Research Report
KTC-05-38/SPR240-02-1F

KENTUCKY TRANSPORTATION CENTER

College of Engineering

DEVELOPMENT, DEPLOYMENT, AND EVALUATION OF A REMOTE MONITORING SYSTEM AND A VIRTUAL WEIGH STATION

(Final Report)

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DEVELOPMENT, DEPLOYMENT, AND EVALUATION OF A REMOTE MONITORING SYSTEM AND A VIRTUAL WEIGH STATION

(Final Report)

by

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in cooperation with

The Kentucky Transportation Cabinet,
The Federal Highway Administration,
and
The Federal Motor Carrier Safety Administration

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16. Abstract

In order to extend commercial vehicle enforcement coverage to routes that are not monitored by fixed weigh stations, Kentucky has developed and implemented a Remote Monitoring System (RMS) and a Virtual Weigh Station (VWS). The RMS captures images of passing trucks (from the side) and transmits those images to a nearby weigh station. Station personnel can view the images, read the USDOT number, and check the number against Kentucky's Clearinghouse of motor carrier data. When a problem is detected with the carrier's registration, taxes, or safety record, an officer can be dispatched to intercept the truck, perform the necessary checks, and, if appropriate, take corrective action. The VWS provides the same functionality as the RMS, but adds a weigh-in-motion system, so that enforcement personnel can also screen trucks for apparent weight violations. Preliminary assessments of the performance of the RMS and VWS have been performed. This report describes the RMS and VWS concepts, discusses the results of the preliminary assessments, and presents recommendations for moving forward with additional deployments and testing.

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EXECUTIVE SUMMARY

The original concept for the Remote Monitoring System (RMS) and Virtual Weigh Station (VWS) was developed in 1997 in response to a concern expressed by Kentucky Vehicle Enforcement personnel. The purpose of the system was to provide an alternative concept for commercial vehicle monitoring and enforcement, a concept that would spread enforcement coverage to additional routes. In essence, the RMS and VWS were intended to provide a low-cost system that could be installed on any roadway and would deliver the functionality of a weigh station.

The RMS was installed in late 1999 on US 25 in northern Kentucky. The system functionality was quite simple; it was designed to capture images of passing trucks and transmit those images to another location (the nearby Kenton County weigh station on I-75). Enforcement personnel at the weigh station could view the images, read the truck's USDOT number,[1] and enter that number into the "Kentucky Clearinghouse" (a motor carrier database with "snapshot" data on safety and credentials). If the Clearinghouse indicated a problem, an officer could be dispatched to intercept the truck.

A cursory evaluation of the RMS was performed in the summer of 2002, using 4,500 system transactions that occurred in March and April of that year. This evaluation showed that readable USDOT numbers were being captured for just over 50 percent of the passing trucks. For those trucks with readable USDOT numbers, the Kentucky Clearinghouse reported some sort of violation on 31 percent of the trucks.

The next step in the process was to combine the RMS concept with a weigh-in-motion (WIM) system to create a VWS. This would enhance the system functionality by adding the capability to detect apparent weight violations. The site selected for the first VWS was on US 25 in southern Kentucky. The system was installed in December 2002. Images and weight data from the system were transmitted to the nearby Laurel County weigh station on northbound I-75, where they could be viewed by weigh station personnel.

A preliminary evaluation of the VWS was conducted using data from a 48-hour continuous enforcement effort in June 2003. During that time period, the system was triggered by trucks 454 times. For those triggers, the system captured a readable USDOT number for 155 trucks (34 percent). The primary problems encountered were blurry images, numbers that were too small to read, lack of contrast, location/timing of the image capture, and shadowing/glare. The system vendor identified several system enhancements that were intended to improve the image quality. Unfortunately, before those enhancements could be implemented, the system was rendered inoperable by a series of unexpected events that were external to the project. The system was shut down in September 2005.

This project validated the potential value and importance of the VWS concept. It showed the need for further refinement and testing of the image capture technology. It also highlighted some inherent difficulties with capturing the USDOT number. Because of the substantial potential of the VWS concept to provide a low-cost, high-value enforcement tool, it is recommended that Kentucky continue to explore and develop this concept. Using the lessons learned from the initial deployments, a "next generation" VWS should be developed and implemented.

[1] A unique identification number issued to each motor carrier by the United States Department of Transportation.

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Jeff Bibb, Kentucky Transportation Cabinet, Transportation Operations Center (Chair)

Glenn Anderson, Kentucky Transportation Cabinet, Division of Traffic Operations

Rob Bostrom, Kentucky Transportation Cabinet, Division of Multimodal Programs (Retired)

Bernadette Dupont, Federal Highway Administration, Kentucky Division

Capt. Philip Frazier, Kentucky Vehicle Enforcement

Glenn Jilek, Federal Highway Administration, Kentucky Division

Officer Jamie Perkins, Kentucky Vehicle Enforcement

Brad Scalos, Federal Motor Carrier Safety Administration, Kentucky Division

Leon Walden, Kentucky Transportation Cabinet, Division of Traffic Operations

In addition, the authors would like to express their appreciation to the Post Commanders of the Kenton County and Laurel County weigh stations. Without their strong support, this project would not have been possible.

Capt. Jim Sutter, Kentucky Vehicle Enforcement, Post 9 (Retired)

Lt. Ronald Bradley, Kentucky Vehicle Enforcement, Post 7 (Retired)

BACKGROUND

The responsibility for monitoring commercial vehicle operations and enforcing commercial vehicle laws and regulations within the Commonwealth of Kentucky rests primarily with two agencies: (1) the Department of Vehicle Regulation (DVR) within the Kentucky Transportation Cabinet and (2) Kentucky Vehicle Enforcement (KVE) within the Justice and Public Safety Cabinet. As part of their strategy for providing the necessary level of monitoring and enforcement, DVR and KVE have invested in constructing, equipping, staffing, and operating fixed enforcement facilities (generally known as weigh stations, inspection stations, or ports of entry) throughout the state. These facilities, along with the personnel who operate them, provide a high level of enforcement for the routes on which they are located.

Kentucky currently has 17 weigh stations. Fourteen of these stations are located on Interstate Highways, and the remaining three are located on U.S. Routes. The locations of these stations are shown in Figure 1. This figure also shows Kentucky's Interstate Highway and Parkway system. As can be seen from the figure, the existing weigh stations provide reasonably complete coverage of that road network.

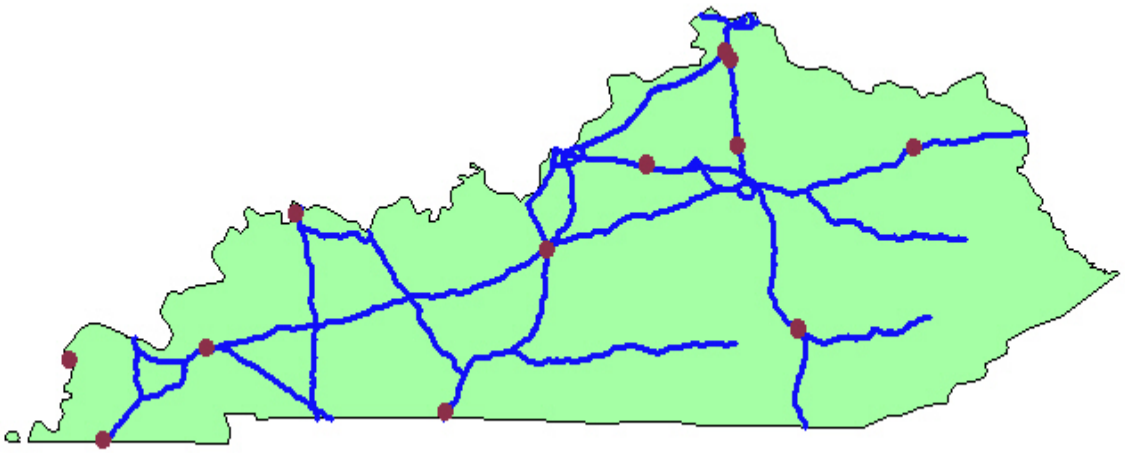

Figure 1. Locations of Weigh Stations in Kentucky

However, the Interstates and Parkways make up only a small portion of Kentucky's road network. Figure 2 shows the same information as Figure 1, but also includes Kentucky's federal and state highways. It is obvious from this figure that the vast majority of road mileage in Kentucky has no monitoring by fixed enforcement facilities. In addition, where fixed stations exist, they can be easily avoided by taking alternate routes to "bypass" the weigh stations.

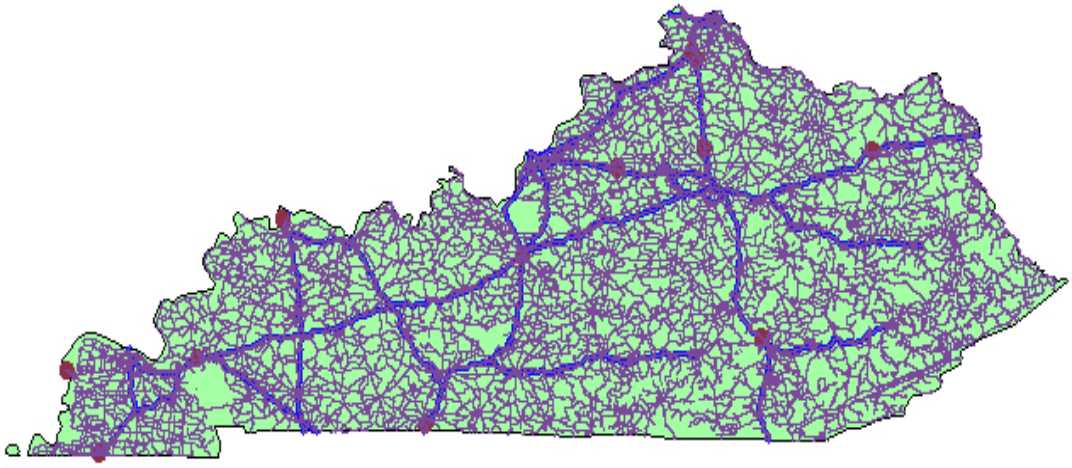

Figure 2. Kentucky's Federal and State-Maintained Roadways

To augment the fixed facilities, and to provide coverage of otherwise unmonitored routes, KVE officers conduct mobile enforcement operations. These operations extend enforcement coverage throughout the state. However, KVE personnel have expressed serious concerns about the effectiveness of mobile operations. Specifically, they are concerned that truckers communicate with each other regarding the location of mobile units, thus making it easy for unsafe or non-compliant truckers to avoid the mobile enforcement activity. This avoidance may consist of taking an alternate route, or it may consist of parking the truck and waiting for the temporary enforcement activity to end or relocate.

THE REMOTE MONITORING SYSTEM

In 1997, DVR and KVE representatives approached researchers at the Kentucky Transportation Center with the desire to develop an alternative concept for commercial vehicle monitoring and enforcement. In cooperation with enforcement personnel, KTC developed the concept for a Remote Monitoring System (RMS). Functional Requirements were developed in late 1997, potential vendors were identified, and a request for proposals (RFP) was issued in the Fall of 1998. A system vendor was selected in January 1999. The selected vendor was Transfomation Systems, Inc. (later shortened to Transfo, Inc.), with Computer Recognition Systems (CRS), Inc., as the primary subcontractor and equipment supplier.

The RMS was installed in October 1999, and acceptance testing was performed in December of that year. The total cost of developing, procuring, integrating, and installing the system (including six months of operational support) was approximately $160,000. Funding for the project came from Kentucky's Commercial Vehicle Information Systems and Networks (CVISN) Model Deployment Program.

The location selected for the installation was on southbound US 25 in Walton, Kentucky. This is a very convenient bypass route for truckers wishing to avoid the Kenton County weigh station on Interstate 75. The RMS location is shown in Figure 3. The roadside equipment for the RMS consists of two cameras (one in a roadside traffic cabinet and the other mounted on a pole across the road) a personal computer (also in the traffic cabinet), a detection loop in the pavement, and a height detector (to distinguish trucks from passenger vehicles). The system also includes lighting to allow the capturing of nighttime images. Figures 4 and 5 show the two cameras, while Figure 6 shows the site layout.

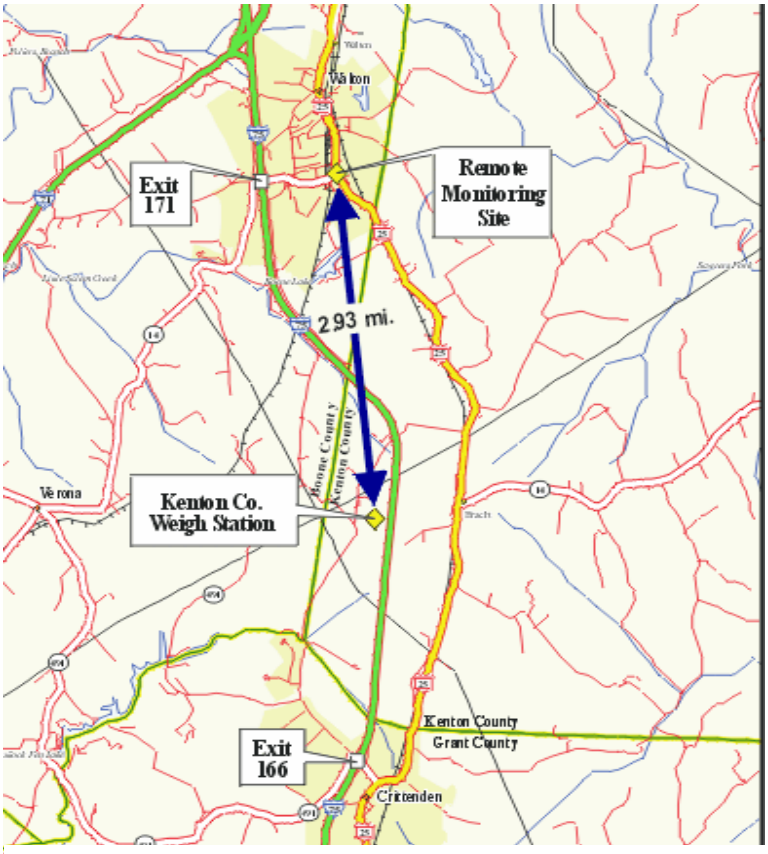

Figure 3. Location of Remote Monitoring System

Figure 4. Roadside Cabinet with Camera

Figure 5. Pole-Mounted Camera

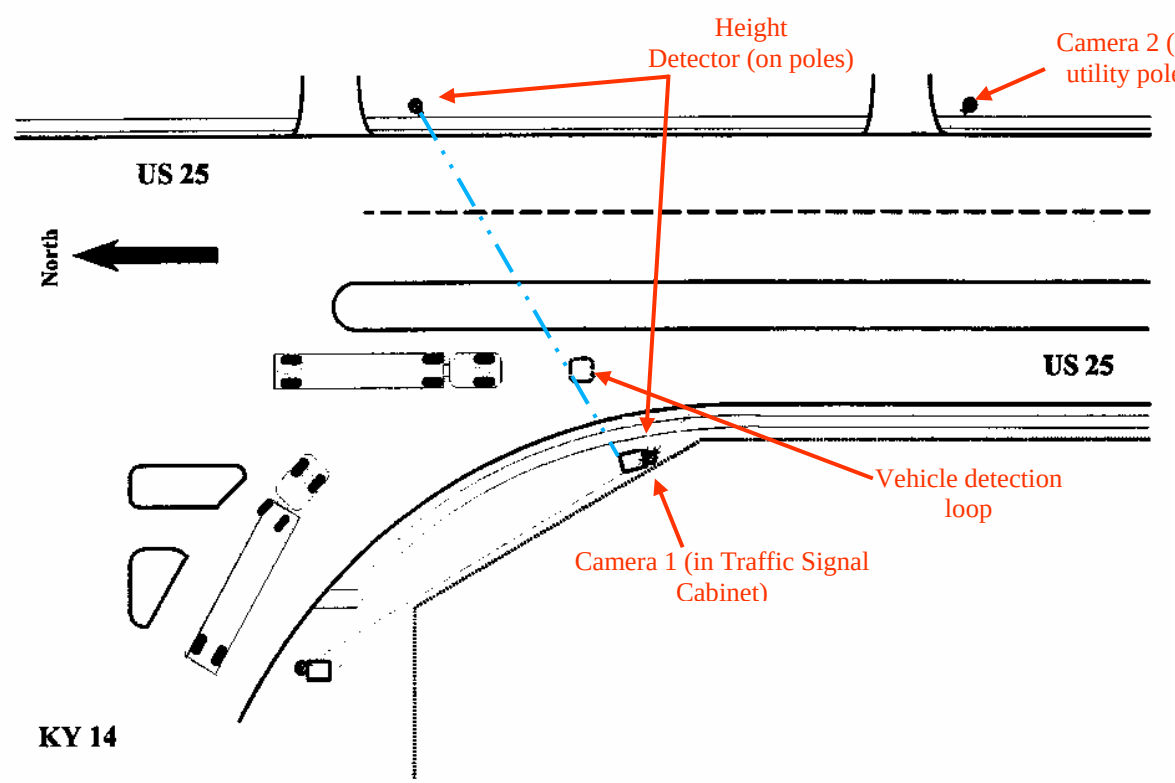

Figure 6. Physical Layout of Remote Monitoring System

The functionality of the RMS is intended to be quite simple. Specifically, the RMS is designed to capture images of passing trucks and transmit those images to another location (in this case, the nearby Kenton County weigh station). The image capture is triggered by the in-pavement detection loop (which detects all southbound vehicles) in combination with a height detector (which distinguishes trucks from passenger cars). For this installation, the images are transmitted over an ISDN[1] line provided by the local telephone company. Enforcement personnel at the weigh station can review the images, read identifying information from the truck (such as the USDOT number[2]), and enter this identifying information into the "Kentucky Clearinghouse" (a motor carrier database with "snapshot" data on safety and credentials). If the Clearinghouse indicates a problem, an officer can be dispatched to intercept the truck.

A sample screenshot of the RMS software is shown in Figure 7. Enforcement personnel can select any image on the screen and expand it by simply clicking it with the mouse. Figure 8 shows an example of an expanded image.

[1] ISDN stands for "Integrated Services Digital Network." This is a circuit-switched telephone network system that allows digital transmission of voice and data over regular telephone lines.
[2] The USDOT number is a unique identification number assigned to each interstate motor carrier (and some intrastate carriers) by the United States Department of Transportation.

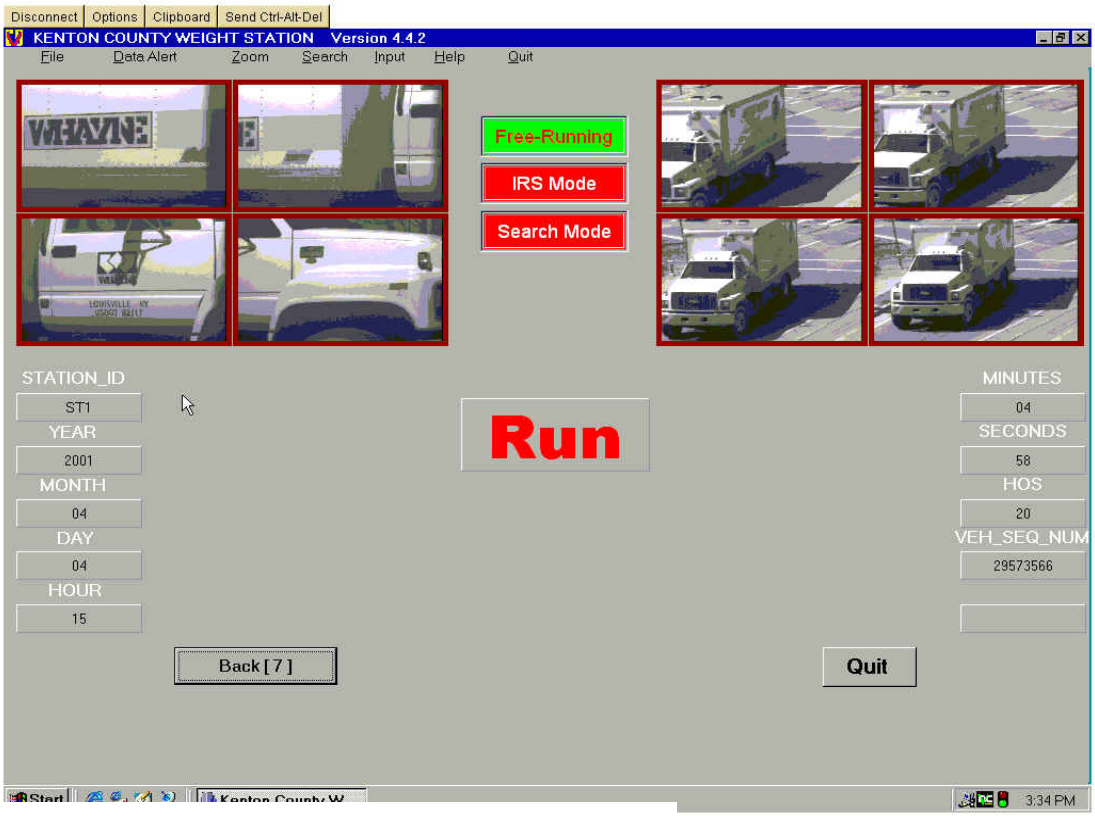

Figure 7. Sample Screenshot of RMS Software

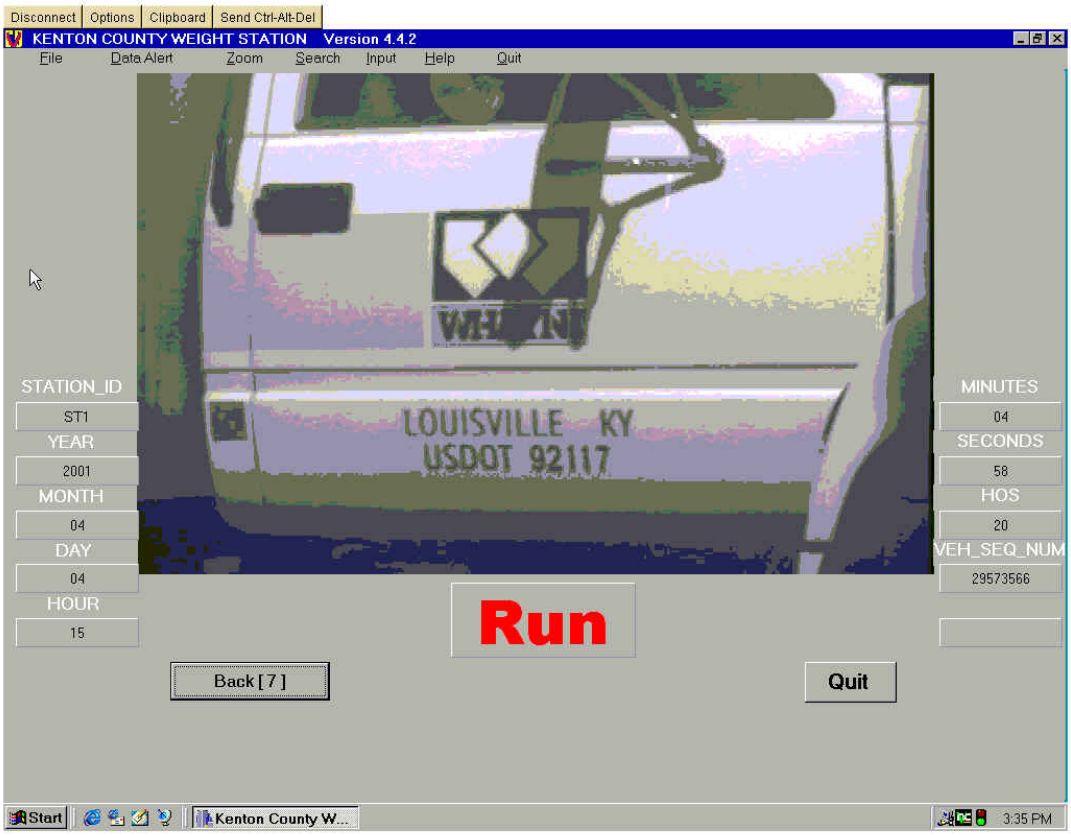

Figure 8. Sample Screenshot with Expanded Image

RMS PRELIMINARY EVALUATION

Funding for the RMS project was not sufficient to provide for a detailed evaluation of the RMS. However, a cursory evaluation was performed using 4,500 system transactions that occurred in March and April of 2002. This evaluation showed that the truck identifying information (i.e., a USDOT number or equivalent) was captured in the image set for 70 percent of the transactions. It was also reported that many of the transactions with no USDOT number were "false triggers" (i.e., transactions where no truck was present). It would be beneficial to remove the false triggers from the analysis, since this would allow us to determine the percentage of trucks for which the USDOT number was captured. Unfortunately, the exact number of false triggers was not recorded, so it was necessary to use estimates. For those cases where a truck triggered the system, it is estimated that the USDOT number (or equivalent) was captured for 80 to 85 percent of the transactions.

When the USDOT number was captured in the image set, it was readable (for a human observer) 65 percent of the time. Primary causes for non-readable numbers included inadequate lighting, small font size, and insufficient contrast between the background color and the numbers. So, if the USDOT number was captured for about 80 percent of the transactions (when triggered by a truck), and the number (when captured) was readable 65 percent of the time, then the net result is that a readable USDOT number was captured for about 52 percent of the trucks that triggered the system.

For the USDOT numbers that were captured and readable, those numbers were entered into Kentucky's Clearinghouse to check for violations. Approximately 31 percent of those trucks were found to have a deficiency associated with their USDOT number. In other words, about one-third of the trucks detected on US 25 (for the time period evaluated) had some sort of problem with their company credentials. Of course, the system could not detect vehicle safety defects, overweight conditions, or driver violations, so the actual percentage of violators on US 25 was something higher (perhaps significantly higher) than 31 percent.

THE VIRTUAL WEIGH STATION

During the development, deployment, and evaluation of the RMS, it became apparent that the RMS could be combined with weigh-in-motion (WIM) technology to produce a system with additional capability. The inclusion of WIM technology would allow enforcement personnel to screen trucks for weight violations in addition to checking the USDOT number. This functionality would duplicate that of a fixed weigh station in Kentucky, where (ideally) every truck is weighed and has its USDOT number checked against the Clearinghouse. Because this new system (the RMS combined with WIM) would duplicate the functionality of a fixed weigh station, it was given the name "Virtual Weigh Station," or VWS.

Initial funding for development and deployment of the VWS was obtained from the Kentucky Transportation Cabinet through the State Planning and Research Program. Approximately $200,000 was made available, with an anticipated project duration of 24 months. A Study Advisory Committee was formed, with representation from multiple departments and divisions

within the Transportation Cabinet. This included Kentucky Vehicle Enforcement (KVE), which at that time was part of the Transportation Cabinet. This Committee guided the project from its inception through its completion.

To develop and implement the VWS, a contract was established with Computer Recognition Systems (CRS), who had supplied the equipment and software for the RMS. Total cost of the contract, including development, procurement, installation, and six months of operational support, was approximately $150,000.

SITE SELECTION FOR THE VWS

Since this was to be Kentucky's first VWS, it was important to select a suitable site for deployment. The project team, with guidance from the Study Advisory Committee, developed a list of ten characteristics that would define the ideal location. These characteristics were:

1. High commercial vehicle violation rate
2. High truck volume
3. Used as a bypass route for a nearby weigh station
4. Access to a safe pullover location for commercial vehicles
5. Level stretch of road with fairly constant vehicle speeds
6. Close proximity to a weigh station
7. Available utilities for power and communication
8. Ease of intercept and short travel distance for enforcement officer
9. Reasonably close to central Kentucky (for ease of evaluation)
10. County court support for enforcement actions on commercial vehicles

Based on these characteristics, a list of 14 candidate sites was developed. Project staff then collected data on each site, conducted site visits, and assessed each site against the ten "ideal" characteristics. This information was presented to the Study Advisory Committee, and the Committee identified the three best candidate sites. Additional data was then collected on those three sites, including the following characteristics:

1. Level of interest of weigh station personnel in having a VWS
2. Availability of sufficient personnel to use the system
3. Physical space within the weigh station
4. Safety considerations along the bypass route and the intercept route
5. Topography of the area
6. Intercept interval (i.e., the time "margin" for intercepting a suspected violator)

After consideration of all these factors, a decision was made to locate the VWS on northbound US 25 in Laurel County, Kentucky. A map and photograph of that location are shown in Figures 9 and 10, respectively.

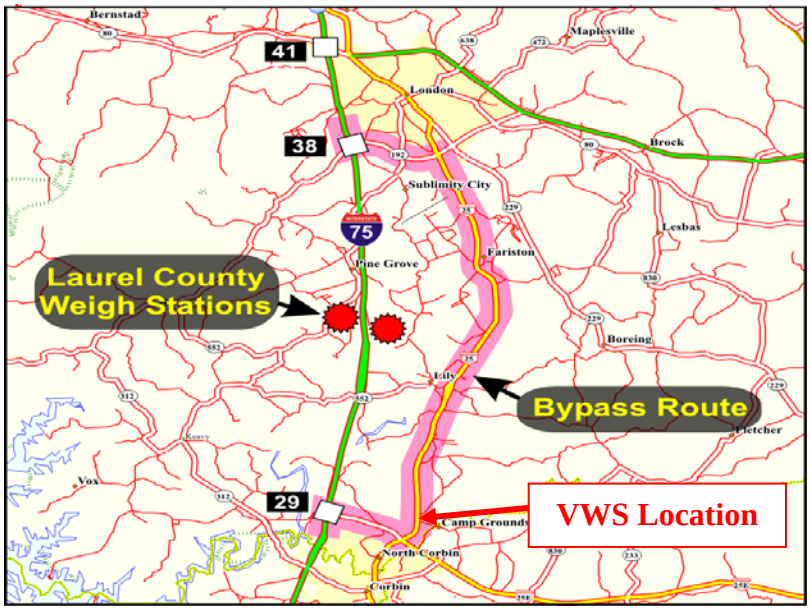

Figure 9. Map Showing VWS Location

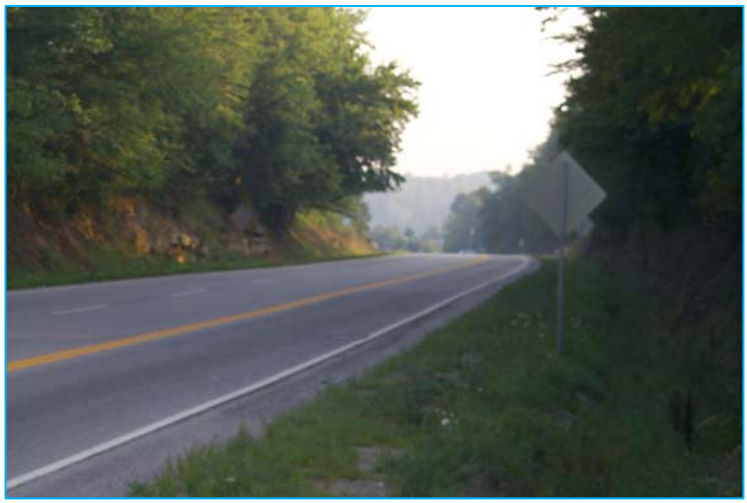

Figure 10. Selected VWS Location (Looking North)

VWS TECHNOLOGY AND SOFTWARE

The VWS equipment, as installed at the roadside, is shown in Figure 11. The VWS was intended to duplicate the functionality of the RMS, with the addition of WIM technology. Thus, much consideration was given to the type of WIM technology to be used. The budget for this project did not allow for installation of an expensive, highly accurate WIM system. Also, Kentucky's enforcement personnel indicated that extreme accuracy was not needed. Since this WIM would be used as a screening tool, to identify potential violators, an accuracy of plus-or-minus ten percent was deemed to be quite adequate. Investigation of various available technologies

Figure 11. VWS Roadside Equipment

showed that a quartz piezoelectric WIM system could provide such accuracy while remaining within the budget constraints of the project.

Selection of the specific vendor for the WIM technology was left up to the VWS system vendor, CRS. CRS elected to go with Kistler quartz piezoelectric technology provided by International Road Dynamics. The actual WIM sensors, as installed at the VWS site, are shown in Figure 12.

In an effort to improve the image capture functionality of the VWS (as compared with the RMS), several changes were made to the camera setup and operation. A single camera was used, eliminating the second, pole-mounted camera across the road. A high-resolution camera was used, with a wider field of view, so that more of the truck could be captured in a single image. This change eliminated the need to capture and transmit multiple side images of the truck.

As with the RMS, it was necessary to choose a communications option for transmitting the images and weight data from the remote site to the weigh station. The topography of the region did not allow for line-of-sight communications. The option chosen for the RMS (an ISDN line) was not practical for the VWS, due to the long-distance charges that would have been incurred. Several other options were considered, including a trial run of a dish-based satellite communications system, but the solution that was finally chosen was a cable modem provided by the local cable TV provider. The cable modem provided a high-speed Internet connection at the VWS site. The weigh station was already connected to the Internet via the Transportation Cabinet's wide area network.

Figure 12. WIM Sensors for VWS

As might be expected, the user interface for the VWS software differs in appearance from the RMS software. The elimination of one camera, the transmission of a single image (instead of eight), and the addition of weight data all contributed to this change in appearance. A screenshot of the VWS software's user interface is shown in Figure 13.

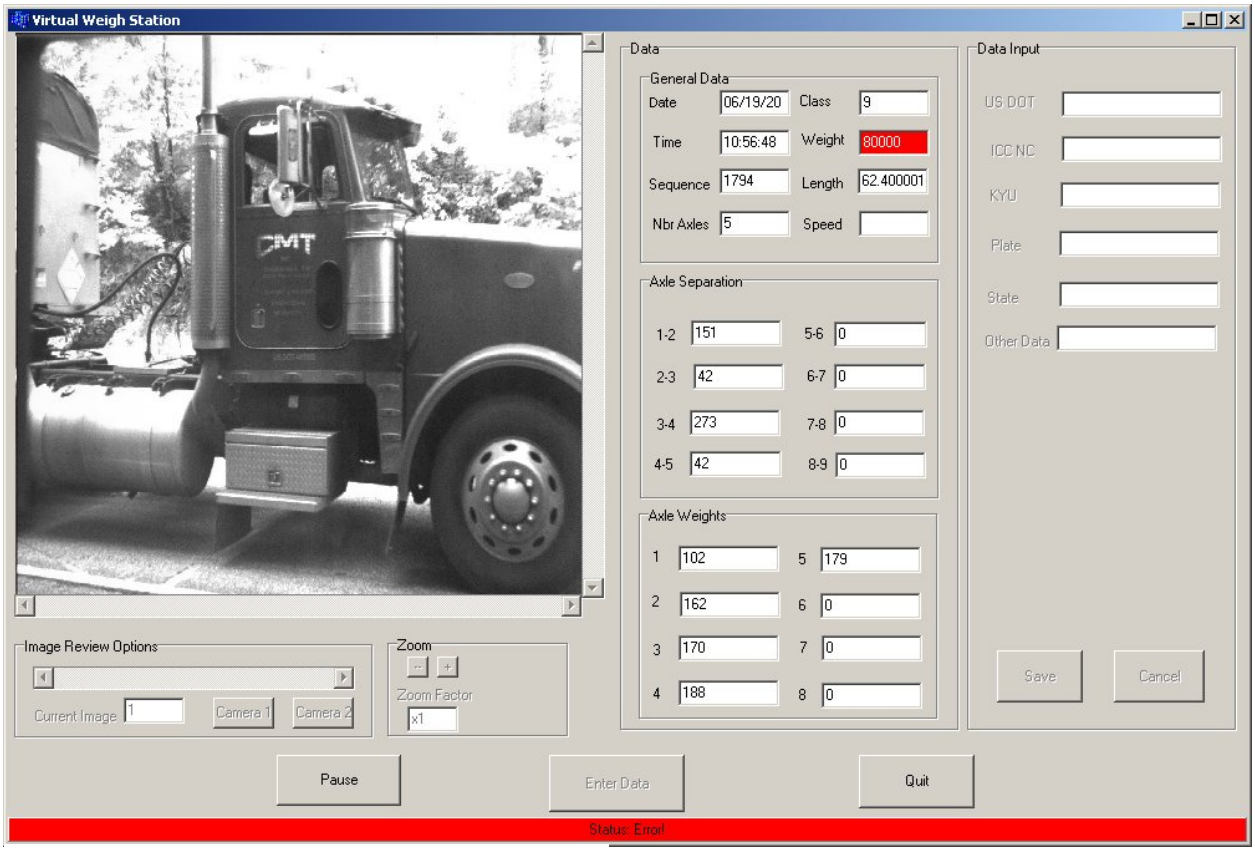

Figure 13. Screenshot of VWS Software

VWS PRELIMINARY ASSESSMENT

The VWS hardware was installed in December 2002. The early months of 2003 were used for testing, refining, and adjusting the system to optimize performance. It was during this period that the dish-based communications option was abandoned in favor of a cable modem.

In June 2003, the Transportation Cabinet conducted a 48-hour, continuous enforcement operation at three weigh stations, including the northbound Laurel County station. As part of this operation, the VWS was operated and monitored continuously for 48 hours. All images and weight data records collected during this time period were saved and compiled, and a preliminary assessment of system performance was conducted.

During the 48-hour assessment, the system was "triggered" 493 times. Of these, 454 (92 percent) were valid transactions, i.e., transactions where the system was triggered by a truck. For these, the USDOT number was captured in the image for 355 observations, which is 78 percent of the valid observations. Unfortunately, the USDOT number was only readable (by a human observer) for 155 of those observations. In other words, when the USDOT number was captured, it was only readable 44 percent of the time. Thus, the overall system performance, in terms of capturing a readable USDOT number was 34 percent of the valid transactions. The primary factors affecting the readability of the USDOT numbers were blurry images, numbers too small to read, lack of contrast between the numbers and the background, the location/timing of the image capture, and various problems associated with lighting, shadowing and glare.

Based on the results of the preliminary assessment, CRS identified several system improvements that could be made. Unfortunately, while CRS was implementing these improvements, the Kentucky Transportation Cabinet implemented enhanced security measures on all their computer systems. This resulted in a disruption of communications between the VWS and the Laurel County weigh station, a disruption that took many months to resolve. When communications were finally restored and stabilized, CRS attempted to resume their work on system adjustments and "fine tuning." At that time, CRS discovered that the WIM system was inoperable and in need of repair. This created a significant "decision point" for the project partners. There was a legitimate concern regarding the expected cost of the WIM repair (which could potentially exceed the remaining funds in the project). There was also a concern about the wisdom of investing more money in a system that had not worked very well. The quality of the images captured by the system had been quite poor, and it wasn't clear just how much improvement could be achieved. So, there was substantial discussion regarding the best way to proceed.

While the project partners were considering and discussing options, an event occurred that made the discussions moot. A paving contractor, hired by the Kentucky Transportation Cabinet to resurface a portion of US 25, paved over the WIM sensors for the VWS. When this occurred, the decision was made to shut down the VWS equipment and close the project.

CONCLUSIONS AND LESSONS LEARNED

The RMS served well as a proof of concept, demonstrating that images of passing trucks could be automatically captured and transmitted to another location. It demonstrated that those images could be used to identify and intercept trucks with credentials-related problems. As a first attempt, it showed that readable USDOT numbers could be captured for a sizeable percentage (slightly more than 50 percent) of the passing trucks. It also demonstrated that this technology has significant potential as an enforcement tool, since a high percentage of trucks going past the RMS have some sort of violation that could be detected using the RMS.

The VWS showed that WIM technology and image capture technology could be successfully integrated to create a virtual weigh station. Unfortunately, the image quality for the VWS was inferior to that of the RMS, with only 34 percent of the trucks having a readable USDOT number captured. This could be due to higher vehicle speeds at the VWS, poor technology choices, poor installation and configuration, or a combination of these factors. It is unknown how much this

performance could have been improved, because various factors conspired to prevent the system vendor from implementing their planned improvements.

Because the RMS and VWS require a human observer to read and check USDOT numbers, their value as enforcement tools depends heavily on the availability of adequate staffing. When staffing levels are short, the RMS and VWS tend to sit unused. When adequate staffing levels are provided, then enforcement personnel are more likely to make use of tools like the RMS and VWS.

Overall, this project validated the potential value and importance of the VWS concept. It showed the need for further refinement and testing of the image capture technology. It also highlighted some inherent difficulties with capturing the USDOT number. These difficulties included the following:

- Capturing nighttime images – Because USDOT numbers are not retro-reflective, they must be illuminated with visible light. Placing bright lights at the roadside can create a glare hazard for motorists and, in some cases, an annoyance for nearby residents.
- Lack of standardization – The display of USDOT numbers is not standardized in terms of location on the truck, color, font, size, or contrast. Usually, there are several other numbers displayed along with the USDOT number, and there is no standard for how these various numbers are arranged.
- A moving target – Because the USDOT number is on the side of the truck, the camera must be oriented perpendicular to the direction of travel of the truck. At high truck speeds, this creates the potential for blurred images, even with rapid shutter speeds.

RECOMMENDATIONS

Because of the substantial potential of the VWS concept to provide a low-cost, high-value enforcement tool, Kentucky should continue to explore and develop this concept. Using the lessons learned from the initial deployments, a "next generation" VWS should be developed and implemented. The following specific steps are recommended:

1. A license plate reader (LPR) and USDOT number reader have just been deployed on the ramp at the northbound Laurel County weigh station on I-75. These systems should be evaluated to determine their accuracy and reliability in reading license plates and USDOT numbers.
2. Based on the results of the evaluation of the LPR and USDOT number reader, one of these technologies should be selected for use in the "next generation" VWS. Functional requirements and system specifications should be developed, the system should be deployed, and an evaluation should be performed.
3. The "next generation" VWS should be fully automated, so that no continuous human monitoring is required. The system should generate an alarm whenever an apparent violation (size, weight, credentials, or safety) is observed.

4. Concurrently with the recommendations above, Kentucky Vehicle Enforcement should develop a strategy for how the VWS concept can best be applied to increase the effectiveness and efficiency of commercial vehicle enforcement throughout the Commonwealth. As a minimum, this strategy should consider the following:

    - Because of the relatively low cost of a VWS (compared to a fixed weigh station), the VWS provides a cost-effective alternative for extending the enforcement presence to additional regions and routes. For the cost of constructing one fixed weigh station, it is possible to deploy approximately 40 virtual weigh stations.
    - If Kentucky decides to deploy more virtual weigh stations, it will soon become impractical to tie each VWS to a fixed weigh station. Alternative deployment scenarios will need to be developed. One such scenario would have images and data from multiple VWS sites coming into a central location. This scenario would allow one person to monitor multiple VWS sites and to dispatch enforcement resources to intercept probable violators. Enforcement resources (i.e., officers in patrol cars) could be strategically located to allow timely response while achieving maximum efficiency in the use of available resources.