 50 teenagers crashed into a low-clearance (3.8 m = 12'- 6") railway bridge across Neasham Road in Darlington, Durham County, in northeast England (Brooke, 2011; see Fig. 1.9). One of the students suffered a broken collarbone and another a head injury. Some had minor cuts on their heads and arms. Fortunately, no one was seriously injured (http://www.dailymail.co.uk/news/article-2040463/Schoolchildren-hospitalised-double-decker-bus-crashes-bridge-opens-like-tin-can.html).

Figure 1.9

Accident at railway bridge on Neasham Road in Darlington, County Durham, England (published September 22, 2011 by Chris Brooke for the Daily Mail)

Regrettably, several fatal accidents involving tall vehicles and low-clearance bridges have been reported around the world. One occurred on September 11, 2010 at about 2:30 A.M. near Syracuse, New York (see Figs. 1.10 and 1.11) (http://www.syracuse.com/news/index.ssf/2010/09/at_least_two_dead_possibly_mor.html). In spite of signs and flashing lights warning about a low, 10-foot, 9-inch railroad bridge on the Onondaga Lake Parkway, a double-decker bus, which was not on its prescribed route, crashed into it. Four passengers died, and twenty-four others were taken to area hospitals with injuries ranging from minor to critical (Hannagan, 2020).

In 2012, the *Post-Standard*, a central New York newspaper, reported that this particular bridge had sustained as many as 90 high-vehicle crashes in the past quarter century (O'Hara, 2012; (http://www.syracuse.com/news/index.ssf/2012/02/judge_hears_gruesome_testimony.html). The tragic 2010 accident prompted the New York State Department of Transportation (NYSDOT) to call for the design and installation of specialized sensors to detect overheight vehicles and trigger additional warning signals to drivers near the Onondaga Lake Parkway Bridge. Eric Hansen, a civil engineer who works for the NYSDOT's Regional Traffic Management Center, assisted in the design of that system (Eisenstadt, 2011). The main idea was to use existing sensors, based on light beams, to detect overheight vehicles. The challenge was to avoid triggering false alarms caused by several prevalent conditions in that location, such as flying geese and other birds, the sunset, lake fog, and snow, which can interrupt the light beams.

Figure 1.10

Onondaga Lake Parkway Bridge, near Syracuse, NY (photograph, David Lassman, Post-Standard, September 14, 2011)

Figure 1.11

Fatal accident at the Onondaga Lake Parkway Bridge, Syracuse, NY, September 11, 2010 (published February 21, 2012, Post-Standard)

Investigators attempted to solve this problem by combining two existing techniques. One is the double beam (Double Eye) approach employed by Trigg Industries, Inc., of Newport News, VA, in which two beams, one infrared and one red, have to be interrupted in the proper order to trigger a signal. The other technique consists of road-embedded wires generating an inductive (magnetic) loop and is typically used at intersections to switch traffic lights from red to green. If the magnetic loop is interrupted by a large metallic object, such as a vehicle, it triggers a signal. By combining these two techniques, three events were required to trigger the alarm: (1 & 2) the interruption, in the proper order, of the two light beams; and (3) interruption of the magnetic loop. The alarm causes large signs to flash, indicating that an overheight vehicle has been detected, and its driver must pull over or stop. A simultaneous email message informs the NYSDOT Regional Traffic Management Center of the incident. The system was installed in 2011 at an approximate cost of $300,000. (http://www.syracuse.com/news/index.ssf/2011/10/state_department_of_transporta_2.html). On January 11, 2016, the *Post-Standard* reported that the system had been activated 15 times during the first eight days of January. It added that since 2014, four trucks have hit the bridge, but hundreds of other large trucks, an average of almost two per day, have turned around on the parkway after the system warned them of the danger ahead (see Hannagan, 2016; http://www.syracuse.com/news/index.ssf/2016/01/onondaga_lake_parkway_bridge.html). On May 14, 2014, New York Governor Andrew M. Cuomo made an announcement on enhanced traffic safety (https://www.governor.ny.gov/news/governor-cuomo-announces-testing-over-height-vehicle-detection-systems-long-island), referring to the installation of the system designed by the NYSDOT to detect overheight vehicles at several locations in the state as part of an approved $5 million pilot program.

On March 26, 2015, an overpass under construction across Interstate Highway 35 (I-35) at Farm-to-Market Road 2484 in Salado, Texas, was hit by a flatbed tractor trailer hauling a toll boom lift (see Fig. 1.12). Two 132-foot-long concrete girders, each weighing over 135,000 lbs., were dislodged and fell on three other vehicles. The 32-year-old driver of a pickup truck died, and three people were injured (http://kxan.com/investigative-story/one-year-later-driver-in-deadly-salado-bridge-crash-no-longer-driving-a-truck/). As reported a year later, on March 25, 2016, by KXAN, an NBC-affiliated television station in Austin, Texas (Maxwell, 2016), a subsequent investigation found that the vertical clearance of the bridge under construction was 14'- ½", while the height of the boom in the truck was 14'-5". Three warning signs posted within two miles of the bridge indicated a conservative clearance of 13'-6", the maximum height for big rigs on a highway without requiring a special permit. The same report indicated that the clearance under the bridge is now 16'-10"; at the time of the accident, the roadbed had not yet been lowered.

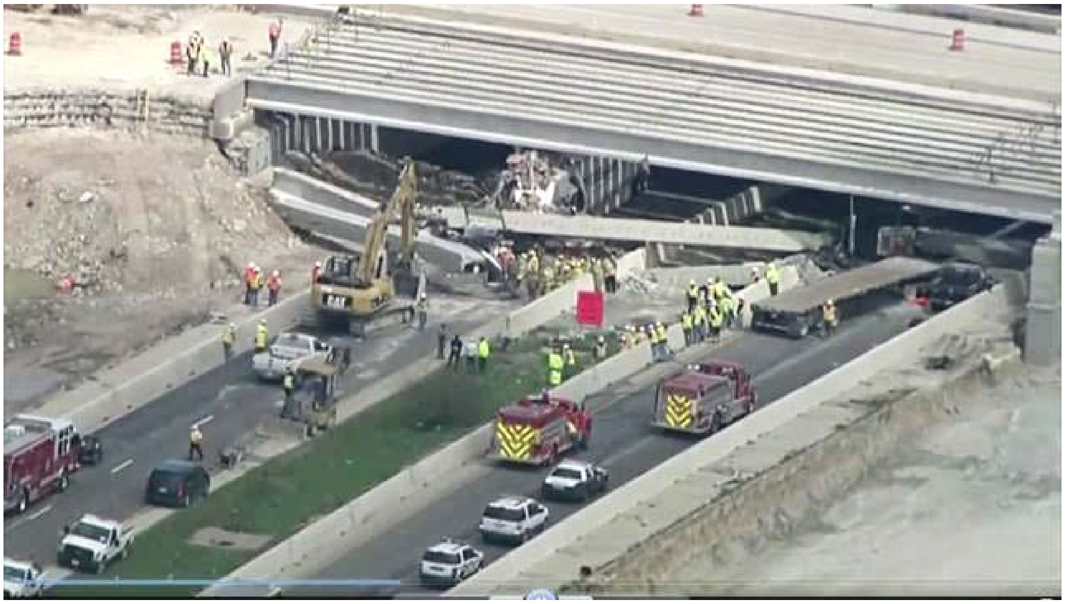

Figure 1.12

Fatal accident at an overpass under construction on I-35 in Salado, Texas, March 25, 2015 (photograph posted online on March 28-April 3, 2015, by KIII TV3)

1.2 LITERATURE REVIEW

This section summarizes information gathered primarily from abstracts, executive summaries, introductions, findings, implementations, conclusions, and other sections of selected refereed articles and documents. Interested readers are encouraged to access the full original documents for more detailed and complete information.

Chung C. Fu and his research associates at the Bridge Engineering Software & Technology (BEST) Center of the University of Maryland (Fu et al., 2004) attempted to obtain via a survey national data on the number of times tall vehicles collided into low-clearance bridges and/or overpasses. The work was part of a larger project with the Maryland State Highway Administration, entitled “Maryland Study, Vehicle Collisions with Highway Bridges.” Unfortunately, only 29 states responded to the survey. At that time, only seven states had computerized accident databases with the requested information. The article concluded: “In all, twelve states provided annual numbers of overheight accidents. The source of this data varies by state, ranging from organized accident databases to occasional reports of damaged bridges. This makes it difficult to compare overheight collision statistics between states.” However, the refereed study collected considerable and reliable information from the State of Maryland. In this regard, they note: “An analysis of the data revealed that the frequency of overheight accidents reported in Maryland increased by 81% between 1995 and 2000. Of the 1496 bridges susceptible to impact by overheight vehicles statewide, 309 (20%) have been struck, with 58 (4%) having required repairs.”

Kin S. Yen and his research associates (2005) presented a vehicle-based system, STRUCTVIEW, capable of measuring the dimensions of numerous roadway features, including horizontal and vertical clearances of overpasses. This device does not detect the dimensions of vehicles but is a system for rapid acquisition of the bridge clearance information needed by most DOTs. The spatial information is acquired from a dedicated vehicle with onboard sensors, traveling at normal highway speeds. The developers claimed: “STRUCTVIEW provides a vehicle-based approach to obtaining structure profile measurements needed by DOTs for issuing permits based on vehicle height, as well as the horizontal dimensions needed by the military and Homeland Security.” They pointed out the following advantages of the system:

> It allows sensing at highway speed, and yields a full 3D point cloud. The STRUCTVIEW user application supports extraction of all the required structure profile dimensions in an efficient and cost-effective manner. STRUCTVIEW gets the Structures Maintenance workers off of the roadway and into a safe environment in the host vehicle. In addition, the sensing and analysis workflow removes many of the opportunities for human error inherent in manual data collection and documentation. With the resulting improvement in the accuracy and timeliness of structure profile information and resulting oversize permitting, there will be a lower probability of related bridge strikes, with associated cost, safety, and congestion benefits. Finally, as highway-speed sensing removes the need for fixed or rolling lane closures, the traveling public will not be impacted by the lane closures required by most current approaches. In summary, STRUCTVIEW will enhance the overall mobility of the transportation system.

The authors mentioned current and future work to improve the capabilities of the system reported in the article. In July 2010, Joseph V. Sinfield published a decision tool that the Indiana Department of Transportation (INDOT) can use to identify equipment options to address site-specific needs for overheight vehicle protection.

> The findings of this study indicate that most states have updated their infrastructure to account for overheight vehicles and permanently avoid collisions. The few states that still actively employ overheight vehicle detection and warning systems (OVD&W) tend to use optoelectronic single- or dual-eye infrared detection systems and report that the devices have decreased the amount of damage occurring to their structures. The initial equipment and installation costs of these systems range from a few thousand to twenty-five thousand dollars based on DOT interviews, and on-going maintenance appears minimal. Overall, considering that the only other completely effective option to avoid overheight

vehicle incidents is to raise the height of affected structures, or lower the roadway surface, an (optoelectronic) OVD&W system is a relatively inexpensive and effective method for decreasing overheight vehicle accidents.

A comprehensive report, "Bridge-Vehicle Impact Assessment," was finalized in December 2011 by Anil K. Agrawal and his research associates at the University Transportation Research Center – Region 2, City College of New York (Agrawal et al., 2011). The sponsoring organizations were the USDOT's Research and Innovative Technology Administration and the NYSDOT. At that time, New York State bridges were experiencing approximately 200 hits by tall vehicles per year. The study had five objectives: "to (i) review and identify major factors contributing to bridge hits, (ii) provide recommendations to the NYSDOT about effective measures for reducing the likelihood of future bridge hits, (iii) provide long term, feasible and economical suggestions to reduce the likelihood of bridge hits, (iv) review and comment on the NYSDOT Collision Vulnerability Assessment Procedure and provide recommended improvements and (v) develop a computer program for analyzing the bridge his phenomenon as new bridge hits data become available." As part of the study, they completed a comprehensive survey of state DOTs across the nation, asking for data on bridge hits and actions taken. A second survey of selected DOTs further explored the performance of adopted OVD&W systems. The researchers then focused their investigation on New York State bridges hit more than once to determine local causes and developed a computer program to analyze the data. They reviewed the NYSDOT's *Collision Vulnerability Procedure* to propose changes in their assessment practices and proposed recommendations for reducing bridge hits in New York State.

Agrawal's report included regulatory, technological, educational, and outreach recommendations. The regulatory recommendations focused on prohibiting the use of consumer GPS devices, as opposed to truck GPS, by drivers of tall vehicles; coordinating with local authorities to restrict truck traffic in certain areas; issuing stiff fines and penalties to drivers of toll vehicles on restricted highways or parkways; mandating additional liability insurance for truck drivers with a history of violations; electronically monitoring restricted highways to summon and penalize drivers; requiring education and tests on bridge strikes and their consequences to obtain Commercial Driver Licenses (CDL); and generating an alert system (similar to Amber alerts) on roadways closed to excessively tall vehicles.

The technological recommendations included installing overheight-detection systems; embedding vertical clearance information in Google Maps; and using (a) CB radio transmissions to warn drivers about low-clearance bridges; (b) specialized truck GPS devices; (c) smart phone apps with embedded maps containing information on low-clearance bridges; and (d) several signage and warning options. In particular, these technological recommendations included the following statements on identified overheight-detection systems:

> In particular, it has been observed that the HISIC450 system manufactured by SICK MAIHAK, Inc. and Trigg detectors have been used by many state DOTS and have been found to be reliable. These systems have a service life of 15-20 years, require minimal maintenance and have an installation cost in the range of $15,000-$20,000 per unit (for a system with digital sign options). For parkways, simple systems with single direction detection, low speed, red /green light options can be configured at significantly lower costs. It should be noted that benefits derived by installing these systems far outweigh installation costs. Truck escort area (parking area) should be provided after the OHDS system so that a truck driver can park the truck and call police for help.

The educational and outreach recommendations focused on developing a bridge strike mitigation website; reaching out to the trucking industry via the Motor Carrier Associations, to independent operators, and driving schools; including a section on bridge hits, their causes and consequences on CDL tests; developing and disseminating educational materials showing the severe consequences of bridge strikes; developing newsletters and seminars including data on bridge hits; and implementing a required annual safety course for drivers.

In August 2012, a Master of Science thesis by Matthew J Sandidge at the Georgia Institute of Technology presented an approximate vehicle height-detection approach using digital video and post processing software. The author indicated that the proposed technique achieved 95.59 percent accuracy in measuring truck heights and reported an error rate of 3.3 percent. The author states: “The merit of this work is the creation of an automatic image based method which can provide height determination of trucks and is a low cost alternative to the current expensive laser and infrared detection systems.”

The Best Student Essay at the June 2015 Intelligent Transportation Society of New York annual meeting (Singhal, 2015) describes the LaRa-OHVD system, which was still under development. It uses laser detection and ranging (LADAR, also known as LiDAR, for light detection and ranging) as an innovative overheight vehicle detection (OHVD) scheme. The author indicates that this system was “… developed to overcome the cost barrier while providing enhanced capabilities as compared to the state of practice OHVDs. Currently under development, the LaRa OHVD has immense potential to reduce the over-height bridge hits and protect the integrity of our transportation infrastructure.” This detection concept is explained below using Abhishek Singhal’s figures.

Figure 1.13 shows a top view of the LaRa detector mounted on the bridge superstructure and transmitting a sheet of laser light covering the full width of the road and a distance greater than the required safe stopping length.

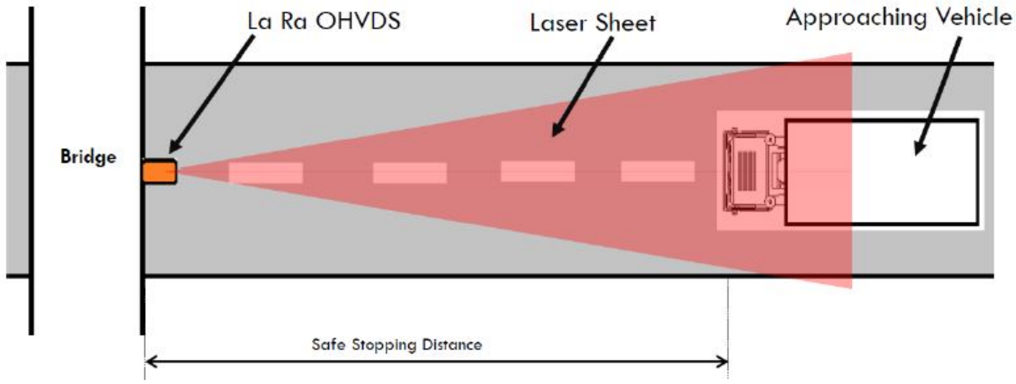

Figure 1.13

LaRa–OHVD top view (Singhal, 2015)

Figure 1.14 shows predefined detection zones before the safe stopping distance. All vehicles (short and tall) are detected in the vehicle detection zone, but those that are overheight are confirmed in the overheight detection zone. While in the overheight-detection zone, the vehicle's measured vertical distance (measured height) will be less than the fixed install height, confirming that the approaching vehicle is overheight and triggering yellow warning lights mounted on the bridge.

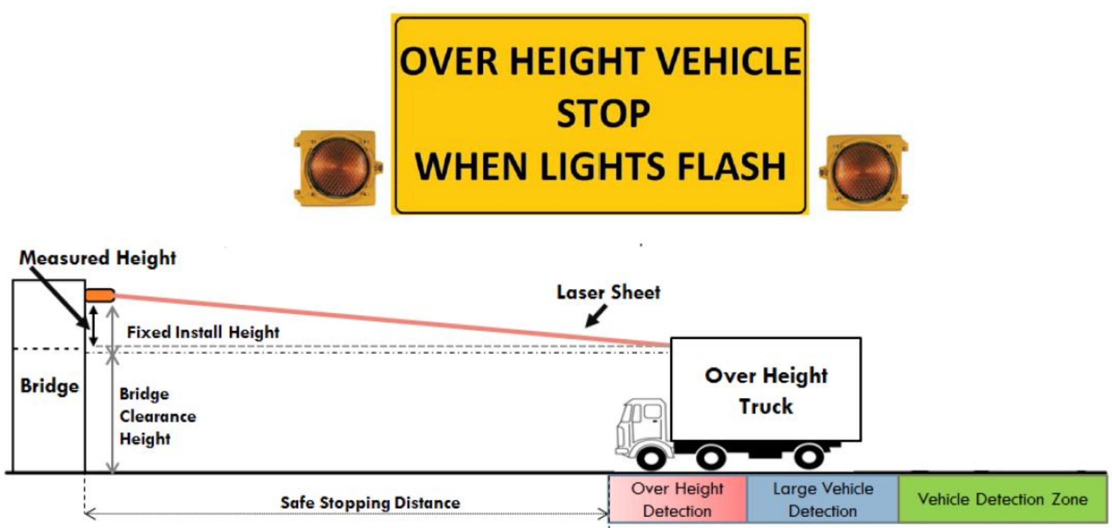

Figure 1.14

LaRa overheight-detection and proposed driver warning system (Singhal, 2015)

Singhal stipulates the advantages of the LaRa-OHVD:

> LaRa is unique it is operation. It is the first OHVD in the world which is installed on the bridge being protected and features long range detection (> 1000 feet). It detects vehicles travelling at highway speeds and provides a broad detection zone instead of single optical beam. Existing OHVDs often utilize inductive road loops to confirm vehicle presence leading to higher installation/system costs. LaRa employs vehicle detection zones and algorithms to detect vehicles and minimize false alarms (due to flying debris, birds), a significant advantage over the beam-break approach used in conventional OHVDs. The total system cost (including detector, warning sign/beacon, installation) is minimal compared to conventional OHVDs enabling mass deployment. A unique advantage is the line of sight warning system. Since the warning sign and traffic beacons are installed on the face of the structure, drivers can always see them and they are hard to miss. This eliminates the need for expensive VMS/Matrix signs or alarm bells reducing cost and simplifying installation. LaRa can measure vehicle speed and predict if collision is imminent. This provides crucial seconds for agencies to plan pre-emptive emergency recovery and response. Also, LaRa continuously measures the vehicle height in detection zones and can provide a very useful collision statistic for the responding agencies to assess the legal vehicle over-height. LaRa can also reduce the level of structural damage for an over speeding driver as he responds to the warning sign and hits the structure at a reduced speed (while braking).

Singhal anticipates a limitation "… the requirement of a straight approach road up till the safe stopping distance to the protected bridge." Again, in June 2015, this system was still under development.

This literature review enabled the research team to identify different devices and systems that are currently in use or under development for overheight vehicle detection and warning. However, as some of these systems were still developing and testing, the team directed their focus of this investigation to off-the-shelf systems available in the market. These warning systems were offered by various manufacturers and implemented directly by some of the state DOTs or through third-party subcontractors to certain state DOTs.

CHAPTER 2. EXISTING STRATEGIES TO REDUCE BRIDGE COLLISIONS

2.1 OVERVIEW OF DOT INQUIRIES

The Georgia Southern University research team designed a questionnaire to learn the strategies other state DOTs have taken to reduce bridge collisions. The short questionnaire was distributed to key personnel in the offices of bridge design or bridge maintenance at other state DOTs. Specifically, they were asked:

- Does their state have any vehicle height-detection/warning system in place to prevent collisions with low-clearance bridges?
    - If not, is there a particular reason why not?
- Based on their experience, which approach is more effective—passive or active (including height-detection sensors)?
    - If passive, do they recommend a rigid system, like a crash beam, or nonrigid, like hanging chains or just signs?
- What does the system the DOT uses do, and how does it work?
- Is the system powered?
- By what percent would you estimate the system has reduced bridge collisions and infrastructure repair/maintenance costs?
- Has the system false triggered and why?
- Would they recommend the implemented system to other DOTs?
- What is the best way to contact the system's vendor?
- Are there any regulations or standards that their DOT must follow regarding the installation and operation of the height-detection/warning system?

The following sections present and analyze survey results obtained from 50 out of 51 state DOTs, excluding Georgia's. One DOT, Massachusetts, was still unresponsive after a third attempt to contact key personnel at the state Bridge Maintenance Office. When a DOT was not responsive, the research team contacted personnel at offices closely related to bridges.

A total of 22 state DOTs reported using various warning systems, but 3 used them only in certain districts. A total of 25 reported not using any warning system for overhead clearance detection.

2.2 RESULTS FOR DOTS THAT IMPLEMENTED SYSTEMS

For ready access, these state DOTs were listed below in alphabetical order. An emphasis was made regarding the specific systems/products currently employed by the respective DOTs. Technical information about some warning systems were also provided for the states where this information was obtained directly from the corresponding State Bridge Office representatives.

Alabama:

ALDOT has a system in place for a low-clearance tunnel. The most effective system is both **passive and active**. The passive system aligns **nonrigid** features with advanced warning systems and **rigid** features as a last resort for protecting the structure. Specifically, they have **overheight sensors** in advance of **flat panel warning signs; DMS signs** with a changeable message that displays STOP DO NOT ENTER when triggered by the overheight sensor; **warning beacons** that flash red when the overheight sensor is triggered; an **audible alarm** triggered by the overheight sensor; **hanging chains** in 2'-long PVC sleeves wrapped in yellow reflective tape; and a **crash beam** at the entrance to the structure. All of these systems are controlled with programmable logic controllers (PLCs) and monitored 24/7 by ALDOT staff. The system is fed by a hard-wired power source backed by generators and an uninterruptible power supply (UPS). This system has been in place for over 30 years, but pre- and post-installation information confirming that it has reduced collisions is not available. However, based on the number of near misses, they believe their systems are very effective in reducing collisions. The bridge engineers stated that every day, vehicles almost hit the structure, but the warning systems stop them right before a collision occurs. Due to the roadway geometry in the approaches to the structure, they experience false alarms. Sometimes a bird breaks the beam; at other times, a driver decides the vehicle is in the wrong lane at the last minute. ALDOT initiated, controls, and maintains its own system and recommends it to other DOTs. The best way to contact them is through their Central Office in Montgomery. The system does not follow any standards or regulations at this time.

Colorado:

Colorado has a vehicle detection/warning system in place to prevent collisions with low-clearance bridges. According to their experience, the active system is more effective. Overheight detection at the Eisenhower tunnel is a **Trigg laser** at a far location and a near location that triggers a **siren and blank out sign** that directs the truck to pull over into a parking lot for further inspection before proceeding through the tunnel. The system is powered by electricity. It has reduced bridge collisions and infrastructure/maintenance costs 99%. It has not false triggered. CDOT recommends it to other DOTs. The best way to contact the vendor is through a Google search (as they recommend). Respondents did not know of any regulations and standards that CDOT must follow.

Delaware:

DELDOT has a system in place to prevent collisions with low-clearance bridges. The most "passive" system is **signs**; their standard installations are purely signs. They have no installations of rigid beams or hanging chains, although they have thought about installing them as the "next step" in some of the high-hit locations. They **supplement a few signs with flashing beacons activated by overheight vehicles**. The system is essentially a garage-door opener that activates a flashing beacon system powered by the commercial provider. DELDOT does not know the percentage of bridge collisions and infrastructure/maintenance costs prevented by its approach. Personnel stated that estimating bridge strikes is very difficult. Evidence on the beams or signs shows that some low-clearance bridges are struck or scraped far more often than the notifications they receive would indicate. Obviously, they are aware of catastrophic hits. The system has false triggered when lasers are out of alignment or snow or debris blocks the laser. **Bridges with activated systems are still hit frequently**. As noted, they have considered and may consider in the future such options as hanging chains and more of the activated systems they are using, which is not very complex and available from various vendors. Signs must be compliant with the Manual on Uniform Traffic Control Devices (MUTCD); projects must be funded properly, within the right-of-way, with NEPA clearance, but nothing specific to an overheight system was mentioned. If static signs work, they recommend sticking with them; they think hanging chains present maintenance (need to "calibrate" them), aesthetic, and liability concerns.

Florida:

FDOT has a system in place to prevent collisions with low-clearance bridges. One district feels that the overheight-detection system is meant to draw more attention to the low-clearance structure rather than to obstruct overheight vehicles with a sacrificial beam and/or hanging chains. Their **Overheight Vehicle Detection System (OHVDS)** uses dual infrared beams to detect the approach of overheight vehicles. They coordinated with the local power company to install a new electrical service and meter that operate from new drops off adjacent power poles in the corridor. The frequency of hits prior to the system's installation is unknown, and unless a camera were set up at the bridge or its condition inventoried weekly, estimating the reduction in bridge collisions is impossible. However, DOT staff who live in the area have observed trucks stopping short of the bridge as a result of the OHVDS. The system has false triggered, but they don't have records of the cause(s); some possibilities are birds, antennas, debris, and sunlight. They recommend the system to other DOTs, and another FDOT district is designing a similar system. The best way to contact the vendor, **Trigg Industries,** is directly. There are no standards and regulations that FDOT must follow at this time. The system might not be implemented because it is not on the FDOT APL and must be approved by the District Traffic Operations Engineer to serve in FDOT Right of Way.

Hawaii:

HDOT has a system in place to prevent low-clearance bridge collisions. Their system, powered by solar panels with battery backup, emits a **siren** before the oversize vehicle approaches the **HDS (height-detection system)**. They believe this **active system** is more effective and would like to add chains before the HDS. Although effectiveness information is not available, it is probably stored at their H3 Tunnel observation group. They have not been notified whether the system has false triggered. HDOT would recommend newer versions of their existing system. They suggested many companies that sell oversize-vehicle warning systems to contact. HDOT must follow MUTCD/AASHTO standards and regulations.

Iowa:

Iowa DOT has a vehicle height-detection/warning system in place to prevent collisions with low-clearance bridges. They have **a passive and an active system** but find it hard to say whether either is effective; **bridges with either system continue to be struck by high loads**. They have no way of knowing whether the number of strikes has been reduced because of the systems. One detects the height of the approaching vehicle with an **infrared sensor**, which **trips flashing lights**, warning the driver that the vehicle is above the minimum clearance. The second system is **hanging chains**, which had to be placed between the bridge and an intersection within about 200 feet of it, so they are too close to the bridge to give ample warning. The height-sensing system is powered by electricity hard-wired at the site. The system was deployed in 2015, not long enough to estimate its effectiveness. There have been some false triggers from unknown causes. They recommend this system to other DOTs. For information on the best way to contact vendors and the standards and regulations that the Iowa DOT must follow, phone call to the Traffic Operations Office is recommended. The main reason more detection systems are not deployed is that most locations are at interchanges or on interstate routes where trucks have too many alternative paths or the distance between exits is significant. At interchanges, the system is expensive and difficult to maintain. Most of their bridge hits are at locations that aren't considered low clearance.

Louisiana:

They have systems on three tunnels, but none has functioned for quite some time. Very limited information is available from this DOT, and there is a need to follow up.

Maine:

The DOT has two bridges with **active systems** to detect overheight vehicles; specifically, **cross road sensors** in advance of the bridge emit **two light beams at a set height**, and when broken in the correct order, they turn on **flashing yellow warning beacons**. The system is connected to 120 volts AC from the local mains. They have no data on the number of collisions avoided due to this system. They believe false triggers are due to sensor failure and birds and insects/plants breaking the light beams. The theory behind the system is sound, but they do not recommend this particular brand of sensors, made by **Trigg**, and provided no contact details. No OHVD-system regulations were reported.

Maryland:

MDTA (Maryland Transportation Authority) has a vehicle height-detection/warning system in place to prevent collisions with low-clearance bridges. It uses no passive systems nor overhead mounted physical barriers but deploys two types of **active height-detection systems** to protect its many bridges and tunnels. The first application, a **Trigg OVDS,** protects a low-clearance bridge on I-895 southbound mainline. When triggered by an overheight vehicle, this stand-alone system activates **flashing beacons** on a static overhead sign that alerts the driver to exit the highway. No other alert is transmitted. The second application protects the I-895 Baltimore Harbor Tunnel using **several sets of photoelectric beam sensors** by **Sick Optics** on both the north- and southbound approaches. When triggered, the system activates **two overhead blank-out signs** that alert the driver to proceed to a pull-off area. The system includes a **camera/DVR** that **takes a snapshot of the vehicle**

triggering the system, activating an **audible alarm with LED flashers** at a manned police enforcement hut. The police are then responsible for flagging down the vehicle for exit prior to the tunnel entrance. Both systems are powered by commercial electrical service. The system at the I-895 tunnel is very effective in reducing collisions—near 100%, when they compare alarms to actual collisions. It is the only system monitored for false alarms, and they do occur due to a number of geometric and other factors (e.g., bridge deck bouncing, birds, weather). The northbound approach is very reliable, with less than a 5% false alarm rate, but the southbound approach has a +/- 20% rate because the approach is on a viaduct that deflects with traffic traveling in either direction. This statistic is tracked for operator and maintainer (O&M) purposes. MDTA recommends their system to other DOTs. The best way to contact the vendor is from its website, *https://www.sick.com/*. MDTA supports the AASHTO legal height requirements. All facilities are at or below the AASHTO height limit of 13'-6". The OVDS systems are set to alarm at 13'-7".

Minnesota:

Minnesota Department of Transportation (MnDOT) has a vehicle height-detection/warning system in place to prevent collisions with low-clearance bridges. They are not sure which system approach is more effective, but theirs is an **active system** that detects overheight vehicles with an **infrared light** that transmits to a receiver. If the beam is blocked by an object 3 inches in diameter or greater, moving between 1 and 75 mph, an **alarm** sounds, and the system activates **flashing yellow beacons** located at **warning signs** that inform the driver of the danger and the corrective actions to take. Even though the **Trigg OHVDS** is powered directly by the local power company, District 1 wanted to insure its reliability by providing a backup source of electrical power with a battery-powered system and an inverter. The Monthly Check System Log indicates when the back-up system provided power to the OHVDS; while the system seems to help, they found no good way to estimate how many times it prevented an accident. It is set approximately 3 inches lower than the deck, so it can activate for loads that do not hit the bridge. In terms of the circumstances and budget, they have been satisfied with this system. The best way to contact the vendor is at http://www.triggindustries.com/. MnDOT is unaware of any standards and regulations other than clear-zone requirements.

Missouri:

- **(First Response)** Missouri Department of Transportation (MODOT) has a system in place to prevent collisions with low-clearance bridges. The **active system** approach is more effective. They have no active systems to protect bridges, but they do have two installations of **lasers** that detect vehicles over a certain height and activate **warning flashers**. They use them at curves with high turnover rates, and they are several years old.
- **(Second Response)** The respondent stated, "I am not aware of any detection systems we use, most of our hits are from garbage trucks with the hooks raised to keep them out of the drivers' eyes, and dump trucks that accidently raise, or other oversize loads." They have used Terrametrix to improve their data and provide more accurate **warning signs**, but signs are all they use. They find this passive approach effective. In the St. Louis region, one railroad bridge has a passive system, but they are not maintaining it, information about it is very limited. The following website was provided as a reference: http://www.terrametrix3d.com/#!bridge-clearances/bc7i2.

North Carolina:

North Carolina Department of Transportation (NCDOT) has no state-wide policy on vehicle height-detection systems, but their Division 6, covering a large portion of an older section of I-95, has had the most experience and finds **active height-detection systems and signs** more effective. They do not use passive systems. Specifically, they use a **TRIGG Industries Model 3400Z** directional dual beam microwave detection system tied to flashing lights placed 700' past the detector, which can detect vehicles that are 6" below minimum clearance. Each system costs $300,000 and is powered with 120 volts. The system has reduced bridge collisions and infrastructure/maintenance costs an estimated 75-80%. It has false triggered due to **failed parts**. NCDOT Division 6 recommends this system to other DOTs. The best way to contact the vendor is at their website, triggindustries.com. The system is regulated by the manufacturer's policies and routine preventative maintenance.

North Dakota:

North Dakota Department of Transportation (NDDOT) has one system in place to prevent collisions with low-clearance bridges and has determined an **active** approach is best. This **Trigg system**, installed on a rural high-speed roadway, warns drivers if their vehicle is too tall to pass safely under the bridge. The height limit is set 3" below the actual clearance height. If the load exceeds this height, a static sign with flashing beacons is activated. The system also **sends an email to a user group to warn of an overheight load approaching the bridge** and can **send system health notifications** about a low battery or beacon status, for example. Due to the rural location, the system is solar powered. A camera near the south end of the bridge is not connected to the overheight-detection system. The respondent stated that they do not have exact data on the decrease in bridge hits; they have had several since it was installed but at slower speeds. Knowing when a hit occurs helps. The system has a fair share of false triggers caused by truck exhaust during cold weather, hay loads, and heavy snowfall, among other things. It has performed well considering its rural deployment, and NDDOT recommends it. **Trigg industries** is the provider. NDDOT know of no standards and regulations.

Nevada:

Nevada Department of Transportation (NVDOT) has a system in place to prevent collisions with low-clearance bridges. Their only permanent systems are **passive (crash beams**), although they have used height-detection sensors and warning systems during the construction of several projects. They do not know if their systems have reduced bridge collisions and infrastructure/maintenance costs or whether any system has false triggered because they are not monitored. The beams they installed were not proprietary. They placed steel beams at some distance from superstructures that had a significant number of previous impacts. There are no standards and regulations that the NVDOT must follow.

New York:

Several responses were received from New York state -

- According to David Woodin, the state has three regions (Syracuse, Hudson Valley, and Long Island) that have implemented vehicle height-detection systems, all **activated** by breaking a **laser beam**. For liability reasons, they do not advocate the use of rigid bars or hanging chains, which can damage a windshield. Several years ago, a task force was formed to deal with the issue of overheight trucks gaining entrance to their parkway system in the Hudson Valley and on Long Island. A statement from the Long Island region sent on 6/17/16 addresses their current efforts to address overheight vehicles:

  > The Department evaluated a physical bar that would overhang the roadway at the legal height and spin around when hit, similar to what you would find at a fast food drive thru. Unfortunately, certain safety concerns could not be addressed due to the risk of injury to the overheight vehicle passengers or passengers in a vehicle following the overheight vehicle. Specifically, the bar could spin around and enter a long vehicle such as a tour bus or not be able to withstand an impact at such a high speed. Therefore, the Department has been focusing its efforts on a few other programs to prevent these intrusions. Enhanced pavement marking letters stating 'NO TRUCKS LOW BRIDGE' and 'LOW BRIDGE AHEAD' have been added to the roadway at high incident locations. In addition, a total of 16 truck intrusion systems are planned at various high incident locations. These systems will include an **overheight optical detector, CCTV camera and electronic variable**

message sign. When an overheight vehicle triggers the system, the CCTV will capture a video of the event, notify our 24 hour INFORM operations center and show a message on the variable message sign downstream to warn the driver of the height restriction. The INFORM operations center will verify the intrusion and notify the appropriate police agency to dispatch to the site. This system is in place at three locations and we anticipate all locations to be operational within the next year.

- Region 3 installed an overheight vehicle-detection system on Route 370 on October 20, 2011. The detectors, **combining infrared and visible red technologies, were installed in conjunction with inductive loop vehicle detectors**. When the beam breaks, and the loops detect a vehicle, a signal is sent to two variable message signs to turn on a warning. The first is OVERHEIGHT VEHICLE DETECTED/ PULL OVER, and the next, near the bridge, is OVERHEIGHT VEHICLE/STOP NOW. A text message and a picture from the camera that monitors the area are sent to the traffic message channel. The overheight-vehicle detectors are powered by direct wiring. The system has reduced bridge collisions from 2.2 per year to 1.5 per year. It has false triggered due to severe blowing snow. New York State Department of Transportation (NYSDOT) recommends this system to other DOTs, because it seems reliable. The best way to contact the vendor, **Trigg Industries,** may be by phone. The contact is Jake Buck. They are unaware of any pertinent regulations and standards.
- Eric Hansen's response: NYSDOT uses an active system to prevent collisions with bridges; it was not permitted to use passive systems based on the concern that a vehicle striking chains or a headache bar at the parkway speed limit, 55 MPH, would distract the driver and cause an accident in addition to damaging the vehicle. Another factor was the responsibility/liability for repairing a passive system once it was struck. Therefore, they

went with an active system using a sensor manufactured by Trigg Industries. There are **two beams and loops in the road**. The beams must be broken in the right order, and a vehicle must be present on the loops to trip the system. When it trips, it sends a wireless (900 MGHz spread spectrum radio) contact closure to two DMS signs with flashing beacons. The signs and beacons are on timers and will flash as long as the timer is active. The system also sends text messages to a cell phone in the TMC to alert operators that it has been tripped, so they can take appropriate action. Some fixed cameras at the sensors take a snapshot of whatever tripped the system, and they are emailed to the TMC as a record that helps them to verify positive and false trips. The system is powered with 120 volts AC. Maintenance costs to the bridge are negligible. It is an old truss bridge, built to carry trains that were much heavier than today's trains, and has never sustained damage that required repair, to their knowledge. The installed system has certainly reduced the number of hits, but it is difficult to know exactly how much because before it was in place, hits were not always reported. Now they know every time it's hit and track it. The system has false triggered due to heavy snow, birds, and weak transmitters in the sensors. They recommend this system to other DOTs. **Trigg Industries** has been a very good company to work with. The system installation and operation did not have to follow any standards and regulations.

Ohio:

Ohio Department of Transportation (ODOT) uses both **passive and active** vehicle height-warning/detection systems in District 5. It had **passive chains** but now has a **laser beam with an audio alarm**. The system operates on electrical power; they tried solar power, but with the cold weather, the batteries would not stay charged. They have no way to quantify the reduction in bridge collisions and infrastructure/maintenance costs or to know whether the system has false triggered, but they would recommend it to other DOTs, if it worked to its full capabilities. They cannot get the ODOT Information Technology department to work with the contractor to make the system send the district a photo and email when it is tripped. The best way to contact the vendor is by phone and/or mail. The ODOT does have standards and regulations that must be followed when installing and operating this system.

Oklahoma:

Oklahoma Department of Transportation (ODOT) has a system to prevent collisions with low-clearance bridges but not as part of a statewide program; in a few isolated cases, divisions have put a warning up. They have found **passive systems of signage and hanging PVC pipe/chains** satisfactory. No power is required. They guess that bridge collisions and infrastructure/ maintenance costs have been reduced approximately 90%, but there aren’t many strikes. The system has definitely been enough for them, but they recognize that other states with bigger problems will need a better system. They mentioned no vendors nor regulations and standards that the system follows.

Oregon:

A system is in place to prevent collisions with low-clearance bridges, but the respondent knows of only two bridges in Oregon that have any kind of vertical height-detection/warning system; there may be more. **One is passive and one active**. The passive system consists of **hanging chains with metal plates attached at the ends** placed before a low-height railroad bridge **in addition to several signs warning of a low-clearance ahead**. The active system precedes a highway truss bridge and consists of a **device that flashes lights when triggered by an overheight load**. The respondent didn’t know how the system is powered and could not give an opinion about performance or make a recommendation since Oregon has so few systems. He also did not know the vendor of the active system. He believes that Oregon has a more indirect method of preventing bridge collisions through permitting and oversight by their Motor Carrier Division; any structure with a vertical clearance under 15 ft. must be posted per their guidelines. No other standards and regulations are known.

South Dakota:

South Dakota Department of Transportation (SDDOT) has only **passive systems** in place to prevent collisions with low-clearance bridges. They prefer **nonrigid** systems. They currently have **overheight portals of rebar suspended on chains** near two through-truss structures. No power is required. They were installed as part of original construction. The system has not false triggered. SDDOT recommends it to other DOTs but is unsure about the best way to contact the vendor. There is no particular reason why the system has not been implemented statewide. Two active height-detection systems were both removed over 15 years ago, one when the adjacent structure was replaced, and the other after a project lowered the roadway. The city of Pierre operates an active height-detection system on a state highway for a privately owned, low-clearance RR structure but **has had limited, if any, success in reducing collisions**.

Tennessee:

Tennessee Department of Transportation (TDOT) has a system in place to prevent collisions with low-clearance bridges. They primarily use **vertical clearance signs** and, recently, **height detection sensors** for bridges that are consistently struck. In the past, they used some passive systems (hanging chains) that reduced number of hits and still consider these systems for lower volume or lower speed routes, as they are considerably less expensive to install and maintain. They have never used rigid systems. The **OVDS activates an alarm bell and a warning sign**. A parabolic shield focuses sound toward the vehicle. The sign alerts the driver to the overheight hazard and provides directions for an appropriate response. Power is obtained from a nearby electrical pole. Less than three years ago, TDOT installed an OVDS on three bridges that were consistently struck, and **none has suffered a strike since**. The Double Eye Z Pattern reduces the chances of false alarms, and they are not aware of any. The system has performed well, and they recommend it to other DOTs. The best ways to contact the vendor, **Trigg Industries**, is by phone, fax, or email: info@triggindutries.com; or through their website: www.triggindustries.com/contacts.htm. They seek advice from the manufacturer for installation standards and regulations.

Texas:

Texas Department of Transportation (TxDOT) finds an active vehicle height-detection/warning system most effective in preventing collisions with low-clearance bridges: a **dual-beam, active infrared**, direction-discerning system manufactured by **Trigg Industries**. Each OVDS demo site has a dedicated camera and dynamic message sign. Infrared beams are aligned across inbound lanes at a threshold height of 14 feet. Whenever that height is met or exceeded, an automatic alert of violation is texted, emailed (w/5 sequential photos), and video archived, and downstream **flashing beacons and a warning message** are automatically activated. The system has an input power of 115 VAC, +/- 20%, 50/60 Hz. Other power options include 24 VDC solar or 230 VAC, +/-10%, 50/60 Hz operation. Savings of $65K to $165K are reported, if the reduction in bridge hits is attributed solely to the OVDS, and it has increased overheight-vehicle diversion by approximately 50%. Texas is going to conduct a study to determine whether OVDS should be deployed at other locations, and the TxDOT official provided URL links to complement the survey questions: http://patch.com/texas/eastaustin/s/fk9vh/txdot-officials-installing-crash-preventing-early-detection-devices-along-i-35; and http://static.tti.tamu.edu/conferences/tsc15/presentations/traffic-ops-2/kozman-stevens.pdf.

Virginia:

Virginia uses **electronic beam overheight detectors** at all of its underwater tunnel facilities, which are all part of the interstate system, so vehicles are moving 55+ MPH, and using a passive device would be dangerous. Some of the tunnels have ceilings as low as 14 ft., which makes protection essential. On each approach, the outermost detectors activate signage that warns the overheight vehicle’s driver to take the next exit or to stop at the inspection station for a height measurement and to adjust the load to lower its height. If the driver fails to stop at the inspection station and trips the next overheight detector, the traffic control system activates all of the traffic control devices near the tunnel and stops all traffic. The overheight vehicle is pulled out of traffic, and the remaining vehicles released. The outer approach detectors are powered from roadside power systems used for lighting. The closer units are powered from the facility's power system. No tunnel portal has been hit in recent years, and ceiling damage has been reduced almost 100%. Some of their older style single-beam detectors are false triggered by birds and heavy rain and snow, but the newer dual-beam units have essentially eliminated the problem. They recommend the **dual beam units** made by **Trigg Industries**. The best way to contact the vendor is by mail, phone, and/or at www.TriggIndustries.com. Virginia DOT follows standard traffic engineering practices on spacing the units and warning signs. There is no particular reason why the system is not implemented widely in the state.

Washington:

The state has two vehicle height-detection/warning systems to prevent collisions with low-clearance bridges. One system is at the 13th Street Bridge on I-5, and the other is at the Snohomish River Bridge on SR 529. Both systems are **active**; they trigger **flashing beacons** and, for the I-5 bridge, **a variable message sign (VMS)**. Both systems are made by **Trigg Industries**. Infrared beams across the roadway detect overheight vehicles and trigger the flashing beacons, alarm bell, and/or VMS. The system is hard-wired to the existing AC power service. WDOT estimates a very slight reduction in bridge collisions and infrastructure/ maintenance costs, and the systems have been false triggered by birds and, during rainy periods, spray off legal-height semi-trucks. **Granted the system is not perfect, it can reduce potential bridge hits**. The best way to contact Trigg Industries is by phone to its representative. The manufacturer's recommendations for standards and regulations are followed. One official observed: "Better would be a system in use with autonomous trucking, where it could take over control of the truck, slow it down and make it exit. Until then, we will keep having over-height hits."

Wisconsin:

Wisconsin Department of Transportation (WisDOT) has very few problematic locations, and one system was recently removed with construction of a new bridge. It takes a passive approach, generally using **signage**. A **nonrigid hanging beam** was once used, but the structure is being replaced. The respondent did not know how the system is powered. It is hard to quantify any reduction in the percentage of bridge collision and infrastructure/maintenance costs. Their permitting system has done a good job of identifying overheight loads and keeping them off restricted height routes. The system has not false triggered, and it works for them. WisDOT has spent time and resources *raising low-clearance structures* and identifying those that remain to route traffic. WisDOT owns and maintains the system. There are no regulations and standards in place that WisDOT has to follow for installation and operation. Wisconsin's *Bridge Vertical Clearance Trip Planner* allows truckers or tall vehicles to input their height and route and see what low clearances will be in the way; see http://www.wsdot.wa.gov/data/tools/bridgeclearance.

Wyoming:

Wyoming has only one installation, an **active** system, in place to prevent collisions with low-clearance bridges. The respondent could not say whether the DOT has a preference. Once **detectors mounted on steel poles** identify an overheight vehicle, they trigger an **overhead DMS** advising the vehicle to exit. The system uses 120VAC. Percent reduction in bridge collisions and infrastructure/maintenance costs is unknown. The bridge in question has been hit once since the installation. Others have observed the system working correctly, but whether it has false triggered is not known. The respondent had no opinion about recommending it to other DOTs and did not know the best way to contact the vendor, **Trigg Industries (Model 3400-Z)**. No standards and regulations for installation were known.

2.3 RESULTS FOR DOTS THAT HAVE NOT IMPLEMENTED SYSTEMS

Alaska:

Alaska does not currently have a vehicle height-warning/detection system but did have an active system, *Trigg Industries Z-Eye Overheight Detector*, which was turned off and will be permanently removed and replaced with a passive system. The University of Alaska-Fairbanks in collaboration with a local industry expert conducted a study on the underperforming system and recommended improving it, but the idea did not receive department-wide support. They determined that a rigid system and such systems as hanging chains could require frequent maintenance due to strikes and damage and the possibility of creating debris on roadways. The state's low-height structures are on the largest highway, which has no alternative routes, so properly permitted overheight loads would have to bypass the passive system in some way, creating the need to construct bypass roads. Instead, they opted to build a system that included large overhead and ground-mounted signs, markings on bridge girders, moving low-bridge-ahead markings, and static warning flashers in an effort to increase awareness. The old active system was AC powered. There was little-to-no information on whether it reduced bridge collisions and infrastructure/maintenance costs; it was quickly turned off due to false calls triggered by heavy rain and snow and missed detection. With needed improvements, perhaps it would have been recommended to other DOTs. It was from a well-established vendor, *Trigg Industries*, which can be contacted through their website and by phone. The state DOT official stated that the troubled history of unreliable and inaccurate system integration led to lack of support from maintenance and operations (M&O) staff and budget tightening led them to favor the least expensive alternative. They were not aware of standards and regulations for installing the old system.

Arkansas:

Arkansas has no system, and as far as it was reported, no one has shown any interest in developing or maintaining one.

Arizona:

Arizona has no system. It used the banger-beam system, but after many complaints from the public, it was abandoned.

California:

Caltrans has no system. All overheight loads must have permits to travel on state highways, and the permit writers then route them to avoid the low-clearance structures. Overheight loads are not allowed off route. In addition, all bridges below 15’6” have signs warning drivers about the actual clearance.

Connecticut:

Connecticut does not install/use permanent vehicle height-detection/warning systems. They use temporary systems on rehabilitation projects when various operations (painting, fascia/façade repairs) might encroach on the vertical clearance. The one permanent facility is simply a metal bar set dangling from chains at the opening of a covered bridge where the speed limit is 10 MPH. The state did a study on these systems in the early 2000s, bringing in some manufacturers, but felt that the level of accuracy and consistency (e.g., when frost heaves affected bridge clearance) was inadequate, and the amount of effort needed to recalibrate for resurfacing projects was another deterrent.

District of Columbia (DC):

DC has not implemented a system to prevent collisions with low-clearance bridges and would like the team to share the results and any recommendations of this study with them.

Indiana:

Indiana had no systems. It looked at them in the past but could not find one that worked well.

Idaho:

This state DOT does not have a vehicle height-detection/warning system to avoid collisions against low clearance bridges.

Illinois:

Illinois had a system in the Chicagoland area about 30 years ago; at that 40-MPH location, most truck drivers either completely ignored the signs or couldn't stop quickly enough, so officials doubt that signage can prevent overheight vehicles from hitting bridges. A new grade separation project in Bensenville, just outside of O'Hare airport, required placing a railroad bridge at only 12' 6" clearance for several months while the track work was completed. When the railroad was moved up onto the bridge, the roadway below could be lowered to accommodate normal trucks. After months of outreach to the trucking industry and hundreds of signs, including changeable message signs warning trucks of the need to detour, *numerous trucks hit the bridge in the few days that the roadway was left open*. The respondent stated: "If trucks drivers are going to ignore signage, not sure much can be done to physically prevent them from hitting the bridge."

Kansas:

The state reported that it does not have a system because of the costs associated with implementation and maintenance. However, it reported that Kansas Turnpike Authority (KTA) uses a warning/height detection system at each of their points of entry due to the low clearances throughout their system. A contact person for more information was mentioned with this reporting.

Kentucky:

Kentucky does not have a system in place but reported that the Kentucky Transportation Cabinet is in the process of ordering and installing new vehicle height-detection/warning system equipment. A contact person was recorded with their response.

Maryland (SHA District):

Maryland's SHA district does not have a stationary vehicle height-detection system but requires a vehicle to travel ahead of a truck carrying a permitted overheight cargo. A vertical pole set to the height of the cargo is attached to the vehicle's bumper, and as it passes under each bridge, it confirms whether the cargo will hit the bridge. State law imposes a penalty on any vehicle that hits a bridge due to negligence on the part of the hauler. Since insurance companies do not pay penalties for negligence, the monetary penalty has to be paid by the owner of the hauling company. The aim is to encourage haulers to be more diligent in loading, securing, and ensuring the safe height of their cargos.

Michigan:

Michigan has no system but is working to implement an active system in the near future. It will use infrared beams to detect when overheight vehicles pass through its influence area and signal the driver via a message sign, possibly an alarm bell, and possibly lights. The DOT will evaluate the area to determine if it is desirable or possible to run power to the system or if solar power is the best option; quotes were requested and received for both scenarios. They are aware that snow build-up on the top of the trailer and other weather conditions can cause false triggers. They have been working with **Trigg Industries, LLC**, through its website, www.triggindustries.com, and a consultant was contacted. The respondent was not aware of any regulations or standards, but system installation might result in future standards.

Mississippi:

The state has not experienced many bridge collisions, and the DOT was unaware of these systems. It tackles the problem by enforcing vehicle-height permits. A vehicle with a permitted high load is usually required to carry a height pole when in operation.

Montana:

With low traffic and few grade-separated crossings, Montana DOT does not need detection systems.

Nebraska:

The state uses the **typical early warning signs**. Overheight collisions have not been a substantial problem, and the cost/benefit ratio is prohibitive.

New Hampshire:

The state has **signposts** in place for any bridge without at least one additional foot of clearance over the legal height of 13’-6”. One town-owned bridge has a **clearance bar** mounted ahead of the bridge.

New Jersey:

The state is not aware of any vehicle warning/height detection systems.

New Mexico:

New Mexico has never considered using these systems.

Ohio:

Ohio DOT (District 8) has no vehicle height-warning/detection systems. It has had guidance in place for a long time that when a deck, superstructure, or bridge is replaced, it *must be raised to current standards*. ODOT follows this stipulation fairly closely, and the number of state system bridges below the legal limit has been reduced to only a couple under 13.5 feet. Overheight impacts used to occur monthly but now only a couple of times a year. They also have a fairly good system of overheight permits that haulers can use if their loads are over the minimum height of 13.5 feet.

Pennsylvania:

Pennsylvania DOT has found any system cost-prohibitive, when installation and maintenance are included. It uses an automated online permit system to ensure accuracy; if an overheight vehicle hits any structure, it checks for the driver’s permit. Usually the offender does not have a permit or is not following its terms.

Puerto Rico:

Departamento de Transportacion y Obras Publicas (DTOP) does not have a height-detection system because they do not have the funds to install and monitor them. They really do not have a problem with low-clearance structures on major highways; they post the heights, and impacts are generally due to vehicles violating the legal height limit.

Rhode Island:

Rhode Island DOT feels that highway signage, posting vertical clearance on the bridge structure, and its oversize vehicle permitting process are adequate to prevent bridge impacts.

South Carolina:

South Carolina DOT does not use any type of vehicle height detection/warning systems for low clearance bridges.

Texas (other districts):

Though TXDOT has a few detection systems around the state, it does not have a formal program. Overheight impacts are a problem, and they are exploring different options to minimize it. A major hurdle to using detection systems is the sheer number of bridges around the state and the wide variety of vehicle types doing the damage. With warning systems that use flashing lights or 6 alarms, drivers often don't know who is being notified, and other vehicles may slow down or stop, creating another hazard. TXDOT is aware that some states are looking into in-cab warning systems that go only to the driver who sets them off. They are interested in our research team's findings, but many hurdles remain before they can move to a statewide program of overheight-detection systems.

Utah:

The Utah DOT does not have any warning systems implemented.

Vermont:

Other than **signage**, Vermont has no systems in place. The respondent is aware that they were once discussed in relation to a municipal covered bridge, and he believes the cost of installing and maintaining them was the reason they were not implemented.

West Virginia:

The state has no system; collisions with low-clearance bridges are not a significant problem.

CHAPTER 3. EXPLORATION OF THE AVAILABLE, STATE-OF-THE-PRACTICE TECHNOLOGIES AND AUTOMATED DEVICES FOR MITIGATING OVERHEIGHT VEHICLE COLLISIONS WITH BRIDGES

3.1 IDENTIFICATION OF SYSTEMS, DEVICES, AND THEIR VENDORS

The task of identifying available devices involved an extensive internet search. Later, the research team followed up by contacting the vendors of the systems to obtain more information about their products. Researchers carefully designed another short survey and emailed it to all the identified vendors, using contact information collected from product websites. Most of the responses have been received, but for unresponsive vendors, we used recorded phone calls asking the same questions that were included in the emailed survey. After the calls were made, the information was transcribed for this report.

The survey asked questions about cost, implementation, maintenance, and potential faults in the systems, such as false warnings. In the initial stage, a total of 44 warning systems were identified (see Appendix A for detailed information on the systems). However, after contacting some of the vendors and obtaining details about their products, we eliminated 5 systems as inappropriate and not aligned with the main purpose of the study. At this time, 2 vendors have not responded to our emails or phone calls, and the products of 2 others are in the research, development, or testing phase, so not enough information is available to include them for consideration. The team has been making efforts to obtain relevant information from all the vendors initially surveyed to continue assisting GDOT in selecting the best systems.

3.2 OVERVIEW OF WARNING SYSTEM INQUIRIES

After identifying relevant systems and vendors from online sources, the research team compiled the needed information into a list of questions. Vendors, manufacturers, or technical personnel who might be involved in sales with the respective companies were contacted. The findings are compiled in the next chapter to inform recommendations to GDOT-OBD.

The researchers asked vendors:

- Can you please describe the vehicle height-detection/warning systems offered?
- Are they currently being used anywhere else in the world?
- If they require power, what are the source options?
- What do your systems cost per single unit (to protect a single bridge) and as a bundle (to protect several bridges)?
- What kind of maintenance is needed, and what does it cost? Will it be necessary to contract with the company, or can it be accomplished by GDOT?
- Do the systems come fully assembled, ready to be deployed and used by GDOT, or must they be installed by outside sources?
- If specialized installations are required, does the company provide them? If so, what will they cost?
- Do the systems have any installation limitations, such as a special mounting structure?
- Are the systems highly sensitive? Will rain, snow, birds, or debris cause them to trigger?
- If the systems contain warning signs, what are their main characteristics, including their dimensions?
- Does the company provide brochures or white papers containing more information about the offered detection/warning systems? If so, would you please send them to us?
- Must these systems comply with any standards and regulations?
- Is there are any other relevant information not covered in the above questions?

3.3 PRODUCT CLASSIFICATION BASED ON VENDOR DATA

All US and most foreign vendors could be reached; some did not respond. Some companies let us know their system would not fit GDOT needs. Responses ranged from providing exactly what was expected to not answering anything and sending us questions about the research. Tables

1-5 summarize our findings. The next chapter provides more detailed information, and it is compiled in a large table included in Appendix A.

TABLE 1
Multibased systems (part one)

No.	Product Name	Vendor	System Type	Cost	Maintenance	Power Supply
1	**ELTEC Warning and Caution System**	**ELTEC**	When a cable suspended over the road is struck, it triggers a sound that alerts the driver; a solar-powered wireless system initiates flashing beacons when red/infrared beams are broken	Sold in Texas. The cost of the beam detector has gone up considerably in the past few years—little to no competition from supplier. One case study = $24,667; Another case study = $14,108	GDOT could easily maintain; requires only an annual inspection, and if DC, a battery must be replaced every 5+ years.	All OH systems have been DC/solar powered, but ELTEC can and does manufacture AC systems. It specializes in solar-powered wireless systems.
2	**Softstop Barrier System**	**Laservision**	Produces a pseudo holographic image, such as a stop sign, that instantly blocks the lanes with the illusion of a floating solid surface	---	---	---
3	**Height Detect 8000**	**SCACO**	Stand-alone system detects height, warns driver, and records data	---	---	---
4	**WATCHMAN Collision Avoidance Systems**	**Q-saq,INC.**	Overhead clearance bar triggers a siren and flashing lights when hit; currently used for parking facilities	$700 for AC powered; $600 for battery powered	No maintenance beyond replacing the batteries, which average ~$40/year. Uses 8x standard C batteries.	115V AC and battery power. WATCHMAN uses standard alkaline batteries that normally last 2 years.
5	**Overheight Vehicle Detection System**	**Trigg Industries International**	Detectors, warning signs, alarms, mounting poles, and accessories	From ~$5000 for the simplest traffic models to ~$15,000 for the most complex	Requires little maintenance assuming correct installation. Since alignment is affected by vibration and gravity over time, they provide instruction for onsite alignment. Otherwise, source and detector eye lenses must be clear of dirt, dust or any substance that obstructs the LED light from leaving or entering.	120V AC is standard, but 230V AC or 24V DC (solar application) can be made available for specific project needs
6	**Overheight Vehicle Detection System**	**International Road Dynamics Inc.**	Sensor technology with optional signs and video	~$25,000	Annual maintenance to check that the sensors are aligned properly and that transmitter and receiver eyes are not obstructed. GDOT can be trained to maintain the systems. Estimated cost of maintenance is $5,000/year.	115V AC, +/- 10%, 50/60 Hz. Other options include 24V DC solar or 230V AC, +/-10%, 50/60 Hz operation.

TABLE 1
Multibased systems (part two)

No.	Product Name	Vendor	System Type	Cost	Maintenance	Power Supply
7	**Overheight Detection System**	**Hi-Lux Technical Services**	Includes a remote unit that detects the vehicle travelling in the defined direction and wirelessly transmits the detection to the sign controller	---	---	Power supply requires 240V AC. Sign wattage is 75W. Detector wattage is 20W.
8	**Overheight Detection and Barrier**	**FutureNet Security Solutions**	Overheight detector, warning signs, and, in some applications, a height restrictor. The overheight detector can be radar beams, long hanging tubes, and/or chains that create noise when they rub the top of the vehicle. The radar detects the oversized vehicle and sends an electronic warning to the LED caution sign, which will light up with the appropriate warning to alert the driver of the danger ahead.	---	---	---
9	**Overheight Detection Monitoring and Control System**	**Applied Information**	An early warning system comprised of a laser beam detection system, warning signals, and integrated CCTV cameras. The Glance Status Monitoring System manages all units in operation.	Depends on whether drivers are warned by flashing beacons or a DMS sign	Very limited maintenance needed; GDOT can contact the maintenance provider very easily.	12-36V DC or AC
10	**Vehicle Detector Measure-in-Motion ®**	**Betamont**	Measures moving vehicle parameters without any speed restriction on the road or motorway.	Depends on project requirements	Maintenance must be performed by authorized personnel, and Betamont can provide training	Needs local adaptation to US standards
11	**BlinkerSign® High-Speed Overheight Warning System**	**TAPCO**	Detects overheight vehicles, which triggers LED BlinkerSign® to warn drivers in all weather conditions.	Signs - $1,500 each; post and mounting - $500 each; high-speed sensors – total system quote: $25,660	system should be checked every 4-6 months	Can be solar powered; 110 V would have to be wired to direct connect box
12	**Low-Bridge Warning Overheight Vehicle-Detection System (OVD)**	**SWARCO**	Infrared beams and an inductive loop to detect vehicle presence and height; a high-speed radio signal sent to a sign activates the warning message	~£20K per approach. = ~$23,044	A health check and clean every 6-12 months. Cost ~£1000 / bridge = $1,152.18	Always mains power supply, a part-time mains would also work through battery backup and charger.

TABLE 2
Signage Systems

No.	Product Name	Vendor	System Type	Cost	Maintenance	Power Supply
1	Clearance Signs	Safety Sign	Specializes in sign printing, manufacturing, and sales. Has a line of signage specifically for low clearance.	Price varies with sign options	---	None
2	Height Clearance Signs	Grainger	Distributor of facility maintenance products and solutions. Has a line of signage specifically for low clearance.	Price varies with sign options	Maintenance varies depending on the material.	Signs - Power not needed
3	Low-Clearance Signs	Road Traffic Signs	Traffic sign manufacturer and distributor. Has a category dedicated to low clearance.	Price varies with sign options	---	---
4	LED Highway Blank Out Signs	Signal-Tech	Wholesale manufacturer of directional LED signs and signals	---	---	Redundant power supplies. 120V AC power supply, optional low-voltage available.
5	Low-Clearance Signs	Custom Products Corporation	Wholesale manufacturer for custom bridge signs	---	---	None
6	Warning Signs	Maneri Sign Company	Automated manufacturing facility offers a streamlined and cost-effective solution to all signage needs.	Contact for quote	---	None

TABLE 3
Systems in/on vehicle

No.	Product Name	Vendor	System Type	Cost	Maintenance	Power Supply
1	**Autonomous Emergency Braking Systems**	**Nufer and Associates**	Built-in braking system to stop vehicle without operator intervention in case of an unforeseen emergency, like low clearance	$2,000	---	---
2	**GiraffeG4 Overhead Collision Avoidance System**	**Wheeling Truck Center**	An aerodynamic sealed sensor unit measures the height of an overhead hazard and sends a read-out to the In-cab unit to alert the driver	$199.95 (current sale price); $299.95 (original price); price can be discounted with a bundle purchase	Little maintenance; 1-year limited warranty.	powered by the 12V system in the vehicle in which it is mounted
3	**Overhead Clearance Assist**	**Bosch - Invented For Life**	A dash video insert that will sense car utensils and measure and detect the height of the vehicle even if it changes with load. Displays height, compares it to any approaching obstacles, and warns the driver.	IP cameras normally cost under $1,000 without installation costs.	A dome camera installation, which requires some programming; many local installers; Vihon Associates could help with install.	Supplied with 12 V DC or 24 V AC with step down transformer or power supply
4	**Copilot Truck**	**Copilot Mobile Navigation**	Multivehicle navigation technology company with different systems for cars, RVs, and trucks.	$149.99	---	---
5	**GPS Technology Bridge Avoidance System**	**Bridgestrike**	GPS system compares the registered vehicle height and a preset GPS device with bridge heights to see if the vehicle is too tall and warns the driver	Follow up with vendor	Follow up with vendor	Follow up with vendor

TABLE 4
Camera-based Systems

No.	Product Name	Vendor	System Type	Cost	Maintenance	Power Supply
1	Overheight vehicle detection system EDS	Isbak	Automatic system to detect vehicles violating height limitations and then warn them to help prevent accidents	R&D	R&D	R&D
2	Piezoelectric transducers	*Study done	Transducers are placed in girders before casting for detection, camera is activated to photograph truck	*Study Done	*Study Done	*Study Done
3	Fixed Plate Hunter - 900	ELSAG North America - A Finmeccanica Company	Camera system allows the user to capture and record images of license plates; can be mounted and records speed	Each camera is priced at $8,950 but requires a Field Control Unit ($7,495), which can manage up to 4 cameras at a max distance of 255 feet. Camera cables range from $260 for 5 feet to $2,145 for 255 feet. The systems also require a $1,275 Operation Center Licensing Fee per camera.	Purchase price includes a 1-year warranty on hardware and software and offers optional warranty plans that range from roughly 10-20% of the purchase cost. Software warranty program ($995 per year per camera)	Power supply requirements are 10-18V DC (2 A); 22 W (35 when internal heater is on). Typically tap into 120V but have created systems using solar power
4	3M Fixed ALPR Camera	3M	A license plate camera recognition system. Captures license plates of vehicles in high-traffic areas	A list cost of $9,000 per P392 camera; $11,000 per P492 camera. Single termination boxes cost $1,300, and mounting brackets are $850	$1,100 per year for the P392 and $1,500 per year for the P492 (remote)	The cameras are connected to termination boxes that operate on 15V or 48V

TABLE 5
Laser-based Systems

No.	Product Name	Vendor	System Type	Cost	Maintenance	Power Supply
1	**Over-height detectors (HISIC450)**	**Sick - Sensor Intelligence**	Photoelectric switches that can be triggered; reliable stop and alarm signals	Quote on request	Clean the screens of the transmitter and the receiver when soiled. Screw connections checked once a year. In the device variants HISIC450-P and N, the transmitter can be switched off via the test input to check the function; and the soiling output signals when light reception is no longer optimal. In device variant HISIC450-R, the relay can be set to pick up or drop out for test purposes using a delay-mode adjusting screw.	HISIC450-R250: 24 ... 240V DC HISIC450-N250, HISIC450-P250: 10 ... 60V DC
2	**TIRTL**	**CEOS**	Infrared detector consisting of a transmitter and receiver unit mounted on either side of roadway/driveway at the required height	~$19,000	Very little	12V DC and ~6W (total)
3	**La-Ra-OHVD**	**City College of New York**	Laser ranging system mounted on the low-clearance structure to measure the height of on-coming traffic and compare it to its own height and the clearance height	Testing stage	Testing stage	Testing stage
4	**Overheight Vehicle Detector System**	**Coeval Limited**	Monitors traffic with 2 infrared light beams on poles on opposite sides of the road.	$13,468.20	Can be sourced independently; sign-case construction; maintenance free, powder-coated aluminum	Mains, solar, and solar/wind powered
6	**Vehicle Overheight (Maximum Height) and Position Detection System**	**Comark**	A laser scanner detects overheight vehicles and their distance from the sensor; 3 models	RAM 20 - $2,735.16 RAM 100 - $3,647.04 RAM 200 - $5,128.65	Depending on installation site, the laser scanner front protection. Must be cleaned every 6-12 months. No other maintenance needed.	Power consumption of 7.2W (600 mA @ 12 V DC). May be powered with a solar panel and battery. Depending on the installation site, a 50-80 Ah battery and a 80-100W solar panel are needed
7	**SAM - Sensing and Activating Module Laser Sensor for Vehicle Detection**	**SCHUH & CO.**	Laser system for overheight detection	~$12,000	Cleaning of the optical parts (SAM lenses and reflector) is recommended at least every 6 months	Power supply requires 24V +/- 10%. Power consumption requires 100mA. Heating power supply requires 24V +/- 30%.

No.	Product Name	Vendor	System Type	Cost	Maintenance	Power Supply
8	IT-B Overheight Vehicle Detection and Warning Systems	FETNLASER	A double-beam laser scanning system sends a signal to an LED display with alarm to alert overheight vehicle driver and guides the vehicle to bypass	Quote on request	Installation and maintenance are very simple, see manual for details	Power supply: DC12V
9	CMP51 and CMP52 Laser Radars	Noptel Oy	Single beam laser radars CMP51 and CMP52; eye-safe sensors used in fixed and portable systems to measure approaching and departing vehicles.	Vary by quantity; see detailed narrative	Sensors are maintenance free. In dusty conditions occasional cleaning of lenses may be required.	10-30 V

CHAPTER 4. COMPILED DATA ON EXISTING WARNING SYSTEMS

4.1 PREFERRED ATTRIBUTES

After discussions with GDOT-OBD staff, the research team created the following list of preferred system attributes to guide the requests for more information from vendors and manufacturers:

- What power source is needed (battery/solar)?
- How much does it cost over the life-cycle, and how effective is it?
- Is any assembly required? What do assembly and installation cost?
- How is the product delivered? Is any subcontract needed?
- How much and what kind of maintenance is required, and what does it cost?
- Is it an off-the-shelf system? Is it used by any other DOTs?
- Can it be combined with any passive system in a multibased system?
- Is there a way to limit GDOT liability?

The narrative information on these warning systems was collected from vendor responses and websites, brochures, and technical documents. We focused on cost and assembly/installation data. To correlate the data obtained from both surveys, the team continued to contact selected state DOTs and manufacturers for more in-depth technical and economic information on overhead clearance detection/warning systems. In some cases, the manufacturers were asked about the system's capacity to detect objects moving at various speeds (between 1 and 100 MPH) and how particular environmental conditions, such as extreme temperatures, humidity, fog, rain, snow, or flying birds or insects, would affect the normal operation and response of their units. Material costs were another important variable. Depending on the vendor or manufacturer, data included some implementation results, such as efficiency after installation, checkup frequency, maintenance process and cost. Likewise, installation costs, whether in-house or by subcontracting with a third-party, were determined for some products from information exchanges with vendors.

4.2 DESCRIPTIVE ANALYSIS OF VENDORS AND ATTRIBUTES

This technical information on warning systems is in alphabetical order by vendor, with its location in parentheses. Appendix B presents more details about each product.

3M (US)

- The **3M Fixed ALPR Cameras** (+P392) and (+P492) are connected to termination boxes that operate on 15V or 48V. The list cost of the +P392 is $9,000 per camera, and the +P492 is $11,000 per camera. Single termination boxes cost $1,300, and mounting brackets are $850. Management software prices ranges with the specific use. Annual maintenance is recommended to clean lenses and confirm alignment, and 3M offers remote maintenance for software and firmware updates. Remote maintenance costs are $1,100 per year for the +P392 and $1,500 per year for the +P492. Onsite service charges for cleaning and alignment by a third-party provider are based on location. The cameras and associated hardware should be preconfigured prior to deployment. The company recommends that a 3M technician be on site for installation training and commissioning. Once installers are trained, they should be able to deploy the systems without 3M oversight.
- **3M field training** costs $1,800 plus a $1,100 travel fee. Alternatively, customers can install the hardware to factory specifications, with a 3M technician on site for commissioning only, which costs $1,300 per 5 cameras plus a $1,100 travel fee. Authorized value-added resellers (VARs) offer turn-key installations. The universal mounts allow the cameras to be installed on most structures; the only limitations are the angle and distance to plate. The cameras operate like infrared flashlights with cameras attached to them. They take photos when a reflective license plate comes into the field of view but are not triggered by nonreflective items. The camera does not come with warning signs. The system does not have to comply with any standards or regulations.

Applied Information (QuickLook Technology, US)

- **A Georgia-based company**, Applied Information provides traffic systems related to intersections, pedestrian safety, preemption, and priority systems. Many are deployed in Georgia and throughout the United States by QuickLook Technology. However, Applied Information has only installed a couple of overheight-detection systems for the South African National Roads Agency Limited (SANRAL) with a local partner. They can provide warning beacons with a physical sign displaying a warning message, or the client can purchase a DMS and customize the message. The early warning system includes a laser-beam detection system, warning signals, and integrated CCTV cameras.
- **The *Glance Status Monitoring System*** manages all units in operation. The cost depends on how drivers are warned: with flashing beacons or a DMS. The power supply is either a 12-36V DC or AC. Maintenance is low and can done by GDOT or a third party, if needed. The system comes ready to deploy but does not include poles and structures. GDOT can install it, or Applied Information can install the equipment and hire a contractor to install the poles and structures. The DMSs comply with National Transportation Communications for Intelligent Transportation System Protocol (NTCIP) codes.

Betamont (Slovakia)

- **Measure-in-Motion® Vehicle Detector** measures a vehicle's parameters as it moves at any speed on a road or motorway. The overheight-detection system has been installed before tunnels on motorways throughout Slovakia. It comprises systems for dynamic weighing, measuring height and speed, and cameras. The power source is based on local law; their system uses one-phase, 230V, 50Hz mains with a backup battery.
- Cost depends on project requirements. Maintenance must be performed by authorized personnel, and Betamont can provide training. Unfortunately, it does not know GDOT's exact requirements, terms, and conditions. In general, their system can be installed by

authorized personnel. It needs a Π-shaped gantry over monitored traffic lanes or poles on both sides of the road. Anti-false-triggering algorithms are applied for element sensitivity. The dimensions of signs and the symbols on them depend on project requirements and local laws and standards. The system must also comply with standards for electronic devices installed on roads; their systems follow EU standards but can be adapted to local standards and regulations. More information can be found on the company website: http://www.betamont.sk/PDF/ISD_eng/mvv.pdf.

Bosch (Germany)

- The **Overhead Clearance Assist** stereo video camera is inserted on the dash, so it can record exterior car utensils and measure the vehicle's height even if it changes with the load. The device displays the height and compares it to any approaching obstacles with which the vehicle might collide and warns the driver. The system provides:
  a. autonomous emergency braking as described in the recently announced Memorandum of Understanding (MoU) of some automotive original equipment manufacturers (OEMs) for vehicles sold in the United States and recommended by the National Highway Traffic Safety Administration (NHTSA) and the Insurance Institute for Highway Safety (IIHS);
  b. lane-departure warnings (LDW), also mandated by NHTSA tests, and lane-keeping support (LKS); and
  c. functions like speed-limit assistance based on road-sign detection and several others.
- Cameras are designed to be powered by a 12V DC or 24V AC down transformer. They normally cost under $1,000 without installation and require no assembly. As dome cameras, their installation requires some programming, but it is used in many other applications and does not demand extensive training. Bosch would not send someone to install it, but Vihon Associates can help in locating local installers. It has limitations under heavy weather conditions. The system is designed to comply with several

automotive standards, including the safety ISO Norm 26262; the AEB and LDW/LKS functions meet NHTSA and EuroNCAP regulations.

- The product is not currently designed to be equipped outside a vehicle. The measurement principle itself can be applied to a product installed at bridges but depends to a certain extent on use. Is it on a high-velocity highway? Are drivers distracted or just unaware of their vehicle's height? At what distance should the warning be applied so that the driver can recognize it and react in time to prevent a collision?

Bridgestrike (UK)

- The UK experiences, on average, 6 strikes per day, and 1 in every 100 results in serious injury and often death, usually to innocent passers-by in cars or on foot. Bridgestrike has been working on the product for over 3 years with an experienced partner from the transportation industry. In the UK, powered devices cannot be attached to bridges due to planning, remote locations without power, too many owners, and no one willing to take responsibility for maintenance and liability. Their device is fitted into high-sided vehicles and verbally and visually warns drivers that they will hit the bridge if they continue. Drivers and transport managers are responsible for ensuring they do not collide and will face prosecution if proven to be at fault, which can cost the company its operator's license or huge fines that could put it out of business. The device also acts as a "black box"; its data can be downloaded to assist the court in deciding where the blame lies.
- **The Bridgeclear Avoidance System** (http://www.bridgeclear.com) is vehicle-based and requires no infrastructure. Vehicle location is compared to known locations of bridges, and audio-visual warnings increase as drivers approach one at or lower than the vehicle's height, so they are not distracted by unnecessary warnings and can take action early enough to avoid collisions. To operate in US areas, the company would have to construct a database of bridge and other low-clearance structures for use with a GPS.

CEOS (Australia)

- **TIRTL** information was provided by CEOS and its US distributer, Control Specialists, in Winter Park, Florida. They have installed vehicle data-collection sites (ATR) using loop/piezo-based recorders throughout the GDOT highway system and TIRTL systems in Illinois, North Carolina, Colorado, Utah, and Florida-Walt Disney World. The TIRTL is a low-power, infrared detector consisting of a transmitter and receiver unit mounted on a pole or gantry on either side of a roadway/driveway at the required detection height. It uses 3G, serial, or Ethernet communications. It can determine the lane that the vehicle is detected in, and status alarms and a heartbeat ensure the device is working. Australian state enforcement agencies use it at ground level for safety camera, toll audit, and heavy vehicle enforcement programs. They have installed overheight detectors in Australia, Europe and the Middle East. Interfacing with a US system usually requires the most discussion.
- Typically, systems use either a direct serial stream over Ethernet, a Modbus interface (TIRTL supports both), or a contact closure via something like a Moxa device. The system does not include signage, but some industrial PC or Modbus hardware can be installed between the TIRTL sensor and output message boards. Overheight systems that drive variable message boards typically have TIRTL requires 12V DC and approximately 6W total and separate power runs to the transmitter (12V DC at 1W) and receiver (12V DC at 5W). In remote locations, it is typically powered by a 140W solar panel and 48Ah batteries. It costs $14,430, less accessories. A TIRTL riser and L-bracket (pair) are $510; install fittings are $2,180; additional items, such as power supply, Ethernet cables, and signal timer, cost up to $825. This price is good for 1-99 units; an additional discount is granted for larger quantities. All prices are "furnish only". TIRTL comes fully assembled, but the installation price depends on the complete scope of work. This vendor quoted us a price of about $19,000 (furnish only, including $750 shipping, taxes to be added).

- The system requires very little maintenance. The lenses on the cabinets that house the TIRTL units must be cleaned periodically, either by department personnel, or Control Specialists can arrange an annual cleaning schedule. It is not affected by weather conditions or dust, but overheight and ground-level sensors can be combined to minimize false-positive triggers caused by debris and birds. There are no regulations it must follow.

City College of New York (US)

- **LaRa-OHVD** is a graduate student research project in the testing stage. It is an active, laser-ranging system that would be mounted on a low-clearance structure to measure the height of the oncoming traffic and compare it to its own height and the clearance height. The graduate student sent a copy of the report with detailed information on the model specifications as well as the performance of pre-2012 overheight vehicle-detection systems. NYSDOT funded the project and is interested in the outcome.

Coeval (UK)

- **ICBridge (**http://www.coeval.uk.com/product/overheight-vehicle-detection) uses two infrared light beams on poles on opposite sides of the road to monitor traffic. When an overheight vehicle is detected, a sign lights up and tells the driver how to avoid the oncoming infrastructure. The system contains wireless and GSM (global system for mobile communication) options to reduce installation costs. The working range is up to 35 meters (109 feet) although 50 meters, or 155 feet, is an option; and message duration is 1-99 seconds.
- In addition to the UK, the system is sold throughout the world, with customers in Hong Kong, Brazil, Singapore, Greece, and Ireland. It is suitable for all road speeds and locations, with vandal-resistant, face-protected LEDs and performance assured. Ex Works (EXW) is an international trade agreement in which the seller is required to make goods ready for pickup at his or her own place of business, but the buyer assumes all

other transportation costs and risks. The EXW Galashiels Scotland price is $13,825.20 to protect a single bridge; for several bridges, the price would have to be discussed.

- It can be mains, solar, or solar/wind powered. Maintenance can be sourced independently. The products come assembled but have to be wired, installed, and commissioned onto posts, although they could be adapted to other structures. Installing validation loops helps to prevent false triggers, which are rare in any case. Documented evidence suggests this system reduces the number of overheight vehicle accidents by at least 80%. Other than removing the obstacle, the system is regarded as the most effective signing measure available.

Cohda Wireless (Michigan, US)

- **MK5-RSU/OBUs** are positioned on the road and inside the vehicle, respectively, to inform drivers of an upcoming interference. The roadside unit (RSU) must be integrated with other systems. In 2012-2013, Cohda worked with an Australian company that was developing a height-detection/warning system. Cohda provided the initial hardware, but the program died; no one confirmed that a system was finalized, and Cohda is not aware of one. The NYC Pilot Deployment team submitted a request for expression of interest (RFEI); an official request for quotation (RFQ) was not expected from Transcore (the NYC consultant) until late September 2016. Trucks have an internal 24V system. The RSU, which would transmit Telstra Integrated Messaging (TIM) about overpass height, would run from a standard line feed. Cohda makes a ready-to-mount RSU; specifications, including power requirements, are provided upon request.
- A single unit runs $1,265 and covers one bridge from one direction. Its range is about 330 yards, so to allow time for the truck to stop, it should probably be mounted 200 yards upstream of the overpass. Pricing for 10-25 RSUs (covering 5-12 bridges) is around $1,000.

- A sample quote: the MK5 alone costs $1,035; less than 10 MK5 OBUs (OnBoard Units), with maintenance that includes tech support and software updates = $1,788; less than 10 MK5 RSUs (including antennas, etc.) = $1,139; with maintenance = $1,890. Maintenance should be minimal as the units are designed to be mounted and run continuously. Some have been in operation for 4+ years with no maintenance needed. The MK5 RSU comes ready-to-mount. To install the MK5 OBU on the truck, they can provide a kit for around $1,500, which includes a magnetic mount antenna for testing, but they recommend a permanent mount antenna for long-term deployment, and do not offer installation. Cohda is essentially a software company that develops applications (as well as the network and facilities layer used on DSRC RF semiconductors). The Tampa Pilot selected the company Brand Motion to integrate vehicle installation, which must follow some basic rules. On a large semi-truck, for instance, the antenna should be on the cab. -range communication (DSRC) signals are omnidirectional, and a clear line of sight is recommended where possible, not so much to prevent false signals as weak signals. A truck passing within 40-50 yards of an RSU would receive the signal even in a downpour. There are no warning signs to their knowledge. DSRC operates at the top end of the Wi-Fi spectrum and is approved by the FCC. Some of the regulations Cohda follows are IEEE 1609, which includes 1609.2, .3, .4 and SAE 2945. Cohda's production software will be developed to SPICE Level 2/3 (ISO/IEC 15504). Cohda and its staff are members of the leading global standards organizations ETSI, IEEE, ISO, SAE, and the Car-2-Car Communications Consortium. They have been central to recent large field trials designed to validate these standards, such as simTD in Europe and the Safety Pilot in the USA.

Comark (Italy)

- The **Vehicle Overheight and Position Detection System** (**RAM ###**) is a laser scanner that detects overheight vehicles and their distance from the sensor. The scanner contains an internal heating system to prevent condensation on the optimal lens, and it filters out such noise as rain, snow, and birds. **RAM 20** has one horizontal laser scanning system; (minimum size of object to be detected: 2 in.; price: $2,735.16). **RAM 100** has one horizontal laser scanning system, two infrared transmitters, and two receivers (minimum size of object to be detected: 2 in.; price $3,647.04. **RAM 200** has two laser scanning systems, vertical and horizontal (minimum size of object to be detected: 0.8 in.; price $5,128.65).

- The system consumes 7.2W (600 mA @ 12V DC) and can be powered with a solar panel and battery. Depending on the site, a 50-80 Ah battery and an 80-100W solar panel are needed. The only maintenance involves cleaning the laser scanner front protection every 6-12 months, depending on location, and it can easily be done by GDOT.
- Shipping follows EXW. The system comes in several parts, depending on the model, and they have to be connected as described in the manual. GDOT can do it. After the installation, GDOT can complete the setup and calibration process following the manual. COMARK can provide remote assistance, if necessary. All of these systems require one pole at least 20 inches higher than the overheight vehicle threshold on the side of the road. The system must comply with laser regulations. All of their laser scanners are CLASS 1 and eye-safe, according to the vendor. All of the systems have internal filters to prevent false alarms. The RAM 20 system is more sensitive to noise but still has a low false alarm rate. The RAM 100 and RAM 200 have a very low false alarms rate.
- They offer warning signs that start flashing when triggered or more sophisticated variable message signs. Their type and dimensions can be customized. The company sent a manual that describes all system functionalities. They have installations in Italy, United Arab Emirates, Kurdistan, and soon Brazil but none in the US.

Copilot Mobile Navigation (US)

- **CoPilot Truck** (https://copilotgps.com/us/truck-navigation/) navigation technology was developed by ALK Technologies, which makes systems for cars, RVs, and trucks. The warning system is an app for mobile devices. The user enters the height, weight, location, and destination of the truck/vehicle, and the system will direct it around low-clearance bridges, choosing a route that is efficient, safe, and the best option.

- Features include customizable route options, load-specific routing, customizable vehicle specifications, offline usage, and GPS updates to assure route safety or changes. Uses official regulations for GPS and truck codes. It costs $149.99.

Custom Products Corp. (US)

- The company produces **warning signs** that call attention to unexpected conditions on or adjacent to a highway, street, or private road open to public travel and to situations that might not be readily apparent. They alert road users to conditions that might call for slowing down or another action in the interest of safety and efficient traffic operations. The signs are in compliance with DOT specifications, and prices vary based on design, material, size, quantity, and installation from $60-$250.
- The information for Custom Product Corporation's Low-Clearance Signs was found on the company's website, so no phone calls were necessary. Their signs can be combined with some of the active systems described and recommended in this section.

ELSAG North America - A Finmeccanica Company (US)

- The **Selex ES Fixed Plate Hunter-900® (FPH-900®)** can be mounted to bridges, overpasses, and other structures to monitor sensitive areas constantly. Cameras, a processing unit, and proprietary software capture images of license plates and cross-check them with Hot Lists to identify vehicles of interest. Alarms are broadcast in real time to a command center and patrolling vehicles for immediate interdiction. Data captured can be reviewed for relevant periods of time to aid investigations.
- The FPH-900 can also determine a vehicle's speed and link it with the license plate. Speed data can be used to create analytical tools that provide valuable traffic statistics, identify traffic patterns, and automatically detect real-time traffic anomalies, such as

jams, stationary vehicles in open lanes, and other dangers. It is a complete plate-reader system for fixed installations, suitable for road traffic control; travel time computation; parking management; access control; and law enforcement

- The all-weather enclosure contains a black and white (B/W) camera with an infrared (IR) illuminator and a color overview camera. It performs on-board image processing using proprietary optical character recognition (OCR) with dedicated digital signal processing (DSP) and provides internet protocol (IP) connectivity. The B/W camera coupled to an IR illuminator accommodates lighting variations from night to full sunlight. For each plate reading, the color camera provides an overview image of the vehicle. The FPH-900 can run in triggerless mode, simplifying installation, or add a trigger for functions like vehicle counting. It can be connected to LANs via a 10/100 Ethernet port.
- Power supply requirements are 10-18V DC (2 A); 22W (35 when internal heater is on). ELSAG typically taps into 120V, but systems can use solar power as well. Each camera costs $8,950 but requires a field control unit (FCU) that costs $7,495. An FCU can manage up to 4 cameras within a maximum distance of 255 feet. Camera cables range from $260 for a 5-foot length to $2,145 for a 255-foot length. They offer a variety of brackets at prices that depend on the mounting infrastructure. Each camera carries a $1,275 Operation Center Licensing Fee. There is no scheduled hardware maintenance required for these products. A one-year warranty on hardware and software is included in the purchase price, and optional warranty plans range from 10-20% of the purchase cost. They recommend keeping the systems in a software warranty program ($995 per year/camera, which entitles the buyer to all future software developments.
- Installation and assembly costs vary based on how much work would require ELSAG’s help. For reference:

- *Project 1* ($11,365): a single camera was mounted on a tripod for portable deployment. The camera plugs into a laptop computer without requiring an FCU. Power was drawn from the cigarette lighter of a vehicle parked nearby.
- *Project 2* ($49,975): 1 FCU and 4 cameras were installed by Selex ES on utility poles using existing guywire to span camera cables over 6 lanes of heavy traffic. Power was already at the location, and minimal traffic management was required (a police car with flashers).
- *Project 3* ($1.6 million/average $94,000 per site): The company managed complete installation of 20 FCUs and 74 cameras primarily on overpasses and sign gantries on major highways at 17 locations. Most sites had 4-6 cameras. The project included all site surveys, permitting, engineering as required by the two authorities that oversee the highways, trenching and site preparation, power installation, coordination with utility companies, conduit runs, camera and FCU installation, aiming, configuration, and all software.

- The distance from traffic and obstructed views are the only limiting factors. The maximum recommended camera height is 25 feet, but most clients deploy them in the 12-20-foot range. The cameras come in 16, 25, 35, and 50-mm focal lengths with a geometrical configuration. For best capture, they recommend one camera per lane, installed over the lane. While cameras are commonly installed on a roadside pole, clients know that a commercial vehicle in the first lane can block camera views of additional lanes. ELSAG uses a weather-tight enclosure, and since there is no trigger in their standard deployment, a false trigger by a bird or animal is impossible. The only possible false alarm is caused by markings near the license plate, especially on commercial vehicles that post “How’s my driving?” or “Call 1-800”. No regulations apply to the technology, but specific applications meet all regulations in the jurisdiction where the product is being built.

- All of their information - white papers, sales kits, and case studies - can be found at www.elsag.com under the Media Center tab in the left menu.

ELTEC Electrotechnics Corporation (US)

- **Warning and Caution Systems** (http://elteccorp.com/warning-systems/) have been supplied to TxDOT in some areas. A cable suspended across the road issues sound alerts when struck, and a solar-powered wireless system using red/infrared beams initiates flashing beacons when broken. The price for the unit is not set at present, but a quote from a 2015 sale came with product specifications and additions. The system can be customized, and the overheight *transmitter* subsystem includes a 3-compartment cabinet with Prostar controller; four 140W solar panels with two racks that can be mounted to poles; four 100-Ahr batteries; and one overheight dual-beam detector with mounting hardware for a 4" pole. The transmitter with all these additions was priced at $12,180. The overheight *receiver* subsystem includes a 3-compartment cabinet with Prostar controller; four 140W solar panels with two racks that can be mounted to poles; two 100-Ahr batteries; one overheight dual-beam detector with mounting hardware for a 4" pole; and one wireless radio with antenna. The package costs a maximum of $12,487. ELTEC supplied a quote for a different system totaling $14,108. They believe all their overheight systems have been DC/solar powered, but they do manufacture AC systems. GDOT could easily maintain the system. It requires only an annual inspection, and the DC battery should be replaced every 5+ years. ELTEC does not do installations and did not mention regulations or specifications.

FETNLASER (China)

- **IT-B Laser Overheight Vehicle Detection and Warning Systems** use a double-beam laser scanning system that sends a signal to an LED display and alarm that alert overheight vehicle drivers and guide them to a safe route. Many have been successfully installed in China. Detection ranges from 50/100/200/300/400/500/1000 m

(155/310/620/930/1240/1550/3100 ft.) determine the price; for example, 50 m (155 ft.) would cost $670. They are powered by 12V DC. A “very simple” manual addresses installation and maintenance, so either GDOT or a third party could handle them. The vender mentioned product protection class IP67 when asked about sensitivity; no false positives have been recorded.

Grainger (US)

- **Height Clearance Signs** (https://www.grainger.com) can be either a clearance bar, signage with exact clearance height, or a simple warning that the upcoming obstacle has low clearance. Price varies with the options, and maintenance varies with the material chosen. Follows guidelines on reflective materials.

Hi-Lux Technical Services (Australia)

- **Radar detectors** are set at the correct height and trigger a warning system; for example, a VMS or flashing lights. Power can be anything from 12V DC to 240V AC. They have installed overheight detection systems only in Victoria and Queensland, and all their systems are built on a job-by-job basis. Maintenance depends on the system; alignment of the radar detectors and general cleaning should be completed on a schedule. They usually mount the radars on at least 100-mm diameter poles. If anything becomes airborne and crosses the radar beam, the system will false trigger. The cost is site-dependent. The basic system consists of one flashing light mounted to a 10-meter wide, full-color VMS on a cantilevered pole across the freeway. Prices vary from $500 to $800,000. The vendor felt our questions were vague, so he could not offer the specifics for a complete “kit”.

International Road Dynamics (Canada)

- The **Overheight Vehicle Detection System (OHVDS)** is a type of sensor technology that includes infrared and visible red light options. It can include a video system that captures images of the vehicle that triggered the device and record the information. It can interface with a wide variety of electronic changeable message signs (CMS) displaying such messages as OVERHEIGHT STOP or OVERHEIGHT EXIT RIGHT. Alternatively, it can include strobe lights, mounted to standard panel highway sign, and triggered to flash when an overheight vehicle is detected. IRD integrated vehicle height-detection equipment as part of its Weigh-In-Motion (WIM) systems across the US and around the world. It also offers stand-alone overheight-detection packages. It supplied height-detection systems as part of its Mainline WIM Sorter Systems to GDOT for installation throughout the state.

- A single system including a single transmitter/receiver pair and downstream signals costs approximately $25,000. A discount may be offered, depending on the number of systems installed under a single contract. Power specifications include 115V AC, +/- 10%, 50/60 Hz. Other options include 24V DC solar or 230V AC, +/-10%, 50/60 Hz operation. The transmitter and receiver are typically mounted on poles on either side of the roadway, and signals or signs must be installed. IRD typically supervises a local electrical contractor, who installs the system. The cost of installation and poles ranges from $25,000-$50,000 depending on the site and equipment options. The system has been installed in a wide variety of environments and has no easily triggered elements. The company provided sensor configuration schematics (a typical drawing showing the layout of the overheight detectors) and the system's specifications.
- Annual maintenance is recommended to check sensor alignment and to ensure that transmitter and receiver eyes are not obstructed. GDOT can be trained to do so, and the estimated annual cost of maintenance is $5,000. Systems meet ISO/IEC Guide 22 Compliance, CE Mark, NEMA 3R Cabinet Enclosure Rating, CALTRANS lightning, and hi/lo voltage parameters.

Isbak (Turkey)

- Isbak's overheight vehicle-detection devices are still in *research & development*. They will be used at tunnel entrances. If an overheight vehicle is detected, the driver will be warned with a VMS posting information about the low-clearance structure as well as traffic density, accidents, weather, and road conditions. An integrated system is not currently available.

Laservision (Australia)

- The **Softstop Barrier System** produces a pseudo-holographic image that instantly blocks the lanes with the illusion of a solid surface floating in the air; for example, a stop sign. There is currently only one, at the Sydney Harbour Tunnel, and it appears when previous warnings have been ignored. It also keeps vehicles out of tunnel during an emergency. The research and development phase focused on:
    - a specialized hydraulic mix based on three decades of hydraulic engineering solutions involving water screens;
    - technical obstacles including, but not limited to, a variable air/mix ratio;
    - critical pressure levels to drive against distortion from wind currents;
    - rapid start techniques (less than three seconds);
    - efficient flow rates and demand-and-catch supply technologies;
    - recycling or limited waste techniques for resource-sensitive environments;
    - critical screen thickness for effective projection avoiding parallax distortion;
    - rapid-response, interlocking projection technologies to compete with opaque surface and daytime use;
    - integration with other safety devices; and
    - monitor loops back key data areas.
- The company did not respond to our emails but mailed us a very extensive package with product details and contact information. They provide state-of-the-art laser light displays; one of their products for tunnels displays a warning image on a “sheet of water”.

Noptel Oy (Finland)

- **CMP51/CMP52** in the **CM5 product class** are new-generation, single-beam laser radar systems for a wide variety of tasks in traffic control and law enforcement. These eye-safe sensors are used in fixed and portable systems for measuring both approaching and departing vehicles. The sensors are small and lightweight; have the high IP rating 67 and low power consumption. The **CM5** laser range finder is mounted horizontally at the desired detection height. The overheight vehicle sensor sends distance information as digital output (open collector FET). Systems like this are used in Finland but not yet in the US. They do not manufacture complete systems but deliver OEM components to system integrators. The CM5 sensor requires 10-30V and a 2.4W power source.
- Noptel Oy would be pleased to provide GDOT with a CM5 sensor for $2099.59 per unit plus $110.50 for delivery by UPS courier service for a trial use in an engineering evaluation. Payment would have to be in advance, and delivery time is 2 weeks after receipt of payment. Delivery includes a 2 m (6.2 ft.) cable, packing materials, and a manual. Since sensors for trial use can come with one of two serial interfaces, RS-232 and RS-422, a LAN and a WLAN interface, the company asks GDOT to specify which interface type it prefers. The additional price for a LAN interface is $142.55 and for a WLAN, $209.96. The additional price for an ER laser component is $177.91. Prices do not include VAT, customs, or other taxes. Below, please find conditions and unit prices in USD for various quantities of CM5 laser sensors:

Unit quantity	1	10	20	50	100	250	500
Price/Unit	2762	2243	2127	1911	1773	1635	1591
Price/Unit	142	116	112	99	93	86	84
(additional price for alternative LAN interface)							
Price/Unit	210	171	166	148	138	130	127
(additional price for alternative WLAN interface)							
Price/Unit	178	144	141	124	117	121	108
(additional price for alternative ER laser component)							

- Sensors are maintenance free. In dusty conditions, occasional lens cleaning may be required but not at this installation height. Either the buyer or a third-party contractor must assemble and install the sensors; installation structures are not included. Sensor sensitivity can be selected so that it only detects the desired objects. Sensors comply with international standards related to optical measurement systems.

Nufer and Associates (Australia)

- The **Autonomous Braking System** is split between the truck cabin and the infrastructure (bridge). Once an incursion is registered, the truck cannot move without special control. Local control is categorized as normal forward, reverse, and creep.

Q-SAQ, Inc. (US)

- **WATCHMAN Collision Avoidance System** alerts drivers of overheight vehicles to a potential collision through a 105db signal and red flashing light. Owners can also receive an alert submitted through a relay output. The product can be powered by 115V AC or batteries. The cost for one 10-foot wide, AC-powered unit is $700 (excluding mounting hardware) and $600 for a 10-foot wide battery-powered unit. Other than replacing the batteries, no maintenance is required. Batteries average $40 annually, and the product uses 8x standard C batteries. No special installation skills are required. It can be assembled by any technician. Mounting hardware is required, and the company recommends hanging the unit on aircraft cables. There are no installation limitations. The system is not very sensitive to elements in the air. It comes completely assembled, with two red flashing warning signs at each end and a 105db signal. The company has 30 years of experience in vehicle detection and provided brochures on the product, which does not follow any standards and regulations. However, it is made for slow-moving vehicles that enter a height-restricted area; it alerts the driver through impact, which might be too late for fast-moving vehicles.

SCHUH & CO. (Germany)

- Two **SAM (Sensing and Activating Module) laser sensors** point across the road to a passive reflector (reflection light barrier). A controller combines their output with signals from inductive loop detectors to generate an overheight alarm. The product is not currently in use anywhere. It requires 24V/3A. The ODS-controller may have a built- in power supply (100-250V AC). For one side of a tunnel or bridge, the user will need 2 SAMs, 1 ODS-controller, 1 reflector plate, and 1 mounting console. Altogether, the product will cost about €10,000 ($11,047).
- Maintenance involves cleaning the optical parts (SAM lenses and reflector) at least every 6 months. The components are ready to be installed. The ODS-controller must be installed in a cabinet. The SAMs and reflector must be fastened on poles, wired, and adjusted, but electrical installation is necessary on only one side of the road. To adjust the SAMs with their invisible infrared laser, a special night-vision system (€800, ~$885) is offered. The SAMs mounting base must be stable enough to ensure that laser beam (10 cm, or 3.94") will hit the reflector on the other side of the road (10/30 m; 32/96 ft.). The SAM can detect small things moving at high speed; it will not detect rain, but birds and heavy snowfall will interrupt it. The ODS-controller software will prevent false alarms; birds will have no loop detection signal, and during heavy snowfall, the system will switch to an error state without triggering an overheight alarm. There are no relevant standards and regulations. The company provides brochures also. (http://www.schuhco.de/en/c13_ods.php?last=c13_ods.php&currentNumber=1.3.2&currentIsExpanded=0).

Sick (Germany, US branch)

- The **HISIC450** monitors the height of vehicles at tunnel entrances, low underpasses, or bridges. Reliable stop and alarm signals are activated when a vehicle infringes both photoelectric switches and then combined with traffic data (e.g., induction loop signal).

Overheight vehicles travelling at speeds up to 100 km/h are reliably detected. The product is powered by direct connection to a current power supply, which is protected against polarity. The screens of the transmitter and receiver must be cleaned, and the screw connections must be checked once a year. Assembly and installation must be carried out by experienced, skilled personnel. Sunlight must not shine directly or reflect on the optics of the receiver. For photoelectric switches used outdoors, an overvoltage protector must be installed because overvoltage caused by thunderstorms cannot be discharged within the devices. To increase reliability, induction loops should be used in addition to the photoelectric switches. The device can cope with rain, snow, or dust clouds due to its wide beam and high signal reserve. The company provided brochures on this product.

- It has a worldwide presence: Australia, Austria, Belgium/Luxembourg, Brazil, Czech Republic, Canada, China, Denmark, Finland, France, Germany, Great Britain, Hungary, India, Israel, Italy, Japan, Mexico, Netherlands, Norway, Poland, Romania, Russia, Singapore, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Turkey, United, Arab Emirates, and the USA. Detailed addresses and additional representatives can be found at https://www.sick.com/us/en/product-portfolio/traffic-sensors/overheight-detectors/c/g284261, and prices can be obtained on request.

Signal-Tech (US)

- This **LED sign and signal manufacturer** does not have a detection/warning system as a complete package but offers sign units that identify overheight vehicles when triggered by other components. A distribution network serves local DOTs nationwide.
- The products can be manufactured to run on line (120V AC) or low voltage (12-24V DC). The cost drivers are type of cabinet (NEMA 4X or NEMA 3R), unit size, voltage required, and the distributor in the region of sale.

- Prices range from $1,500- $8,000, depending on the size of the sign, message produced (text options, image, shapes), number of LEDs, and weather sensitivity.
- The units have a 5-year warranty. There are no moving parts to maintain. The LEDs have a life expectancy of 100,000 hours of continuous illumination. The product comes fully assembled and can be supplied with complete mounting devices. Local distributors can help with installation. Typically the products are mounted to vertical poles, mast arms, or span wires. The NEMA 4X cabinet is weatherproof; the NEMA 3R cabinet offers weather protection. Typical warning signs are 24” square, 30” square, and 36” square. Larger sizes are available depending on the symbol size or text requirements. The company provides brochures identifying the sign types and sizes in hard copy or at www.signal-tech.com. They comply with NEMA standards, and all units are UL- and CUL-rated.

SWARCO (UK)

The **Low-Bridge Warning System** consists of infrared beams and an inductive loop to detect vehicle position and height (below beams, OK; beams broken, too high). If an overheight vehicle is detected, a high-speed radio signal is sent to the sign to activate the warning message, normally one of the messages from the Traffic Signs Regulations and General Directions (TSRGD), with amber corner flashers and stating OVERHEIGHT VEHICLE. The systems are installed widely across the UK. Always uses mains power supply, but a part-time mains would work through battery backup and charger. The cost of the product per single unit is approximately £20,000 per approach (~$23,044). It comes assembled with a sign, controller, beams, and a beam controller. Once fitted on site, the interconnecting cables can be fitted. The infrared beams are not affected by fog, snow, or heavy rain. An inductive loop beneath the beams, cut into the carriageway, prevents false activations by birds. The company provided brochures on the product as well as the standards and regulations that the product follows. The systems are good for arched bridges; the sign directs the overheight vehicle to use the middle of road.

Tapco (US)

- **BlinkerSign® High-Speed Overheight Warning System** contains 24/7 LEDs around the outer perimeter of a sign. Two sensors are further down the road. Radio signals activate the sign. Lasers are at most 50 feet apart over the highway. Some of the systems are in New Jersey and Texas but were bought by someone other than DOT personnel. The product can be solar-powered or power directly to a connection box. It operates on 110V. For high-speed options (45-55 MPH), signs cost $1,500, and the post costs $500. The system must be checked every 4-6 months. The product does not have any installation limitations. The camera option must be run by an engineer. The product has not experienced any sensitivity problems. The modem in the box can send text alerts and emails. The company provided a sales quote to the research team: "furnish only", installation not included, the total is $25,660.

Terrametrix, LLC (US)

- Their terrestrial, mobile **LiDAR scan unit** is mounted on a vehicle to collect horizontal and vertical clearances for bridges. The resulting data is used in database form as a record of minimum clearance for bridges. It can be used to post accurate signs about bridge heights to warn vehicles. The Missouri DOT uses it. It is not a product GDOT can buy, but more of a service. More information can be found at http://www.terrametrix3d.com/
- Cost of the scan per bridge is $120-$175. Rain, snow, birds, and debris will create data points that can readily be removed, but they typically do not scan in adverse weather due to safety issues and the quality of the data, For example, wet shiny pavement refracts rather than reflects the laser energy; snow accumulation provides a false surface model. Birds and debris are not dense enough to mislead the system. The scan system is water resistant, not waterproof. It can be further protected from water, but since they do not

collect data in rain or snow events, it is not a priority. The system has been very durable but must be treated as the precision equipment it is. They adjust the scanners as they wear out, and the inertial measurement unit (IMU) is a fiber-optic gyro with no moving parts. In 6 years of service, only one scanner has failed, and it was 6 years old. The entire system is powered off the vehicle's 12V system. They have installed it on an ATV and powered it with a 12V car battery charging with a portable generator. It takes about one hour to install the system on any vehicle platform, including an SUV, ATV, hi-rail, or boat. The system does not follow any standards and regulations. The lasers are classified as eye-safe and invisible to the human eye. The IMU is regulated by the US government if you take it out of the country.

Trigg Industries (US)

- **Overheight Vehicle Detection Systems (OHVDS)** are deployed worldwide. The devices employ high-power LED source and detector eye pairs in combination with numerous internal electronic circuits to provide form C contact closures to activate alarm devices. The systems incorporate dials that allow the customer to physically set the duration of alarm activation. The standard power option is 120V AC, but 230V AC and 24V DC (solar application) are available for specific project needs. Some models are more complex than others, and prices range from around $5,000 for the simplest to approximately $15,000 for the most complex. The company also provides a variety of audible and visual alarm devices priced separately. The systems require little maintenance if installation was done correctly. As physical alignment is affected by vibration and gravity over time, the company provides instruction for on-site alignment. The only other maintenance required is assuring the source and detector eye lenses are clear of dirt, dust, or any substance that obstructs the LED light from leaving or entering.
- The systems are complete and tested before leaving the warehouse and often sold with appropriate mounting brackets and accessories, but Trigg Industries does not provide

installation. Systems are mounted, wired, and aligned by on-site DOT staff or contracted technicians. They are aligned through the top of the system via a bore sight, so installers must be able to fit their head behind it, which limits the positions available when mounting to the side of a pole or beam. Heavy rain, snow, dust, fog, or any object of as big as, or bigger than, the eyes can obstruct them and cause a false alarm. Infrared LEDs can be used to limit environmental disruption, and Direction Discerning systems are activated only by sequential movement, which helps to prevent smaller objects from causing false alarms. The system does not include warning signs but can be wired to a variety of audible, visual, and. in some cases, wireless alarms that allow transmission or logging of an event. The company often provides specifications and system manuals. As they have many products, they provided a manual and specifications for one system. Their OHVDS have been fielded in the US for over 50 years and are considered standard. They assist in ensuring that all project specification are met, and as these specifications change from area to area, they try to adapt.

Wheeling Truck Center (US)

- The **Giraffe G4 Overhead Collision Avoidance System** is an aerodynamic, sealed sensor unit that measures the height of an overhead hazard up to 20 feet and sends a read-out to an in-cab unit that flashes and beeps to alert the driver. The readout measures 7” w x 2” h. The in-cab unit can be programed by drivers. This system is not installed on bridges but on individual trucks and RVs and costs $199.95 per unit with discounts for bulk purchases.
- It is powered by the 12V system in the vehicle and requires little maintenance. The company provides a 1-year, limited warranty. It is easily assembled. To mount it, drivers must measure the height of the trailer and the height where the sensor will be placed. Easy instructions are included. The system is made for west-coast mirrors with aluminum brackets and comes with a bottom bracket. They also have a magnet mount, and a single-

arm mirror mount for Cascadia-type mirrors. It is up to 80% signal-loss tolerant. It works in any kind of weather because it is signaled by sound waves. As of now, no DOTs are using it. The representative suggested that, to protect Georgia's infrastructure, the state insist that trucks traveling through it have a GiraffeG4 System! They have an informative website, www.giraffeg4.com, with an FAQ page and a whiteboard animation video that explains how the GiraffeG4 works.

CHAPTER 5. RECOMMENDATIONS FOR ON-THE-MARKET OVERHEAD CLEARANCE-DETECTION/WARNING SYSTEMS

This study was designed to enable GDOT-OBD to make informed decisions on the most appropriate single or compound detection systems to minimize tall vehicle collisions with low-clearance bridges. Its significance will be realized in substantially fewer bridge collisions generated by overheight vehicles in Georgia and substantially lower annual repair costs.

5.1 CONCLUSIONS AND RECOMMENDATIONS

From the survey responses collected from other state DOTs and information acquired at the South-East Bridge Preservation Convention in San Antonio, Texas, we observe that many, if not most, state DOTs are looking for a way to prevent overheight vehicles from colliding with low-clearance structures. Our inquiries revealed that most of the states adopting such systems lean toward those produced by ***Trigg Industries***; 12 out of the 24 state DOTs that use warning systems use models produced by Trigg Industries.

Other state DOTs have decided to use a combination of active and passive systems, and most of the passive systems consist of nonrigid elements. Most reported that location characteristics and the geometry of the low-clearance structure weighted their decisions.

Unfortunately, most have not reported or submitted performance data on their systems. Consequently, the research team had difficulties in compiling and evaluating their efficiency. More research is needed to properly evaluate performance. We recommended that GDOT install and monitor one or two of the proposed systems for at least one year before adopting any for widespread use in Georgia.

Based on our literature review and system investigations, we recommend systems with laser-based detectors that can trigger flashing signs. From the proposed options, Georgia DOT should carefully select the most cost-effective system(s) that are least likely to false trigger. The final decision should consider the installation procedures, the best place to locate the system relative to the structure of the respective bridges and road conditions, and the required maintenance protocols. In the near future, investigators should monitor the performance of the system(s) to optimize wider implementation.

5.2 SUMMARY OF RECOMMENDED SYSTEMS

After analyzing information obtained from various vendors/manufacturers in the USA and overseas and communicating with other state DOTs, the research team proposes the systems listed in Table 6 for consideration by GDOT personnel. The main factors were cost, effectiveness, low maintenance, and power supply. As requested, we considered license plate readers since, for certain bridges, capturing license plate information for the offending vehicles is an increasing need. Appendix C presents technical information on the recommended systems based on brochures, manuals, and/or online information gathered by the researchers and their assistants. The team will share any other technical information needed to further assist the selection decision upon request.

Again, our final recommendation is that GDOT select one or two of these systems, install them in the most critically affected bridges/overpasses in Georgia, and monitor their performance for at least one year. The information collected from such a pilot study will be crucial in attaining a final adoption decision for wider implementation.

TABLE 6
Recommended Options – Systems and Vendors

Product Name	Vendor/ Manufacturer	Cost (approximation or quote)	Performance
3M Fixed ALPR Camera ***(camera-based only)***	**3M**	Two options: P392 at a list cost of $9,000 per camera; P492, $11,000 per camera. Single termination boxes, $1,300, and mounting brackets, $850 (cameras are connected to termination boxes that operate on 15V or 48V)	High-quality image resolution and accurate performance; metal housing for longevity in a variety of operating environments
TIRTL ***(laser-based, IR detector)***	**CEOS (Control Specialists are the US distributor)**	$14,430, less accessories. TIRTL riser and L-bracket (pair), $510; install fittings, $2,180; additional items, such as power supply, Ethernet cables, and signal timer, up to $825 (quotation from vendor: total $19,000, furnish only, includes $750 shipping, taxes to be added)	Low-power consumption; rugged, impact and corrosion-resistant construction; rated for industrial temperature ranges; IP67 immersion and ingress resistant; detects vehicles traveling up to 155 mph; rejects birds, leaves, rubbish; all features as per standard TIRTL with extra overheight alarms
ELTEC Warning and Caution System ***(combined system)***	**ELTEC**	Up to $25,000, depending on the case (quote provided on request)	No functionality problems reported; very little maintenance (annual inspection required)
BlinkerSign® (High-Speed Overheight Warning System) ***(multibased system)***	**TAPCO**	The company provided a sales quote to the research team: $25,660, "furnish only", installation not included	No sensitivity problems; independent of power grid - effective even during power outages; sensor height tailored to each system; records the number of activations
Overheight Vehicle Detection System (OVDS) ***(combined system)***	**TRIGG Industries**	Range from around $5,000 for the simplest traffic models to $15,000 for the most complex	Alerts and directs the driver via warning signs and warning bells to take corrective action; provides secondary warning beyond existing signage in the interest of public safety; proven to minimize/eliminate the occurrence of accidents and incidents caused by overheight vehicles (see appendix C for catalog information)

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Appendix A

Warning Systems for Overhead Clearance Detection

Due to the large amount of information on all the identified systems (active and passive, rigid and nonrigid), this appendix is provided as PDF titled "Appendix A - Warning Systems for OCD", publicly accessible at:

https://drive.google.com/file/d/0BwEukPsCVZuhMWFMcjA4U2Mtemc/view?usp=sharing

Appendix B

Summary sheet on identified warning systems

1. ELTEC Warning System - ELTEC

The ELTEC overheight-detection/warning system is solar-powered. A red/infrared beam is directed across the highway and, when broken, initiates a flashing beacon to alert the driver that the vehicle is over the allowable height for the overpass or other structure. The system can detect direction of travel and does not activate the beacon if the vehicle is traveling away from the structure. It has been installed in Texas and has had no functioning problems nor needed maintenance since installation. ELTEC produces traffic products and warning systems and has several offices; the closest office to Georgia is in Nashville, TN. This system is considered active because the vehicle must pass through the beam to activate the alert beacon.

2. Overheight Detectors (HISIC450) - Sick - Sensor Intelligence

Sick Sensor Intelligence overheight detection for vehicles is labeled type HISIC450. It is a double photoelectric switch. When both switches are tripped by a passing vehicle, an alarm signal is activated. The photoelectric switch still functions as a beam. It can detect vehicles traveling at speeds up to 100 km/h, and because of the size of the beam and the high signal reserve, it provides reliable alarm signals even in nasty weather, such as rain, sleet, snow, and dust. Enclosed in an aluminum anticorrosion shell with a high enclosure rating, it has built-it lens heaters for extreme weather and is insensitive to ambient light. It was created for use in front of tunnels and bridges. The company, with headquarters located in southern Germany, was founded in 1946 and is a leading manufacturer of sensors and sensor solutions.

3. TIRTL - CEOS

The TIRTL (Infrared Traffic Logger) Overheight Vehicle-Detection System uses a dual beam. CEOS produced and first deployed TIRTL in Australia in July 1998, and it has been sold to state agencies in New Zealand, India, Pakistan, Singapore, South Africa, Turkey, Europe and the USA. It allows redundant overheight detection and can be operated with one beam. It also determines vehicle speed and direction, vehicle lane (bi-directional), vehicle position across the road, and vehicle width. It can detect vehicles at speeds up to 155 MPH. It rejects birds, leaves, and other obstructing materials. The system is active because it uses beam detection.

4. Softstop Barrier System - Laservision

The Softstop Barrier System is a tunnel warning system designed to signal drivers who have ignored previous warning signs to stop before entering the tunnel or passing under a bridge. It projects a holographic image of a stop sign in midair, so motorists will come to a complete halt. Once the holographic image is activated, it immediately blocks the entrance way to the tunnel or bridge. The main purposes of the system is to protect the infrastructure and to keep vehicles safe. Drivers may not see warning signs in their peripheral vision, but the Softstop Barrier appears directly in front of them, so they are clearly aware. The system has been installed only at the Sydney Harbour Tunnel. It is considered an active system because it is triggered by an overheight detection system consisting of laser beams and augments previous warning signs.

5. La-Ra-OHVD - Designed at City College of New York

The La-Ra-OHVD, or the Laser-Ranging Overheight Vehicle Detector, is an infrared laser-based warning system. With its long detection range, over 1,000 feet, it can detect oncoming traffic and signal the approach of an overheight vehicle. The warning sign is positioned on the overhead infrastructure, so motorists can see it clearly. It can also measure the overheight vehicle and its speed to collect data to predict collisions. This system is considered active because its laser beam sends a signal to a warning sign that operates with flashing lights.

6. Overheight Detection System - Vic Roads

The system has two components, a height gauge and advisory signs. The height gauge detects overheight vehicles on the roadway and sends a signal to the advisory signs to display a warning message about a low-clearance structure ahead. The height gauge is set at the exact height of the structure ahead. The advisory signs allow the drivers enough time to find an alternate route.

Alternatively, the height gauge can trigger two flashing lights. The system operates properly in direct sunlight, at any time of day, in almost any weather conditions, at temperatures between 5°F and 131°F, and can record speeds between 3 and 75 MPH. It is weather resistant, increasing its longevity. It must follow such standards and regulations as EMC, in accordance with the ACMA, all requirements of AS/NZS 2144, and STREAMS compatibility regulations. It records, logs, and stores all data in the system for every activation. It is considered an active system because the height gauge activates the advisory signs. It is still in development, and there is no North American contractor yet.

7. <u>Height Detect 8000 - SCACO</u>

The Height Detect 8000 is a stand-alone system that records the height of the vehicle and warns drivers of overheight vehicles to exit the road immediately. It can be integrated with vehicle weighing systems, tag readers, traffic lights, message displays, and other features. It is weather resistant, increasing its longevity. It is considered an active system because it detects overheight vehicles and sends a signal to a message display to warn their drivers.

8. <u>Autonomous Emergency Braking Systems (Mitigating Overheight Truck Tunnel and Bridge Collisions) - Nufer and Associates</u>

This system is installed in trucks and costs approximately $2,000 per truck. First, it documents the height of individual trucks, the height of bridges and tunnels, and determines the difference between the two. Second, it automatically stops the vehicle dead in its tracks without driver input unless the driver overrides it. The system is activated to stop the truck when signaled that it is approaching a structure that it will not clear to guard against unforeseen events. Nufer and Associates is an Australia-based, consulting electrical engineering company that specializes in electronics and telecommunication services. The system is active because braking is activated once the vehicle approaches a low-clearance bridge or tunnel logged in its database. However, it is considered “another type” of detection because it is located in the vehicle, and the driver would have it installed.

9. Giraffe G4 - Wheeling Truck Center

The Giraffe G4 is a collision-alert system composed of a mirror-mounted unit and an in-cab unit. The mirror-mounted unit detects the height of the overhead structure and sends a signal to the in-cab unit. The in-cab unit then displays the height reading, and if the overhead structure is too low for clearance, the in-cab unit will sound an alarm to warn the driver. The system is able to read overhead structures up to 20-feet high. The driver can program the vehicle's operational height into the unit to receive accurate overhead warnings. The mirror-mounted unit is waterproof. This system is considered active because the mirror-mounted unit sends a signal to the in-cab unit to warn the driver of the overhead clearance height.

10. The Overheight Detector System - Coeval Ltd.

The Overheight Detector System is designed to monitor traffic and warn any overheight vehicles of the oncoming low-clearance on route. The system consists of pole-mounted infrared laser beams that emit to two detectors on the opposite side of the road. The laser beams are positioned at the height of the low-clearance overhead. Once an overheight vehicle activates the laser system, a signal travels to an LED sign and warns the driver to detour from the current route to avoid the low-overhead structure. The system gives the driver enough time to make a decision to exit the roadway. The detector system can also be integrated with a web-based remote monitoring system for more control. This system is considered active due to the laser beams sending a signal to a warning sign to alert drivers of the low-clearance structure.

11. Overheight Detection System - The Electro Automation Group

The Overheight Detection System is a laser-based system that detects and warns drivers that their vehicles are too high for the oncoming infrastructure. It contains twin infrared beams that are positioned opposite each other on both sides of the road. Once the system is triggered by an overheight vehicle, a signal is sent to an LED display that warns its driver to stop immediately. The system is integrated with a GSM (Global System of Mobile communication) remote monitoring system that sends an email to DP World, an enabler of global trade, that the system has been activated. The system is considered active because the laser beams send a signal to the message display to warn the driver of the overheight vehicle.

12. <u>Watchman Collision Avoidance Systems - Q-saq, Inc.</u>

The Watchman Collision Avoidance System contains a low-clearance bar with red lights on each end, designed to prevent overhead collisions in parking facilities. When an overheight vehicle collides with the low-clearance bar, a siren sounds, and the red lights flash. These warning tactics allow the driver to stop immediately and make a decision about another route. The system also alerts management when it is activated. It is considered active because the low-clearance bar warns the driver with a siren and flashing lights when the vehicle makes contact.

13. <u>Mobileye 560 - Mobileye INC.</u>

Mobileye is a smart camera located on the vehicle's windshield that uses technologies to detect traffic signs, the distance to other vehicles, lane markings, and pedestrians and sends the driver real-time warnings that can also be sent to a smartphone. It can be installed in just about any vehicle type and used day or night in any type of weather. It dramatically reduces collisions and related costs. It includes a windshield-mounted vision sensor unit with a compact high dynamic range CMOS (HDRC) camera; Mobileye's SeeQ2® image-processing board; a high-quality audio-alert buzzer; and a high-visibility eye-watch display and control unit. A brochure on the system is available. Mobileye, Inc. is a worldwide leader in designing and marketing technology to process visual information for driver assistance systems (DAS). The system is active because it uses real-time detection to alert the driver of a situation ahead of the vehicle. It falls into the "another" category because it is located in the vehicle, and the driver must have it installed. While it is not currently used for overheight detection, it seems quite capable of it.

14. <u>Overheight Vehicle Detection System EDS - Isbak</u>

This electronic detection system (EDS) is laser-based and also uses IP camera systems. The sensor technology works under any weather conditions, dirt, and dust. It can take, record, and send pictures to supervisors. It detects vehicles that are too tall for the road or tunnel and activate a warning system that will alert the driver in time to prevent a collision. Isbak (ISBAK Istanbul Transportation Telecommunication and Security Technologies Industry & Trade Inc.) is located in Istanbul and was established in 1986 to manufacture centrally controlled traffic signaling systems. The product is in the research and development phase and will probably be tested at the end of the year.

15. Overheight Vehicle Detection System - Trigg Industries International

Trigg Industries' detection systems are an all-inclusive package including detectors, warning signs, alarms, mounting poles, and accessories. Their patented Z-Pattern® Red/Infrared dual beam array detects that the vehicle is over the restricted height and alerts the driver with signs and bells. Additional warning signs are available upon request. It can be implemented for any height-clearance problem. It rejects ambient light and virtually eliminates false alarms. Their website does not state whether they produce a solar-powered option but indicates that installation instructions are easy and straightforward to follow, so GDOT would probably have to do the installation. Trigg Industries has been designing and manufacturing products for the traffic engineering industry since 1965 and has an evolving, industry-standard line of overheight-detection systems. This system is active because the vehicle activates the warning systems by triggering the infrared beams.

16. Piezoelectric Transducers - Study done

A Houston-based company has done a study with piezoelectric transducers. When a truck collides with a bridge, the impact triggers a camera to take a picture of the truck, and the damage is recorded on a computer by the piezoelectric sensors. It is not an actual warning system. More information can be obtained about this product upon request.

17. Vehicle Overheight (Maximum Height) and Position Detection System - Comark

This laser-based system was designed to detect an overheight vehicle and its location on the road. There are three models. The first is the RAM 20, which scans the overheight vehicle horizontally. The second is the RAM 100, which scans the overheight vehicle horizontally and contains two infrared transmitters and receivers. The third model is the RAM 200, which scans the overheight vehicle vertically and horizontally. The systems contain four planes of detection for increased precision and a beam width of 96 degrees. The scanner has internal heating to avoid moisture condensation on the optical lens. It filters out rain, snow, birds, and other noises. It also detects the lane in which the overheight vehicle is traveling. The system is considered active because it scans the overheight vehicle and sends a signal to a configured digital output to warn the driver of the low-clearance obstacle.

18. <u>Fixed Plate Hunter 900 - ELSAG North America - A Finmeccanica Company</u>

This system aims, not to monitor height, but to record license plates for tracking purposes. It would capture the license plate of a vehicle that might collide with a bridge and enable the owner to be tracked down and held accountable for repair costs or injuries. The system can be mounted to bridges, gates, overpasses, or other stationary structures and can capture data for certain periods of time. The company, ELSAG, has the most advanced automatic license plate recognition technology available, and the product is made in the USA.

19. <u>SAM - Sensing and Activating Module Laser Sensor for Vehicle Detection - SCHUH & Co.</u>

SAM is a laser-based system made in Germany that assures no disturbance in the flow of traffic while offering various forms of traffic surveillance. It can be used to help control overheight vehicle collisions with bridges and tunnels. It is installed on only one side of the highway; the other part of the system works with reflectors. It can detect certain vehicles and the lane in which they are driving, and once the laser is triggered, the overheight alarm output activates warning signs, flashing lights, and traffic signals. It is designed not to be triggered by birds, leaves, or weather conditions. The system requires power input. It is considered both active and passive because it is activated by lasers that activate many forms of signage. SCHUH & Co. is a leading specialist in the areas of traffic and systems engineering.

20. Overheight Vehicle-Detection System - International Road Dynamics, Inc. (IRD)

IRD's overheight system uses a laser that activates warning signs and flashing lights. It detects an overheight vehicle moving toward a low-clearance structure and warns the individual driver both visually with signs and flashing lights and with an audio warning. It must be mounted. The head office is in Canada, and the company requested interested parties to contact them for more information. They integrate leading intelligent transportation systems into solutions for unique transportation problems. This system is active because the lasers trigger the flashing lights, signs, and sounds.

21. Overheight-Detection System - Hi-Lux Technical Services

Hi-Lux Overheight-Detection Systems use a remote infrared-beam unit that detects an overheight vehicle traveling in a defined direction and wirelessly transmits the information to the sign controller, which activates flashing lights and initiates a stop sign. Australian-designed and manufactured, it is solar powered and can be mounted on a pole or a wall. Each event can be recorded and reported to the control center. It has an aluminum enclosure and battery backup. The system works through radio links. Hi-Lux Technical Services is a supplier of LED signs, traffic management systems, and associated control and detection systems, supplying turn-key solutions since 1991. This system is active because the infrared remote must be triggered to warn the driver through flashing lights and a stop sign. A brochure on this product is posted on the company website.

22. Overheight Detection and Barrier - FutureNet Security Solutions

a. The overheight detection and barrier is a collection of systems provided by FutureNet Security Solutions. The three main forms consist of radar beams, long hanging tubes or chains, and height restrictors. The radar beams detect a vehicle that surpasses the restricted height limit and send a signal to the LED signage, which then displays the appropriate visual warning to the driver. The long hanging tubes or chains are placed at a certain height so that when a vehicle strikes them, the noise will alert the driver. The final product is a rigid barrier placed on the route to a destination that has serious height restrictions. It will either stop the vehicle in its tracks or dismantle the part of the vehicle above the height restrictor. These overheight products are intended for use in front of bridges, tunnels, overpasses, canopies, and parking structures. They are simple and easy to install, adjust to fit specific roadway needs, easily integrated with existing roadway structures, and cost effective. FutureNet Security Solutions is a "Complete Package Company" that will work with each client to design a product that meets the specific need and manufacture and install it within the budget. FutureNet is a highly recognized and used company. This system would be classified as a mixture of active, passive, and rigid solutions.

b. A FutureNet representative informed our team that the **Tattle Tales Overheight Detection System** is the only system the company carries as a product. It is a nonrigid, passive system of 18-foot-long, hanging tubes that alerts drivers of oversized/overheight vehicles that they cannot enter an area safely. The "Tattle Tales" are suspended at a predetermined height to ensure that the vehicle will clear the canopy structure, which prevents damage to both vehicle and structure, decreases traffic backups due to a collision, and reduces accidents. The Tattle Tales are centered and spaced evenly across a section of road using two vertical strain poles and wire roping. The tubes are clearly marked with red and white stripes. The system also uses warning signage with simple text to alert drivers to the overheight-detection system.

23. <u>IT-B Overheight Vehicle Detection and Warning Systems - FETNLASER</u>

IT-B is a laser-based system that is precise and reliable in detecting when a vehicle has exceeded a set height and setting off an LED alarm system and a sound alarm in the vehicle's path. The system will then use visual displays to direct the vehicle to an alternate route. If the vehicle does not take the proper alternate route, the system will take snapshots and video that show its license number, and the images will be logged and sent to the proper monitors. This system requires a mounting product or a place to mount it and a source of power input. It uses a double-beam blocking alarm. FETNLASER specializes in the production and sale of photoelectric detection systems. Specific product dimensions and specifications are posted online. This product would be considered an active system.

24. Overheight Detection Monitoring and Control System - Applied Information

Applied Information's Overheight Monitoring and Control System is an all-in-one control system that detects, warns, monitors, and reports. It uses highly accurate laser detectors that, once activated, trigger a warning signal that tries to alert the driver before impact. The warning signals can consist of either flashing beacons or small DMS electronic signs. The lasers also trigger CCTV cameras to record the event for 5 seconds, regardless of whether the bridge is struck, to record the status of the bridge. This product uses the **Glance Status Monitoring System**, cellular communications for managing and using the product. It can provide such information as current status, current alarms, power status, current error status, time zone, and time since last contact. The system can run off solar power to reduce cost. Applied Information is in Suwanee, Georgia, so the location is ideal. They provide devices that record field data that can be used and run through cellular connections. This system is active.

25. Vehicle Detector Measure-in-Motion® - Betamont

The Measure-In-Motion vehicle detector measures the dimensions of a moving vehicle without any speed restriction. It is composed of many systems that measure speed, vehicle height, and dynamic vehicle weight, and capture license-plate information. To measure height, the system uses double optimal sensors composed of two transmitters and two receivers and a control unit that provides all the data collected graphically. The camera system records the passing overheight vehicle, captures the license-plate information, and transforms it into text. For night use, the camera system uses an infrareflector for illumination. The system is considered active because it detects an overheight vehicle and transforms the collected data graphically.

26. Stand-Alone Bridgeclear System - Bridgeclear

The UK Stand-Alone Bridgeclear system uses GPS technology to locate low-clearance structures on route. The driver must input the vehicle height into the warning unit to receive an accurate determination of a low bridge. The system contains a database of approximately 6,000 low bridges in Great Britain and Ireland and alerts the driver with audio and visual warnings as the vehicle approaches the bridge. These warnings become more aggressive as the vehicle gets closer. They are set at a distance that enables the driver to take evasive action. The system is considered active because it warns the driver when the CPS detects a low bridge.

27. Overhead Clearance Assist - Bosch

This system is a dash insert video screen that calculates and shows the vehicle's current height. In the ad for the system, a vehicle is shown carrying bikes that change its height. The system then records and registers this height and compares it to any low-clearance structures in the projected path. The system will warn the driver about the obstacle. It is considered active.

28. Clearance Signs - Sign Safety

This company specializes in the manufacture, printing, and sale of a wide variety of signage. Increasing warning signage will clearly increase the average person's safety. The company has a certain category of signs dedicated to low clearance or overhead clearance. They can be printed on permanent acrylic adhesive vinyl, treated polyethene plastic, or coated aluminum. The company can also provide the accessories needed to mount or post the signs. The price varies by size, materials, and other factors. The website gives details. This approach is considered passive.

29. Height Clearance Signs - Grainger

This company is a distributor of facility maintenance products and solutions and has a line of products dedicated to overheight clearance. They have branches all over the US and the world. Products range from a clearance bar to a sign that posts the exact overheight to a sign that warns that the following structure or obstacle has a low clearance. Prices vary. The clearance bar, for example, runs from $196.50 to $237.50, while the signs showing the specific height would cost approximately $16.02 each. This solution would be considered passive and can be rigid or nonrigid.

30. Low-Clearance Signs - Road Traffic Signs

This company is a leading manufacturer and distributor of road traffic signs, the web's largest site for MUTCD traffic signs and road signs. They either meet or exceed MUTCD and other federal regulations. They have a line of low-clearance signs that can be customized. Prices differ based on sizes and prints. This approach is passive.

31. BlinkerSign® High-Speed Overheight Warning System-TAPCO

The BlinkerSign High-Speed Overheight Warning System is designed to warn drivers of a low-bridge ahead. It consists of a sign that says LOW BRIDGE, OVERHEIGHT WHEN FLASHING, which is integrated with a sensor that detects overheight vehicles and triggers flashing lights. The height sensor consists of a transmitter and a receiver. The system can operate day and night in all weather conditions and is very durable. It operates on an independent power grid, so it can function even during a power outage. It is considered active because the vehicle triggers the warning sign to flash.

32. LED Highway Blank-Out Signs - Signal-tech

Signal-Tech is a wholesale manufacturer and distributor of LED signs and signals. No particular sign focuses on overheight warnings, but they can customize a sign or signal. They have a section that provides warnings or directional messages at tunnels, bridges, and toll booths. The signs need direct wiring. They are encased in a highly durable material and can be just about any size. The LEDs are super-bright, and the signs can blank out when deactivated. This approach would be considered passive.

33. Copilot Truck - Copilot Mobile Navigation

ALK Technologies is a software company that has created a line of navigation systems to help drivers everywhere based on their specific needs. One of the systems is made for trucks and takes into account height, weight, and other details to keep drivers out of truck-restricted areas and on the safest, most efficient route. The system uses GPS and would be installed in the individual truck. It can be used in just about any application from on foot to a car, a boat, a truck, or RV. The system would be evaluated as active.

34. Low Clearance Signs - Custom Products Corporation

Custom Products Corporation is a wholesale manufacturer of customized road signs. It provides three types of warning signs. Two of different dimensions display the height restriction; the third displays the warning message, Low Clearance. All three can be customized to needs in a specific area. This system is considered passive.

35. Warning Signs - Maneri Sign Company

This California Company manufactures signs, including warning signs, and a few are dedicated to low clearance. While the options are few, they do offer posts, hardware, and installation personnel. This approach is passive.

36. Overhead Sign Structures - American Lighting and Signalization

This Florida Company specializes in roadway lighting and traffic signals. They maintain a staff of licensed electricians, professional engineers, and technicians qualified according to International Municipal Signal Association (IMSA) standards. Their systems can include signage and some kind of radar-triggered warning. The NCDOT had one of their systems installed on the bridge nicknamed the “Can Opener”; if an overhead signal was triggered, it stopped traffic at the intersection in the hope that the driver would become aware of the problem and take an alternate route. The website is very vague, but they seem to offer an active electronic system that activates signs.

37. Low-Bridge Warning - (OVD) - SWARCO

This company is under another company in North Yorkshire, England, and they have or 70 years of design and manufacturing experience in traffic signals and control systems. Their product combines inductive loops and infrared detection to detect overheight vehicles and activate an LED warning sign that alerts the driver to the oncoming clearance problem and advises turning around or taking an alternate route. Details online are vague, so we made contact to get more details. This system is considered active.

38. GPS Technology Bridge Avoidance System - Bridgestrike

This UK Company stated that in 2014 alone, the country experiences 1,708 bridge strikes, about 5 every day. Their system is an interactive GPS component that allows users to input the truck height and compares it to its database of heights to warn of an approaching low-clearance structure. This system is considered active.

39. Vehicle Height Clearance Detector - Han-D-Man & Co.

This California manufacturer produces four models of the system, available with or without sound detector. It contains a retracting arm to detect overheight vehicles and warn their drivers of approaching low-overhead structures, and the arm can use a sound detector. The system could be installed on all parkway ramps to drastically decrease bridge collisions. This system is considered both passive and active because of the optional sound detector.

40. TruckOn - Nicta

This system uses a beam-break detector that wirelessly sends a message to the offending vehicle and warns of the low-clearance structure ahead through the stereo. It tracks the driver's reaction and can calculate speed and direction through GPS. If the driver does not react, it will apply the brakes to prevent collision. This system has components inside and outside of the vehicle. This Australian company stated that TruckOn is a forward-looking ‘proof-of-concept’ project that demonstrates how emerging wireless vehicle communication technologies can prevent overheight truck collisions with tunnels, overpasses, and enclosed bridges. The system would be considered active.

41. Bridge Clearances - Terrametrix, LLC

The Terrametrix, LLC, system is a mobile scanning unit that is mounted on a vehicle to record bridge clearance heights. It scans vertically and horizontally. Data from the readings are collected in a database. This system is not a warning system but can be used to keep track of minimum bridge clearance heights.

42. <u>3M Fixed ALPR Camera - 3M</u>

The 3M Fixed ALPR Camera is available for many applications and is designed to provide accuracy and affordability. Its multiple cameras are highly configurable and can cover a full lane of traffic with two parallel vehicles in the field of view. The fixed system monitors continuously capture the license plates of vehicles of interest in high-traffic areas and alert agencies, which allows fast, efficient, and appropriate deployment of resources. 3M's fully integrated license plate recognition cameras are rugged and compact, incorporating the fixed ALPR camera, illuminator, and processor in a single, sealed enclosure. This system is considered active.

43. <u>CMP51 and CMP52 Laser Radars - Noptel Oy</u>

The CMP51 and CMP52 are single laser beam systems applicable to wide variety of tasks in traffic control and law enforcement. The safe sensors are used in both fixed installations and portable systems to measure approaching and departing vehicles; they are small and lightweight, have the high IP rating 67, and feature low power consumption. One is mounted for each lane of traffic on a tall structure like a gantry, bridge, or overpass. They can also be installed on a post or tripod at the side of the road to control one or several lanes. This laser radar system is considered active.

44. <u>MK5-RSU - Cohda Wireless America</u>

The MK5-RSU is a road-side unit version of the MK5, which is based upon the automotive-grade RoadLink chipset. The system is installed in a weatherproof enclosure with integrated antennas and a pole-mounting kit. With dual antennas to maximize range and coverage, the MK5-RSU is a self-contained unit that can cover all the approaches to an intersection. This system is considered active.

Appendix C

Technical information on the recommended warning systems

Due to the large amount of technical documentation on the recommended systems, this appendix is provided as a separate PDF, entitled "Appendix C - Technical Info for WS", publicly accessible at:

https://drive.google.com/file/d/0BwEukPsCVZuhY256WHpRcjFmbTQ/view?usp=sharing