# Impact Assessment of the Smart Roadside Initiative (SRI) Prototype

## Final Report

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16. Abstract

This report summarizes the independent assessment of the effectiveness and lessons learned from roadside motor carrier compliance systems including assessment of the Smart Roadside Initiative (SRI) Prototype and other SRI-like technologies. The locations selected for the assessment were Grass Lake, Michigan; West Friendship, Maryland; Lyon and Simpson, Kentucky; and Mount Airy, North Carolina. The objective of the project was to prepare and conduct a comprehensive independent assessment of SRI-like applications using data from before and after deployments. This document describes in detail the methodology used for the analysis and the results obtained for the systems assessed at each site.

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# Executive Summary

The objective of this study is to conduct a comprehensive independent assessment of Smart Roadside Initiative (SRI)-like applications using data from before and after deployments. The systems and sites included in the study are the Kentucky Automated Trucking Screening (KATS) system deployed in Lyon and Simpson, Kentucky; the Smart Roadside Initiative (SRI) Prototype deployed in Grass Lake, Michigan and West Friendship, Maryland; and Weigh in Motion (WIM) scale and Automated License Plate Reader (ALPR) deployed in Mount Airy, North Carolina.

In order to assess the effect of these systems, the impact assessment team accomplished the following:

1. Defined appropriate performance measures to objectively evaluate the effectiveness of systems under study
2. Collected pre-and post-deployment data related to the performance measures and operational processes at each of the sites
3. Produced fundamentally sound statistical analysis relative to each of the performance metrics for each site
4. Determined the quantitative and qualitative impacts of the technologies on the operations of the inspection stations
5. Identified the key attributes or characteristics that must be considered in applying studied site findings to the broader environment (e.g., state, region)

The methodology employed in this study included four main steps:

- Capture and map the business process
- Define performance measures
- Collect before and after deployment data
- Analyze data and document findings

For the process mapping it was necessary to study the operations before and after deployment of the SRI-like applications; this provided the basis for building the process maps and provided a better understanding of the flow process of trucks. The team held several meetings with stakeholders and system experts to review the process and to define the performance measures and transformative targets used to evaluate the effectiveness of the deployed SRI-like applications. The performance measures used for the impact assessment are:

- Average proportion of time processing (inspection and paperwork) non-compliant vehicles
- Number of productive inspections (those with violations) per unit of resource
- Number of driver Out of Service (OOS) violations issued
- Number of vehicle OOS violations issued,
- Number of OOS assessments
- Number of satisfied users
- Revenue generated through inspections

Well-defined performance measures facilitated the process of identifying the type of data required for the analysis. The data elements for the study were identified based on the relevance to performance measures and transformative targets and the relevance to the operations and processes studied at the sites.

The types of analysis conducted in this study, include:

- Statistical analysis of the provided datasets to assess the statistical difference between the pre- and post-deployment periods. The analysis includes descriptive statistics, tests of hypotheses, and inferential statistics.
- Stakeholders' surveys to draw a conclusion from law enforcement officials and motor carriers responses.
- Simulation modeling and analysis to evaluate the impact of mainline smart roadside technology on the number of vehicles inspected.

In this study, all the data were provided by the state police departments for commercial vehicle enforcement and state DOTs, as they keep detailed records of all activities performed on each site. Datasets provided include WIM and static balance daily counts, inspection records with violation, station revenue, traffic flow in the corridor, etc. However, feedback from the trucking community was not sufficient for a proper assessment on metrics like the number of satisfied users.

The analysis successfully assessed the impact of the different systems at each site. The report includes the details of the analysis. Below is a summary of the results and findings by system and site:

*The KATS systems* deployed at Lyon County, Kentucky and Simpson, Kentucky.
Lyon showed great positive impact and significant improvement on every performance measure used in the assessment from the number of violations detected, to productive time, as well as site revenue. On the other hand, the KATS system at Simpson site only provided significant positive improvement on site revenue. The stakeholder survey in Kentucky showed positive feedback for the system with 100% of the respondents confirming that the system improved their ability to identify violations particularly those that are credential-related such as suspended licenses and delinquent taxes, among others.

*The SRI Prototype by Leidos* deployed in West Friendship, Maryland and Grass Lake, Michigan.
The assessment was limited to the analysis of the stakeholders' surveys due to the lack of sufficient data to perform a sound statistical analysis. The stakeholders' surveys in Maryland site showed positive feedback with 43% of the responses indicating that the system improved their ability to detect violations, and 29% believed it could improve the safety of individual truck drivers. At the Michigan site, 23% of the participants indicated that the system improved their ability to detect violations while 31% stated that safety for individual truck drivers and conditions in the corridor could improve with the deployment of this system.

*The WIM and ALPR systems* deployed in the Mount Airy, NC.
The assessment showed great positive impact and significant improvement on every performance measure used in the assessment, from the number of violations detected, to productive time, as well as site revenue. The stakeholders' surveys indicated that 40% of respondents believed there has been an improvement on driver's attitude towards inspection because drivers are more aware given that they are screened every time they enter the station. Also, 69% of survey participants believed that the system has improved their ability to detect potential violations and over half of them responded that the system has improved the safety of individual truck drivers and the safety conditions in the corridor.

*Simulation and modeling of SRI-like applications.*

In addition to the statistical analysis and the stakeholders' surveys, a simulation model was developed to mimic the operation of weigh stations. The model enabled the team to analyze the impact of different settings and configurations of SRI like technologies on the pre-set performance measures. To complete this analysis it was necessary to apply certain assumptions, for example technologies being 100% accurate, no inspector discretion, and unlimited staff capacity, among others. These assumptions, although they may not be true in all cases, were needed in order to develop clear findings and reduce variability in the results.

During the simulation analysis two use cases were developed. In the first case, we studied the effect of having the compliance screening systems on the mainline versus in the ramp. The output showed that the location of the compliance screening systems has no significant impact on the number of violators found; however, the mainline system benefits drivers and enforcement operations by allowing those compliant vehicles to by-pass the station, reducing delays for drivers and improving the productivity at the station. The second use case studied the effect of user adoption rate for by-passing technologies combined with the variation in the random-pull setting of these systems. The simulation output showed that user adoption has a significant impact on the rate of vehicle by-passes. It also showed that the impact of the system's random-pull rate depends on the adoption rate. However, given the assumptions used for the simulation runs in this use case, neither variable was found to have a major impact on the number of vehicles found with violations.

In light of the limited deployment of the SRI prototype in Maryland and Michigan, and some of the results found in the Simpson assessment; overall, the SRI-like systems and technologies studied and modeled in this assessment project positively affected in one way or another, the productivity, efficiency, and safety of commercial vehicle enforcement operations and of the carriers, drivers, and users. Such positive effects of technology were more noticeable in Lyon and Mount Airy. Although additional deployments would allow for a more thorough understanding of the impacts of smart roadside technologies, current deployments of similar technologies in different areas of the country, have demonstrated the partial benefits that these systems may bring in the future.

# Project Background

This report summarizes the independent assessment of the effectiveness and lessons learned from roadside motor carrier compliance systems including assessment of the Smart Roadside Initiative (SRI) Prototype, sponsored by the United States Department of Transportation (USDOT) and developed by Leidos. This report was prepared by the impact assessment contractor for the project and referred to in this report as “the impact assessment team”. The team’s assessment was limited for the SRI Prototype, where data was only available at two sites. Three other sites were selected due to their use of SRI-like systems; these depict a more comprehensive picture of the potential impact generated from an automated enforcement approach. With as many as five sites planned, the goal of the impact assessment was to acquire data and perform a comprehensive analysis of the prototypes and existing systems and their potential use throughout the states involved and beyond.

## Smart Roadside Initiative

The Smart Roadside Initiative (SRI) is a joint effort of the Federal Motor Carrier Safety Administration (FMCSA) and the Federal Highway Administration (FHWA) with support from the Intelligent Transportation Systems Joint Program Office (ITS JPO). The vision for Smart Roadside is one in which commercial vehicles, motor carriers, enforcement resources, highway facilities, intermodal facilities, toll facilities, and other nodes on the transportation system collect data for their own purposes and share the data seamlessly with the relevant parties, with a goal of improving motor carrier safety, security, operational efficiency, and freight mobility. This vision could be furthered through the application of interoperable technologies and information sharing among in-vehicle, on-the-road, and freight facility systems. Whenever possible, SRI leverages stakeholders’ current technology investments in order to augment existing programs and support new activities.

Goals for research and deployment of Smart Roadside systems include the following:

- To enhance roadside enforcement operations through improved screening and automation of inspection/compliance checks
- To identify key entities (e.g. motor carrier, commercial vehicle or driver, cargo) and communicate with commercial vehicles in real time at highway speeds
- To ensure that the necessary standards and architecture are in place to support interoperable operations across the country

The Smart Roadside Initiative included, under a separate contract with Leidos, the development and testing of prototype compliance technologies during 2012-15. The goal of that SRI Prototype project was to test new SRI applications with existing screening systems. The test results are documented in *Smart Roadside Initiative Final Report* FHWA-JPO 16-258 September 2015. As described in more detail below, the impact assessment team examined two SRI Prototype sites and three other state-operated stations with a variety of compliance systems.

Multiple systems currently in operation in several locations were assessed in this project.  These commercial vehicle enforcement systems included:

**SRI Prototype:** An integrated system that displays WIM and static scale results, and Safety and Fitness Electronic Records (SAFER) data to inspectors and on drivers' mobile devices. This system was developed during the Smart Roadside Initiative Project.

**Weigh in Motion (WIM) scales:** This system records axle weights and gross vehicle weights as trucks drive through a weigh station. There are both ramp and mainline WIMs.

**Kentucky Automated Truck Screening (KATS):** Is an automated screening of trucks based on license plate and USDOT numbers

**Automated License Plate Reader (ALPR):** The system captures license plate images and using optical character recognition (OCR) technology, it compares those values with safety databases.

The technology devices used and their capability for integration with other systems relate in a great extent to the capabilities looked for in smart roadside systems. Future SRI-like Systems will use sensor technologies similar to the current weigh-in-motion systems that have been successfully deployed at weigh station ramps and on highways' mainline throughout the country to accurately measure vehicles' weight. Additionally, although mobile and radio technologies were used on this deployment of the SRI prototype, license plate reader systems with OCR technology, like the ones used for KATS in Kentucky and the ALPR in North Carolina, have also been deployed both in-ramp and roadside at highway speeds for successfully identifying vehicles for compliance.

Furthermore, the integration capabilities that these systems have demonstrated, by effectively communicating data from multiple sources and incorporating it into a single interface, are one of the most important features SRI systems are striving to achieve. Hence, the assessment of these technologies will provide additional insight on the impact to stakeholders.

There were also other systems already deployed at the studied sites that were not directly evaluated by this team. Those included:

**Static scales -** set of scales installed on pull-off stations that weigh trucks while stationary.

**Bypassing Systems**

- **PrePass:** transponder based system allows pre-screened commercial vehicles to bypass PrePass-equipped weigh stations
- **Drivewyze:** mobile radio system using smartphone technology allows commercial vehicles to bypass Drivewyze-equipped weigh stations
- **NCPass:** North Carolina weighs station pre-clearance transponder system that allows carriers to bypass weigh stations in the state.

**Infrared cameras:** System used to inspect the brakes and tire pressure of trucks in weigh station.

Further information regarding these systems is presented in the upcoming sections of this report.

# Project Objectives

The objective of the project was to prepare and conduct a comprehensive independent assessment of SRI-like applications using data from before and after deployments. Assessment of the SRI Prototype application was performed at two sites, namely West Friendship in Maryland and Grass Lake in Michigan. Other sites were included in this impact assessment to provide a broader view of the impact an automated enforcement approach generates, in addition to the presence of SRI-like operations. These additional sites were Lyon and Simpson in Kentucky, and Mount Airy in North Carolina.

The evaluation documented here includes an impact analysis of the SRI Prototype and the existing technologies at other sites, analytical activities necessary to estimate the effectiveness and impact of the SRI-like operational deployments at the sites included in this study, and feedback via surveys and interviews from site stakeholders including commercial vehicle safety and enforcement personnel, and private carriers.

In order to assess the effect of the SRI Prototype application and similar systems, the impact assessment team needed to accomplish several tasks:

1. Define appropriate performance measures to objectively evaluate the effectiveness of systems under study
2. Collect pre- and post-deployment data related to the performance measures and operational processes at each of the sites
3. Produce fundamentally sound analysis relative to each of the performance metrics for each site
4. Determine the quantitative and qualitative impacts of the technologies on the operations of the inspection stations.
5. Identify the key attributes or characteristics that must be considered in applying studied site findings to the broader environment (e.g., state, region)

# Performance Measures and Transformative Benefits

A number of performance measures and transformative targets were developed to objectively evaluate the performance and effectiveness of the previously mentioned systems. This was accomplished by holding multiple meetings with the SRI Prototype developer where the scope, objectives, and functionalities of the SRI technology were discussed in depth in order to select the proper performance measures. First, it was stated that Smart Roadside systems should improve the safety, mobility, and efficiency of truck movement and operations on the roadway by facilitating:

- The integration of external systems that enhance the exchange of information (such as safety history and credential status) for commercial motor vehicle (CMV) operations to support roadside operations
- Access to information at roadside, including information that will enable the identification of the driver and vehicle as well as the motor carrier; and
- The deployment of supporting infrastructure at strategic points along CMV routes to support the exchange of information.

Moreover, systems under SRI should do at least three things:

- Streamline methods and mechanisms used to locate and access information, to accelerate and improve the accuracy of decision-making processes;
- Provide an electronic means both to identify CMVs at highway speeds and to manage the exchange of information between vehicles and infrastructure-based systems; and
- Enable the delivery of a broad variety of applications that enhance safety and mobility.

Finally, potential impacts of deployments of SRI and SRI-related technologies include:

- Safety - Reduction in the number and severity of crashes by more effective screening and inspection of unsafe trucks and drivers as well as reducing backups at weigh station ramps by eliminating legally operating trucks
- Mobility - Travel time savings to legally operating trucks and drivers able to forego an inspection pull-in
- Energy - Reduction in fuel use through eliminating legally operating trucks from enforcement queues;
- Emissions - Reduction in greenhouse gas emissions and pollutants
- Cost Savings - Reduction in vehicle operating costs including labor, and the reduction of enforcement program costs
- Agency Efficiency - Cost savings of "wasted enforcement" –time spent on inspections performed on "compliant trucks and drivers"

From the above impacts, the impact assessment team, with input from other stakeholders, defined the following measures and targets presented in Table 1 below.

**Table 1. Performance Measures for Data Analysis**

| Performance Measure | Goal | Data | Quantitative / Qualitative | Predominant Benefit |
|---|---|---|---|---|
| **Average proportion of time processing (inspection and paperwork) non-compliant vehicles** | Increased Productive Inspections Time | Inspection Duration Times, Inspection Start Timestamps, Inspection End Timestamps | Quantitative | Freight Mobility; Agency Efficiency |
| | | Inspection Duration Times, Inspection Start Timestamps, Inspection End Timestamps, Vehicle Fuel Consumption Data, Vehicle Emissions Data | Quantitative | Energy; Cost Savings |
| | | | Quantitative | Emissions |
| **Number of productive inspections (those with violations) per unit of resource** | Increased Inspection Efficiency | Inspections Results (Level I-III), Total Resources (Officers) | Quantitative | Agency Efficiency; Safety; Freight Mobility |

| Performance Measure | Goal | Data | Quantitative / Qualitative | Predominant Benefit |
|---|---|---|---|---|
| **Number of driver OOS violations issued** | Increased Safety | Inspection Results (Level I-III) | Quantitative | Safety & Agency Efficiency |
| **Number of vehicle OOS violations issued** | | Inspection Results (Level I-III) | Quantitative | Safety & Agency Efficiency |
| **Number of OOS assessments** | | Inspection Results (Level I-III), OOS counts | Quantitative | Safety & Agency Efficiency |
| **Number of satisfied users** | User Acceptance | Stakeholder Input | Qualitative | Agency Efficiency |
| **Revenue generated through inspections** | Increased Revenue | Financial metrics & historical data | Quantitative | Cost Benefit |

*Source: Productivity Apex, Inc.*

After reviewing the previous table it is important to clarify that inspection procedures vary from a Level 1-7: Level 1 is the most comprehensive covering a total mechanical and credential check; Level 2 is only a basic mechanical check with full credential check; Level 3 is only a credential check; Levels 4-7 are special checks that are rarely used. For more information about inspection levels please refer to Appendix B.

## Studied Sites

This section provides an overview of the five sites that were selected to evaluate the impact of smart roadside system deployments. Two weigh stations in the state of Kentucky, and one station each in Michigan, Maryland, and North Carolina were selected for analysis in order to determine the effect that the implementation of these kinds of systems had on those sites. The weigh station sites and principal systems assessed and documented in this report are listed below and shown on the map in Figure 1:

- Kentucky –KATS
  a. Lyon County (I-24/69)
  b. Simpson County (I-65)
- Maryland –SRI Prototype:
  a. West Friendship (I-70)
- Michigan –SRI Prototype:
  a. Grass Lake (I-94)
- North Carolina – WIM scale & ALPR:
  a. Mount Airy (I-77)

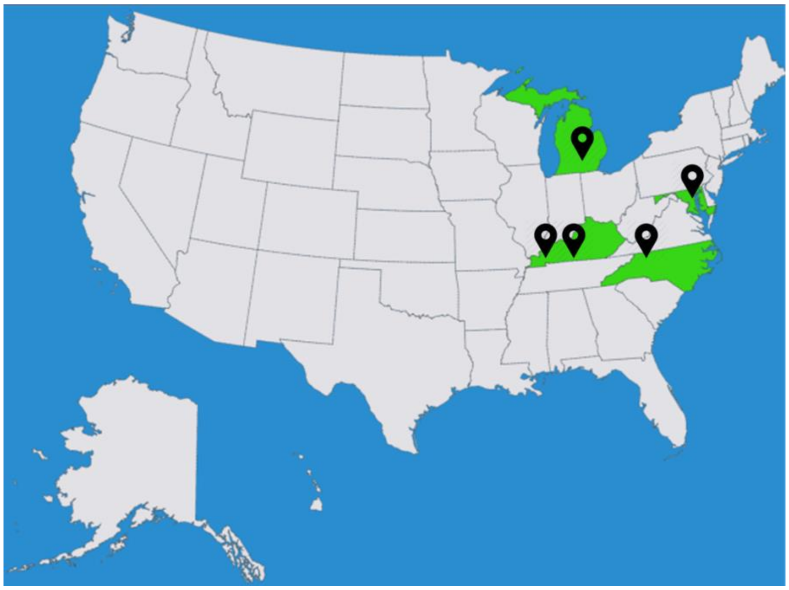

***Figure 1. Map of Assessment Sites***

*Source: Productivity Apex, Inc.*

The assessment of the SRI Prototype application was originally intended for a minimum of four sites, with the possibility of up to six sites. Schedule and budget limited the study to two sites: Grass Lake in Michigan on I-94 between Jackson and Ann Arbor and West Friendship in Maryland on I-70 near its intersection with SR 32. Due to the limited field testing performed on the SRI Prototype application, existing sites were added to the impact assessment. In each case, the technologies and operations of these sites demonstrated SRI-related characteristics.

Sites in Kentucky and North Carolina were selected for inclusion in the impact assessment since having recently completed delivery of noteworthy automated truck enforcement programs and facilities. Kentucky's Automated Truck System program exhibits the characteristics envisioned by the Smart Roadside Initiative. North Carolina recently updated its truck screening system, NCPass, producing a system with characteristics aligned closely with the SRI vision.

## Kentucky

The two stations selected in Kentucky were the Lyon County weigh station located in the I-24 corridor and the Simpson County weigh station located in the I-65 near the Tennessee border. A unique aspect of Kentucky's commercial vehicle enforcement (CVE) laws is the requirement to have a Kentucky User permit, which requires truck drivers to pay usage taxes based on weight and distance travelled. Not having this permit is a violation, therefore drivers can purchase temporary permits at weigh stations if found without one. The main systems utilized at these stations are in-ramp weigh-in-motion scales (WIM), a static scale, a weigh station bypassing system, and an automated credential screening system, with others specified later in this report. Both sites included in this study in Kentucky use PrePass and Drivewyze as bypass systems. The system chosen to be evaluated is the Kentucky Automated Trucking Screening (KATS), which is an automated credential screening system.

This system is described in more details below in the Description of Commercial Vehicle Enforcement Systems section.

***Lyon County***

The Lyon County weigh stations are located on the east- and westbound directions of I-24 at mile marker 36. The annual average daily traffic (AADT: the average 24-hour volume of vehicles in a year) near the Lyon County station is over 26,000, with 27% being trucks. For the period studied, Lyon averaged about 1,300 trucks per day driving through their scales. This station operates during one shift per day, with one or two people (civilian inspectors, sworn officers, or a supervisor) on duty on each side. The station has a covered inspection area with a pit for the inspector to walk under the truck to perform Level 1 inspections. KATS was activated at this site on August 14, 2015.

Before KATS was deployed, inspectors usually randomly selected trucks to be inspected, unless there was a weight violation that was caught by the static scale. The station used to have civilian clerks watching trucks go by and entering their USDOT numbers to check for credentials, that position was eliminated by 2011 and inspectors were not required to continue live spot checks. KATS can do this job automatically for every truck that passes through the station.

***Simpson County***

The Simpson County weigh station is located at mile marker 4 of I-65 northbound only, and just north of the Tennessee border. The AADT through Simpson County is over 41,000, with about 45% trucks. For the period studied, Simpson averaged about 1,600 trucks per day through their scales. This station operates for one or two shifts per day, with: two inspectors and one officer on Monday-Thursday day shifts; one officer on Friday and Sunday day shift; and one officer on typically three night shifts per week during peak hours. In addition to the main screening system in Kentucky, the Simpson station also has an infrared (IR) camera that inspectors use to look at the condition of brakes and tires of trucks that drive through the station. The IR camera is not automatic, and thus requires an inspector to be present, observing the video feed of trucks driving through the station to spot violations and pull over trucks. Inspectors manually enter USDOT numbers to check federal inspection selection system (ISS) scores for companies. This station also has a covered inspection area with a pit. KATS was deployed at this station on January 1, 2015.

## Maryland

The station selected in Maryland is the West Friendship station located on I-70. The bypass technology utilized in Maryland is Drivewyze. The system chosen for evaluation is the SRI Prototype. The weigh station studied is staffed by sworn officers, not civilian inspectors. Due to the station's high volume of local freight traffic, officers take recent inspections into account when selecting vehicles for inspection, by using the systems available to them; in order to avoid inspecting vehicles that have been inspected recently and try to pull those that haven't been inspected lately.

***West Friendship***

The West Friendship station is located on I-70 westbound at mile marker 79, west of Baltimore. The main systems in this station are the static scale, ramp WIM scale, Drivewyze, LPR, and SRI Prototype. Inspectors at West Friendship will use the LPR to obtain license plate numbers and look up

ISS or SAFER scores. These databases are described in more details in the Description of Commercial Vehicle Enforcement Systems section.

## Michigan

The station selected in Michigan is the Grass Lake weigh station located in the I-94 corridor. A unique aspect of Michigan's CVE laws is that Michigan is a "probable cause" state. This means that any officer or inspector who pulls over a truck must have a legitimate reason for doing so, such as seeing a violation on the vehicle or hazardous driving. This does not allow a truck to be pulled over "randomly" as in the other states in this study. Michigan allows trucks to operate at the upper weight limits—up to 160,000 pounds. Livestock haulers are exempt from stops and out of service (OOS) violations to keep animals healthy. An Out of Service (OOS) violation that in which a driver cannot continue to operate until any mechanical or credential issue is corrected; officers will hold the driver and truck at the weigh station until resolution. The system chosen to be evaluated is the SRI Prototype, which is an automated credential screening system.

### *Grass Lake*

The Grass Lake station is located at mile marker 151 of I-94 East and West between Detroit, MI and Chicago, IL. The main systems in these stations are a mainline WIM scale, ramp WIM scale, static scale, Drivewyze bypassing system, and the SRI Prototype automated credential screening system. The mainline WIM is only used as part of the pre-screening system, and thus does not allow trucks without the necessary technology to bypass the station. Trucks selected for the static scale go over a small 9' x 9' scale that must be slowly driven over. There is an electronic sign and speakers used for officers to communicate with drivers. The station is open for 3 shifts 5 days per week, intermittent weekends, and looks at about 100-300 trucks per hour. This station had an IR camera in the past, but officers didn't use it for commercial vehicle enforcement so it was removed.

## North Carolina

The North Carolina weigh station selected for the assessment is the Mount Airy station located on I-77. In North Carolina the NCDOT developed its own bypass system, called NCPass, which is operated by International Roadway Dynamics (IRD) and deployed at weigh stations on interstate highways. During the data collection period, the Mount Airy station was under construction upgrading to a new generation of NCPass. NCPass is described later in the Description of Commercial Vehicle Enforcement Systems section.

### *Mt. Airy*

The Mount Airy weigh station is located at mile marker 103 on the north- and southbound sides of I-77, which is just south of the Virginia border. The AADT is 32,000 vehicles per day, and trucks make up about a quarter of this amount. The primary systems found in this station are a static scale, ramp WIM scale, an automated license plate reader (ALPR), and weigh station bypassing system (NCPass). The systems chosen to be evaluated on this site is the WIM and ALPR system combination, which was deployed in January of 2014, and estimates the weight of a vehicle while checking a carriers' ISS scores automatically. The ISS scores are used by inspectors to help decide whether to pull over trucks; scores above 90 are automatically sent to the static scale and are often inspected regardless of weight. Before WIM+ALPR deployment, inspectors could only choose trucks at random or based on their previous experiences spotting trucks baring violations.

# Description of Commercial Vehicle Enforcement Systems

There are many commercial vehicle enforcement systems deployed at the studied sites that contribute to inspection operations; however, this section will discuss the most relevant systems deployed, including those that are evaluated in this project.

### Static Scale

Static scales are a set of scales installed on the road adjacent to station houses that capture the weight of a truck while it is stationary. All trucks that fail the weigh in motion scale check, or all trucks that enter a station without a WIM, must stop at this scale to verify their weight. There are light signals installed to communicate to drivers whether they have passed and may continue onto the road or if they need to pull over for further inspection. These scales must be calibrated annually to ensure accurate measurements.

### Weigh in Motion (WIM) Scale

Weigh in Motion (WIM) scales are designed to capture and record axle weights and gross vehicle weights as trucks drive through a weigh station. These systems do not require vehicles to stop and are able to record the measurements of vehicles traveling at a reduced traffic speed. WIM devices are installed whether in the mainline highway or in the ramp pavement entering the weigh station and connected to data collection instruments. The data is sent to various program areas and agencies to support their needs for highway weight-based information.

Weigh in Motion scales are commonly deployed at weight enforcement facilities where traffic is high and ramp sorting with such a large volume cannot be done on static scales. Traditionally, WIM has been used as a weight enforcement tool to sort trucks on the approach ramp into a weigh station. When a truck driving over a WIM scale exceeds the maximum regulation weight, they are redirected to static scales where their weight can be verified. Weigh stations are equipped with signs and lights to direct drivers to the static scale or WIM bypass lane.

Some sites throughout the country have WIMs on the mainline highway to either pre-sort trucks so that only weight violators go to the scales or as a complement to other pre-screening systems. Mainline WIMs have great advantages given that they allow trucks to drive at highway speeds, which reduce fuel consumption and emissions.

Every site studied for this project had a ramp WIM. The only site that used a mainline WIM for pre-clearance screening was Grass Lake in Michigan.

#### PrePass

PrePass is a transponder-based system using 915 MHz telecommunication connectivity that allows pre-screened commercial vehicles to bypass weigh stations that are equipped with PrePass systems. To be certified to bypass weigh stations, carriers must have up-to-date credentials and maintain good safety records with state and federal agencies. Some weigh stations are also equipped with mainline WIM scales that factor weight into the bypass decision. Trucks use a windshield-mounted transponder to communicate identification details to the roadside equipment and to receive bypass/no bypass signals. The transponders have green and red lights with audible signals to communicate authorization to bypass or directions to pull in, respectively. Trucks can also be pulled in randomly regardless of their credential status. Inspectors and state police can decide what random percentage of trucks to pull in; the system default is usually 5%.

Weigh stations are equipped with computer terminals and support equipment that displays PrePass inspection results. It lists all trucks that have PrePass that bypass or enter the station and is updated in real time. The list highlights trucks in green for authorized bypasses and red for pull-in designations or unauthorized bypasses. The dashboard informs inspectors of the reasons trucks were flagged to be pulled in so they can make decisions about whether or not to inspect them.

#### Drivewyze

Drivewyze is a commercial mobile radio system using smartphone technology that allows commercial vehicles to bypass weigh stations that are equipped with Drivewyze systems. Drivewyze allows carriers with good safety scores (identified by USDOT number) to bypass at higher rates. A carrier with poor safety scores will get no bypasses and those with perfect scores could bypass up to 98% of the time. Some weigh stations are also equipped with mainline WIM scales that also factor weight into the bypass decision. Drivers need to download a mobile application, and through this they send and receive information on their mobile devices, which tells them to “Bypass” if allowed to bypass, “Follow Road Signs” if they must pull in, or “Follow Transponder” if they have a another transponder for a different bypass program. Trucks can also be pulled in randomly regardless of their credential status. Inspectors and state police can decide what random percentage of trucks to pull in; the system default is usually 5%.

Weigh stations are equipped with computer terminals and support equipment that displays Drivewyze inspection results. It lists all trucks having Drivewyze that either bypass or enter the station and is updated in real time. The list highlights trucks in green for authorized bypasses and red for pull-in designations or unauthorized bypasses. The dashboard informs inspectors of the reasons trucks were flagged to be pulled in so they can make decisions about whether or not to inspect them.

#### NCPass

NCPass is a weigh station pre-clearance system that was developed by the state of North Carolina; it uses a transponder in a 915 MHz telecommunication environment and allows carriers to bypass weigh stations in the state. Trucking companies that apply to the North Carolina State Highway Patrol will be authorized to participate based on credentials and compliance history, number of trucks participating, and requested length of enrollment. Once enrolled, carriers are permitted to bypass between 35% and 90% of the time. Drivers use specific NCPass transponders or can use compatible transponders from other pre-clearance programs that provide bypass or pull-in signals to drivers.

Weigh stations are equipped with computer terminals and support equipment that displays NCPass inspection results. It lists all trucks that have NCPass that bypass or enter the station and is updated in real time. The list highlights trucks in green and the equipment audibly chimes for authorized bypasses and highlights trucks in red for pull-in designations or unauthorized bypasses. The dashboard provides truck information with pictures to inform inspectors of the reasons trucks were flagged to be pulled in so they can make decisions about whether or not to inspect them.

**SRI Prototype**

The SRI Prototype was developed under a contract with the Federal Highway Administration. The system integrates existing technologies already available at the weigh stations to provide one common user interface, referred as the SRI Dashboard, for law enforcement officers to use. The system integrates WIM and static scale results, SAFER data, LPR, iyeCitation, and Aspen; and was accessible to officers online via web. Figure 2 below shows the dashboard design for the SRI Prototype.


***Figure 2. SRI Prototype Dashboard***

*Source: Extracted from "Smart Roadside Initiative –Final Report" Chapter 3*

The SRI Prototype includes a mobile application for truck drivers that provides audio and visual cues notifying the driver to either pull into the weigh station for further inspection or to bypass the static scale. While stationary, the driver can also access electronically available truck parking information to locate available truck parking spaces. The application provides a mechanism for drivers to enter their license number, VIN, USDOT number, and license plate number, as well as a photo of their specific vehicle. In addition, the application provides the communication back to the driver regarding their weigh station instructions.

As the vehicle approached the weigh station the mobile application could only display SAFER data for drivers that have the mobile application, but it always displays scale results. The Dashboard displays a real time list of trucks that enter the weigh station and highlights them in green or red depending on whether they pass the scale and SAFER check. The list will also show a picture of the truck if there is a picture uploaded to the user profile on the app. Figure 3 below shows the app developed for the SRI Prototype.

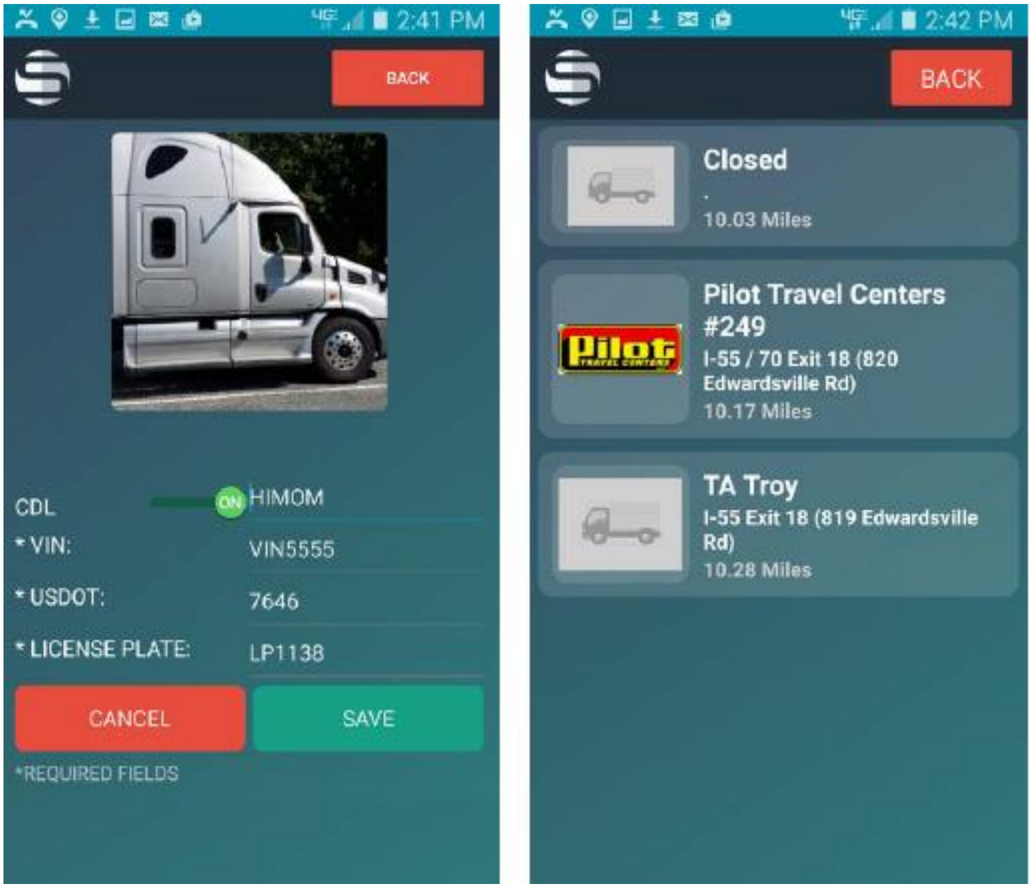


***Figure 3. SRI Prototype Mobile Application***

*Source: Extracted from "Smart Roadside Initiative –Final Report" Chapter 3*

A DSRC version of the mobile application was also tested in the Maryland pilot. In that scenario a backend server receives the data from a roadside unit (RSU) and requests a scale weight assessment from the SRI Web Services. The response is processed by the backend server, converted into a J2735 compliant message using SAE J2735-Nov 2009 (J2735_200911) and sent to the RSU. The RSU then broadcasts that message to the on-board unit (OBU) via dedicated short-range communication (DSRC), and the OBU sends the message to the mobile application via Bluetooth.

Some of the core functionalities of the SRI Prototype are:

- Dynamic web interface that displays CMV information to officers in real time,
- The collection of CMV weight information from WIM and static scales,
- The storage of CMV weight information on the SRI database for 24 hours,

- The collection of license plate images and data from the LPR,
- The storage of license plate data on the SRI database for 24 hours,
- The storage of license plate images on the SRI App Server for 24 hours,
- The collection of CMV credential information from SRI Mobile,
- The storage of CMV credential information on the SRI database for 24 hours,
- The exchange of Aspen data to iyeCitation for reduction in data entry,
- The automatic retrieval of SAFER information via SRI Mobile credentials,
- The manual retrieval process for SAFER data,
- The notification of Pass/Fail weight status from weigh station to mobile application,

**Kentucky Automated Truck Screening (KATS)**

The system, developed in Kentucky, provides automated screening of trucks based on the license plate number and the USDOT number displayed on the vehicle. This automated screening checks the safety history, credentials, registration, PRISM (the Performance and Registration Information System Management) status, and if a Federal Out of Service (FOOS) order has been issued against the vehicle. In all, 16 tests are run on every vehicle by screening against several state and federal record systems. (Wolfe, 2015)

While the system is designed to screen vehicles automatically, it also allows enforcement personnel to monitor and interact with the system. In addition to inspectors, there is a full-time civilian clerk on duty at each station to monitor KATS results. Specifically, when license plate, KYU, or USDOT number information is displayed, enforcement personnel have the ability to check the optical character recognition (OCR) results against photographs displayed on the user interface and make on-the-fly corrections. If corrections are made on the user interface, trucks are rescreened based on the corrected data. The cameras are placed at the entrance to the inspection station ramp to allow sufficient time for identification data to be displayed, reviewed, and corrected before the screening decision is made and communicated to the driver of the truck through the directional arrows of the existing truck sorting system.

If the clerk or inspector determines that a vehicle should be stopped for inspection, that decision is communicated to truck drivers via the existing directional arrows that direct drivers to the static scale or to park and come in for inspection. This ensures that potentially-violating carriers and vehicles are not only identified, but are actually stopped for inspection.

Inspectors have the ability to adjust what criteria KATS screens for trucks and carriers. They can choose to flag all, none, or a percentage of violators of the following options:

- Credentials
    - HVUT – Heavy Vehicle Use Tax
    - IFTA – International Fuel Tax Agreement License status
    - KYU – Kentucky Highway Use License status
    - KIT – Kentucky Intrastate Tax License status
    - KY Hire – KY-for-Hire status
    - UCR - Unified Carrier Registration status

- Registration
  - Expired or not
  - KY Prorate
  - Registered Weight Exceeded
- Safety
  - USDOT status
  - Driver OOS %
  - Federal OOS status
  - Hazmat OOS %
  - Vehicle OOS %
  - PRISM status
- Miscellaneous: No data for truck

#### Automated License Plate Reader (ALPR)

The Automated License Plate Reader (ALPR) is a compliance screening tool that captures images of license plates and compares it to safety databases. This can be deployed at traditional or virtual weigh stations. The ALPR scans multiple databases for potential violations, including SAFER, CVIEW, and PRISM. Then, search results appear on a screen to assist inspectors and officers in making inspection decisions based on safety and credential compliance.

### Optical Character Recognition (OCR) Technology

OCR is a technology that enables the conversion of images captured by a digital camera into editable and searchable data. For example, USDOT numbers can be captured from a digital image of the tractor, enabling enforcement officials to verify the company has the right to conduct business and is not in Out-of-Service status. OCR is also a subsystem employed by ALPR as license plate images are translated into text, in this case, license plate numbers.

### Infrared Camera

Infrared (IR) cameras are used to inspect the brakes and tire pressure of trucks driving through the weigh station. The IR camera is capable of showing worn-out brakes or under-inflated tires. Inspectors or automated IR systems will pull over trucks that are observed having either of these problems and a Level 1 inspection will be performed.

### System's Data Sources

Some of the databases accessed by the ALPR, KATS, and the SRI Prototype Application are described below:

- SAFER: Is the Safety and Fitness Electronics Records, it consist of a website that displays carrier information available to the public, a store and forward mailbox system, secondary databases, and communication links. It handles user queries, database refreshes, and inbound data transfers. SAFER is currently and integral communication link for most FMCSA data transfers.
- CVIEW: The Commercial Vehicle information Exchange Window is a state system that collects information from the commercial vehicle credentialing and tax systems to generate

portions of the interstate carrier, vehicle, and driver snapshots and reports for exchange within the state (e.g.., to roadside sites) and with the SAFER system.

- PRISM: The Performance and Registration Information Systems Management (PRISM) program was developed to meet the challenge of reducing the number of commercial vehicle crashes of a rapidly expanding interstate carrier population. It has increased the efficiency and effectiveness of Federal and State safety efforts through a more accurate process for targeting the highest-risk carriers, which allows for a more efficient allocation of scarce resources for compliance reviews and roadside inspections. The PRISM program requires that motor carriers improve their identified safety deficiencies or face progressively more stringent sanctions up to the ultimate sanction of a Federal Out-of-Service order and concurrent State registration suspensions.
- Inspection Selection System (ISS): The ISS is the primary tool used on the roadside to screen motor carrier vehicles and determine the usefulness of conducting an inspection. ISS returns the carrier snapshot which includes critical safety performance indicators. It is linked to Aspen to auto-populate id and address data fields and initiate the inspection. ISS uses a local database, but individual carrier data can be updated via a RAS connection to SAFER. Database updates are also available monthly via a web service.[1]

### *Other Weigh Station Tools*

#### Automated Licensing and Taxation System (ALTS)

ALTS is a mainframe system developed by the Commonwealth Office of Technology in the state of Kentucky. It allows the station personnel to key in identifying information from vehicles as they pass through the weigh station. An alarm activates if a credential, registration, or historical safety issue is identified.[2]

#### Aspen

Aspen is an application, maintained by the FMCSA, which collects all the commercial driver/vehicle roadside details. It utilizes several other applications that pull data from remote sources – ISS, PIQ, CDLIS Access, and QC. It also includes communication features to electronically transfer inspection details to SAFER and/or SAFETYNET.

#### Commercial Driver's License Information System (CDLIS)

The CDLIS Access software is used nationwide to retrieve driver status and conviction history reports via a RAS (remote access server) connection to CDLIS. It accepts Driver Query data from Aspen or CAPRI.

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[1] Federal Motor Carrier Safety Administration - https://www.fmcsa.dot.gov/mission/information-systems/information-systems

[2] Walton, Jennifer R.; Spellman, Mark S.; and Crabtree, Joseph D., "Evaluation of Thermal Imaging Technology for Commercial Vehicle Screening" (2015). *Kentucky Transportation Center Research Report.* Paper 1500

#### CME Registry

Drivers will be required to obtain their FMCSA medical examination from a certified medical examiner that is listed on the National Registry. Designed to improve safety by achieving high-quality medical exams that are consistent with Federal regulations and guidelines, the National Registry will help commercial motor vehicle drivers, and employees, find trained and qualified medical examiners to perform physical qualification examinations.[3]

#### CVE Log

The Commercial Vehicle Enforcement Division (CVED) operated 14 weigh stations at 10 locations throughout the state of Michigan. Officers at these locations monitor vehicles for compliance with size and weight requirements, perform driver/vehicle safety inspections, verify driver's credentials, enforce regulatory violations, enforce hours-of-service requirements, interdict criminal activities including cargo theft, vehicle theft, CCW, drugs, illegal tobacco products, and promote homeland security.[4]

#### E-Citation

E-Citation is an electronic citation software that allows officers to input data and scan driver's license information directly onto an online citation form. This system utilizes fast information sharing by recording convictions, which would normally take 12 days to process, in one or two days. It also exports commercial driving violations to Aspen.

#### Electronic Traffic Information Exchange (E-TIX)

E-TIX software is capable of collecting citations, warnings, field observations reports and vehicle safety equipment repair orders by making use of a mobile data computer and barcode reading hardware to read the barcode information off driver's licenses and registrations in Maryland. Once the information is scanned, E-TIX automatically checks it against a local database and sends the information to CapWIN so it may be checked against MILES and NCIC.[5]

#### Fuel Tax Compliance System (FUELTACS)

FUEL TaCS is a three phase system developed in North Carolina: phase 1, computerization of truck weigh station operations, develops an overweight citation for electronic recording and collect fuel tax information to create a "sighting" report on trucks; phase 2, mobile data terminals will be installed in DMV vehicles to allow electronic entry citations and sighting reports by vehicle-based officers; phase 3, development of "intelligent highway" systems that track truck movements through electronic transponders. The goal of this system is to create an interstate motor carrier database that would

[3] Federal Motor Carrier Safety Administration - https://www.fmcsa.dot.gov/mission/information-systems/information-systems
[4] Michigan State Police - http://www.michigan.gov/msp/0,4643,7-123-3493_72291-294063--,00.html
[5] Governor's Office of Crime Control & Prevention - http://www.goccp.maryland.gov/msac/documents/FactSheets/eCitations.pdf

identify those interstate carriers who falsely reported or failed to report their mileage to USDOT in their quarterly report.[6]

**inSPECT**

inSPECT is a software product, created by Iteris, that provides commercial vehicle inspectors with an easy-to-use, federally compliant tool for performing roadside inspections of heavy trucks, buses and other commercial vehicles. inSPECT meets all states' requirements and was developed with the help of multiple jurisdictions over a series of field and ride-along work sessions. inSPECT is compliant with federal requirements for the collection and transmission of commercial vehicle inspection data to federal and state data systems and has successfully completed the certification process with FMCSA.[7]

**InterAct**

InterAct, created by Caliber, is a provider of telephony, dispatch, and records management systems for enforcement agents. The InterAct records management software allows enforcement agents to access data from multiple public safety agencies without separate logins, data queries from multiple trusted sources without storing information locally. This tool also allows officer to create incident reports. [8]

**Law Enforcement Information Network (LEIN)**

The Michigan Law Enforcement Information Network is a statewide computerized information system. The goal of LEIN is to assist the criminal justice community in the performance of its duties by providing and maintaining a computerized filling system of accurate and timely documented criminal justice information readily available to all criminal justice agencies. Works with an ALPR and communicates with NCIC.[9]

**METERS (Maryland Electronic Telecommunications Enforcement Resource System)**

Allows Maryland law enforcement personnel to access Maryland's Hot Files, the Motor Vehicle Administration (MVA) database, the National Law Enforcement Telecommunications Services (NLETS), Sex Offender, Convicted Person on Supervised Release, and SENTRY (an index of persons incarcerated in federal prisons) on their mobile data terminals and; gives law enforcement the ability to transmit and view images which include mug shots, fingerprints, signatures, and identifying photographs to confirm a subject's identity and enables the capability of attaching photos to missing person and stolen property files.[10]

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[6]Bostic, Richard; Knapp, Karl; Perusse, Charles; and Nelson, Michele. "North Carolina General Assembly Legislative Fiscal Note." Fiscal Research Division.ftp://www.ncga.state.nc.us/Bills/1997/FiscalNotes/House/HTML/hfn1226.html

[7]Iteris Software Products - http://www.iteris.com/products/software/inspect

[8]https://caliberpublicsafety.com/record-management-software/interact-rms/

[9] Michigan State Police - http://www.michigan.gov/msp/0,4643,7-123-3493_72291-294063--,00.html

[10]O'Malley, Martin; Brown, Anthony G., "2009 Annual Report on Interoperability" (2010). Criminal Justice Information Advisory Board

**Query Central (QC)**

QC is a web-based application that retrieves safety compliance and enforcement data on commercial motor vehicle drivers, vehicles, and carriers from multiple sources using a single input. The response data is analyzed and summarized before being presented in the user's browser. This tool is widely used in North Carolina for motor vehicle enforcement. Response data can also be downloaded to pre-populate Aspen. Data sources include MCMIS, SAFER, L&I, PRISM, CDLIS, SCT, and LIFIS.[11]

**Height Detection System**


***Figure 4. Height Detection System***

*Source: Richard Easley*

A height detection system will consist of a laser detector or optical sensor which points across the roadway at a certain height and includes a method of communication to alert the driver, or enforcement personnel, when a vehicle exceeding a pre-determined height drives past. When a vehicle breaks the laser beam, it can trigger a series of safety measures including warning the driver, providing the driver with an alternate and safe diversion, or alerting motor carrier enforcement that a triggering event has occurred. While there are no height restrictions in Federal law or regulation, most States impose enforceable State height limits ranging from 13.6 feet to 14.6 feet (USDOT, FHWA, 2014b).

Height detection systems can be valuable in areas with low overpasses or where tunnels are present. In addition, these systems can prove valuable in areas where accidents related to high winds regularly occur, such as on bridges. With respect to size and weight enforcement, when this technology is deployed near a weigh station, any triggered events can alert enforcement personnel to check for the proper permits or issue citations if the proper permits have not been purchased (i.e., the oversized vehicle is not operating legally).

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[11] Federal Motor Carrier Safety Administration - https://www.fmcsa.dot.gov/mission/information-systems/information-systems

Approximate Cost:
The cost to furnish and install the two poles, light source, optical sensor and associated equipment is approximately $30,000. Yearly maintenance costs are approximately $2,700.[12]

***Matrix of Deployed systems by Location***

In order to accurately assess the impact of a system on a particular site or corridor, a system inventory was conducted for the sites included in this study. This includes physical equipment, like scales and cameras, and virtual tools, like Aspen and E-Citation. The web tools are to log inspection results and look up credential information, past inspections, tax statuses, medical records, and safety scores. Table 2 presents the active status of technologies being used on all the selected sites for this study either before or after deployment of the key systems at those sites.

[12]Comprehensive Truck Size and Weight Limits Study: Compliance Comparative Analysis Technical Report (USDOT; June, 2015)

**Table 2. Pre- and Post-Deployment System Grid**

| | Kentucky | | North Carolina | Maryland | Michigan |
|---|---|---|---|---|---|
| **Systems** | **Lyon** | **Simpson** | **Mt. Airy** | **West Friendship** | **Grass Lake** |
| Static Scale | B | B | B | B | B |
| WIM Scale (In Ramp) | B | B | A̲ | B | B |
| WIM Scale (Mainline) | | | | B | B |
| PrePass | B | B | | | |
| Drivewyze | B | B | | B | B |
| USDOT Number Reader | A̲ | A̲ | | | |
| IR Camera | | B | | | |
| KATS | A̲ | A̲ | | | |
| License Plate Reader | A̲ | A̲ | A̲ | A | |
| NCPass | | | B | | |
| Portable LPR | | | R | | |
| SRI Prototype | | | | A̲ | A̲ |
| **Web Tools** | | | | | |
| ALTS | B | B | | | |
| Aspen | | R | | B | B |
| CDLIS | B | B | B | B | R |
| CME Registry | | | | B | |
| CVE Log | | | | | B |
| CVIEW | B | B | | | |
| E-Citation | B | B | B | | B |
| E-TIX | | | | B | |
| FUELTACS | | | B | | |
| inSpect | B | A | | | A |
| InterAct | B | B | | | |
| LEIN | | | | | B |
| METERS | | | | B | |
| SAFER | B | B | | B | B |
| Query Central | B | B | B | B | B |

LEGEND:
A̲ = After deployment system included in the analysis
B = Before deployment active system
A = After deployment active system
R = Replaced by newer system (not used)

*Source: Productivity Apex, Inc.*

***Cost of Technologies***

Although the principal objective of this impact assessment is to examine the potential impacts of the compliance systems, it is also important to assess their cost effectiveness, and to be able to measure quantitative benefits of such technologies against the anticipated cost of implementation and operation of SRI-like systems. There exists a concern associated with allowing heavier and longer trucks, there is a potential for these vehicles to escalate enforcement costs because enforcement tasks become more onerous or trucks exceed the capacity of existing enforcement technologies. The following table lists the cost ranges for compliance and similar systems. They were derived from the USDOT Truck Size and Weight study, *Compliance Comparative Analysis Technical Report*, June 2015. That study included both fixed and portable scales, but for the SRI impact assessment, the team only needed to look at fixed technologies.

**Table 3. Technology Equipment and Maintenance Costs**

| Technology | Cost Range (Equipment & Install) | Maintenance Cost Range (Annual) |
|---|---|---|
| Fixed Static Scale | $100,000 - $200,000 | $9,000 - $18,000 |
| WIM Load Cell | $100,000 - $150,000 | $12,600 - $16,200 |
| Thermal Imaging | | |
| - Hand-Held | $6,000 - $10,000 | $540 - $900 |
| - Mobile Van | $300,000 | $27,000 |
| - Fixed Roadside | $150,000 | $13,500 |
| - Fixed Pavement | $250,000 | $22,500 |
| License Plate Recognition | $90,000 – $150,000 | $8,100 – $13,500 |
| Optical Character Recognition (USDOT Numbers) | $90,000 – $150,000 | $8,100 – $13,500 |
| Electronic Screening System | $200,000 – $600,000 | $18,000 – $54,000 |

*Source: Extracted from Table 4, Compliance Comparative Analysis Technical Report USDOT June 2015*

*Fixed Static Scales* are used at fixed weigh stations, and trucks must stop on the scale. They are the principal means used to obtain certified weights needed for legally –enforceable compliance checks. The *WIM Load Cell* system involves a hydraulic load cell installed at the center of each of two weighing platforms across a roadway travel land. The cells measure the force applied to the scales. The load measurements are recorded and analyzed by the system electronics to determine the axle loads. If properly installed, the useful lifespan of the single load cell WIM is considerably longer than some other less expensive WIM systems, making total lifecycle costs and increased accuracy a consideration.

The primary purpose of *Thermal Imaging* technologies is to check brakes, which is the single most frequent form of equipment failure responsible for placing commercial vehicles out of service. An ancillary benefit of thermal imaging is its ability to detect overloaded vehicles through the heat signature of the tires.

*License Plate Recognition* and *Optical Character Recognition* are important ways to identify trucks and allow other data about these trucks to be accessed. The License Plate Recognition system uses optical character recognition software to accurately read the truck's license plate. The separate OCR system is used to read the USDOT number on the side of trucks. This is more difficult and less accurate because of the varying size, color, location and background color associated with those numbers, as compared with the relatively standard license plates in the U.S.

*Electronic screening systems* are used so that trucks do not have to stop at weigh stations. Electronic screening is based on an electronic check of a truck or motor carrier's information, which is located in a database and accessed when any truck comes into the vicinity of a weigh station. Based on the information, if truck is deemed to have a satisfactory safety record and is operating with all legally required credentials, the driver is electronically notified that he/she may bypass the weigh station. An improvement to electronic screening operations, at least from the point of view of the trucking industry, would be to establish a single communications protocol that to overcome the problem that the systems used among the various states are not interoperable.

More details on the systems can be found in the *Compliance Comparative Analysis Technical Report.*[13]

[13] Comprehensive Truck Size and Weight Limits Study: Compliance Comparative Analysis Technical Report (USDOT; June, 2015)

# Methodology

A methodology was developed in this study to objectively and quantitatively evaluate the impacts of smart roadside systems. This methodology provides a framework that will help to accurately assess the impacts of the SRI systems on the studied sites where they were deployed. It is expected that this framework will also work as a reference in the future to help quantify the potential benefits of deployment across the corridors within which the sites in this study are located and ultimately at the state and national level as well.

This approach is comprised of detailed planning, extensive data collection and stakeholder outreach, mathematical modeling techniques, simulation modeling and analysis, and rigorous statistical data analysis to ensure that it delivers accurate and robust assessments for each of the studied sites. The impact assessment methodology approach is detailed in the following sections ensuring that each of these key elements is addressed and that the analysis takes into account the views of public and private stakeholders.

Figure 5 provides an overview of the pre- and post- deployment activities that must be accomplished in order to deliver an accurate impact assessment. Each of these activities is described in detail within this report.

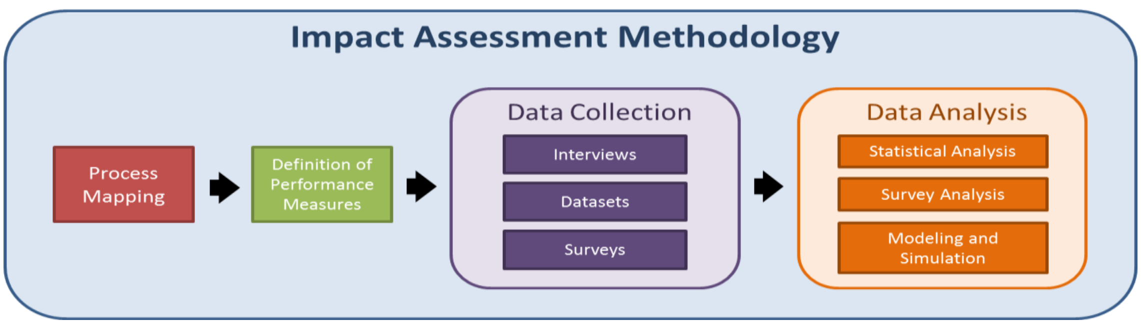


***Figure 5. Pre- and Post-Deployment Activity Overview***

*Source: Productivity Apex, Inc.*

## Process Mapping

A critical step in understanding the impact of the SRI system deployments is accurately capturing the changes to the operational processes the SRI systems are designed to improve. This is accomplished by mapping the baseline or “as-is” operational processes during the pre-deployment phase at each site studied and then capturing the post-deployment (“to-be”) processes and comparing them. The “as-is” process was captured taking into consideration the process that was followed in the weigh station before the implementation of the system to be evaluated. The “to-be” process is an update of the as is, but describing the post-deployment processes, after the implementation of the selected system and how it helps inspectors make more informed decisions about what trucks to pull over. These operational process maps help define and document the relationships and interdependencies between processes, resources, and relevant participants or stakeholders. They also document agreed-upon definitions for key operational terms, establishing a nomenclature to help mitigate the risk of misinterpretation and promote consistency from site to site where possible. These process maps are included in the Impact Assessment Results section for each of the sites evaluated. The operational process details were captured through a multi-faceted approach that includes, but may not be limited to:

- Subject Matter Expert input (e.g. interviews with key stakeholders)
- System observation
- Leveraging existing documentation (e.g. procedural guides, USDOT or state DOT standards, ConOps, system specifications, etc.)

# Definition of performance measures

The selection and development of performance measures and transformative benefits was discussed previously in this report. However, a more detailed description of each metric used in the analysis is presented in Table 4, which also explains the method for calculating these parameters used in the data analysis results tables for each site. The table also shows the expected outcome after deployment of the SRI system for each metric used in the data analysis.

**Table 4. Definition of Metrics used in the Analysis**

| Parameters Description | Explanation | Expected Outcome |
|---|---|---|
| Total violations found per inspection | Ratio of total violations found and total number of inspections performed | This measure is expected to increase with the use of SRI systems given that these help more accurately target violators to be pulled for inspections |
| Total violations found per inspection level | Ratio of total violations found while performing an inspection at a given level and total number of inspections performed at that same level | This measure is expected to increase for all inspections levels, given that SRI systems target violators to be pulled for inspections |
| Out of Service violations found per inspection | Ratio of total out of service violations found and total number of inspections performed | This measure is expected to increase given that these systems help enforcement agents more accurately target violators to pull for inspections |
| Out of Service violations found per inspection level | Ratio of total out of service violations found while performing an inspection at that level and total number of inspections performed at that level | This measure is expected to increase for all levels given that these systems help enforcement agents more accurately target violators |
| Average daily number of inspections with n violations | Average of the total number of inspections that have the given number of violations (n) for each day during the analysis period | By deploying SRI systems it is expected that larger number of the inspections performed will contain at least one violation |

| Parameters Description | Explanation | Expected Outcome |
|---|---|---|
| Average daily number of Level X inspections with violations | Average of the total number of inspections, performed at the given inspection level (X), that have violations for each day during the analysis period | By deploying SRI systems it is expected that larger number of the inspections performed will contain at least one violation |
| Average daily number of inspections with OOS violations | Average of the total number of inspections that have an out of service violation for each day during the analysis period | By deploying SRI systems it is expected that larger number of the inspections performed that result in Out-of-Service violations |
| Average daily number of inspections with Driver OOS violations | Average of the total number of inspections that have a driver out of service violation for each day during the analysis period | By deploying SRI systems it is expected that larger number of the inspections performed that result in Driver related Out-of-Service violations |
| Average daily number of inspections with Vehicle OOS violations | Average of the total number of inspections that have a vehicle out of service violation for each day during the analysis period | By deploying SRI systems it is expected that larger number of the inspections performed that result in Vehicle related Out-of-Service violations |
| Percentage of time doing productive inspections | Ratio of the sum of time spent performing an inspection that has any violation and the total time spend performing all inspections | By deploying SRI systems it is expected that most of the time of the inspector will be spent performing inspections that will result in violations |
| Proportion of inspections with n violations | Ratio of the total number of inspections that have the given number of violations (n) and the total number of inspections performed | It is expected that the proportion of inspections without violations will decrease, but the proportion of inspections with at least one violation will increase. |
| Proportion of Level X inspections with violations | Ratio of the total number of inspections, performed at the given inspection level (X), that have violations and the total number of inspections performed at that level | It is expected that the proportions of inspection of any level resulting in at least one violation will increase |
| Average monthly revenue | Average of the total monthly revenue collected during the analysis period | By deploying SRI systems it is expected that the revenue at the weigh station will increase, given that a larger number of inspections resulting in violations with fines is expected |
| Average revenue per inspection | Ratio of the total revenue collected during the analysis period and the number of inspections performed during that period | By deploying SRI systems it is expected that the revenue at the weigh station will increase, given that a larger number of inspections resulting in violations with fines is expected |

| Parameters Description | Explanation | Expected Outcome |
|---|---|---|
| Average duration for Level X inspections (minutes) | Average of the duration of every inspection at the given inspection level (X) | It is expected that the duration of inspections at any level to decrease given that enforcement agents will know where to focus in order to find a violation when pulling a vehicle |
| Throughput before/after in-ramp WIM installation | Comparison between total number of trucks that enter the station before and after in-ramp WIM deployment | It is expected that the throughput of trucks would increase given that the process of weighing and screening a truck would be done much faster |

*Source: Productivity Apex, Inc.*

# Data Collection

***Data Needs***

In order to support a rich and robust impacts assessment, it was imperative that the appropriate data was collected and analyzed. The data elements for this study are identified based primarily on two key factors:

- Relevance to Performance Measures and Transformative Targets
- Relevance to Operational Processes at the Studied Sites

Collecting pre- and post-deployment data, relevant to the established performance measures and operational processes for each site studied provided the foundation needed for the impacts assessment team to accurately gauge the impact of the SRI Prototype applications and technologies. Some of the data collected consisted of WIM and static balance daily counts, inspection records with violation results, station revenue amounts, traffic flow in the corridor, etc. A more detailed list of data collected is presented in the sections below corresponding to the analysis of each site.

## Data Collection Methods

The data used for the analysis in this project was all collected by the state police departments for commercial vehicle enforcement, state DOTs, or electronic screening system vendors. This data was requested from each site for time periods that cover at least 3 to 6 months of pre- and post-deployment activity. The impact assessment team also worked with HELP, Inc. (creators of PrePass) and Intelligent Imaging Systems (creators of Drivewyze) to obtain bypass and violation counts from their databases; although no relevant datasets were provided for the corresponding sites studied in this project. Regarding NCPass, during the data collection period, the Mount Airy station was under construction upgrading to a new generation of the system; so no data was provided.

## Data Collection Frequency

The data for this project did not need to be collected through in-person studies as weigh stations collect the data either automatically or through inspector logs. Scale counts are continuously tracked during the day as trucks are weighed. PrePass and Drivewyze continuously track credential checks as they occur. Inspection data is added when inspectors submit inspection results or when all new inspection details are uploaded to databases at the end of the day or week. The time frame for data sets is between 3 and 12 months for each station depending on availability.

## Stakeholder Feedback

A key component in successfully assessing the impact of the SRI Prototype technologies was to work closely with key stakeholders, allowing the impact assessment team to gather information and feedback related to performance measures and operational processes, and obtain their perceived impact of the deployed systems. Primary stakeholders included officials from state and federal agencies working within each of the sites and project managers from private companies involved in this project. Primary stakeholder information is provided in Table 5. Secondary stakeholders are comprised of weigh station officers and inspectors who use these systems daily, as well as drivers and motor carriers who utilize screening systems and are impacted by new inspection technology.

**Table 5. Primary Stakeholder List**

| Name | Affiliation | Role | Associated Site |
|---|---|---|---|
| Ron Schaefer | Leidos | Leidos PM | Michigan; Maryland |
| David Leddy | Kentucky State Police | POC (Kentucky) | Kentucky |
| Randy Coplin | Michigan State Police | POC (Michigan) | Michigan |
| Lieut. James Rigsbee | North Carolina Dept. of Public Safety | POC (North Carolina) | North Carolina |
| Maj. Norman Dofflemyer | Maryland Dept. of State Police | POC (Maryland) | Maryland |
| Brian Heath | IIS (Drivewyze) | POC | All |
| Jan Skouby | Help Inc. (PrePass) | POC | All |
| John Rotz | Maryland State Highway Administration | POC | Maryland |
| Dave Czorapinski | Maryland State Highway Administration | POC | Maryland |

*Source: Productivity Apex, Inc.*

Stakeholders were engaged throughout the project using a number of different approaches including:

- Telephone interviews
- Web-based collaborative tools
- Reviewing documents
- Eliciting feedback via questionnaires and surveys

The selected approach was dictated by several factors, most importantly which method would be the most effective for eliciting necessary feedback, and followed closely by identifying the method that placed the lowest burden on the stakeholder.

***Survey Development***

Surveys were created to gather feedback from the many secondary stakeholders to the project including inspectors and officers, as well as motor carriers. Because of the large number of stakeholders, the team decided to use an online survey tool—SurveyMonkey—to distribute and collect surveys. There were two versions of the survey, one specifically designed for inspectors and officers, and the other designed for targeting motor carriers— in order to obtain impressions from both operators and consumers of the technology.

Respondents could answer the survey questions with either Yes/No or a range of options to express how they view the impacts of the system: Very Positively, Positively, No Impact, Negatively, Very Negatively, and Don't Know. Respondents were also asked to explain their answers to get a better understanding for analysis. Surveys were tailored to each state based on the system being assessed. The analysis and results for these surveys are included in the Survey Results and Analysis section and the complete surveys are included in Appendix C.

# Data Analysis

Accurately assessing the impact of the selected systems required a robust set of performance measures. Evaluating the pre- and post-deployment phases of each site included in the study relative to performance measures required a number of disparate data elements, each with its own unique characteristics, and its own analysis techniques. A series of analysis methods were selected taking into consideration factors like the size of the dataset, the variability or uncertainty exhibited by the data, interdependencies, and the scope of the performance measures. Microsoft Excel was used for most of the statistical tests conducted in this project.  These included descriptive statistics, tests of hypotheses, and inferential statistics which details are described below. Additionally, the data was analyzed for its use in the simulation modeling and analysis that was conducted in this project. An example of the data used in the simulation included probability distribution of violations, average flow through the ramp, average processing times, etc. A more detailed description of the model and its analysis is presented below in the Simulation Modeling and Analysis section

***Analyzing Raw Data***

During the analysis phase of the project, quality assurance techniques were implemented to ensure proper data have been collected and that the sample size of the collected data is sufficient to conduct statistically valid analysis. The impact assessment team verified the following:

- All the required data elements were available
- Sufficient samples were collected to execute the analysis
- The collected data was valid, accurate, and consistent
- The data was clean and free of invalid or anomalous data points

These quality assurance checks were performed to make sure that the collected data is accurate and trustworthy. When inconsistencies or inaccuracies were detected, the appropriate stakeholders were involved to address those issues, to correct anomalous data and ensure that the data analysis and pre- and post- deployment comparisons were statistically valid. The impact assessment team analyzed the data for trends related to environmental or systemic factors that could influence the pre- and post- deployment data sets and took steps to eliminate any bias on the estimated values due to these factors.

### *Statistical Methods*

This section describes the statistical methods that were used in this study and the reasons for their selection:

- Descriptive statistics were used to calculate the averages and standard deviation during the data analysis. These methods portray individuals or events in terms of some predefined characteristics, like measure of central tendency and dispersion –Mean, Median, Range, Standard Deviation, etc.
- Inferential statistics seek to assess the characteristics of a sample in order to make more general statements about the parent population, or about the relationship between different samples or populations. These methods were used for assessing the statistical difference between two population samples, specifically in the before and after results analysis in this study. The assessment team performed the following test of hypothesis to make the comparison between two datasets.
- Since most of the sample sets were large enough, with more than 30 data points each, the team performed the test of hypothesis by assuming data followed a normal distribution (Z-test). A test of hypothesis for two population means (independent samples) was applied when comparing total violations found per inspection, out of service violations found per inspections, average daily number of inspections, and average daily time performing inspections between the before and after datasets collected for this study. Additionally, z-test was applied for testing the difference between two populations proportions (p1- p2=0). This was applied specifically for testing the difference in the average percentage of time doing productive inspections, and the proportion of inspections with and without violations between the before and after datasets collected for this study.
- A t-test for independent samples was applied for the small sample test of hypothesis between two population means with different population variances. This test was applied for the comparison of revenue per inspection between the before and after data sets, given that the number of observations for this parameter was less than 30.
- Finally a test of hypothesis for the ratio of two population variances using the F-test for independent samples, for assessing the equality on the population variances for the use of the t-test on the revenue per inspection comparison.

### *Data Analysis Results*

The data analysis results are presented below in the Impact Assessment Results section and are discussed in detail for each of the sites studied.

# Impact Assessment Results

## Lyon County, KY

### System to Evaluate

The system being evaluated in this site is Kentucky Automated Truck Screening (KATS). This system was deployed on August 14th of 2015. Figure 6 depicts this testing site as a satellite image and superimposed are the different systems and components of the station.

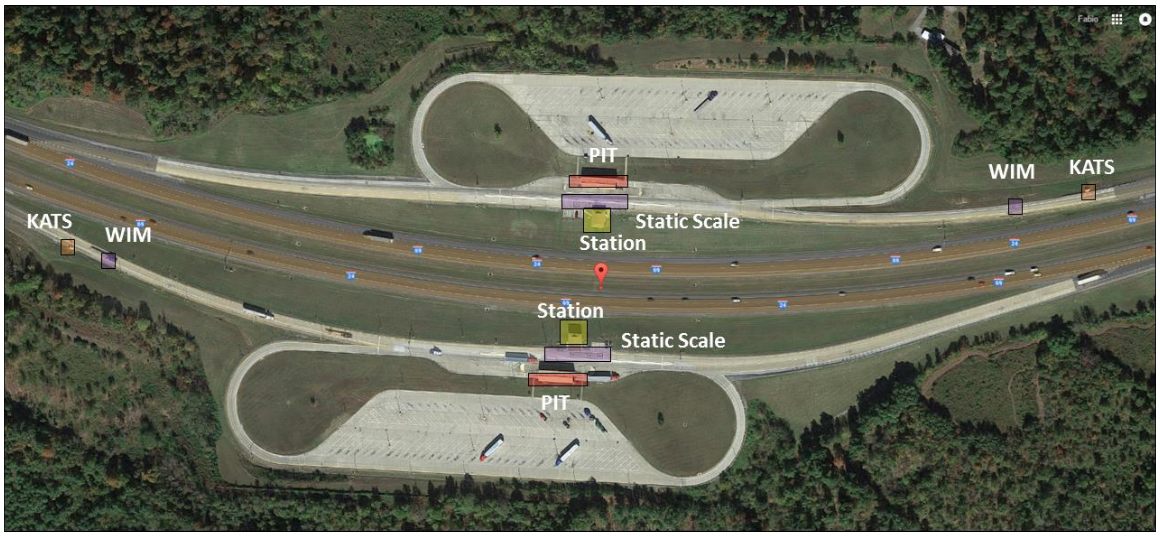


***Figure 6. Satellite Image of Lyon County, KY Weigh Station***

*Source: Productivity Apex/Google Maps*

### Process Mapping

The pre-deployment process (Figure 7) at Lyon County starts with a truck approaching the weigh station. If the truck has PrePass or Drivewyze, then that system determines whether it meets all credential requirements to bypass. Trucks that fail this screening and trucks that do not have bypass technology are directed to enter the station. Trucks drive over the WIM scale, if passed they continue through the station. However, they could be asked to stop for an inspection if site enforcement decides it is necessary. Trucks that fail the WIM check are directed toward the static scale to verify weight. Trucks with violations for exceeding weight limits and trucks that need evaluation per inspector discretion are directed to the parking lot. A level of inspection is decided upon by experienced enforcement officers and conducted on parked trucks; in the case of level I inspections, the truck is directed over the Pit area at the station, so the inspector can perform the proper inspection of the mechanical components of the truck. If no violations are found then drivers are allowed to leave, otherwise inspectors issue citations and/or directions for corrective action. If any truck or driver is taken out of service (OOS), then said driver is not allowed to leave until corresponding violations are corrected.

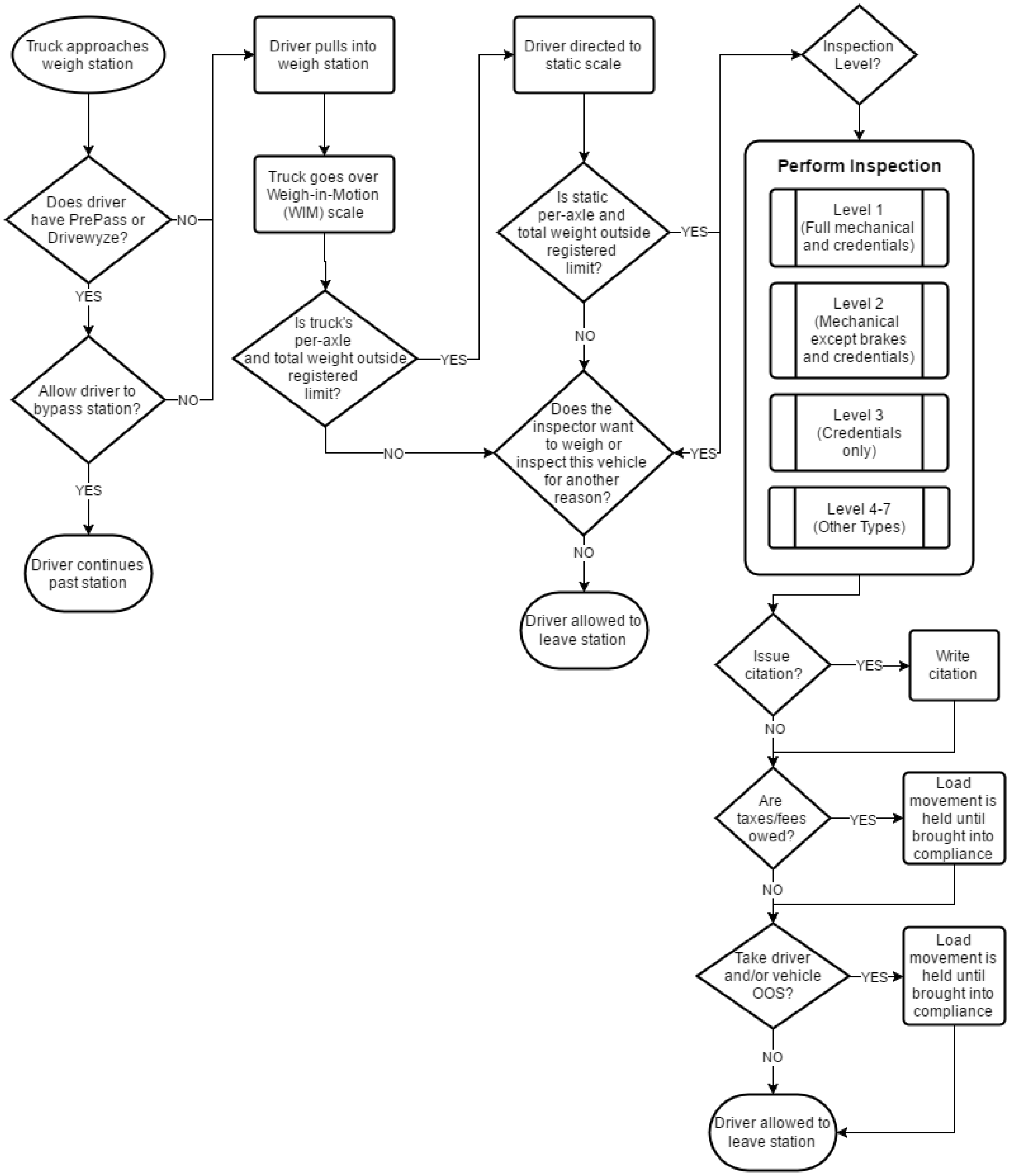


***Figure 7. Lyon, KY - Pre-Deployment Process Map***

*Source: Productivity Apex, Inc.*

The post-deployment process (Figure 8) at Lyon County starts with a truck approaching the weigh station. If the truck has PrePass or Drivewyze, then that system determines whether it meets all credential requirements to bypass. Trucks that fail this inspection and trucks that do not have bypass system are directed to enter the station. When trucks enter the ramp, cameras capture images of the truck's license plate number, USDOT number, and KYU number, which are then processed through Optical Character Recognition (OCR) software. The numbers are then run through the KATS system, which checks the numbers in credential databases for violations. One full-time civilian employee monitors OCR results, corrects any errors, and reruns corrected numbers through the KATS databases. Meanwhile, trucks drive over the WIM scale, if passed they are directed to drive down the ramp; if failed they are diverted toward the static scale to verify weight. Trucks that violate weight limits are directed to the parking lot for inspection. Trucks in either the WIM or static scale lanes will be directed to the parking lot if KATS finds any credential violations or if they need to be examined per inspector discretion. Certain levels of inspection are chosen by enforcement officers and conducted upon parked trucks; in case of level I inspections, the truck is directed over the Pit area at the station, so the inspector could perform the proper inspection of the mechanical components of the truck. If violations/fees are found, drivers must address them before being allowed to exit the station.

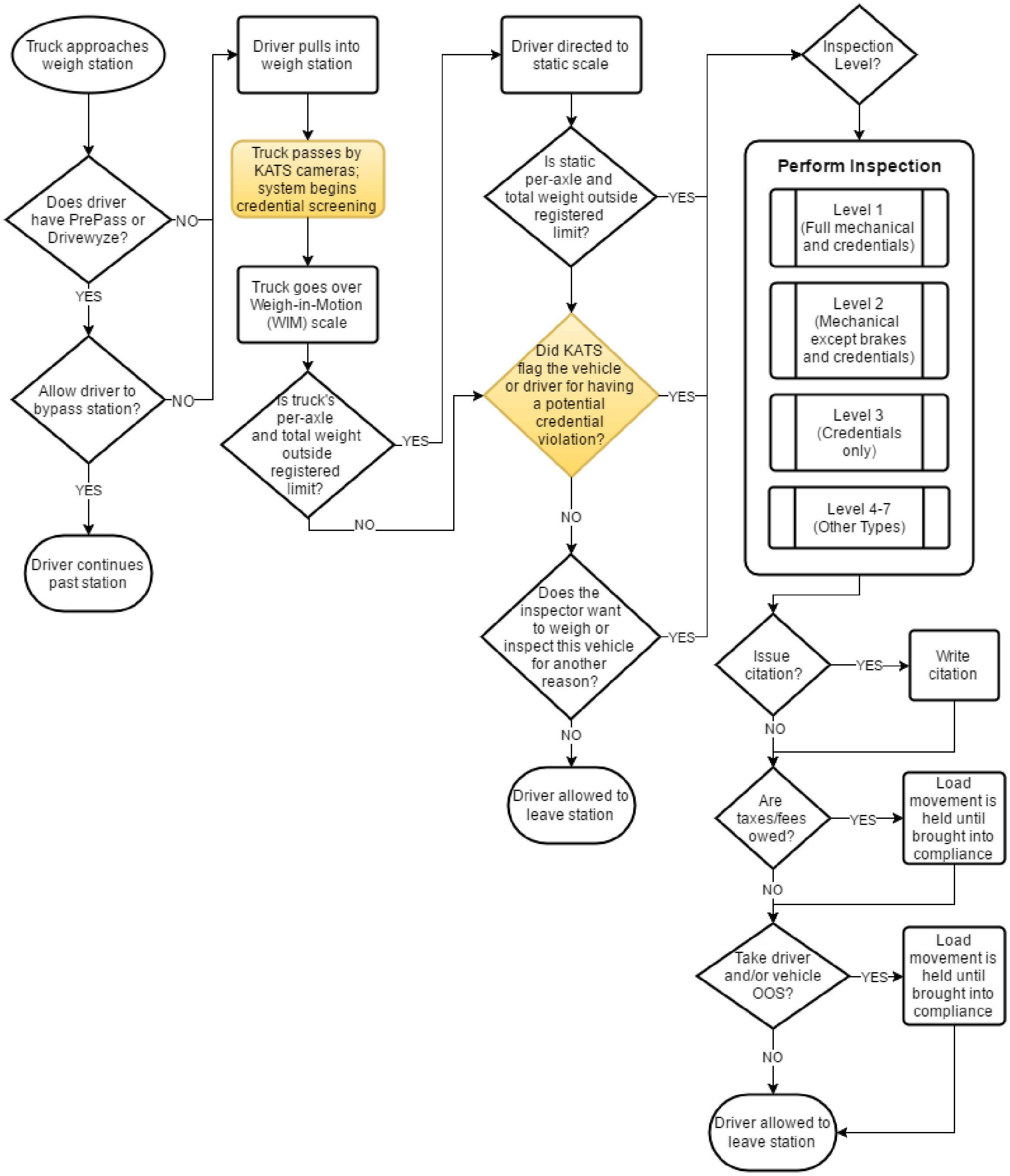


***Figure 8. Lyon, KY - Post-Deployment Process Map***

*Source: Productivity Apex, Inc.*

## Data Acquired

Table 6 lists the types of data acquired, the time period included in the data, and the agency that provided that data.

**Table 6. Lyon, KY - List of Data Acquired and Sources**

| Data Acquired | Period | Source |
|---|---|---|
| Static Scale Daily Counts | 1/1/15 – 5/31/15 | Kentucky State Police (KSP) |
| WIM Scale Daily Counts | 1/1/15 – 5/31/15 | Kentucky State Police (KSP) |
| Annual Average Daily Traffic (AADT) | 1986 – 2012 | Kentucky Transportation Cabinet (KYTC) |
| List of all Inspections performed and violation results | 10/1/11 – 11/30/15 | Kentucky State Police (KSP) |
| Monthly total weigh station revenue | 1/2014 – 12/2015 | Kentucky Transportation Cabinet (KYTC) |
| Station staffing schedule per year | 2012 – 2015 | Kentucky State Police (KSP) |
| List of vehicle crashes in the corridor | 10/1/11 – 9/30/15 | Kentucky State Police (KSP) |
| Detailed list of violations, including code and description | 10/1/13 – 11/30/15 | Kentucky State Police (KSP) |

*Source: Productivity Apex, Inc.*

## Performance Measures and Hypothesis

Based on the previously stated performance measures the impact assessment team together with the USDOT COR determined the hypotheses that were tested during this study. These are presented in Table 7 below.

**Table 7. Lyon, KY - Performance Measures and Hypotheses**

| Goal | Performance Measure | Hypothesis |
|---|---|---|
| Increased Productive Inspections Time | Percentage of time doing Productive Inspections | **$H_0$:** If KATS is implemented, the time performing productive inspections will remain the same<br><br>**$H_1$:** If KATS is implemented, the time performing productive inspections will change |
| Increased Inspection Efficiency | Average number of violations found per inspection | **$H_0$:** If KATS is implemented, the number of violations found per inspection will remain the same<br><br>**$H_2$:** If KATS is implemented, the number of violations found per inspection will change |
| Increased Safety | Average daily number of inspections with Driver OOS violations | **$H_0$:** If KATS is implemented, the number of inspections with OOS driver violations will remain the same<br><br>**$H_3$:** If KATS is implemented, the number of inspections with OOS driver violations will change |
| | Average daily number of inspections with Vehicle OOS violations | **$H_0$:** If KATS is implemented, the number of inspection with OOS vehicle violations will remain the same<br><br>**$H_4$:** If KATS is implemented, the number of inspection with OOS vehicle violations will change |
| | Average daily number of inspections with OOS violations | **$H_0$:** If KATS is implemented, the number OOS violations per inspection will remain the same<br><br>**$H_5$:** If KATS is implemented, the number OOS violations per inspection will change |
| Increased Revenue | Average Monthly Revenue | **$H_0$:** If KATS is implemented, the monthly revenue generated through inspections will remain the same<br><br>**$H_6$:** If KATS is implemented, the monthly revenue generated through inspections will change |

*Source: Productivity Apex, Inc.*

## Data Analysis and Results

The impact assessment team analyzed the collected data in order to determine the differences in performance measures between the pre- and post- deployment periods for KATS. The pre-deployment period for the KATS system in Lyon County goes from January 1st, 2015 to August 13th, 2015. The post-deployment period is between August 14th, 2015 and November 30th, 2015.

During the execution of the study, KATS had been recently installed in Lyon; because of that, it didn't provide as many inspection records desired for performing an equal or balanced comparison for before and after deployment. However, even with the inequality of data between pre- and post-deployment, it is possible to observe a trend in the behavior and calculate statistical differences. A two sample statistical test was performed for each of the calculated performance measures; this helped to determine if there was a significant difference between the parameters of the two samples. A two-tailed z-test was used as both samples had more than 30 records each for almost all parameters, allowing the team to estimate the standard deviation of each sample population, assuming a normal distribution and using a confidence level of 95%. However, a two-tailed t-test was used for comparing revenue per inspection given the limited amount of records for this parameter. Revenue information was provided as a total value per month, so a t-test was used given that there were fewer than 30 monthly records.

To better interpret the table below, if the P-Value column for a specific record or performance measure is less than 0.050, then it can be concluded that there is a statistically significant difference between the two samples. For each of the metrics in the table, a P-Value below 0.050 simply means that there is at least a 95% level of confidence that the values for the Pre and Post-deployment periods are different.

**Table 8. Lyon, KY - Data Analysis and Statistical Testing Results**

| Data Analysis Description | Analysis Results | | | |
|---|---|---|---|---|
| VIOLATIONS PER INSPECTION | Pre | Post | Change | P-Value |
| Average number of violations found per inspection | 0.164 | 1.431 | 770% | 0.000 |
| Average number of violations found per Level 1 inspection | 1.268 | 1.829 | 44% | 0.000 |
| Average number of violations found per Level 2 inspection | 0.783 | 1.804 | 130% | 0.000 |
| Average number of violations found per Level 3 inspection | 0.130 | 0.723 | 457% | 0.000 |
| Average number of out of service violations found per inspection | 0.139 | 0.228 | 64% | 0.000 |
| Average number of out of service violations found per Level 1 inspection | 0.242 | 0.298 | 23% | 0.107 |
| Average number of out of service violations found per Level 2 inspection | 0.121 | 0.279 | 131% | 0.003 |
| Average number of out of service violations found per Level 3 inspection | 0.016 | 0.109 | 587% | 0.000 |
| DAILY INSPECTIONS | Pre | Post | Change | P-Value |
| Average daily number of inspections | 9.6302 | 14.707 | 58% | 0.000 |
| Average daily number of inspections with No violations | 5.810 | 6.061 | 4% | 0.590 |
| Average daily number of inspections with 1 violation | 1.548 | 3.768 | 143% | 0.000 |
| Average daily number of inspections with 2+ violations | 1.944 | 4.878 | 151% | 0.000 |
| Average daily number of Level 1 inspections with violations | 2.683 | 4.841 | 80% | 0.000 |

| Data Analysis Description | Analysis Results | | | |
|---|---|---|---|---|
| DAILY INSPECTIONS | Pre | Post | Change | P-Value |
| Average daily number of Level 2 inspections with violations | 0.595 | 2.049 | 244% | 0.000 |
| Average daily number of Level 3 inspections with violations | 0.214 | 1.756 | 720% | 0.000 |
| Average daily number of inspections with OOS violations | 1.143 | 2.500 | 119% | 0.007 |
| Average daily number of inspections with Driver OOS violations | 0.214 | 0.915 | 327% | 0.003 |
| Average daily number of inspections with Vehicle OOS violations | 0.929 | 1.744 | 88% | 0.000 |
| Average daily time performing inspections resulting in one or more violation (minutes) | 148.690 | 365.220 | 146% | 0.000 |
| INSPECTIONS WITH VIOLATIONS | Pre | Post | Change | P-Value |
| Percentage of time doing Productive Inspections | 47% | 67% | 20% | 0.000 |
| Proportion of inspections with No violations | 88% | 41% | -47% | 0.000 |
| Proportion of inspections with 1 violation | 9% | 26% | 17% | 0.000 |
| Proportion of inspections with 2+ violations | 3% | 33% | 30% | 0.000 |
| Proportion of inspections with violations | 12% | 59% | 47% | 0.000 |
| Proportion of Level 1 inspections with violations | 50% | 65% | 15% | 0.000 |
| Proportion of Level 2 inspections with violations | 42% | 77% | 35% | 0.000 |
| Proportion of Level 3 inspections with violations | 10% | 51% | 41% | 0.000 |
| INSPECTION TIME PER LEVEL | Pre | Post | Change | P-Value |
| Average Duration for Level 1 Inspection (minutes) | 38.6 | 43.0 | 11% | 0.000 |
| Average Duration for Level 2 Inspection (minutes) | 40.4 | 42.1 | 4% | 0.303 |
| Average Duration for Level 3 Inspection (minutes) | 20.0 | 26.5 | 33% | 0.000 |
| INSPECTION REVENUE | Pre | Post | Change | P-Value |
| Average Monthly Revenue | $1,545.31 | $16,071.26 | 940% | 0.063 |

*Source: Productivity Apex, Inc.*

The Lyon County weigh station was able to provide daily values for number of inspections, number of violations, inspection duration, number of OOS violations, etc. From this data theimpact assessment team was able to analyze the safety and productivity improvements that the KATS system may have afforded this location.

The figures below show the safety improvement data broken down monthly. The vertical red line indicates the implementation of KATS in August 2015. Figure 9 displays the average total violations per inspection. Although there is an increasing trend, there is considerable variability observed in the data. This average was calculated by dividing the sum of all daily inspections by the sum of all violations given within each month. There could be many possible factors responsible for the fluctuation of this daily data; from the number of inspections completed on any particular day, the number of hours the weigh station was open for, to the number of violations foundon one vehicle.  Any one of these previously-stated variables would cause a shift, not only day-to-day, but as expressed in the figure below month-to-month.

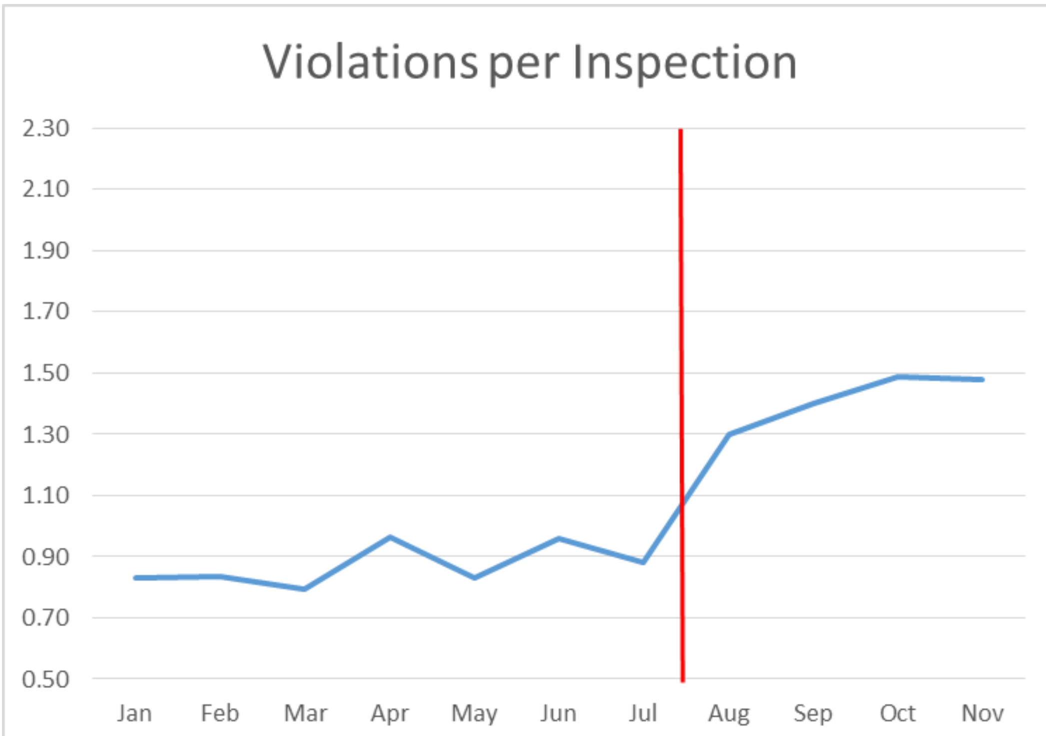


***Figure 9. Safety Improvement: Violations per Inspection***

*Source: Productivity Apex, Inc.*

Figure 10 presents an average of the total out of service violations. This is just one type of violation that, although will not occur to every vehicle and/or driver given a violation, is affected by the same industry variables as stated above. For this particular performance measure, the average was calculated by dividing the sum of all daily inspections by the sum of all OOS violations given within each month. This chart also shows an increasing trend that could be resulting from a more accurate process in selecting vehicles that have violations; nonetheless, is still susceptible to the inconsistent tendencies common for these operations.

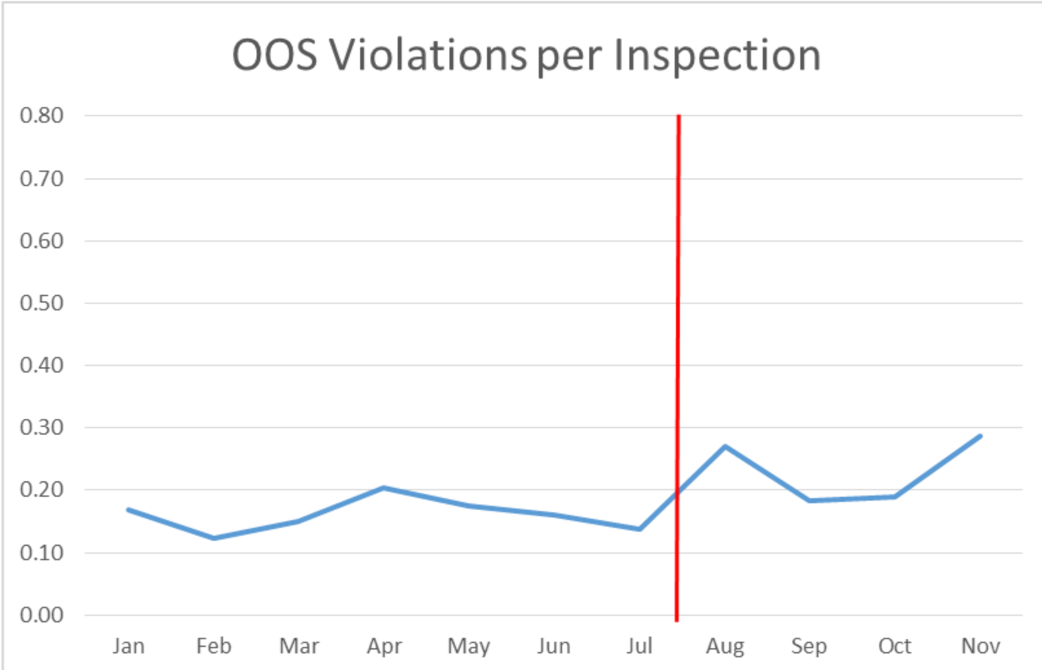


***Figure 10. Safety Improvement: OOS Violations per Inspection***

*Source: Productivity Apex, Inc.*

Figure 11 below shows the productivity improvement data broken down monthly. The vertical red line indicates the implementation of KATS in August 2015. The figure shows the percent of time taken to perform a productive inspections (blue line) and the percent of inspections administered where a violation was presented (orange line). The time for productive inspections was calculated attaining the total productive inspection time over the total inspection time. The total productive inspection time was extablished by adding the time spent on any one inspection that resulted in a violation. Similarly, the percent of inspections with violations was acquired from the total number of inspections with violations over the number of total violations. The number of inspections with violations was allotted to any inspection that produced at least one violation.

For both of these lines there appears to be an overall possitive trend, regarless of its variability. The reasons for this type of unpredictability stems from the nature of these proceedings. The values used for analysis may be susceptible to factors like: the number of vehicles driving on this higway or the number of hours the weigh station was open. As shown in Table 8, overall averages for these performance measures increased. The chart also shows a trending increase for the percent of inspections with violations after the implementation of KATS; this may derive from the accuracy to inspect vehicles that produce a violation. As a result, the productive time at the weigh station correlates positively for that time period as well.

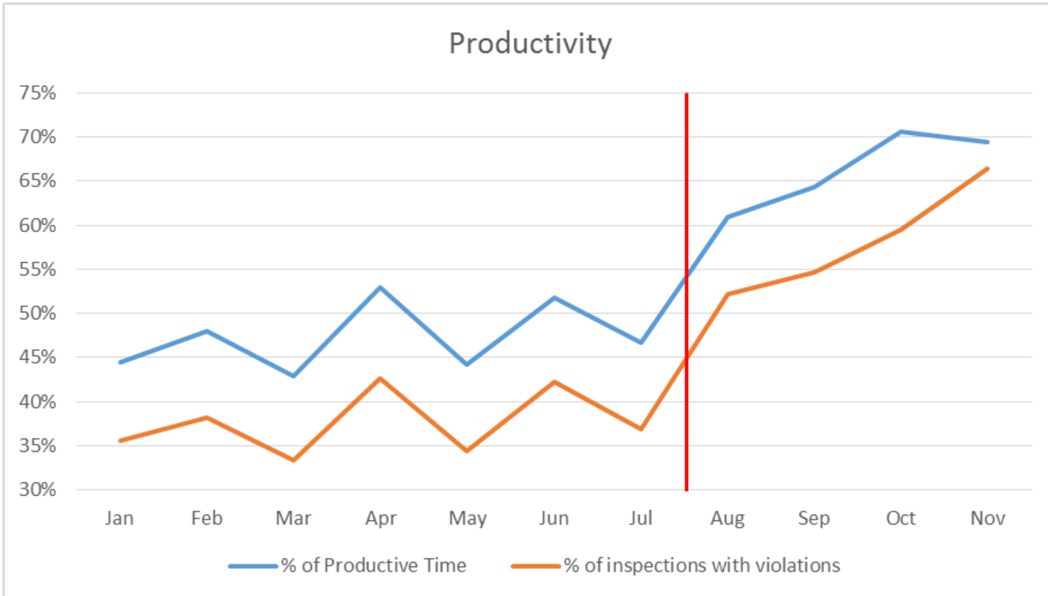


***Figure 11. Productivity Improvement***

*Source: Productivity Apex, Inc.*

Figure 12 below shows the montly revenue for the Lyon site. The vertical red line indicates the implementation of KATS in August 2015. The data provided by Kentucky state officials for this analysis was the total monthly impounds collected at the Lyon site. As shown in the graph, the monthly revenue from impounds initially increased after deployment. The sudden increment in revenue between August and October may represent an increase in vehicles with violations or even vehicles with pending fees that had not been previously stopped. However, it could have also been caused by the recent deployment of KATS at the site. This is sometimes expected when new systems are deployed and users are testing all capabilities. Further discussion with Kentucky state officials indicates that the revenue in Lyon reached a steady state level after December of 2015, reporting a fourfold increase from the pre-deployment months. It is important to note that the data from the month of November was removed from the analysis due to technical problems with the internet connection at the site, rendering the data biased for that month.

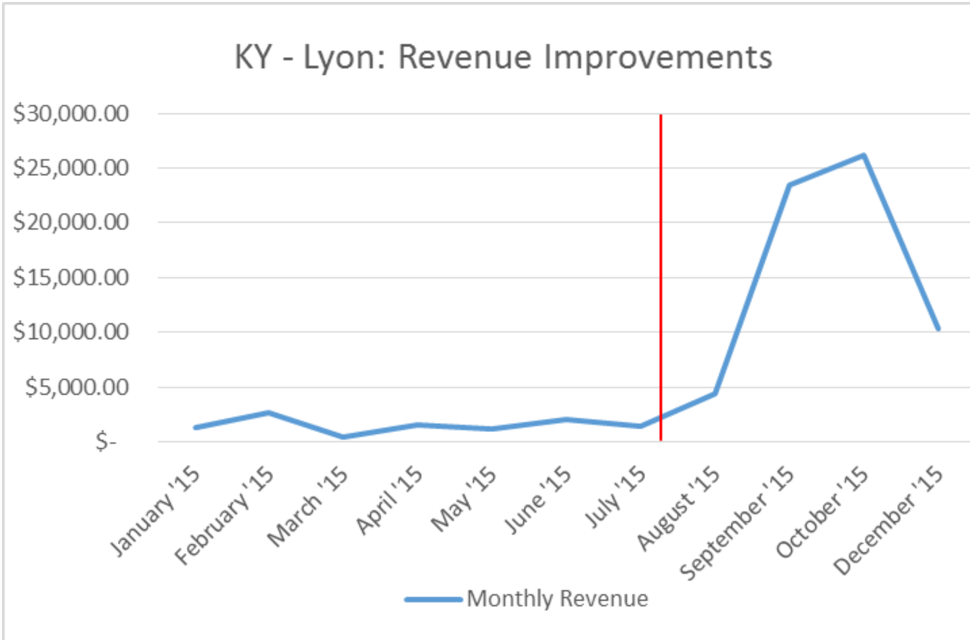


***Figure 12. Lyon, KY - Monthly Revenue***

*Source: Productivity Apex, Inc.*

The next table shows the values used to prove the hypotheses that were formulated for the analysis. Parameters from Table 4 were used as the test statistic for the analysis.

**Table 9. Lyon, KY - Hypothesis Test Results**

| Hypothesis Statement | Evaluated Parameter | Pre- | Post- | P-Value | Conclusion |
|---|---|---|---|---|---|
| **$H_0$:** If KATS is implemented, the time performing productive inspections will remain the same<br><br>**$H_1$:** If KATS is implemented, the time performing productive inspections will change | Percentage of time doing Productive Inspections | 148.690 | 365.220 | 0.000 | Reject $H_0$ |

| Hypothesis Statement | Evaluated Parameter | Pre- | Post- | P-Value | Conclusion |
|---|---|---|---|---|---|
| **$H_0$**: If KATS is implemented, the number of violations found per inspection will remain the same<br><br>**$H_2$**: If KATS is implemented, the number of violations found per inspection will change | Average number of violations found per inspection | 0.164 | 1.431 | 0.000 | Reject $H_0$ |
| **$H_0$**: If KATS is implemented, the number of inspections with OOS driver violations will remain the same<br><br>**$H_3$**: If KATS is implemented, the number of inspections with OOS driver violations will change | Average daily number of inspections with Driver OOS violations | 0.214 | 0.915 | 0.003 | Reject $H_0$ |
| **$H_0$**: If KATS is implemented, the number of inspection with OOS vehicle violations will remain the same<br><br>**$H_4$**: If KATS is implemented, the number of inspection with OOS vehicle violations will change | Average daily number of inspections with Vehicle OOS violations | 0.929 | 1.744 | 0.000 | Reject $H_0$ |
| **$H_0$**: If KATS is implemented, the number OOS violations per inspection will remain the same<br><br>**$H_5$**: If KATS is implemented, the number OOS violations per inspection will change | Average daily number of inspections with OOS violations | 3.492 | 2.500 | 0.007 | Reject $H_0$ |

| Hypothesis Statement | Evaluated Parameter | Pre- | Post- | P-Value | Conclusion |
|---|---|---|---|---|---|
| **$H_0$:** If KATS is implemented, the monthly revenue generated through inspections will remain the same<br><br>**$H_6$:** If KATS is implemented, the monthly revenue generated through inspections will change | Average Monthly Revenue | $1,545.31 | $16,071.26 | 0.063 | Reject $H_0$ |

*Source: Productivity Apex, Inc.*

The above analysis shows that in all cases, the null hypothesis was rejected leading to the conclusion that there was a significant change in all parameters when comparing pre-deployment with the post-deployment period. In Lyon, during the post-deployment period all of the parameters seem to have improved from the original values during pre-deployment. Even though these improvements can be attributed to a myriad of different factors, from seasonal behaviors to the amount and skill of inspectors at the stations, or the sites' hours of operation; discussions with site personnel indicated an overall improvement in the productivity and efficiency of the site after the system was implemented.

# Simpson County, KY

## System to Evaluate

The system being evaluated in this site is Kentucky Automated Truck Screening (KATS). This system was deployed on January 1st, 2015. Figure 13 depicts this testing site as a satellite image and superimposed are the different systems and components of the station.

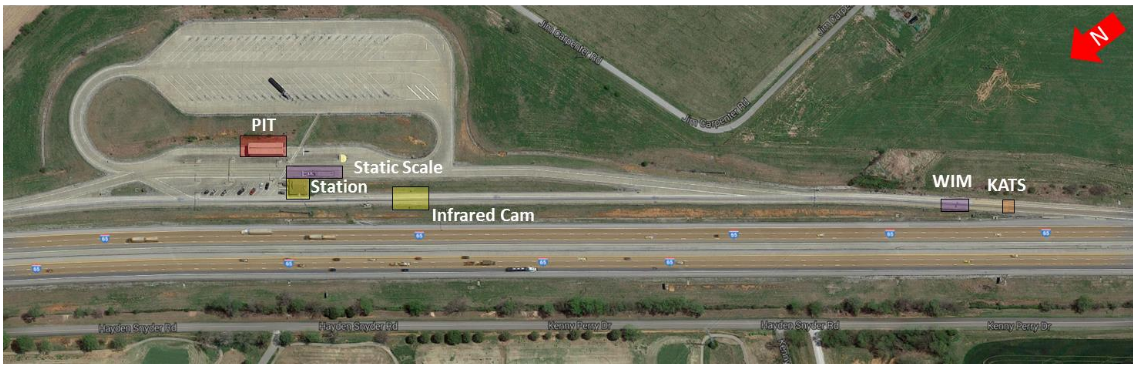


***Figure 13. Satellite Image of Simpson County, KY Weigh Station***

*Source: Productivity Apex/Google Maps*

## Process Mapping

The pre-deployment process (Figure 14) at Simpson County starts with trucks approaching the weigh station. If any truck has PrePass or Drivewyze, then that system determines whether it meets all credential requirements to bypass. Trucks that fail this screening and trucks that do not have bypass technology are directed to enter the station. Trucks that drive over the WIM scale and are in regulation are then diverted to the WIM lane where they drive by the Thermal Eye infrared (IR) camera. As inspectors watch the camera feed at the station they can pull any truck over for detected low tire pressure or bad brakes. Trucks may also be stopped for any other reason an inspector might think is necessary. Trucks that fail the WIM check are directed toward the static scale to verify weight. These trucks could be observed with the IR camera, but the camera is usually pointing at the WIM lane. Trucks that violate any of these inspections, or seem unfit by site enforcement are directed to the parking lot for further evaluation. An advanced inspection is conducted on these trucks at the level decided by the present inspector. If violations/fees are found, drivers are given citations and must address these before being allowed to leave; otherwise trucks/drivers will remain out of service (OOS).

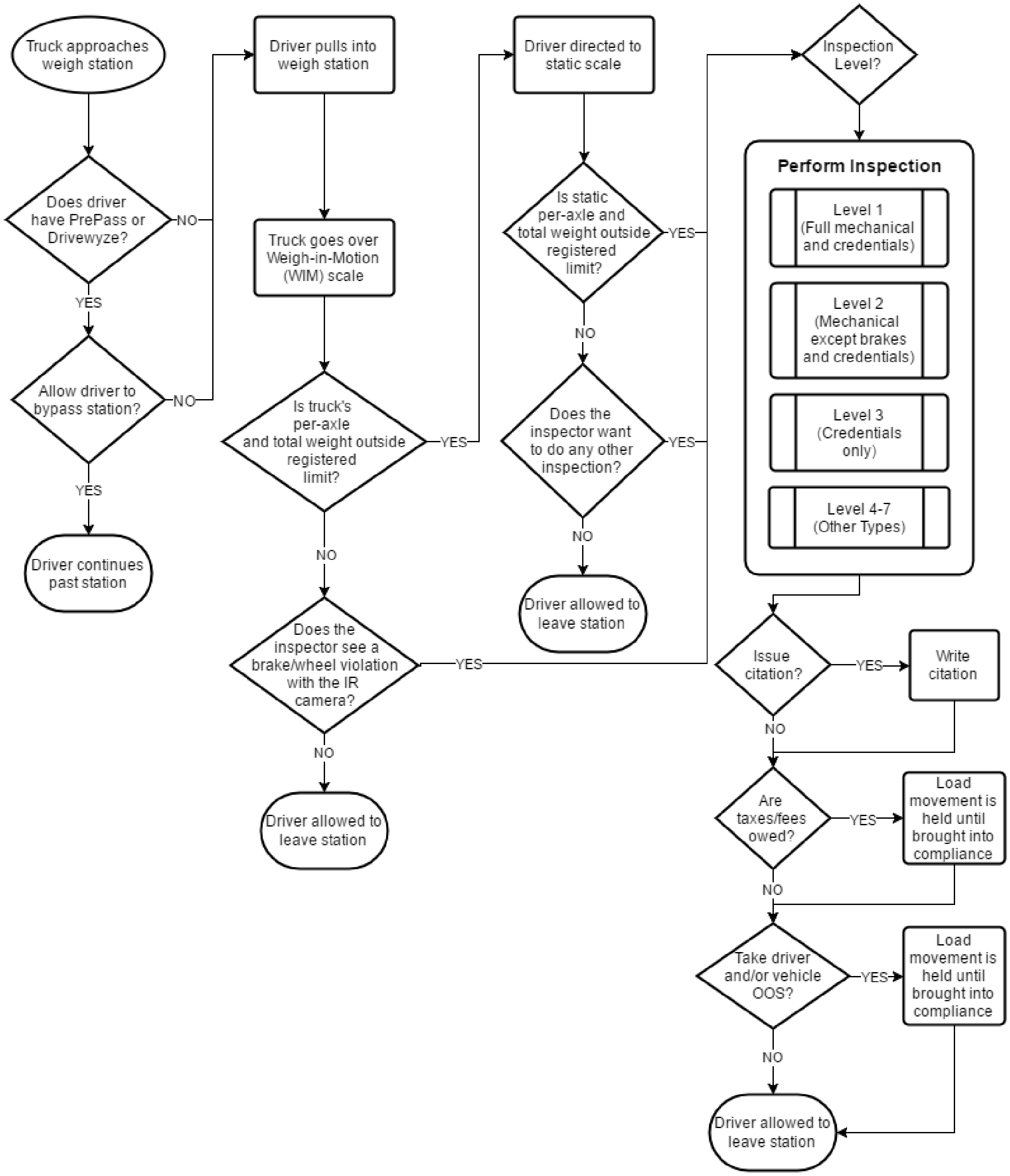


***Figure 14. Simpson, KY - Pre-Deployment Process Map***

*Source: Productivity Apex, Inc.*

The post-deployment process (Figure 15) at Simpson County starts with trucks approaching the weigh station. If any truck has PrePass or Drivewyze, then that system determines whether it meets all credential requirements to bypass. Trucks that fail this screening and trucks that do not have bypass technology are directed to enter the station. When trucks enter the ramp, cameras capture images of the truck's license plate number, USDOT number, and KYU number, which are then processed through an optical character recognition (OCR) software. These numbers are then run through the KATS system, which checks credential databases for violations. A full-time civilian employee monitors OCR results, corrects any errors, and reruns corrected numbers through the KATS databases. Meanwhile, trucks drive over the WIM scale; if they passed then are diverted to the WIM lane for a scan by the Thermal Eye infrared (IR) camera. Inspectors watching the camera feed at the station could pull over any truck for low tire pressure or for bad brakes. Trucks that fail the WIM check are directed toward the static scale to verify weight. These trucks could also be observed with the IR camera, but the camera is usually pointing at the WIM lane. Trucks that violate any of these inspections, or seem unfit by site enforcement, are directed to the parking lot for further evaluation. A level of inspection is decided upon by an experienced enforcement officer and conducted on parked trucks. If no violations are found then drivers are allowed to leave; otherwise an inspector issues citations and/or directions for corrective action.

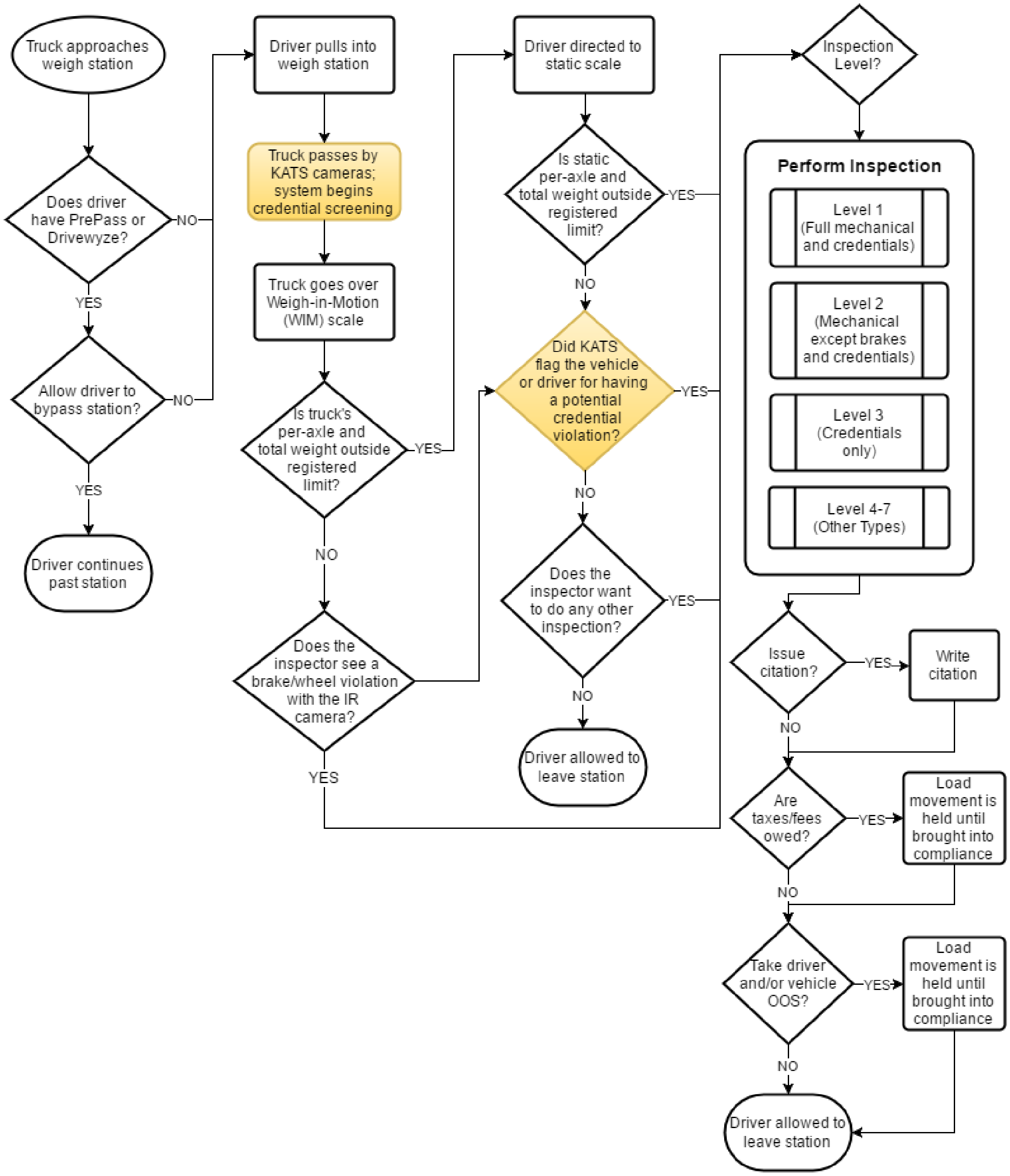


***Figure 15. Simpson, KY - Post-Deployment Process Map***

*Source: Productivity Apex, Inc.*

## Data Acquired

Table 10 lists the types of data acquired, the time period included in the data, and the agency that provided that data.

**Table 10. Simpson, KY - List of Data Acquired and Sources**

| Data Collected | Period | Source |
|---|---|---|
| Static Scale Daily Counts | 1/1/14 – 5/31/14 and 1/1/15 – 5/31/15 | Kentucky State Police (KSP) |
| WIM Scale Daily Counts | 1/1/14 – 5/31/14 and 1/1/15 – 5/31/15 | Kentucky State Police (KSP) |
| Annual Average Daily Traffic (AADT) | 1986 – 2014 | Kentucky Transportation Cabinet (KYTC) |
| List of all Inspections performed, including violations found and inspection level | 10/1/11 – 11/30/15 | Kentucky State Police (KSP) |
| Monthly total weigh station revenue | 1/2014 – 12/2015 | Kentucky Transportation Cabinet (KYTC) |
| Staffing station schedule per year | 2012 – 2015 | Kentucky State Police (KSP) |
| List of vehicle crashes in the corridor | 10/1/11 – 9/30/15 | Kentucky State Police (KSP) |
| Detailed list of violations, including code and description | 10/1/13 – 11/30/15 | Kentucky State Police (KSP) |

*Source: Productivity Apex, Inc.*

## Performance Measures and Hypothesis:

Based on the previously stated performance measures the impact assessment team together with the USDOT COR determined the hypothesis that was tested during this study.

**Table 11. Simpson, KY - Performance Measures and Hypotheses**

| Goal | Performance Measure | Hypothesis |
|---|---|---|
| Increased Productive Inspections Time | Percentage of time doing Productive Inspections | **$H_0$:** If KATS is implemented, the time performing productive inspections will remain the same<br><br>**$H_1$:** If KATS is implemented, the time performing productive inspections will change |
| Increased Inspection Efficiency | Average number of violations found per inspection | **$H_0$:** If KATS is implemented, the number of violations found per inspection will remain the same<br><br>**$H_2$:** If KATS is implemented, the number of violations found per inspection will change |

| Goal | Performance Measure | Hypothesis |
|---|---|---|
| Increased Safety | Average daily number of inspections with Driver OOS violations | **$H_0$:** If KATS is implemented, the number of inspections with OOS driver violations will remain the same<br><br>**$H_3$:** If KATS is implemented, the number of inspections with OOS driver violations will change |
| | Average daily number of inspections with Vehicle OOS violations | **$H_0$:** If KATS is implemented, the number of inspections with OOS vehicle violations will remain the same<br><br>**$H_4$:** If KATS is implemented, the number of inspections with OOS vehicle violations will change |
| | Average daily number of inspections with OOS violations | **$H_0$:** If KATS is implemented, the number OOS violations per inspection will remain the same<br><br>**$H_5$:** If KATS is implemented, the number OOS violations per inspection will change |
| Increased Revenue | Average Monthly Revenue | **$H_0$:** If KATS is implemented, the monthly revenue generated through inspections will remain the same<br><br>**$H_6$:** If KATS is implemented, the monthly revenue generated through inspections will change |

*Source: Productivity Apex, Inc.*

## Data Analysis and Results

The impact assessment team analyzed the collected data in order to determine the differences in performance measures between the pre- and post-deployment periods for KATS. The pre-deployment period for the KATS system in Simpson County is between January 1st, 2014 and December31st, 2014. The post-deployment period starts on January 1st, 2015 and continues through November 30th, 2015.

KATS was deployed in Simpson much earlier than in Lyon County, providing the impact assessment team a larger set of inspection records—about eleven months of data instead of four—for performing a more balanced comparison between before and after deployment parameters. A two sample statistical test was performed for each calculated performance measure, to determine the possibility of a significant difference between the two samples. A two-tailed z-test was used for both samples as they had more than 30 records each, allowing the team to estimate the standard deviation of each population, assuming a normal distribution and using a confidence level of 95%. However, a two-tailed t-test was used for comparing revenue per inspection given the limited amount of records for this parameter. Revenue information was provided as a total value per month, so a t-test was used given that the number of monthly records was less than 30.

To better interpret the table below, a P-Value was calculated for each performance measure, if the result is less than 0.050 it can be deduced that there is a statistically-significant difference between the two samples. For each of the metrics in the table, a P-Value below 0.050 simply means that there is at least a 95% level of confidence that the values for the Pre and Post-deployment periods are different.

**Table 12. Simpson, KY - Data Analysis Results**

| Data Analysis Description | Analysis Results | | | |
|---|---|---|---|---|
| VIOLATIONS PER INSPECTION | Pre | Post | Change | P-Value |
| Average number of violations found per inspection | 1.619 | 1.572 | -3% | 0.288 |
| Average number of violations found per Level 1 inspection | 2.082 | 1.871 | -10% | 0.001 |
| Average number of violations found per Level 2 inspection | 1.056 | 1.013 | -4% | 0.431 |
| Average number of violations found per Level 3 inspection | 0.704 | 0.856 | 22% | 0.101 |
| Average number of out of service violations found per inspection | 0.543 | 0.532 | -2% | 0.549 |
| Average number of out of service violations found per Level 1 inspection | 0.696 | 0.676 | -3% | 0.442 |
| Average number of out of service violations found per Level 2 inspection | 0.381 | 0.280 | -27% | 0.000 |
| Average number of out of service violations found per Level 3 inspection | 0.160 | 0.075 | -53% | 0.308 |
| DAILY INSPECTIONS | Pre | Post | Change | P-Value |
| Average daily number of inspections | 15.892 | 13.070 | -18% | 0.001 |
| Average daily number of inspections with No violations | 5.201 | 3.955 | -24% | 0.000 |
| Average daily number of inspections with 1 violation | 4.946 | 4.393 | -11% | 0.114 |
| Average daily number of inspections with 2+ violations | 5.745 | 4.721 | -18% | 0.002 |
| Average daily number of Level 1 inspections with violations | 6.867 | 6.458 | -6% | 0.366 |
| Average daily number of Level 2 inspections with violations | 3.058 | 2.328 | -24% | 0.003 |
| Average daily number of Level 3 inspections with violations | 0.741 | 0.328 | -56% | 0.002 |
| Average daily number of inspections with OOS violations | 6.299 | 5.333 | -15% | 0.012 |
| Average daily number of inspections with Driver OOS violations | 0.759 | 0.562 | -26% | 0.026 |
| Average daily number of inspections with Vehicle OOS violations | 5.741 | 5.055 | -12% | 0.062 |
| Average daily time performing inspections resulting in one or more violation (minutes) | 537.414 | 492.060 | -8% | 0.151 |
| INSPECTIONS WITH VIOLATIONS | Pre | Post | Change | P-Value |
| Percentage of Time Doing Productive Inspections | 73% | 73% | 0% | 0.664 |

| Data Analysis Description | Analysis Results | | | |
|---|---|---|---|---|
| INSPECTIONS WITH VIOLATIONS | Pre | Post | Change | P-Value |
| Proportion of inspections with No violations | 33% | 32% | -1% | 0.453 |
| Proportion of inspections with 1 violation | 31% | 33% | 1% | 0.069 |
| Proportion of inspections with 2+ violations | 36% | 35% | -1% | 0.301 |
| Proportion of inspections with violations | 67% | 68% | 1% | 0.453 |
| Proportion of Level 1 inspections with violations | 74% | 72% | -2% | 0.044 |
| Proportion of Level 2 inspections with violations | 60% | 61% | 1% | 0.797 |
| Proportion of Level 3 inspections with violations | 48% | 64% | 16% | 0.001 |
| INSPECTION TIME PER LEVEL | Pre | Post | Change | P-Value |
| Average Duration for Level 1 Inspection (minutes) | 53.6 | 54.6 | 2% | 0.182 |
| Average Duration for Level 2 Inspection (minutes) | 38.5 | 41.5 | 8% | 0.000 |
| Average Duration for Level 3 Inspection (minutes) | 31.4 | 40.2 | 28% | 0.000 |
| INSPECTION REVENUE | Pre | Post | Change | P-Value |
| Average Monthly Revenue | $7,775.25 | $17,865.02 | 130% | 0.019 |

*Source: Productivity Apex, Inc.*

The Simpson weigh station was able to provide daily values per inspection, number of violations, inspection duration, number of OOS violations, etc. From this data, the safety and productivity improvements that the KATS system may have provided this site were analyzed and are displayed in the following sections.

The figures below show the safety improvement data broken down monthly. The vertical red line indicates the implementation of KATS in January 2015. Figure 16 displays the average total violations per inspection. This average was calculated by dividing the sum of all daily inspections by the sum of all violations given within each month.  As shown in Table 12 above, the overall average violations found per inspection was statistically unchanged and the graph shows monthly averages were in the same range before and after deployment.

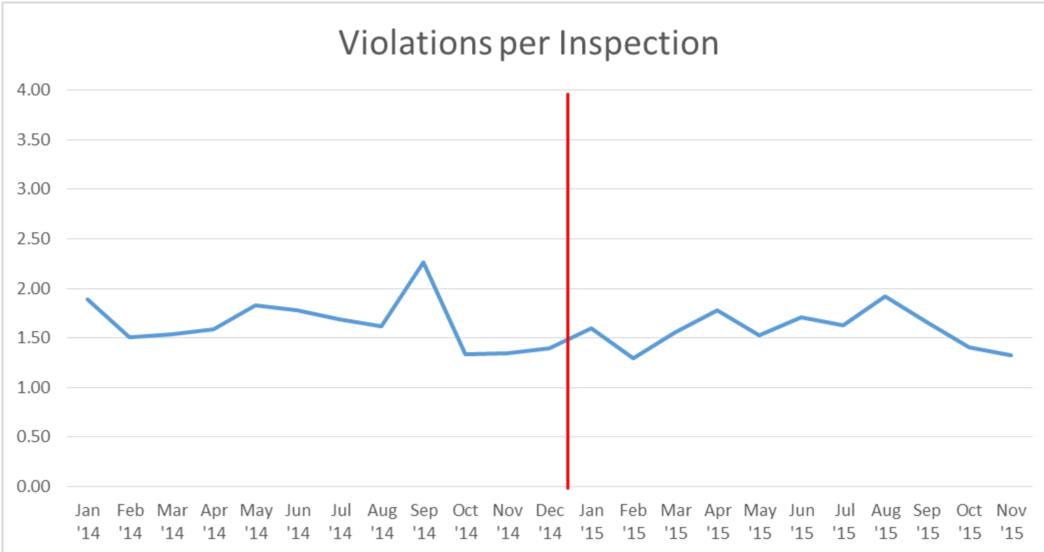


***Figure 16. Safety Improvement: Violations per Inspection***

*Source: Productivity Apex, Inc.*

Figure 17 presents an average of total out of service (OOS) violations. OOS is only one of the violations that can be given to a vehicle and/or driver, and due to its nature, anyone operating on the road while under this status is extremely unsafe. For this particular performance measure, the average was calculated by dividing the sum of all daily inspections by the sum of all OOS violations given within each month. This chart, just as Table 12 above, shows no statistical change after the implementation of KATS.

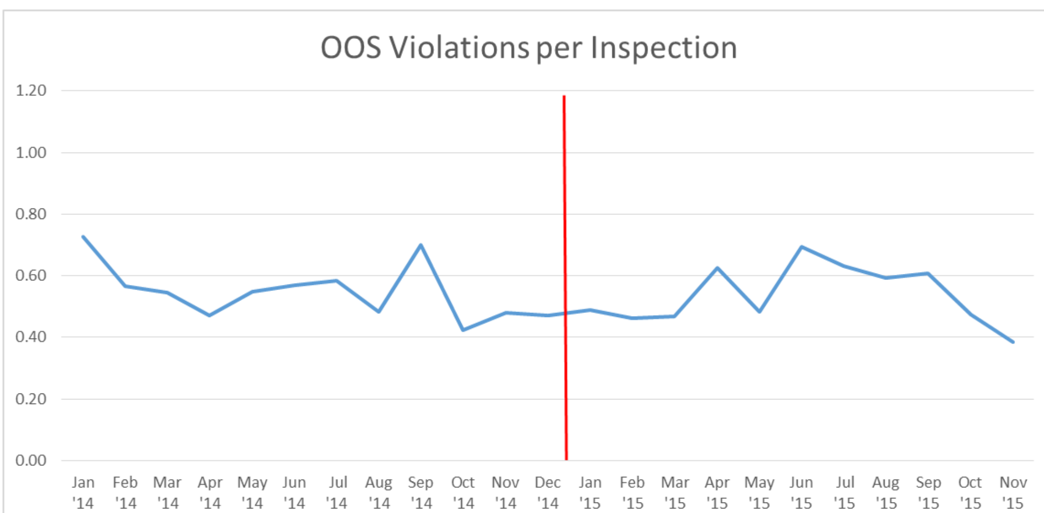


***Figure 17. Safety Improvement: OOS Violations per Inspection***

*Source: Productivity Apex, Inc.*

Figure 18 below shows the productivity improvement data broken down monthly. The vertical red line indicates the implementation of KATS in January 2015. Shown are the performance measures for the percent of time taken to perform a productive inspection (blue line) and the percent of inspections that resulted in violations (orange line). The time for productive inspections was calculated attaining the total productive inspection time over the total inspection time. The total productive inspection time was established by adding the time spent on any inspection that resulted in one or more violations. Similarly, the percent of inspections with violations was acquired from the total number of inspections with violations over the number of total violations. The number of inspections with violations was allotted to any inspection that produced at least one violation.

For both of these lines, there appears not to be a difference between the pre and post-deployment periods. There seems to be the same drop in productivity during the months of September, October, and November for both years, with or without the KATS system; this could be observed as a seasonal occurrence and not a direct correlation to the effetiveness of the system. Conversely, for the months from January to April there was an increase in productivity before and after implementation. Although some trends can be drawn from this graph, there still exists an unpredictability in the data that could stem from the time of year, to the number of hours the weigh station is open on any given day. Additionally Table 12 above reflects no statistical difference in productivity between the two periods.

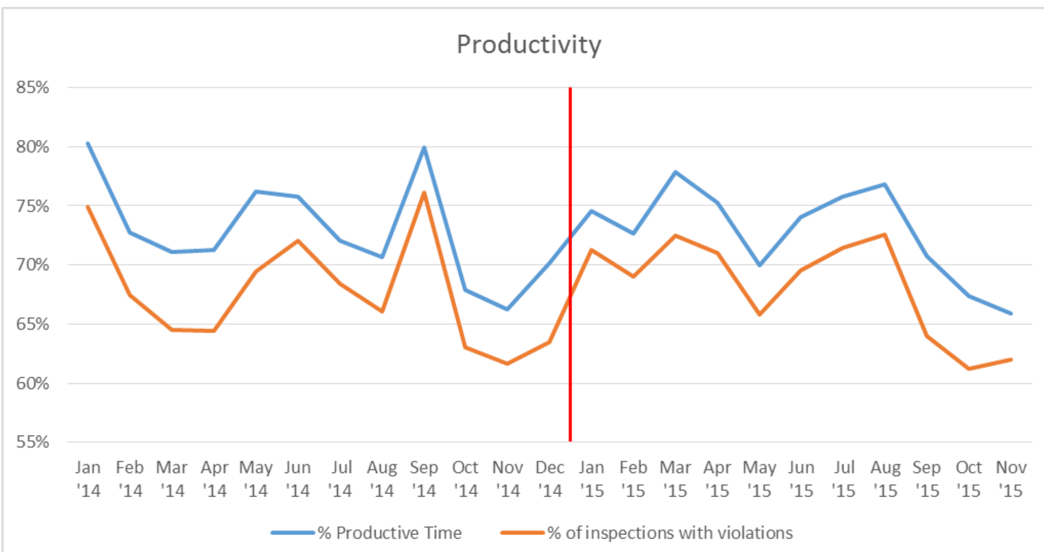


***Figure 18. Productivity Improvement***

*Source: Productivity Apex, Inc.*

Figure 19 below shows the revenue data broken down monthly from January 2014 till December 2015, and Figure 20 as well as the data table shows the revenue data with September 2015 adjusted to exclude one large impound. Figure 19 shows the actual data including the month of September 2015 without adjusting. That instance was the result of an inspection of a truck whose company had outstanding taxes totalling $211,000. Although that data point is significant, because the inspectors wouldn’t have caught that violator without KATS, it needed to be removed from the analysis given that is a very uncommon occurrence. The red line indicates the implementation of KATS in January 2015.

As shown in Table 12 above, the overall average revenue per inspection increased and the adjusted graph shows an immediate improvement to monthly revenue after deployment. Although April and October2014 were relatively good months and better than several months in 2015, the average for 2014 was significantly lower than the average of 2015.

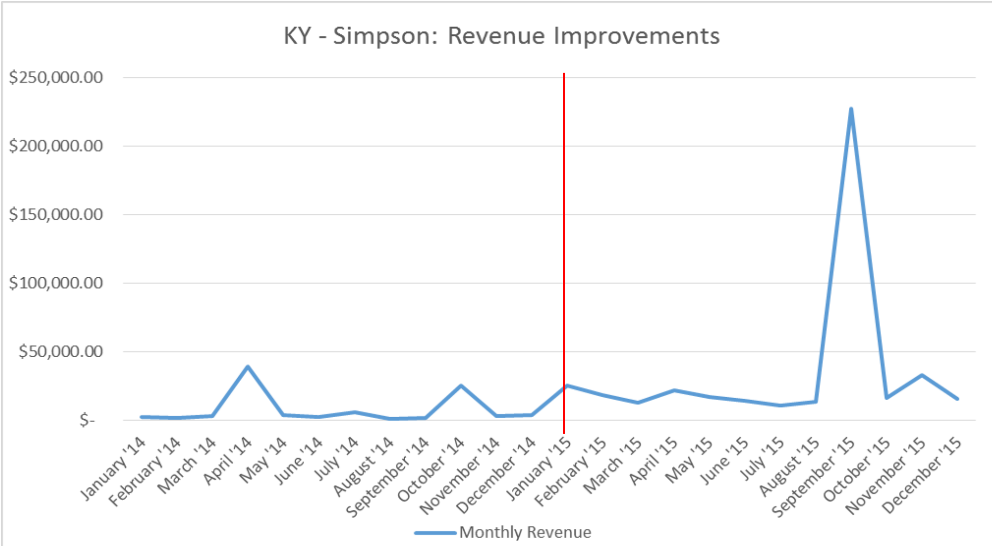


***Figure 19. Simpson, KY - Monthly Revenue Data***

*Source: Productivity Apex, Inc.*

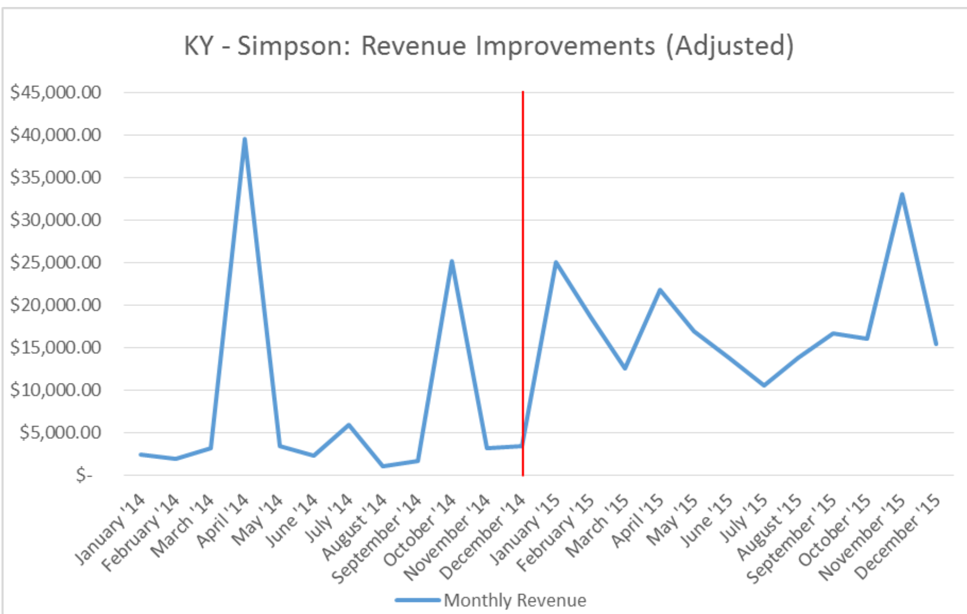


***Figure 20. Simpson, KY - Monthly Revenue Data with Adjusted September 2015***

*Source: Productivity Apex, Inc.*

The next table shows the values used to prove the hypotheses that were formulated for the analysis. Parameters from Table 4 were used as the test statistic for the analysis.

**Table 13. Simpson, KY - Tests of Hypothesis Results**

| Hypothesis Statement | Evaluated parameter | Pre- | Post- | P-Value | Conclusion |
|---|---|---|---|---|---|
| **$H_0$**: If KATS is implemented, the time performing productive inspections will remain the same<br><br>**$H_1$**: If KATS is implemented, the time performing productive inspections will change | Percentage of time doing Productive Inspections | 537.414 | 492.060 | 0.151 | Do not Reject $H_0$ |
| **$H_0$**: If KATS is implemented, the number of violations found per inspection will remain the same<br><br>**$H_2$**: If KATS is implemented, the number of violations found per inspection will change | Average number of violations found per inspection | 1.619 | 1.572 | 0.288 | Do not Reject $H_0$ |
| **$H_0$**: If KATS is implemented, the number of inspections with OOS driver violations will remain the same<br><br>**$H_3$**: If KATS is implemented, the number of inspections with OOS driver violations will change | Average daily number of inspections with Driver OOS violations | 0.759 | 0.562 | 0.026 | Reject $H_0$ |

| Hypothesis Statement | Evaluated parameter | Pre- | Post- | P-Value | Conclusion |
|---|---|---|---|---|---|
| **$H_0$**: If KATS is implemented, the number of inspection with OOS vehicle violations will remain the same<br><br>**$H_4$**: If KATS is implemented, the number of inspection with OOS vehicle violations will change | Average daily number of inspections with Vehicle OOS violations | 5.741 | 5.055 | 0.062 | Do not Reject $H_0$ |
| **$H_0$**: If KATS is implemented, the number OOS violations per inspection will remain the same<br><br>**$H_5$**: If KATS is implemented, the number OOS violations per inspection will change | Average daily number of inspections with OOS violations | 6.299 | 5.333 | 0.012 | Reject $H_0$ |
| **$H_0$**: If KATS is implemented, the monthly revenue generated through inspections will remain the same<br><br>**$H_6$**: If KATS is implemented, the monthly revenue generated through inspections will change | Average Monthly Revenue | $7,775.25 | $17,865.02 | 0.019 | Reject $H_0$ |

*Source: Productivity Apex, Inc.*

The above table shows a significant difference among the parameters at the Simpson weigh station. There was not enough statistical evidence to prove any difference in the time performing productive inspections, the number of violations found per inspection, and the daily average number of inspection with OOS vehicle violations between the pre and post-deployment period in Kentucky. A significant reduction in the values for daily average number of inspection with out of service violations, more specifically for driver out of service violations was observed during the two test periods; and although it was not expected, it is hard to pinpoint the factors that played a significant role on those outcomes. Nonetheless, it can be observed a significant increase in the average monthly revenue of the weigh station.

When analyzing KATS data closely, a disconnect can be observed between Simpson and Lyons' results. Although it is hard to point out a specific cause or reason for these results, it is believed that the assessment period for each site may have played a role here. It is important to remember that there were only about three months of post-deployment data for Lyon compared to 11 months of post-deployment data in Simpson. When deployments of technologies that more efficiently allow detection of potential violations are made, a change in driver behavior is expected within some time from the implementation date. It is possible that the change in driver behavior was not observed in the three months assessment for Lyon, thus explaining the lower number of violations and other metrics in Simpson.

# West Friendship Station, MD

## System to evaluate

The system evaluated in this site is the SRI Prototype developed by Leidos under contract with USDOT. This system was deployed on August 17th, 2015. Figure 21 depicts this testing site as a satellite image and overlaid are the different systems and assets installed at the weigh station. Figure 22 represents a map view of the area, illustrating the location of geofences and relevant sensors.


***Figure 21. Satellite Image of Maryland West Friendship Weigh Station***

*Source: Productivity Apex/Google Maps*

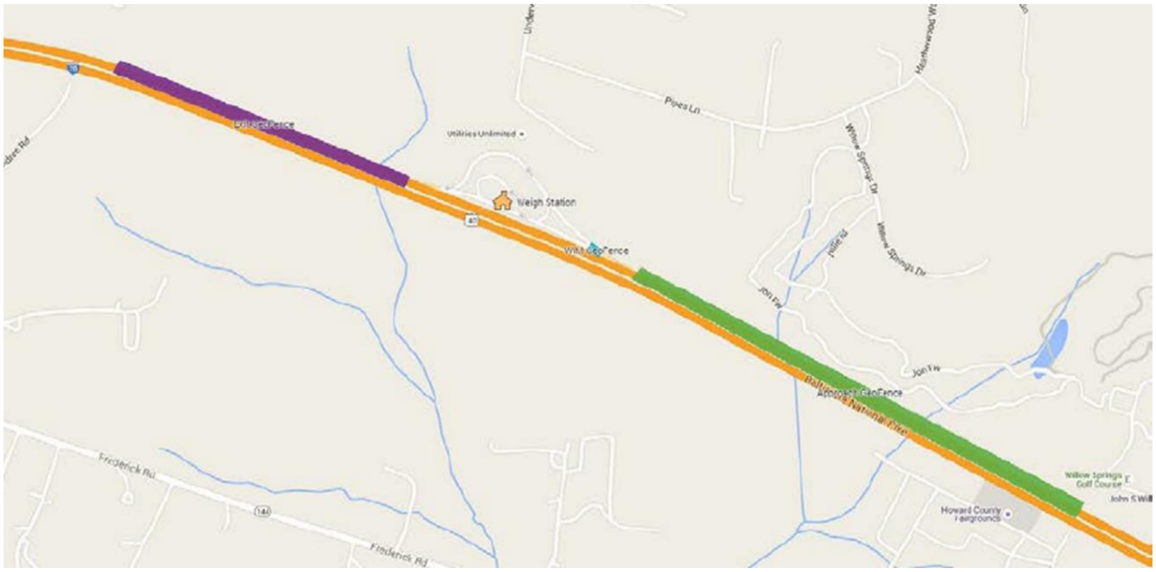


***Figure 22. Maryland West Friendship Weigh Station SRI Configuration***

*Source: Leidos/Google Maps*

## Process Mapping

The pre-deployment process (Figure 23) at West Friendship starts with trucks approaching the weigh station. If any truck has Drivewyze, then that system determines whether it meets all credential requirements to bypass. Trucks that fail this screening and trucks that do not have bypass technology are directed to enter the station. Trucks drive over the WIM scale; if passed they continue through the station, otherwise are directed toward the static scale to verify weight. As trucks drive over the WIM, the license plate is photographed by an LPR; officers then use this to manually look up the carrier's SAFER score. Trucks that violate weight limits, carriers with poor safety scores, and any other trucks that the inspector decides to inspect for other reasons are directed to the parking lot for an inspection. A level of inspection is chosen by experienced enforcement and then conducted on parked trucks. If no violations/fees are found, then the driver is allowed to leave, or else the inspector issues citations and/or directions for corrective action. Trucks or drivers taken out of service (OOS) are not allowed to leave until corrections are met.

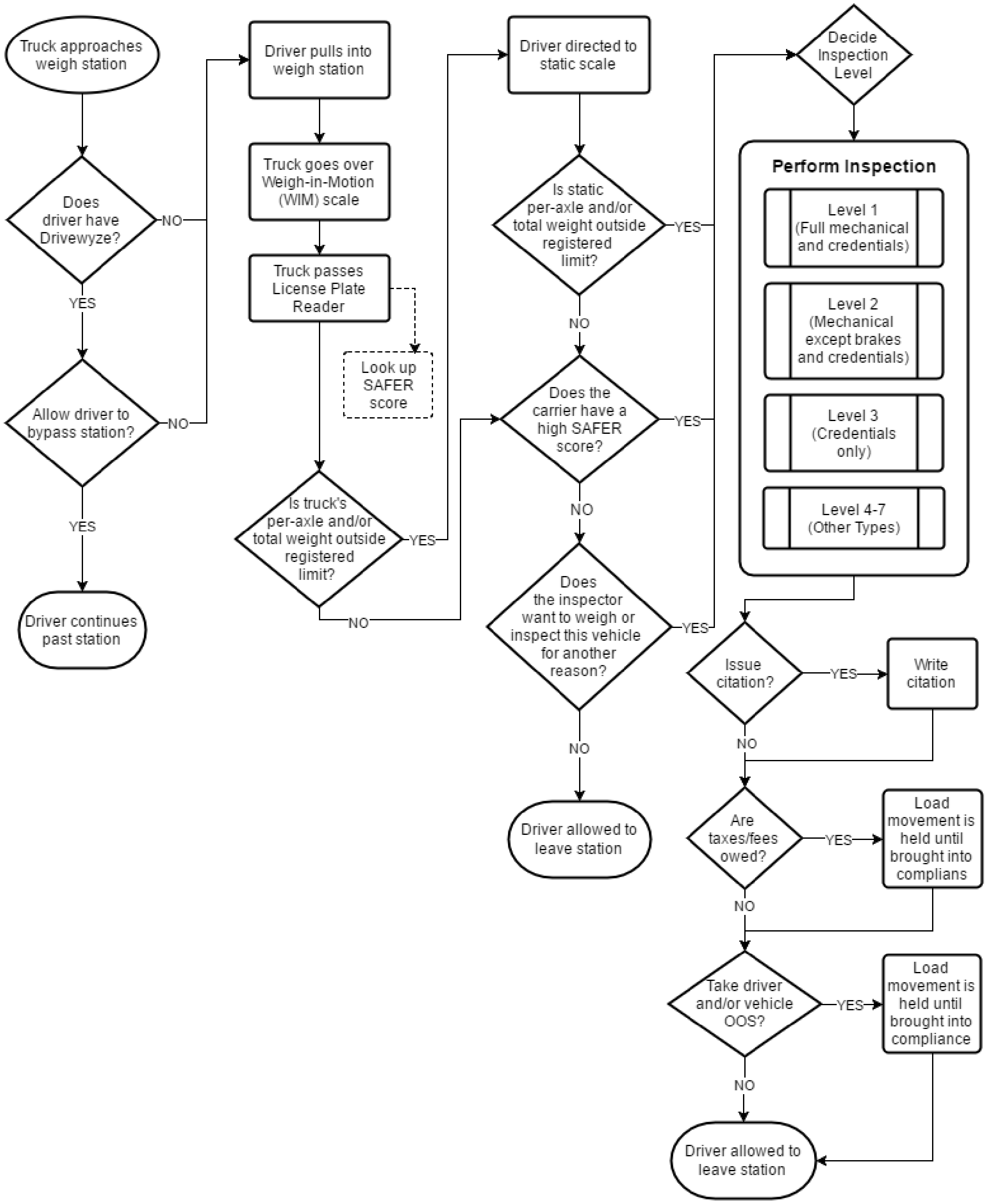


***Figure 23. West Friendship, MD - Pre-Deployment Process Map***

*Source: Productivity Apex, Inc.*

The post-deployment process (Figure 24) at West Friendship starts with trucks approaching the weigh station. If any truck has Drivewyze, then this system determines whether it meets all credential requirements to bypass. Trucks that fail this screening and trucks that do not have bypass technology are directed to enter the station. Similarly to the bypass technology, if drivers have the SRI application on their mobile device, then as their truck passes through the weigh station it drives over the WIM, the system sends safety records, scale results, and carrier data from the driver app to the SRI Dashboard, displaying credentials and SAFER scores for inspectors. Inspectors check the provided data in the dashboard, and based on their decision, a message is sent to the mobile device indicating to the driver to either pull into the weigh station for further inspection or to bypass the static scale.

For trucks without the SRI mobile application, an LPR will photograph their license plate as they drive over the WIM, officers can then use this to manually look up the carrier's SAFER score. Trucks that violate weight limits, those that have poor safety scores, and any other trucks that inspectors decide to inspect for other reasons are directed to the parking lot for further inspection. Inspectors conducting evaluations decide which level of inspection to perform. If violations are found, drivers are given a citation, and corrections must be made before they are allowed to leave the weigh station.

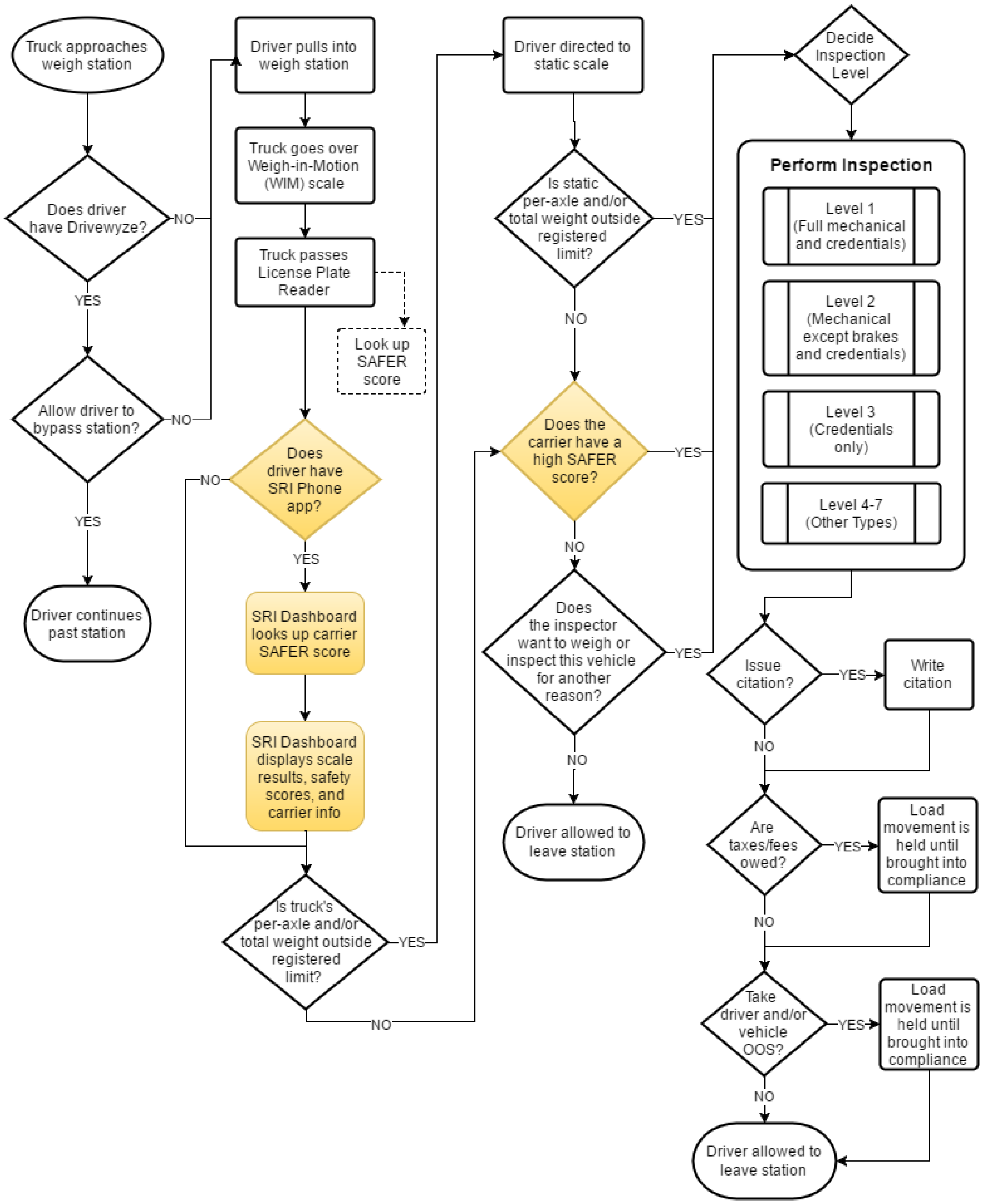


***Figure 24. West Friendship, MD - Post-Deployment Process Map***

*Source: Productivity Apex, Inc.*

## Data Acquired

Table 14 lists the types of data acquired, the time period included in the data, and the agency that provided that data.

**Table 14. West Friendship, MD - List of Data Acquired and Sources**

| Data Collected | Period | Source |
|---|---|---|
| Static Scale Daily Counts | 8/17/15 – 9/14/15 | MD Department of State Police |
| WIM Scale Daily Counts | 8/17/15 – 9/14/15 | MD Department of State Police |
| List of all Inspections performed, including violations found and inspection level | 8/17/15 – 9/14/15 | MD Department of State Police |

*Source: Productivity Apex, Inc.*

## Performance Measures and Hypothesis

The SRI Dashboard was deployed in West Friendship on August 17th, 2015. The deployment at this site provided one vehicle with the full installation of the technology, leading to a single data point. Therefore, the data acquired from this site was not sufficient for an accurate statistical analysis of the impact of the system in this area. Additionally, the inspection data provided by Maryland for this site consisted only of a single month of data after the implementation of the system, still not enough for a formal statistical analysis.

Because of the deficiency of data for the analysis, the impact assessment team was not able to formulate the hypotheses to statistically evaluate the before and after of the prototype implementation. Table 15 shows the performance measures the project team was able to calculate for the site based on the data provided; it consisted of one month of inspection results after the deployment of the system.

**Table 15. West Friendship, MD - Data Analysis Results**

| Data Analysis Description | Analysis Results |
|---|---|
| VIOLATIONS PER INSPECTION | Post |
| Average number of violations found per inspection | 1.64 |
| Average number of violations found per Level 1 inspection | 3.62 |
| Average number of violations found per Level 2 inspection | 0.90 |
| Average number of violations found per Level 3 inspection | 0.27 |
| Average number of out of service violations found per inspection | 0.43 |
| Average number of out of service violations found per Level 1 inspection | 1.03 |
| Average number of out of service violations found per Level 2 inspection | 0.20 |
| Average number of out of service violations found per Level 3 inspection | 0.09 |

| Data Analysis Description | Analysis Results |
|---|---|
| INSPECTIONS WITH VIOLATIONS | Post |
| Percentage of Time Doing Productive Inspections | 73% |
| Proportion of inspections with No violations | 40% |
| Proportion of inspections with 1 violation | 24% |
| Proportion of inspections with 2+ violations | 36% |
| Proportion of inspections with violations | 60% |
| Proportion of Level 1 inspections with violations | 87% |
| Proportion of Level 2 inspections with violations | 47% |
| Proportion of Level 3 inspections with violations | 27% |
| INSPECTION TIME PER LEVEL | Post |
| Average Duration for Level 1 Inspection (minutes) | 32.6 |
| Average Duration for Level 2 Inspection (minutes) | 19.6 |
| Average Duration for Level 3 Inspection (minutes) | 12.5 |

*Source: Productivity Apex, Inc.*

Along with the data provided from that one vehicle, a survey was conducted to judge performance and popular opinion from stakeholders (refer to the Survey Results and Analysis section). Through these results, it was clear that an abundant number of stakeholders in the area were unaware of the system or had no opportunity to use it. From those responders that had worked with the system, an overall positive response was received. Although these results are inconclusive for the impact of the SRI Dashboard, they can be used as preliminary feedback for implementation on a large scale.

## Highlights on the Maryland SRI Prototype Deployment

One of the most important characteristic of this deployment in Maryland was the integration with DSRC Technology, which allowed for Road Side Unit (RSU) and a vehicle’s on-board application to share information. The RSU was a fixed infrastructure that had a DSRC transceiver, a GPS location system, an application processor and router. Using all these features, this system monitored roadway, parking management, and commercial vehicles. This specific technology enriched the SRI Dashboard.

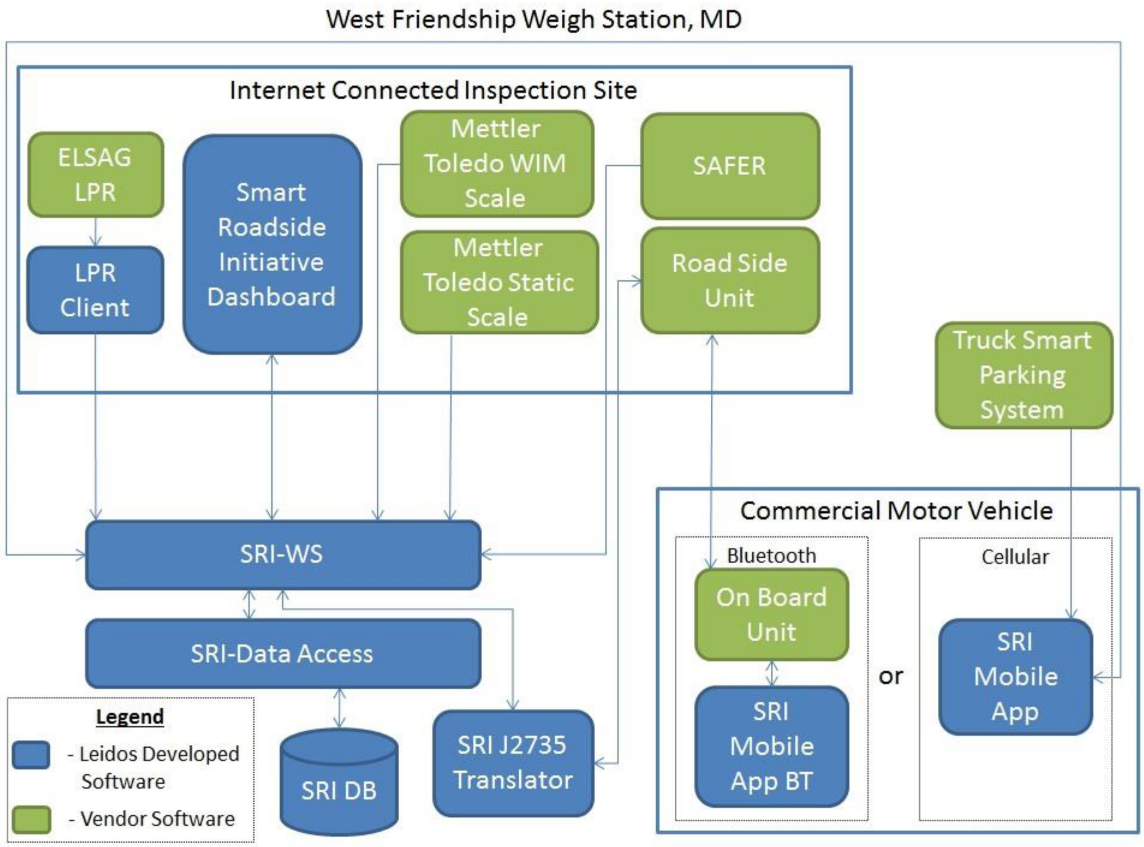


***Figure 25. West Friendship Weigh Station Communication Diagram***

*Source: Extracted from "Smart Roadside Initiative –Final Report" Chapter 4*

Figure 25 represents the communication diagram for the West Friendship weigh station; this was a perfect site for the analysis of the SRI Dashboard. It had access to both the WIM and static, and the License Plate Reader. The site had also internet, cellular, and DSRC access, allowing communication between stakeholders. DSRC was developed to provide high-quality roadside-vehicle communication services for intelligent highways. The on-board and roadside interfaces were meant to expedite freight inspection and travel delays through a seamless, secure, and reliable information exchange; and although the deployment suffered of some implementation issues, more specifically with the On Board Unit (OBU); some improvements in the software would allow for a smooth operation. All these components could have provided the ability for drivers and companies in compliance to bypass weigh stations.

Although there was no sufficient data to support an impact assessment for the SRI Dashboard in West Friendship, all information provided both numerical and through survey can be used as preliminary feedback for any future large-scale deployment of systems with SRI-like functionalities.

# Grass Lake Station, MI

## System to evaluate

The system to evaluate in this site is the SRI Prototype developed by Leidos under contract with USDOT. This system was deployed on August 18th, 2015. Figure 26 depicts this testing site as a satellite image and overlaid are the different systems and assets installed at the weigh station. In addition, Figure 27 represents a map view of the area, which illustrates the location of the geofences and relevant sensors.


***Figure 26. Satellite Image of Michigan Grass Lake Weigh Station***

*Source: Productivity Apex/Google Maps*

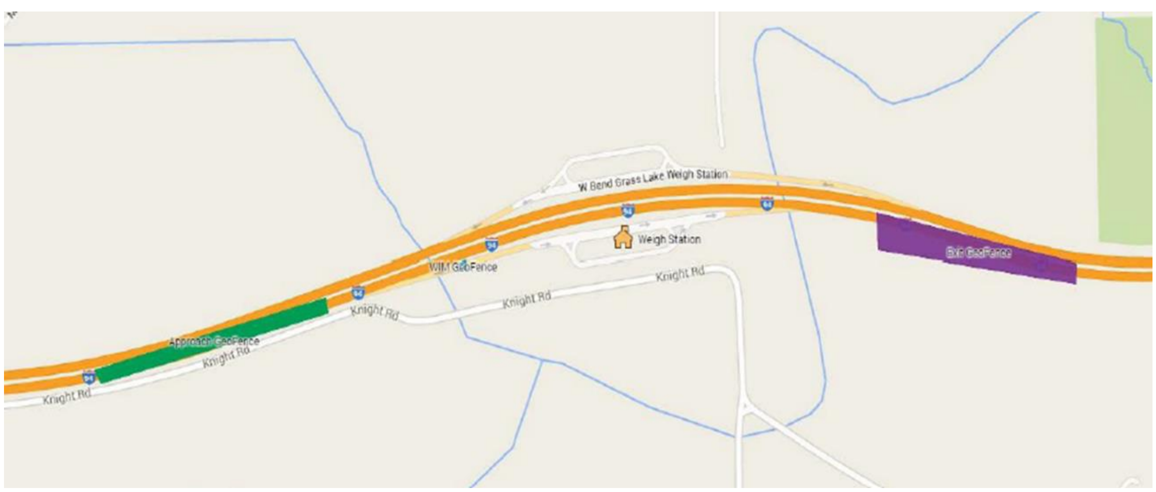


***Figure 27. Michigan Grass Lake Weigh Station SRI Configuration***

*Source: Leidos/Google Maps*

## Process Mapping

The pre-deployment process (Figure 28) at Grass Lake starts with trucks approaching the weigh station. If any truck has Drivewyze, then this system determines whether it meets all credential requirements to bypass. Trucks that fail this screening and trucks that do not have bypass technology are directed to enter the station. Trucks drive over the WIM scale; if passed, an overhead indicator on the ramp will signal them to continue through the station; otherwise they would be directed toward the static scale to verify weight. Trucks that violate weight limits or any trucks that inspectors decide to inspect for other reasons are directed to the parking lot for an inspection. A level of inspection is chosen by experienced enforcement and then conducted on parked trucks. If no violations/fees are found then drivers are allowed to leave, or else inspectors issue citations and/or directions for corrective action. Trucks or drivers taken out of service (OOS) and are not allowed to leave until corrections are met.

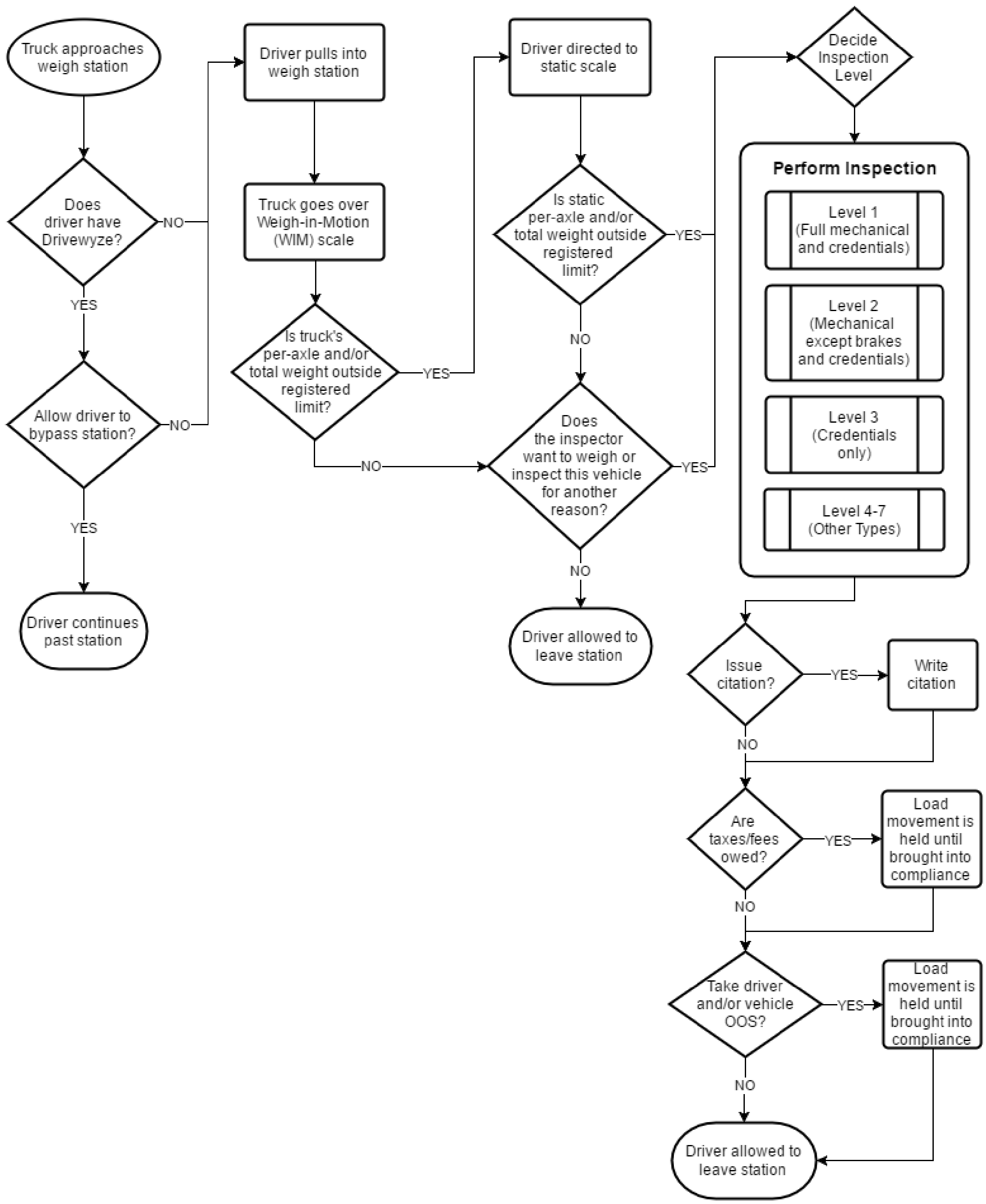


***Figure 28. Grass Lake, MI - Pre-Deployment Process Map***

*Source: Productivity Apex, Inc.*

The post-deployment process (Figure 29) at Grass Lake starts with trucks approaching the weigh station. If any truck has Drivewyze, then this system determines whether it meets all credential requirements to bypass. Trucks that fail this screening and trucks that do not have bypass technology are directed to enter the station. If drivers have the SRI application on their mobile device, then as their truck enters the station and go through the ramp WIM the app sends truck and carrier data to the SRI Dashboard, displaying credentials, weight, and SAFER scores for inspectors. If the trucks pass this check, the app will indicate to continue through the station; otherwise it will direct them toward the static scale to verify weight. For trucks without the SRI mobile application, an overhead indicator on the ramp will signal them to continue through the ramp and exit the station or to stop to be inspected. Inspector conducting evaluations decide which level of inspection to perform. If violations/fees are found, drivers are given citations and any corrections must be met before they are allowed to leave the station, or to be removed from out of service (OOS) status.

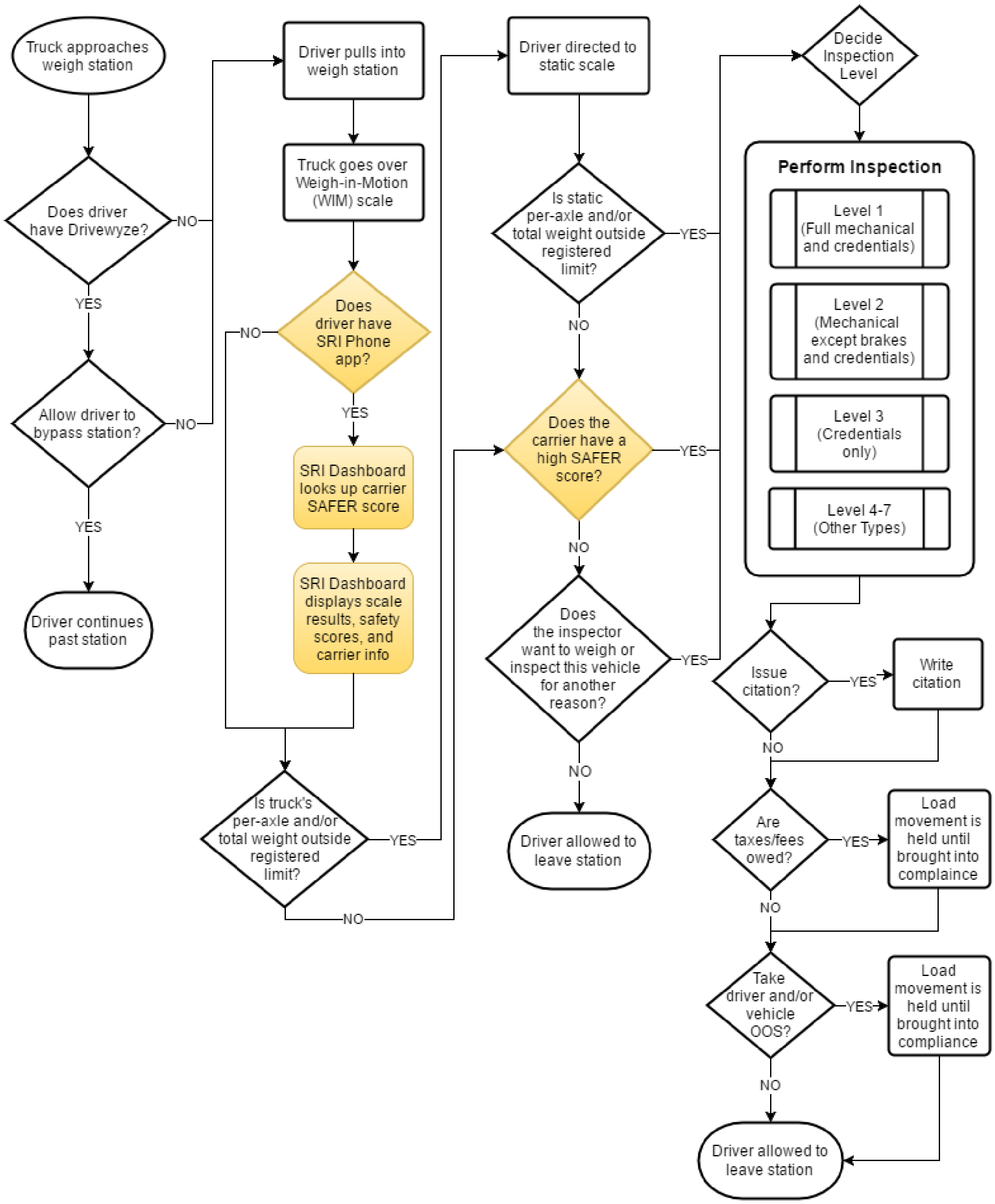


***Figure 29. Grass Lake, MI - Post-Deployment Process Map***

*Source: Productivity Apex, Inc.*

## Data Acquired

Table 16 lists the types of data acquired, the time period included in the data, and the agency that provided that data.

**Table 16. Grass Lake, MI - List of Data Acquired and Sources**

| Data Collected | Period | Source |
|---|---|---|
| Static Scale Daily Counts | 1/2/2015 – 10/28/2015 | Mettler Toledo North America |
| WIM Scale Daily Counts | 1/2/2015 – 10/28/2015 | Mettler Toledo North America |
| Annual Average Daily Traffic (AADT) | 2014 | Michigan DOT |
| List of all Inspections performed, including violations found and inspection level | 1/2/2015 – 10/22/2015 | Michigan State Police |
| List of vehicle crashes in the corridor | 1/2/2015 – 11/20/2015 | Michigan State Police |

*Source: Productivity Apex, Inc.*

## Performance Measures, Transformative Targets, and Hypothesis

The SRI Prototype was deployed in Grass Lake on August 18th, 2015. As in Maryland, the deployment at this site also provided one vehicle with the full installation of the technology, leading to having a single data point for the study. Data acquired from this site was not sufficient for an accurate statistical analysis of the impact of the system in the area.

Although some data was provided, given the deficiency in meaningful data for the analysis, the impact assessment team was not able to formulate the hypotheses to statistically evaluate the before and after of the prototype implementation.

In additional to the data provided, a survey was conducted to judge performance and popular opinion from stakeholders. Results showed that an abundant number of stakeholders in the area were unaware of the system or had no opportunity to use it. However, from those responders that had worked with the system, an overall positive response was received (refer to the Survey Results and Analysis section). Although these results are inconclusive for the impact of the SRI Dashboard, they can be used as preliminary feedback for implementation on a large scale.

## Highlights on the Michigan Prototype Deployment

Even though the site at Grass Lake, MI did not have an LPR system in place and lacked support for DSRC technology; the site functioned as a good candidate for integration with other commonly used technologies like iyeCitation, SAFER, Aspen, and the truck smart parking system. This site also had internet and cellular access allowing communication between stakeholders through the dashboard and mobile application. The diagram represented in Figure 30 display the integration between the Leidos developed systems and the pre-existing technology at the site. The diagram shows how software developed by Leidos (Aspen to iyeCitation Client) allowed for the communication between the Aspen and iyeCitation system which were previously independent systems.

This made possible seamless communication between systems like SAFER, WIM and the static scale with the SRI Prototype displaying the information on the SRI website or dashboard (SRI-WS)

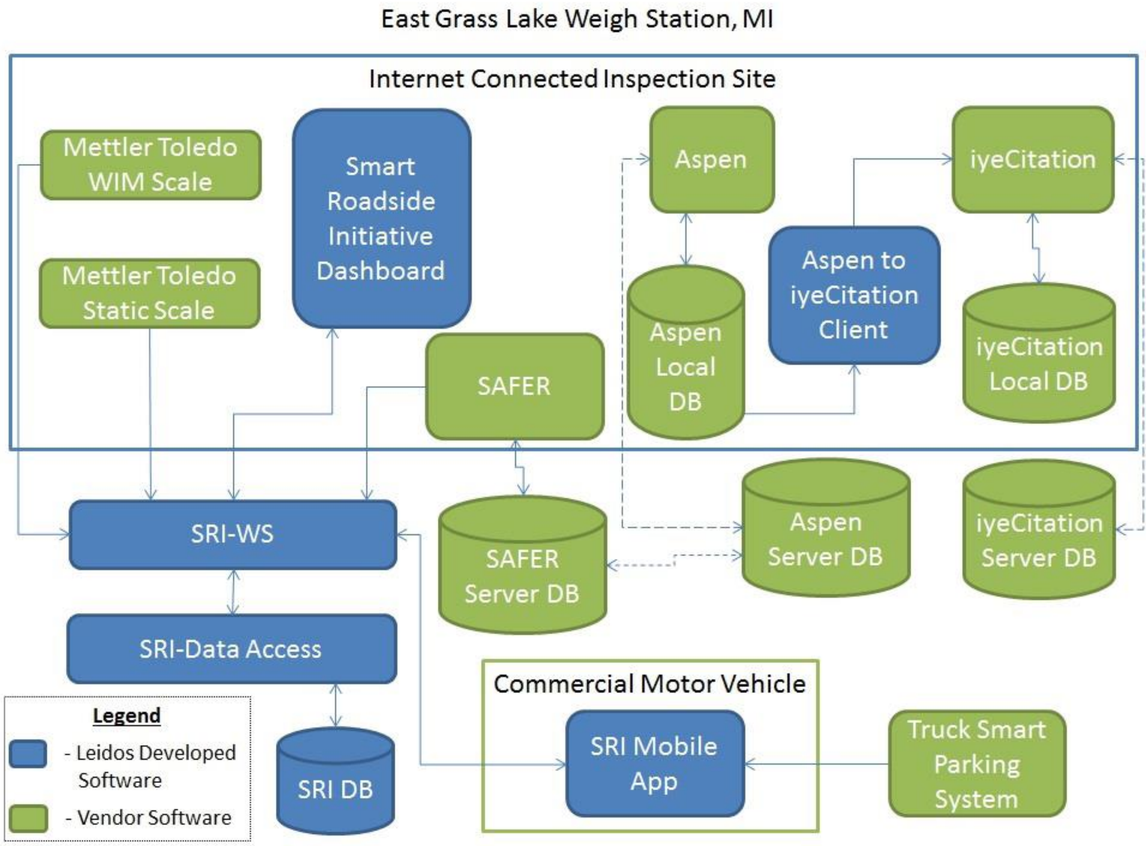


***Figure 30. East Grass Lake Weigh Station Communication Diagram***

*Source: Extracted from "Smart Roadside Initiative –Final Report" Chapter 4*

One of the highlights of this deployment was the integration of the system with iyeCitation. The iyeCitation is an application accessible at this site and known to the Michigan Police Department. Information on citations and crashes are directly reported to the courts and are made available instantaneously through this software.

Leidos created an Aspen to iyeCitation client for information transfer between these systems. If an electronic ticket is to be created by iyeCitation, Aspen will pre-populate the system with data saved after inspection via the SRI Dashboard. This network demonstrates the flexibility for integration with a locally used system. It adequately provided multiple internal and external interfaces for such systems to allow for simple integration.

The deployment at this site also included the truck driver mobile application. This application allowed drivers to enter information like their USDOT number, license plate, VIN, and driver's license number, as well as a picture of their truck. As in the Maryland deployment this application provided communication to the drivers regarding weigh station instructions, and also communicated information back to the prototype system for presentation to law enforcement officers' through the SRI Dashboard.

Although there was no sufficient data to support an impact assessment for the SRI Dashboard in Grass Lake, all information collected both numerical and through survey can be used as preliminary feedback for any future large-scale deployment of systems with SRI-like functionalities.

# Mt. Airy Station, NC

## System to Evaluate

The system evaluated in this site is a Weigh-in-Motion scale (WIM) augmented with an Automated License Plate Reader (ALPR). This system was deployed on January 1st, 2014. Figure 31 depicts this testing site as a satellite image and superimposed is the layout of the different systems installed at the site.


***Figure 31. Satellite Image of North Carolina Mt. Airy Weigh Station***

*Source: Productivity Apex/Google Maps*

## Process Mapping

The pre-deployment process (Figure 32) at Mt. Airy starts with trucks approaching the weigh station. If any truck has NCPass, then this system determines whether it meets all credential requirements to bypass the weigh station. The state of North Carolina uses Query Central for credential verification, as it retrieves safety compliance and enforcement data on commercial motor vehicle drivers, vehicles, and carriers from multiple sources using a single input. Trucks that fail this screening and trucks that do not have NCPass are directed to enter the station. No WIM scale is accessible at this weigh station; therefore trucks go directly to the static scale to measure truck weight. Trucks that violate weight limits and any other trucks that the inspector decides to inspect for other reasons are directed to the parking lot for further evaluation. The site's enforcement decides which level of inspection to perform and conducts this on parked trucks. If no violations are found then the driver is allowed to leave; otherwise inspectors issue citations and/or directions for corrective action. If any truck or driver was taken out of service (OOS), then drivers is not allowed to leave until the violations are corrected.

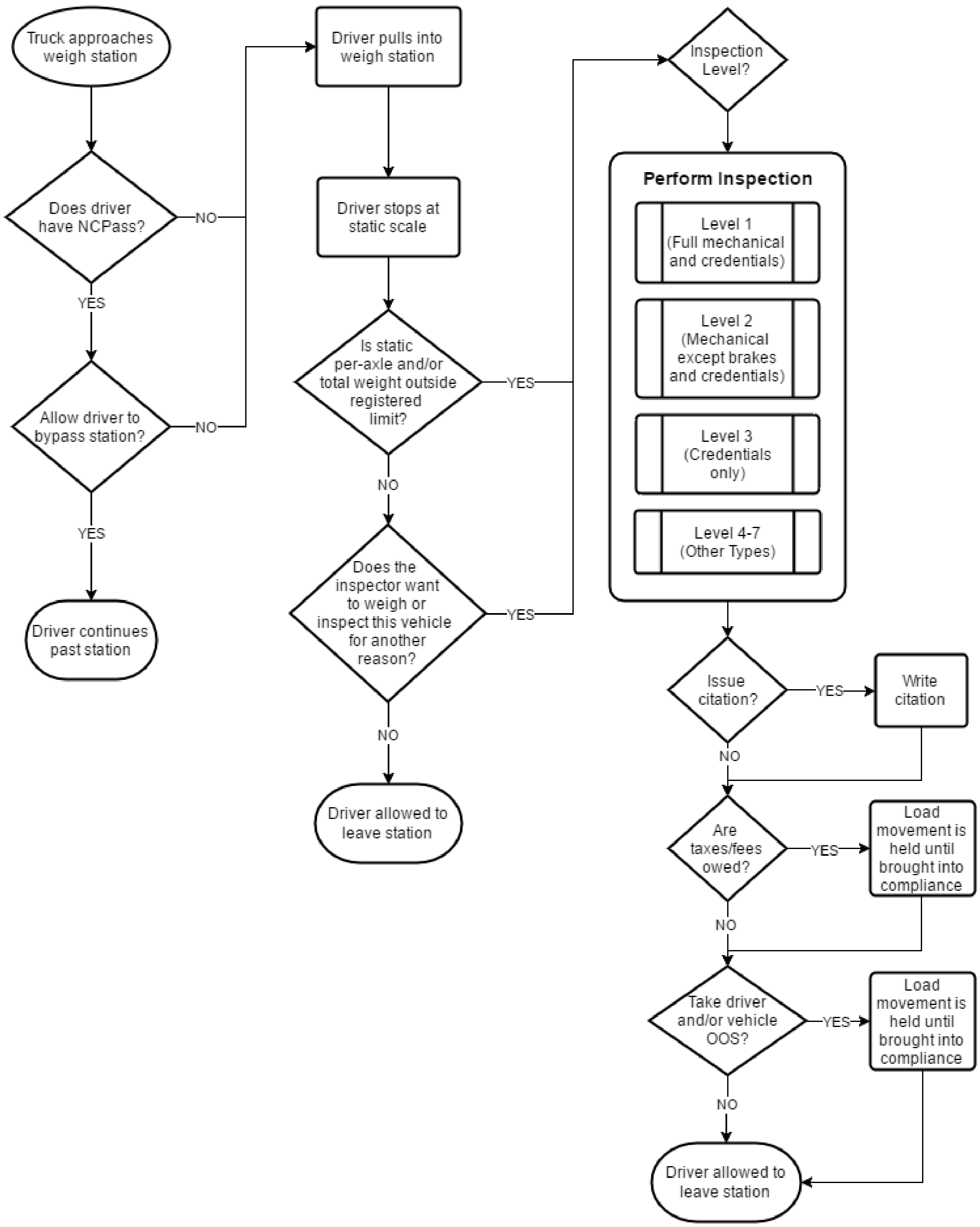


***Figure 32. Mt. Airy, NC - Pre-Deployment Process Map***

*Source: Productivity Apex, Inc.*

The post-deployment process (Figure 33) at Mt. Airy starts with trucks approaching the weigh station. If any truck has NCPass, then that system determines whether it meets all credential requirements to bypass. Query Central is used in this state for cross-referencing among multiple databases. Trucks that fail this screening and trucks that do not have NCPass are directed to enter the station. Trucks drive over the WIM scale while simultaneously having the ALPR capturing the license plate number to acquire credentials. Trucks within weight regulations can continue through the station, those in violation are directed toward the static scale to verify weight. The ALPR uses OCR technology to read and look up the ISS score in the federal safety score database. Trucks that violate weight limits, carriers with poor safety scores (90+), and any other trucks that the inspector decides to inspect for other reasons are directed to the parking lot for further evaluation. Inspection level is decided by experience enforcement and conducted to parked trucks. If no violations are found then drivers are allowed to leave; otherwise inspectors issue citations and/or directions for corrective action and truck/driver can be taken out of service (OOS).

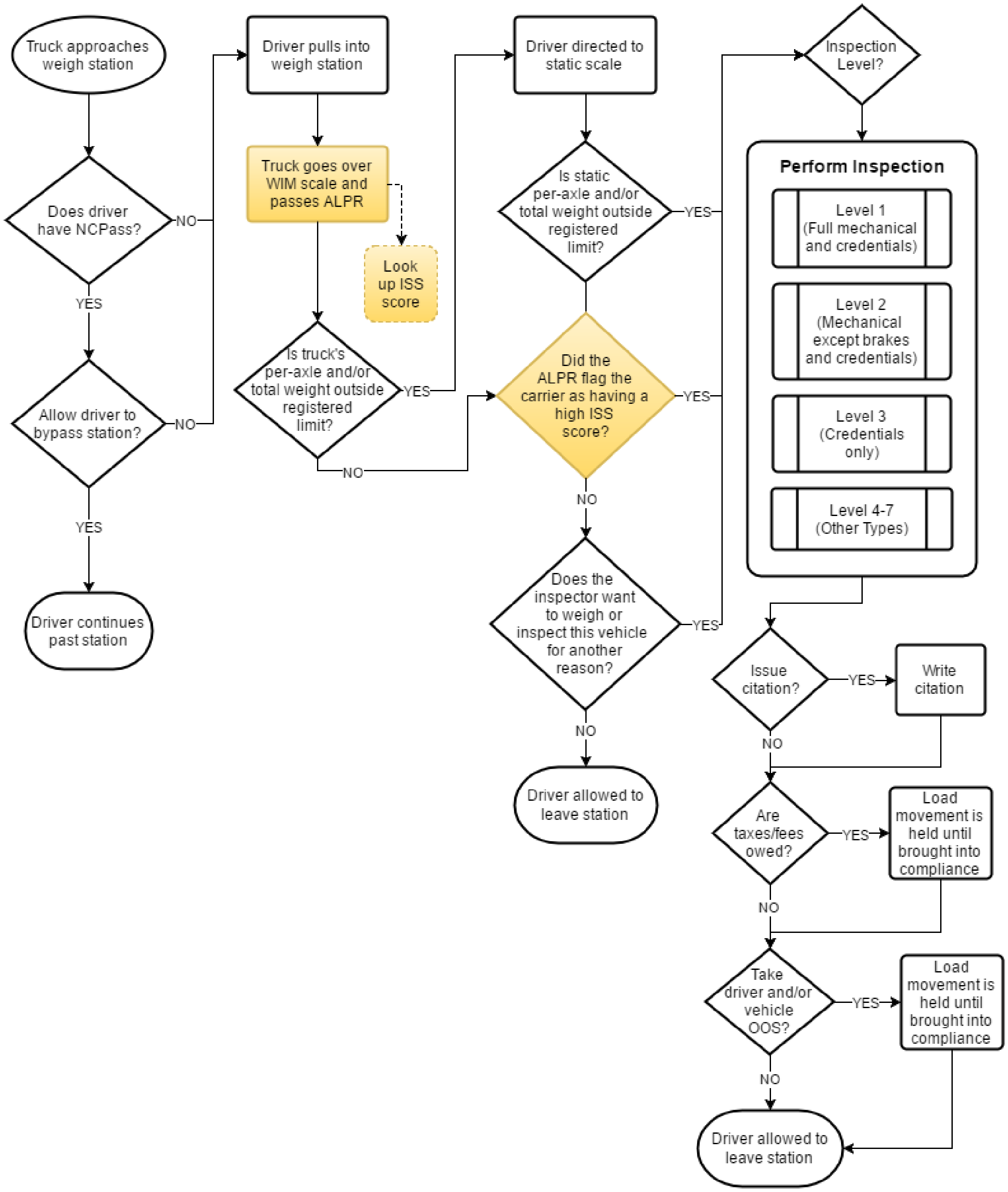


***Figure 33. Mt. Airy, NC - Post-Deployment Process Map***

*Source: Productivity Apex, Inc.*

## Data Acquired

Table 17 lists the types of data acquired, the time period included in the data, and the agency that provided that data.

**Table 17. Mt. Airy, NC - List of Data Acquired and Sources**

| Data Collected | Period | Source |
|---|---|---|
| Static Scale Daily Counts | 1/1/2013 – 12/31/2014 | NC State Highway Patrol (2013); NC State Institute for Transportation Research and Education (2014) |
| WIM Scale Daily Counts | 1/1/2014 – 12/31/2014 | NC State Institute for Transportation Research and Education |
| Annual Average Daily Traffic (AADT) | 2013 – 2014 | North Carolina DOT |
| List of all Inspections performed, including violations found and inspection level | 1/1/2013 – 4/30/2015 | NC State Highway Patrol |
| Total revenue per inspection | 1/1/2013 – 4/30/2015 | NC State Highway Patrol |
| List of vehicle crashes in the corridor | 1/8/2013 – 12/312014 | North Carolina DOT |

*Source: Productivity Apex, Inc.*

## Performance Measures and Hypothesis

Based on the previously-stated performance measures, the impact assessment team together with the USDOT COR determined the hypothesis that was tested during this study.

**Table 18. Mt. Airy, NC - Performance Measures and Hypotheses**

| Goal | Performance Measure | Hypothesis |
|---|---|---|
| Increased Productive Inspections Time | Percentage of time doing Productive Inspections | **$H_0$:** If WIM+ALPR is implemented, the time performing productive inspections will remain the same<br><br>**$H_1$:** If WIM+ALPR is implemented, the time performing productive inspections will change |

| Goal | Performance Measure | Hypothesis |
|---|---|---|
| Increased Inspection Efficiency | Average number of violations found per inspection | **$H_0$:** If WIM+ALPR is implemented, the number of violations found per inspection will remain the same<br><br>**$H_2$:** If WIM+ALPR is implemented, the number of violations found per inspection will change |
| Increased Safety | Average daily number of inspections with Driver OOS violations | **$H_0$:** If WIM+ALPR is implemented, the number of inspections with OOS driver violations will remain the same<br><br>**$H_3$:** If WIM+ALPR is implemented, the number of inspections with OOS driver violations will change |
| | Average daily number of inspections with Vehicle OOS violations | **$H_0$:** If WIM+ALPR is implemented, the number of inspection with OOS vehicle violations will remain the same<br><br>**$H_4$:** If WIM+ALPR is implemented, the number of inspection with OOS vehicle violations will change |
| | Average daily number of inspections with OOS violations | **$H_0$:** If WIM+ALPR is implemented, the number OOS violations per inspection will remain the same<br><br>**$H_5$:** If WIM+ALPR is implemented, the number OOS violations per inspection will change |
| Increased Revenue | Average Monthly Revenue | **$H_0$:** If WIM+ALPR is implemented, the monthly revenue generated through inspections will remain the same<br><br>**$H_6$:** If WIM+ALPR is implemented, the monthly revenue generated through inspections will change |

*Source: Productivity Apex, Inc.*

## Data Analysis and Results

Data was analyzed and collected to determine the differences in performance measures affected by the WIM scale and ALPR between the pre- and post- deployment periods. The pre-deployment period for the system in Mt. Airy starts January 1st, 2013 and continues through December 31th, 2013. The post-deployment period is January 1st, 2014 to April 30th, 2015.

The WIM scale with the ALPR was deployed in Mt. Airy on January 1st of 2014; hence there is a large number of inspection records available to perform a proper comparison. A two sample statistical test was performed to each of the calculated performance measures, so that it could be determined if there was a significant difference between the parameters of the two samples. A z-test was used because both samples had more than 30 records each, which allowed estimating the standard deviation of the populations, assuming a normal distribution and using a confidence level of 95%.

To better interpret the table below, a P-Value was calculated for each performance measure; if the results is less than 0.050, it can be deduced that there is a statistically significant difference between the two samples. For each of the metrics in the table, a P-Value below 0.050 simply means that there is at least a 95% level of confidence that the values for the Pre and Post-deployment periods are different.

**Table 19. Mt. Airy, NC - Data Analysis Results**

| Data Analysis Description | Analysis Results | | | |
|---|---|---|---|---|
| VIOLATIONS PER INSPECTION | Pre | Post | Change | P-Value |
| Average number of violations found per inspection | 2.139 | 2.730 | 28% | 0.000 |
| Average number of violations found per Level 1 inspection | 2.586 | 3.743 | 45% | 0.000 |
| Average number of violations found per Level 2 inspection | 2.362 | 2.645 | 12% | 0.004 |
| Average number of violations found per Level 3 inspection | 0.731 | 0.815 | 11% | 0.436 |
| Average number of out of service violations found per inspection | 0.336 | 0.468 | 39% | 0.000 |
| Average number of out of service violations found per Level 1 inspection | 0.568 | 0.762 | 34% | 0.029 |
| Average number of out of service violations found per Level 2 inspection | 0.317 | 0.416 | 31% | 0.001 |
| Average number of out of service violations found per Level 3 inspection | 0.111 | 0.117 | 6% | 0.876 |
| DAILY INSPECTIONS | Pre | Post | Change | P-Value |
| Average daily number of inspections | 5.746 | 5.930 | 3% | 0.533 |
| Average daily number of inspections with No violations | 1.537 | 1.156 | -25% | 0.004 |
| Average daily number of inspections with 1 violation | 1.500 | 1.348 | -10% | 0.194 |
| Average daily number of inspections with 2+ violations | 2.710 | 3.427 | 26% | 0.000 |
| Average daily number of Level 1 inspections with violations | 0.779 | 1.066 | 37% | 0.032 |
| Average daily number of Level 2 inspections with violations | 2.989 | 3.427 | 15% | 0.046 |
| Average daily number of Level 3 inspections with violations | 0.441 | 0.281 | -36% | 0.026 |
| Average daily number of inspections with OOS violations | 1.250 | 1.818 | 45% | 0.000 |

| Data Analysis Description | Analysis Results | | | |
|---|---|---|---|---|
| DAILY INSPECTIONS | Pre | Post | Change | P-Value |
| Average daily number of inspections with Driver OOS violations | 0.548 | 0.825 | 51% | 0.000 |
| Average daily number of inspections with Vehicle OOS violations | 0.831 | 1.219 | 47% | 0.000 |
| Average daily time performing inspections resulting in one or more violation (minutes) | 158.077 | 200.364 | 27% | 0.000 |
| INSPECTIONS WITH VIOLATIONS | Pre | Post | Change | P-Value |
| Percentage of Time Doing Productive Inspections | 79% | 86% | 7% | 0.000 |
| Proportion of inspections with No violations | 27% | 19% | -8% | 0.000 |
| Proportion of inspections with 1 violation | 26% | 23% | -3% | 0.000 |
| Proportion of inspections with 2+ violations | 47% | 58% | 11% | 0.000 |
| Proportion of inspections with violations | 73% | 81% | 8% | 0.000 |
| Proportion of Level 1 inspections with violations | 64% | 79% | 15% | 0.000 |
| Proportion of Level 2 inspections with violations | 84% | 85% | 1% | 0.440 |
| Proportion of Level 3 inspections with violations | 47% | 52% | 5% | 0.317 |
| INSPECTION TIME PER LEVEL | Pre | Post | Change | P-Value |
| Average Duration for Level 1 Inspection (minutes) | 45.9 | 50.2 | 9% | 0.009 |
| Average Duration for Level 2 Inspection (minutes) | 32.9 | 37.5 | 14% | 0.000 |
| Average Duration for Level 3 Inspection (minutes) | 26.4 | 28.4 | 8% | 0.128 |
| INSPECTION REVENUE | Pre | Post | Change | P-Value |
| Average Monthly Revenue | $ 3,625.00 | $ 5,729.38 | 58% | 0.004 |
| THROUGHPUT | Pre | Post | Change | P-Value |
| Average Monthly Throughput | 42,735.33 | 58,461.67 | 37% | 0.000 |

*Source: Productivity Apex, Inc.*

The Mt. Airy weigh station was able to provide daily values for number of inspections, number of violations, inspection duration, number of OOS violations, etc. From this data our team was able to analyze the safety and productivity improvements that the WIM and ALPR systems may have provided this site.

The figure below shows the safety improvement data broken down monthly. The vertical red line indicates the implementation of WIM and ALPR in January 2014. As shown in Table 19 above, the average number of violations and out of service violations found per inspection increased 28% and

39%, respectively, and the graph shows the monthly values increasing on average over time after initial deployment, especially OOS violations.

Figure 34 displays the monthly average number of violations per inspection. Although there is a slight increasing trend, there is still much variability in the data to visually draw any conclusions. However, the statistical test performed to both the average number of violation per inspections and out of service violations per inspection shows a statistically significant difference between the pre-deployment and post-deployment period. These averages were calculated by dividing the sum of all violations by the sum of all daily inspections given within each month. Several factors could have been responsible for the variability of this data; from the number of daily inspections completed, to the number of hours of operation. However, the large amount of data points and time length of both pre- and post-deployment periods for this site leads to think that the deployment of these technologies had a significant effect in the detection of vehicles with potential violations.

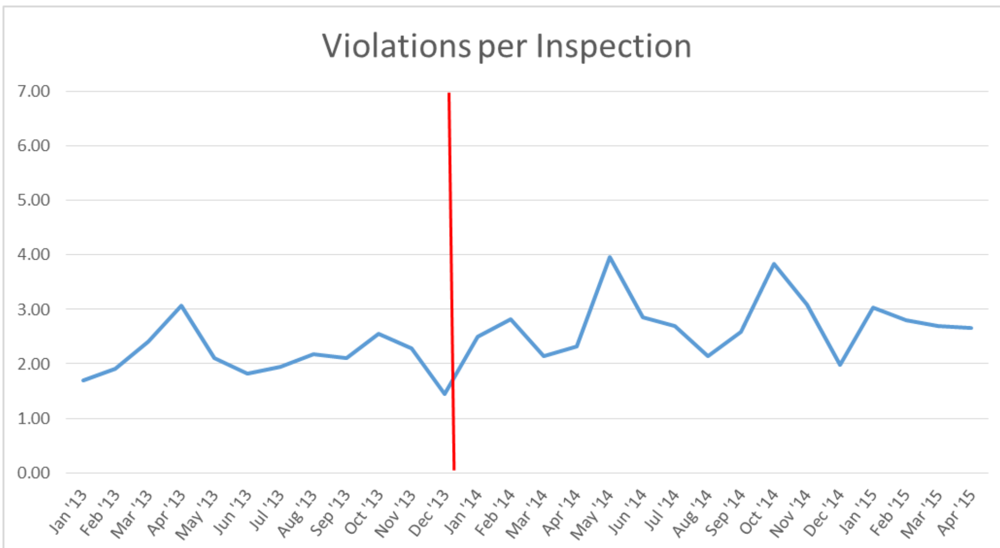


***Figure 34. Safety Improvement: Violations per Inspection***

*Source: Productivity Apex, Inc.*

Figure 35 displays the monthly average number of out of service violations. Concerning safety, this is just one of the type of violations that, although it does not occur to every vehicle and/or driver given a violation, it is affected by the same industry variables as stated above. For this specific performance measure, the average was calculated by dividing the sum of all OOS violations by the sum of all daily inspections given within each month. This chart also shows an increment in the average number of OOS violations per inspection during the post-deployment period compared to the pre-deployment period. As stated previously, given the amount of data and time length for these two periods of evaluation, this could mean that the WIM and ALPR  technologies deployed at this location had a significant impact in the detection of vehicles with potential OOS violations

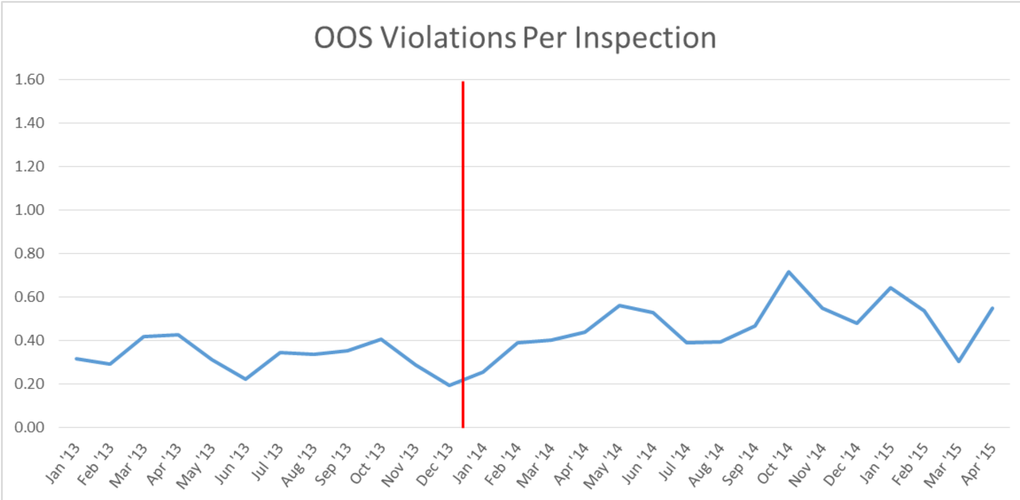


***Figure 35. Safety Improvement: OOS Violations per Inspection***

*Source: Productivity Apex, Inc.*

Figure 36 below shows the productivity improvement data broken down monthly. The vertical red line indicates the implementation of WIM and ALPR systems in January 2014. Displayed are the performance measures for the percentage of time taken to perform productive inspections (blue line) and the proportion of inspections administered where at least one violation was found (orange line). The time for productive inspections was calculated attaining the total productive inspection time over the total inspection time. The total productive inspection time was calculated by adding the time spent on any inspection that resulted in violations. Likewise, the proportion of inspections with violations resulted from the total number of inspections that resulted in at least one violation over the number of total inspections.

A slight increase can be seen for both the lines in the graph below from the moment the new systems were implemented. The average percentage of time doing productive inspections seems to be related to the number of productive inspections, so a similar behavior is noticeable. Although a lot of variability is noticeable month to month in the data, both before and after deployment; the minimun values for the pre-deployment periods range from near 65% to 72%, compared to near 75% and 80% for the proportion of productive inspections, and the percentage of productive time respectively. These could mean that although the systems might not have reduced the variability on these metrics, they may have increase their mean value, as represented in Table 19 which shows that both performance measures proportions show a statistically significant difference between the pre and post-deployment periods with P-values under 5% (0.05).

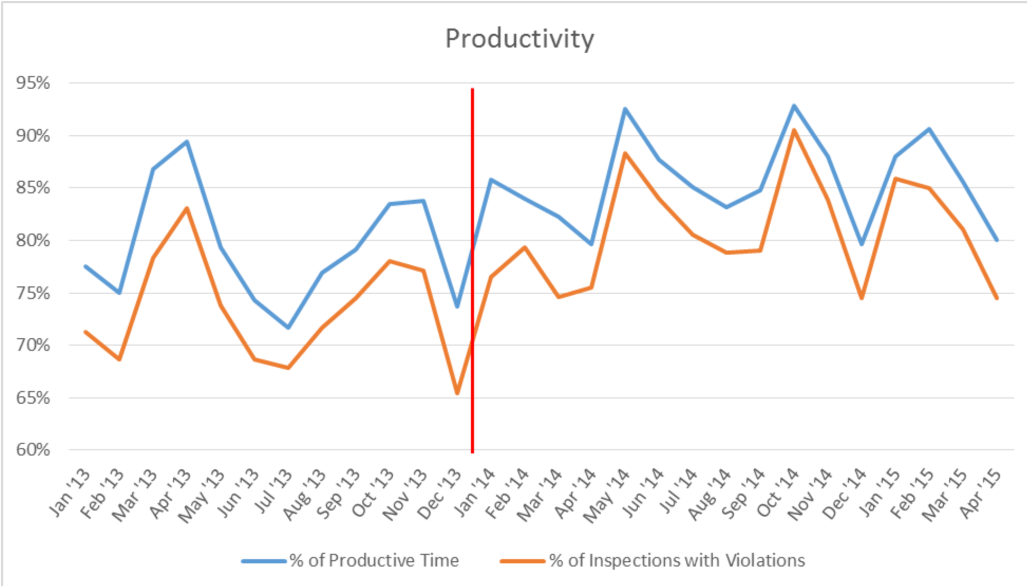


***Figure 36. Productivity Improvement***

*Source: Productivity Apex, Inc.*

Figure 37 below shows the revenue data broken down monthly. The vertical red line indicates the implementation of WIM and ALPR in January 2014. The data provided was very comprehensive containing dollar values corresponding to OOS violation fines both for drivers and vehicles and also for Haz-mat violations, broken down per inspection. These data was processed to calculate the total monthly revenue resulted from violation fines, by adding up fines due to vehicle OOS violations, driver OOS violations, and Haz-mat violations and grouping them by month.

As shown in Table 19 above, the overall average revenue per month significantly increased during the post-deployment period and the graph shows monthly values much higher since deployment. While no months before deployment exceeded $6200; after January of 2014 seven months presented revenues above that value and as high as over $9500.

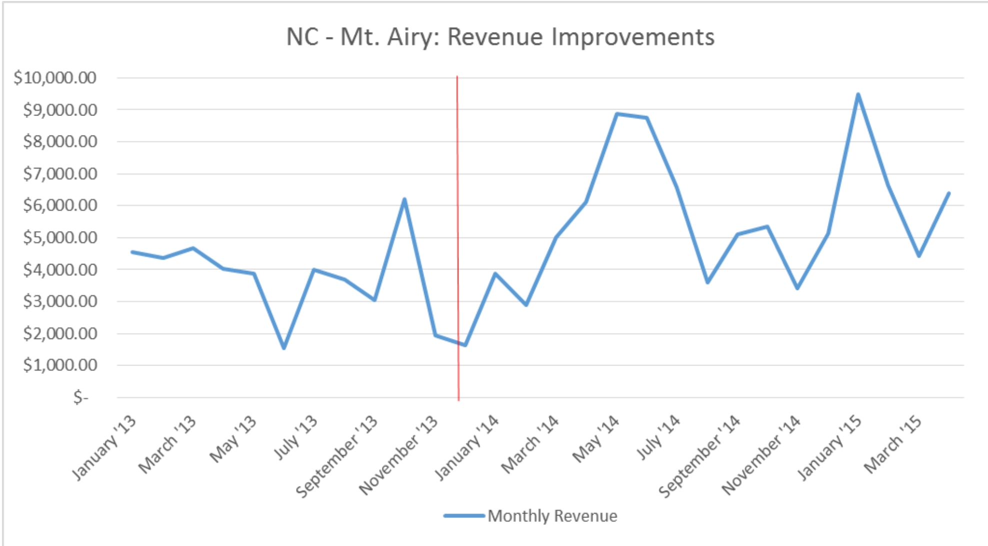


***Figure 37. Mt. Airy, NC - Monthly Revenue Data***

*Source: Production Apex, Inc.*

The next table shows the values used to prove the hypotheses that were formulated for the analysis. Parameters from Table 4 were used as the test statistic for the analysis.

**Table 20. Mt. Airy, NC - Tests of Hypothesis Results**

| Hypothesis Statement | Evaluated parameter | Pre- | Post- | P-Value | Conclusion |
|---|---|---|---|---|---|
| **$H_0$:** If WIM+ALPR is implemented, the time performing productive inspections will remain the same<br><br>**$H_1$:** If WIM+ALPR is implemented, the time performing productive inspections will change | Percentage of time doing Productive Inspections | 158.077 | 200.364 | 0.000 | Reject $H_0$ |
| **$H_0$:** If WIM+ALPR is implemented, the number of violations found per inspection will remain the same<br><br>**$H_2$:** If WIM+ALPR is implemented, the number of violations found per inspection will change | Average number of violations found per inspection | 2.139 | 2.730 | 0.000 | Reject $H_0$ |

| Hypothesis Statement | Evaluated parameter | Pre- | Post- | P-Value | Conclusion |
|---|---|---|---|---|---|
| **$H_0$:** If WIM+ALPR is implemented, the number of inspections with OOS driver violations will remain the same<br><br>**$H_3$:** If WIM+ALPR is implemented, the number of inspections with OOS driver violations will change | Average daily number of inspections with Driver OOS violations | 0.548 | 0.825 | 0.000 | Reject $H_0$ |
| **$H_0$:** If WIM+ALPR is implemented, the number of inspection with OOS vehicle violations will remain the same<br><br>**$H_4$:** If WIM+ALPR is implemented, the number of inspection with OOS vehicle violations will change | Average daily number of inspections with Vehicle OOS violations | 0.831 | 1.219 | 0.000 | Reject $H_0$ |
| **$H_0$:** If WIM+ALPR is implemented, the number OOS violations per inspection will remain the same<br><br>**$H_5$:** If WIM+ALPR is implemented, the number OOS violations per inspection will change | Average daily number of inspections with OOS violations | 1.250 | 1.818 | 0.000 | Reject $H_0$ |
| **$H_0$:** If WIM+ALPR is implemented, the monthly revenue generated through inspections will remain the same<br><br>**$H_6$:** If WIM+ALPR is implemented, the monthly revenue generated through inspections will change | Average Monthly Revenue | $3,625.00 | $5,729.38 | 0.004 | Reject $H_0$ |

*Source: Productivity Apex, Inc.*

The previous table shows that all the analyses done since the deployment of the WIM and ALPR systems indicate that there has been a significant change in the performance measures used in this study. Almost every parameter seems to have improved during the post-deployment, compared to the pre-deployment period. Although external factors could always have an effect in the operations, based on the timespan of the data provided of over a year, it is hard to attribute this improvements to seasonal fluctuations or variations in the traffic flow. Additionally, as presented in the Survey Results and Analysis section below, feedback from the site staff indicates that there has been an improvement since the deployment of the system specifically helping them identify potential violators and weight related compliance issues.

# Survey Results and Analysis

As stated in the methodology, two surveys were developed to address the perceived impact of these systems on the daily operations of its users. The first survey was addressed to motor carriers; they were to communicate their experience with the stated systems and any impacts on daily operations. Although this survey was distributed and responses were collected, there was not sufficient information to represent the true impact of these technologies on the tested sites or, more importantly, on the motor carrier population.

The second survey was specifically designed and addressed for the enforcement agents and staff working at the weigh stations, to provide their feedback on the use of these systems and on how it has affected their vehicle selection process. The results of this survey are displayed into two groups; group A represents the Yes/No questions being responded and group B represents questions answered on a scale from improvement to non-improvement. This survey received ample responses representative of this population of stakeholders, conclusions were drawn from the results found and are presented below.

## Smart Roadside Initiative (SRI) Commercial Vehicle Enforcement Perception Survey

This survey was developed to capture feedback from operators of the assessed systems on their daily operations and on the effect that these have had in the corridor. The survey was developed using an online service called Survey Monkey; this allowed the impact assessment team to distribute the surveys across the different sites in the study. The survey was divided in four sections, one for each state specifically addressing the system implemented on that site. All surveys were anonymous and no personal information was collected from any of the respondents of the survey. Respondents were presented an introductory section describing the purpose and structure of the survey; they would then select their corresponding State and the survey structure automatically directed responders to the appropriate section corresponding to their selected site. Overall, the survey was well received by the enforcement community with fifty-two total responses received from weigh station inspectors and officers in the four states. A detailed breakdown of all survey responses is listed below in Table 21, as well as, the summary results and analysis for each site.

**Table 21. Survey Count by State**

| State | Number of Respondents |
|---|---|
| Kentucky | 19 |
| Maryland | 7 |
| Michigan | 13 |
| North Carolina | 13 |

*Source: Productivity Apex, Inc.; data from Survey Monkey*

### *Kentucky*

Table 22 shows that almost all respondents in Kentucky have used KATS to support commercial vehicle inspections. However, few of them believed that it affected driver behavior or attitude. Those that thought it had an impact said that drivers are more aware that they are checked every time they enter the station, which makes them more “cautious” and more likely to have what they need. Those that said it did not have an impact noted that most drivers have never heard of KATS, so they couldn’t change behavior because of it.

**Table 22. Survey Results - Kentucky A**

| Question | Yes | No |
|---|---|---|
| Have you used KATS to perform commercial vehicle inspections? | 95% | 5% |
| Have you noticed a change in driver behavior during inspections? | 16% | 82% |
| Do you think KATS has changed drivers’ attitudes toward inspections? | 26% | 74% |

*Source: Productivity Apex, Inc.; data from Survey Monkey*

Table 23 shows summary results of the qualitative questions. 100% of respondents believed that KATS improved their ability to identify violations. Nearly all respondents said that the type of violation most improved by KATS was credential-related, including suspended license, delinquent taxes, Federal out of service, KYU, UCR, IFTA, and KIT.

When questioned regarding the impact of KATS on safety, the majority responded that there was either improvement or no change. Many respondents acknowledged that although this system may be geared toward improved compliance with required fees and payments, a large number of vehicles that are stopped for paperwork issues are also ones with safety violations after inspection. Those that didn’t see a benefit believe that there are still some drivers and/or companies that are unaware of the existence of KATS and therefore are not changing their behavior. In addition, knowledge of this roadside system gives the opportunity for companies and/or drivers to correct and be prepared for any problems that may hinder their inspection.

**Table 23. Survey Results - Kentucky B**

| Question | Improved | No Change | Worse | Don’t Know |
|---|---|---|---|---|
| How has KATS changed your ability to identify commercial vehicle violations | 100% | 0% | 0% | 0% |
| How has KATS impacted the safety of individual truck drivers? | 47% | 32% | 0% | 21% |
| How has KATS impacted the safety conditions in this corridor? | 58% | 32% | 0% | 10% |

*Source: Productivity Apex, Inc.; data from Survey Monkey*

***Maryland***

Table 24 shows that about half of respondents in Maryland have used the SRI Prototype to support commercial vehicle inspections. However, few of them believed that it affected driver behavior or attitude. Those that thought it had an impact said that it helps identify carriers with poor safety scores. Those that said it did not have an impact noted that drivers had never heard of SRI Dashboard, so they couldn't change behavior because of it, and that it wasn't deployed long enough to form an opinion.

**Table 24. Survey Results - Maryland A**

| Question | Yes | No |
|---|---|---|
| Have you used SRI Dashboard to perform commercial vehicle inspections? | 57% | 43% |
| Have you noticed a change in driver behavior during inspections? | 0% | 100% |
| Do you think SRI Dashboard has changed drivers' attitudes toward inspections? | 14% | 86% |

*Source: Productivity Apex, Inc.; data from Survey Monkey*

Table 25 shows summary results of the qualitative questions. Less than half of respondents believed that SRI Prototype improved their ability to identify violations. A large volume of respondents were either unaware of the system or have not utilized it; this rationalizes the responses that were given throughout this survey. Those that have used the dashboard thought it helped in identifying a high ISS score and displaying if there is an active USDOT number. It also serves in detecting overweight and vehicle maintenance violations. The most significant impact on safety from the use of this dashboard is encouragement of drivers and/or companies to stay in compliance with the system; that way they have the eligibility for potential bypass. There was a concern about the impact the SRI Dashboard would have on safety in this corridor; this is mostly due to the uncertainty of trucks that are given bypass status that should be routinely inspected. Although the results from this survey are to be looked upon further, the deployment of this device has not reached enough drivers in this area for a significant impact or a true evaluation of its usability.

**Table 25. Survey Results - Maryland B**

| Question | Improved | No Change | Worse | Don't Know |
|---|---|---|---|---|
| How has SRI Dashboard changed your ability to identify commercial vehicle violations | 43% | 43% | 0% | 14% |
| How has SRI Dashboard impacted the safety of individual truck drivers? | 29% | 0% | 0% | 71% |
| How has SRI Dashboard impacted the safety conditions in this corridor? | 0% | 29% | 14% | 57% |

*Source: Productivity Apex, Inc.; data from Survey Monkey*

***Michigan***

Table 26 shows that about half of respondents in Michigan have used the SRI Dashboard to support commercial vehicle inspections. However, most of them believed that it had no effect on driver behavior or attitude. Those that thought it had an impact said that drivers like the focus on companies that are more likely to have violations and they are personally concerned about their safety scores. Respondents did not state reasons why it did not have impacts on behavior, but their reasons can be inferred from their responses to other questions, which are discussed below.

**Table 26. Survey Results - Michigan A**

| Question | Yes | No |
|---|---|---|
| Have you used SRI Dashboard to perform commercial vehicle inspections? | 46% | 54% |
| Have you noticed a change in driver behavior during inspections? | 15% | 85% |
| Do you think SRI Dashboard has changed drivers' attitudes toward inspections? | 31% | 69% |

*Source: Productivity Apex, Inc.; data from Survey Monkey*

Table 27 shows summary results of the qualitative questions. Most respondents believed that the SRI Dashboard did not change their ability to identify violations or did not know the effect. This hesitance from respondents toward a sense of improvement comes from the inexperience they have with the system. The majority of responses clarified that they had either not heard of the system or had not used it. In addition, those with minimal exposure to the system were concerned with the possibility of allowing vehicles that might have serious mechanical problems to bypass the station. They also expressed that it became difficult to identify the vehicle being flagged by the system in such a high volume area. This is where most of the “no change” or “don’t know” answers came from. On the contrary, inspectors that were familiar and had used the system conveyed that the system assists in better tracking of carriers with equipment issues and violations like UCR, Fuel Tax, registration and overweight vehicles.

The knowledge of this system has impacted drivers in the increased concern with enforcement tools and how they may affect their CSA scores. This is also a tool that drivers prefer for its focus on companies that are more likely to have violations. Regardless of its limited deployment, the concept of the SRI Prototype has been accepted by those that have indeed used it, but could use some adjustments to meet the needs of specific areas.

**Table 27. Survey Results - Michigan B**

| Question | Improved | No Change | Worse | Don't Know |
|---|---|---|---|---|
| How has SRI Dashboard changed your ability to identify commercial vehicle violations | 23% | 31% | 0% | 46% |
| How has SRI Dashboard impacted the safety of individual truck drivers? | 31% | 15% | 0% | 54% |
| How has SRI Dashboard impacted the safety conditions in this corridor? | 31% | 31% | 0% | 38% |

*Source: Productivity Apex, Inc.; data from Survey Monkey*

***North Carolina***

Table 28 shows that about half of respondents in North Carolina have used the ALPR to support commercial vehicle inspections. Only about a quarter believed that it affected driver behavior and nearly 40% thought it improved drivers' attitudes towards inspection. Those that thought it had an impact said that they are able to pull over carriers with poor safety scores, and because drivers are more aware that they are checked every time they enter the station, they are able to correct violations, in addition to saving them time if they have a good score. Some that said it did not have an impact noted that they hadn't used the system.

**Table 28. Survey Results - North Carolina A**

| Question | Yes | No |
|---|---|---|
| Have you used the ALPR to perform commercial vehicle inspections? | 54% | 46% |
| Have you noticed a change in driver behavior during inspections? | 23% | 77% |
| Do you think the ALPR has changed drivers' attitudes toward inspections? | 38% | 62% |

*Source: Productivity Apex, Inc.; data from Survey Monkey*

Table 29 shows summary results of the qualitative questions. Over half of respondents believed that the ALPR improved their ability to identify violations. From their experience, the system pulls in units with bad safety ratings and targets trucks/companies that really need to be inspected. Using the SafetyNet score to determine inspections has helped stop carriers that are operating under Federal Out of Service order. Although there is concern with an inconsistency in the effectiveness of the ALPR, it has allowed for trucks that are over the required weight to be pulled in for inspection. As a result of the specific selection requirements above, there has been very little time waiting in line. Respondents have experienced that there is no traffic back up onto the interstate and the crashes normally occurring on I-77 and US 52 have minimized since the implementation of the ALPR device.

From the multiple selection responses there has been mixed responses about the impact of ALPR on safety, but from individual's written responses we see a sense of improvement. The cause of this can be accounted to the system being installed only on the southbound side and out of state companies being unaware of this system. Albeit, the drivers specifically impacted are those that own their own trucks, on account of being stopped for their company's poor safety rating. Furthermore, drivers and companies are more likely to follow regulations to avoid being stopped for inspections. Those that have been unaffected have either not had access to the tool or are focused strictly on weight enforcement.

**Table 29. Survey Results - North Carolina B**

| Question | Improved | No Change | Worse | Don't Know |
|---|---|---|---|---|
| How has the ALPR changed your ability to identify commercial vehicle violations | 69% | 8% | 0% | 23% |
| How has the ALPR impacted the safety of individual truck drivers? | 54% | 8% | 0% | 38% |
| How has the ALPR impacted the safety conditions in this corridor? | 54% | 15% | 0% | 31% |

*Source: Productivity Apex, Inc.; data from Survey Monkey*

# Simulation Modeling and Analysis

Simulation modeling is a widely used tool for analysis of probabilistic systems that cannot be modeled easily by other mathematical and statistical methods. It has successfully been applied to a variety of domains such as manufacturing, transportation, business, government, ecology and environment, society and behavior, and bio-systems. The popularity of simulation is due to its ability to model complex systems to the desired level of detail, its cost-effectiveness when compared to experimenting with the actual system to test a wide array of systems configurations, and its ability to account for both randomness and dynamic interaction over time. Furthermore, simulation provides a more intuitive solution process when compared to numerical methods since the process used to solve the problem is similar to the operation of the system.

The main purpose of this project is to conduct a comprehensive independent assessment of the impact of SRI-like applications on the performance of weigh stations using data from before and after deployments. Given that the deployment of the SRI prototype application was limited to only two sites, the simulation model provided the opportunity to expand this assessment and analyze the impact of implementing the technology on any of the different studied sites, taking into consideration the different environment configurations. Furthermore, it allowed performing this analysis without the disruption of weigh station operations. The sections that follow will describe the details of the approach taken and provide an analysis of the results obtained from the simulation scenarios.

## Simulation Methodology

In order to build a valid simulation model of the weigh stations to serve as an aid in the assessment for the SRI technologies, the team began by studying and capturing the current weigh station operations without SRI technologies and future operations with SRI technologies and documented the processes. Data and information from quantitative data sources (e.g., databases, information systems) and qualitative sources (e.g., subject matter experts' input on work flows, processes, and policies) were collected. A simulation model was then built based on the "Before" and "After" flows and acquired data. Once the model was validated, various scenarios related to truck flows, technology configuration, operating hours, inspectors and staff scheduling were tested and results were analyzed.

Figure 38 shows the technical approach and specific tasks that were executed according to the simulation methodology. Each task has clearly defined objectives and deliverables that collectively produce a valid simulation model of the weigh stations and the technologies included in this study.

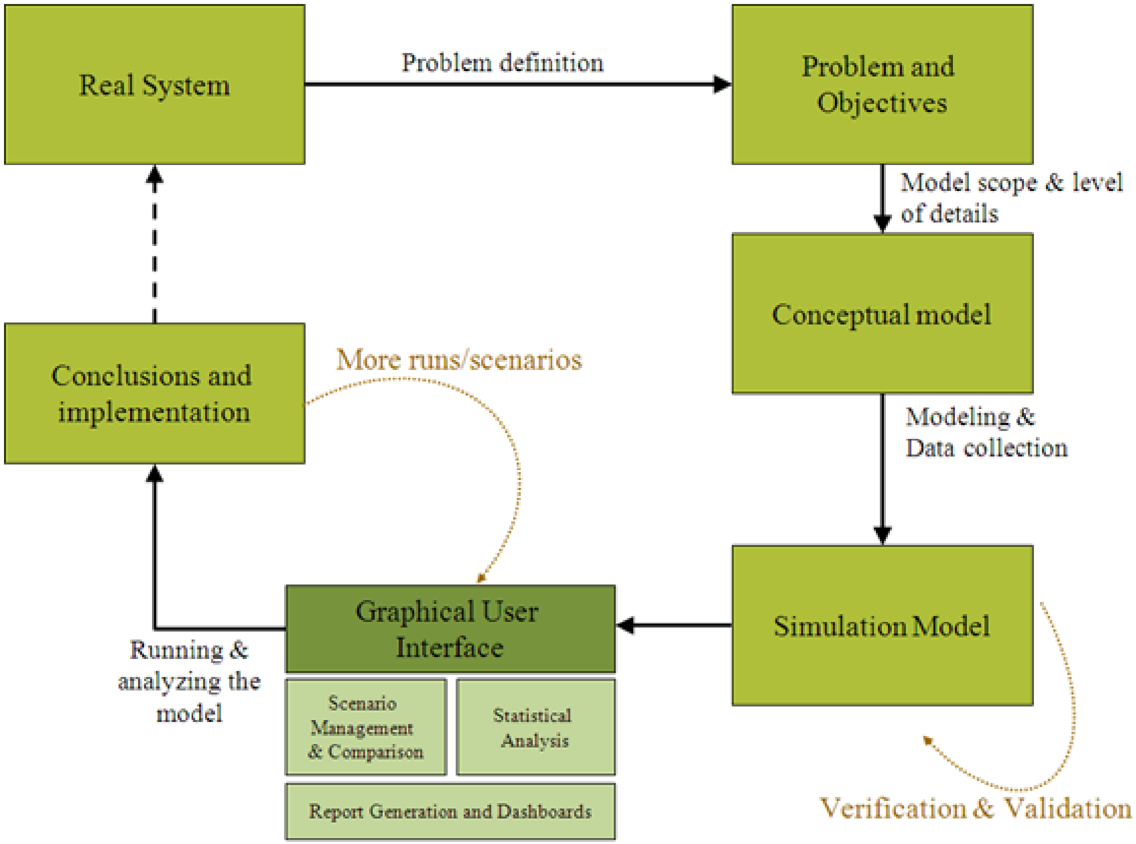


***Figure 38. Simulation Methodology***

*Source: Productivity Apex, Inc.*

# Problems and Objective

As previously mentioned, one of the difficulties in performing the impact assessment of the SRI prototype was the limited deployment that this had during implementation. However, in pursue of capturing the impact that smart roadside technologies may have over weigh station operations and corridors, a simulation model can be designed to assess these circumstances. Some of the most important factors that need to be studied are the ways that the deployment of these systems would impact the weigh station operations, in terms of the number of vehicles that would enter the station or by-pass it based on the probability of a vehicle having a potential violation; as well as how the variation in the adoption of the technology by the user would play a role both in the operations and the corridor.

Hence, the following two main objectives were formulated for the development of this simulation model:

1. To measure and compare the impact of deploying mainline and in-ramp technologies at a weigh station

2. To analyze the effect of technology adoption by the user

# Conceptual Model Development

The conceptual model defines the process flow, interactions, dependencies, and the rules in a simulation format. In this study the conceptual model was created by:

- Defining the entities that will flow through the system
- Defining the basic flow patterns of entities through the stations in the flow diagrams
- Developing flow charts to show the routing logic for flexible paths
- Calculating the probability of having a specific type of violation based on historical data
- Identifying cause and effect relationships for the flow of entities within the decision pathways of the vehicle screening process

The conceptual model was developed through discussions with several experts, including inspectors, state police, and operation managers. Once the flow was captured it was drawn on a whiteboard for further, refinement, and validation and the final version was captured in Microsoft Visio (Figure 39). This figure represents a generalized flow chart of a weigh station. The model was used as the foundation for the simulation modules and logic.

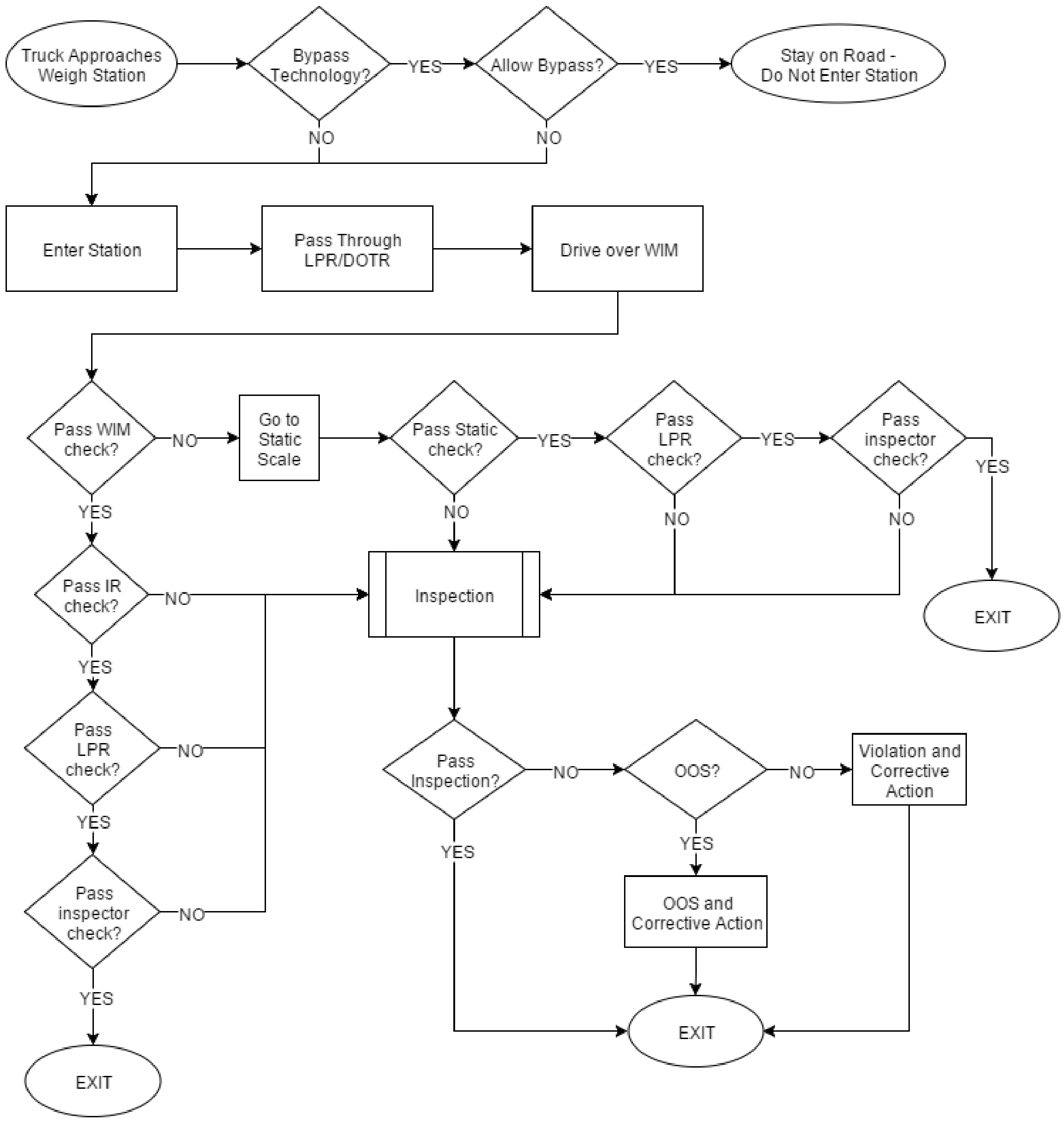


***Figure 39. Conceptual Model***

*Source: Productivity Apex, Inc.*

# Simulation Model Development

A simulation model was developed based on the above conceptual model and data captured to serve as a predictive decision support tool for experimenting with various technology deployments and weigh station configurations. This model captures the interaction among processes, resources, and technologies and provides an effective mechanism for understating the behavior of the system over the model run time. The model was built using Arena® Simulation Engine, developed by Rockwell Automation. The Arena software was selected because of its flexibility to model complex systems, its sound statistical foundation, and its ability to easily integrate with databases and spreadsheets. A detailed description of the model entities, processes, resources, etc. are provided in the following sections.

## Truck Entities

Each entity in the model is a commercial vehicle. The entities are created using a random exponential distribution; which mimics the variation of traffic flows over the course of an operating shift. The mean for the distribution is derived from the amount of traffic through the weigh station and corridor during operating hours at a particular location in a state. For example, the mean of the exponential distribution for the amount of traffic on the northbound corridor of the Interstate I-65 in Kentucky between 8:00am and 4:00pm is approximately 2,768 vehicles. Accordingly, the truck entities are also created having a random number of violations derived from the distribution of the inspection data from a weigh station in a particular location. The value of these parameters along with other pertinent data determines the process that a generated truck entity goes through in the model.

## Analysis of Violations

In order to create truck entities with violations in the model, the project team performed a detailed analysis on data provided by the Kentucky State Police. It is important to note that there are no records of trucks that had violations but were never pulled for inspection; these are trucks that simply bypassed the station or exited the ramp without being subjected to any inspection, even though, in fact they could have had one or more violations.

The large dataset of inspections' records provided by Kentucky State Police consisted of two years of inspection records including all inspections that resulted in violations. The set contained more than 23,000 records between the months of October 2013 and November 2015 for the entire state of Kentucky.

The objective of the analysis was to determine the probability of a truck having a certain type of violation. In order to analyze such a large set of records the team divided the violations into four categories, based on the way the violation could be detected. The four categories were:

1. **Violations that could be detected only through visual inspection:** These included any internal and external issues that could only be detected by the eye, like missing windshield wiper, broken or failing tail lights or headlights, dashboard check light indicators, etc.

2. **Violations that could be detected through a Weight Scale or Weigh in Motion (WIM) system:** These included violations for excessive weight for axle group, tandem axles, gross weight, etc.

3. **Violations that could be detected using an Infrared camera system:** These mainly included violations related to inoperable/defective brakes, and flat tires.

4. **Violations that can be detected using compliance screening system:** These credential-related violations included expired licenses, failure to file taxes, failure to pay fees, operating without appropriate permits or license, state vehicle registration violations, etc.

The assessment team used the provided federal violation code to classify and cluster the types of violations within the four categories described above. The categories were specifically determined based on the type of technologies that were analyzed within this study. However, the data provided did not allow the team to establish dependencies between the different categories of violations, for example the probability of finding a credential-related violation if the vehicle has a weight violation. Hence, for the purpose of this study the probabilities of violations across the categories are independent of each other. Below is a table showing the probability distribution for a single truck of having one or more violations based on the violation categories. For example, a truck entity generated in the model will have a 20.98% probability of having one violation that could be detected through a compliance screening system; at the same time a truck will have a probability of 10.02% of having two violations that could be detected through visual inspection.

**Table 30. Probability distribution of violations per truck based on the violation detection categories**

| N. of Violations Detected | Compliance Screening System | Infrared Camera System | Weight Scale or Weigh in Motion System | Visual Inspection |
|---|---|---|---|---|
| **0** | 74.24% | 76.68% | 95.55% | 59.17% |
| **1** | 20.98% | 17.45% | 4.22% | 20.75% |
| **2** | 3.90% | 3.97% | 0.21% | 10.02% |
| **3 or more** | 0.88% | 1.90% | 0.03% | 9.87% |

*Source: Productivity Apex, Inc.*

## Detection System's Logic

### *By-Pass System*

In the simulation model, the By-Pass system works as a compliance screening system located in the mainline that will pull trucks that have adopted this technology, if violations are found or if selected randomly; and would allow trucks to bypass the ramp and continue on the main road if no violations are found or if they are not selected randomly for inspection. This technology was modeled taking into consideration an accuracy level for detecting violations, as well as a random pull factor that will send compliant trucks for inspection based on a percentage defined by the modeler. This random pull factor is present in these systems in real life, and can be adjusted at any time by the inspectors. For example, a 25% random pull configuration would pull for inspection 25% of the trucks that are not found to have violations, providing an extra layer of verification for enforcement officials.

### *WIM Scale*

There are two WIM scales modeled in the simulation model. The first one is present before the truck entity passes through the Bypass system, and is the first technology or verification layer the truck encounters in the entire model. The WIM scale would check for weight related violations, as per the categories stated above, and will send a truck directly to the static scale if at least one weight related violation is found. The second WIM scale is present inside the ramp in the simulation model, and will also send trucks to the static scale if any weight related violation is detected. The reason for modeling the two WIM scales in-ramp and mainline is to have a generic model capable of running multiple analyses to assess for impact.

#### *Infrared Camera*

The infrared camera, also known as the red eye, was modeled based on the data collected from the Simpson Station in Kentucky. This technology checks for the presence of any violation that could be detected through an infrared camera every time a truck entity enters the weigh station ramp and drives passed this system. It is located on the weigh station ramp and it sends a truck to inspection if a violation is detected; otherwise, it would allow the truck to continue through the remaining technologies and exit the station.

#### *Static Scale*

The static scale is located in the weigh station and all trucks that are detected to have potential violations from any of the WIM systems are redirected there. This system checks for any weight related violation in the truck, and if a violation is found then the truck is also sent to be inspected by an officer; if no violation is found, the truck most likely will exit the ramp without violation and without being inspected after successfully passing through any additional technology.

#### *Compliance Screening*

All truck entities pass through this system when they enter the ramp. The compliance screening system plays the role of a License Plate Reader (LPR) with Optical Character Recognition (OCR) technology and a USDOT Number Reader with OCR. Generally, these technologies consist of cameras with OCR technology and are integrated with federal and local databases like SAFER, CVIEW, and PRISM for the search of records. For the purpose of this simulation model, the compliance screening system takes the roles of the Kentucky Automated Truck Screening system and the License Plate Reader in North Carolina. Just as in the previous detection systems, trucks that go through this system are checked for any violations that could be detected by a compliance screening system; and if a violation is found, they are redirected for inspection. If no violation is found the truck entity continues its flow and ultimately exits the station if no other violations are detected by the other system.

An accuracy level module was included on every detection system in the model, so modelers could select the desire level of accuracy for the specific technology before running a scenario. This accuracy level module can be populated with percentage values ranging from 0 to 100 percent, and those values determine the percentages of non-compliant entities that the technology would detect. For example, if the accuracy level for a technology is set to 60%, only 60% of the non-compliant entities (trucks having violations) that pass through that technology will be detected and sent for inspection; 40% of those non-compliant entities will pass through the technology as if they didn't have a violation and will not be sent for inspection and continue their way. However, for the purpose of this study, trucks that do not have violations would not be sent for inspection regardless of the system's accuracy level.

## Inspectors

Inspectors are the last layer for verification. As trucks move on the ramp and after passing through every technology, the inspector in the model has the last decision to pull a truck for inspection. As entities flow through the inspector section in the model, they are checked for potential violations that could be visually detected. If a potential violation is detected, the truck is redirected to the inspection area for a more detailed assessment. The model also allows for flexibility in considering inspector discretion as the user can select the percentage of trucks that would be pulled for inspection when no violations are detected. For example, if a value of 10% is set for inspector discretion that means that 1 out of 10 trucks that were not found to have violations would be pulled for inspection by the inspectors. This is a measure taken on occasion by the inspector depending on the different detection systems available at the site. This capability was incorporated into the simulation model to ensure the availability of a generic model for analysis.

## Inspections

After a truck entity is detected to have a potential violation from any of the detection systems in the model, there is a decision module that determines the inspection level that would be performed on that truck based on the results from the detection systems. This decision module is populated with a discrete probability distribution that was calculated using the same dataset containing all inspections and their results in Kentucky between October 2013 and November 2015. The dataset not only contained the specifics of violations found after performing the inspections, it also contained the inspection levels that led to finding those violations. With this information the project team calculated the number of violations, per violation category that were found on each inspection level. For example, 72% of the trucks that are pulled for inspection from a compliance screening system would be performed a Level 1 inspection. Table 31 below shows this probability distribution.

**Table 31. Percentage of performed inspection levels 1, 2, and 3 based on the technology that detected a violation**

| Inspection Level to perform | Compliance Screening System | Infrared Camera System | Weight Scale or Weigh in Motion System | Visual Screening |
|---|---|---|---|---|
| **Level 1** | 72% | 84% | 72% | 57% |
| **Level 2** | 16% | 16% | 24% | 27% |
| **Level 3** | 12% | 0% | 4% | 16% |

*Source: Productivity Apex, Inc.*

Once a truck entity is redirected for inspection in the simulation model, and has a violation, it is counted as an entity containing a violation. This information is used as part of the output in the model.

# Verification and Validation

While the simulation model was being built and before performing any of the scenarios and analysis, the impact assessment team followed a structured process for model verification and validation to ensure the model behaves as intended and is an accurate representative of the real world system. The process of model verification and validation is described below.

## Model Verification

The simulation model was verified using several techniques discussed by Law and Kelton (2000), such as running the model with simplified assumptions to easily detect logical mistakes and running the model under a variety of settings to ensure that the outputs were at reasonable levels.

The conceptual models were at the same time reviewed by experts and personnel on the sites included in this study and deemed accurate. A process of visual verification was also performed by turning on system animation and tracking different entities in the model to ensure that they follow proper logic, and looking for anomalies such as large queues or unutilized resources.

## Model Validation

Once the model was verified, the next step was the validation to determine whether the computerized model was an accurate representation of the system under study. Several techniques were used to validate the simulation model. These included statistical comparison of the simulation model output against the system's outputs for a set of identical inputs. Another technique used was to test the model under extreme conditions and ensure that the output behaved as expected. Finally, the model was presented to experts who are familiar with the operations to ensure validity.

After validating the simulation model, a design of experiment was developed to run the different scenarios of interest in this study with the appropriate number of replications to estimate the effect of each factor under study.

# Simulation Analysis

Recall that the simulation model in this project was developed to:

1. Measure and compare the impact of deploying roadside and in-ramp technologies at a weigh station
2. Analyze the effect of technology adoption by the user

To meet these objectives, a design of experiment methodology was applied to develop each use case; details are described in sections below.

For each use case, the project team defined the following elements:

- *Response Variables*, which measure the effects of changes made to input variables in the scenario.
- *Factors*, which are the input or independent variables in the scenario.
- *Levels*, which are the different values or intensity settings given to a factor in the scenario.
- *Treatments*, representing the different combinations of levels of the factors involved in the scenario.

Is important to mention that for the purpose of this simulation analysis, the metrics selected to be assessed (in this case, the response variables) may differ from the performance measures used on each of the site analyses in the previous sections due to the limitations on data availability. Most of the data resulted from the previous analyses was used as input for the development of the model. Hence in this simulation analysis, the focus would be on the effects that these technologies have in the flow of trucks through the station, and how the different level of user adoption and system configurations play a role in that flow; to ultimately derive the potential environmental, operational, and safety impacts that smart roadside technologies may cause.

## Analysis Assumptions

- *The technologies are all 100% accurate*. This would help reduce the noise in the results of the model; technologies or systems inaccuracies play a major role in the variability of the output parameters.
- *There are no vehicles pulled for inspection based on inspector discretion*. This is also a measure to reduce the variability in the simulation results.
- *The following systems and technologies are active in the model: mainline WIM, In-Ramp WIM, Static Scale, Compliance Screening system in the mainline (By-Passing technology), In-Ramp compliance screening system.*
- *Compliance screening technologies both in-ramp and in the mainline would have the same capability for detecting the same type of violations:* This assumption was made after all data were collected and interviews with experts were conducted and found that there was no way of differentiating in the data the types of violations that could be captured with one or the other system. It is important to recall, that most of these systems are integrated with the same or similar databases, previously described in section Description of Commercial Vehicle Enforcement Systems of this report. Note that some of the key differences between mainline and in-ramp system lies in the speed of the vehicle at the moment of the screening; and the fact that for a mainline system the vehicle/driver is required to have some sort of On-Board technology, whether is a transponder or a mobile application, in order to follow the instructions to by-pass or not the weigh station after the screening results. However, both systems share similarities in the sense that after capturing carrier or vehicle ID credentials, they access databases like SAFER, CVIEW, PRISM, etc.; meaning that similar types of potential violations could be detected using either system.
- *Probability distribution of violations per truck is based on the analysis done on inspection data from Kentucky.* This was presented in the Analysis of Violations, in the Simulation Model Development section above.
- *There is only one inspection pit at a site for inspection level 1* as it is common for most sites to only have 1 pit. Visited sites in Kentucky and Maryland for this study had only one inspection pit.
- *The staff capacity is infinite and there are always at least one staff personnel for monitoring the systems (this person does not perform inspections)*. This assumption is made in the model because, just as in real life, as the available inspectors are seized by performing inspections, a queue starts forming, and after that queue reaches a certain size, the ramp is closed and all incoming trucks by-pass the station, until the queue reaches an acceptable level and the ramp is open again. This assumption can lead to biased outcome, both in the model and real life, in that as trucks by-pass the station for capacity issues may be considered and counted as by-passing the site due to successful compliance screening.
- *The site is in operations eight hours a day.* This is a common timeframe used by weigh station for operation.
- *The average flowrate of trucks through the weigh station per day of trucks is 2,768 trucks*. Below are the calculations used to reach this value:

- First, the Annual Average Daily Truck Traffic (AADTT) was provided by KY state officials near the Simpson site. The number was 10,645 trucks (bi-directional).
- Second, it was assumed an eight hours of operation shift with a one hour for lunch break, between the 7:00 – 16:00 hours.
- Third, the ratio of traffic flow between hours of operation (7:00 and 16:00) and 24 hours in a day was calculated with a resulting value of approximately 52%. Therefore, it was assumed 52% of all the daily traffic flows during hours of 7:00 – 16:00.
    - For this calculation, data for the last week of August for years 2014 and 2015 was used. See table below showing the percentage of daily flow:

**Table 32. Percentage of daily trucks flowing between 7:00 and 16:00 during weekdays**

| | Monday | Tuesday | Wednesday | Thursday |
|---|---|---|---|---|
| **2014** | 53% | 52% | 52% | 51% |
| **2015** | 52% | 51% | 52% | 52% |

Source Productivity Apex, Inc.

- Fourth, the ratio between North bound and South bound Flow in Simpson KY was calculated, resulting in near 50%. This means that the total truck flow is split almost equally between the north and south bounds in Kentucky.
- Finally, the Estimated Flow Parameter is: 10,645 x 50% x 52% = 2,768 trucks flow on either bound of the I-65 Interstate near the weigh station in Simpson Kentucky on weekdays between the hours of 7:00 – 16:00 .

## Use Case #1: Impact of compliance screening technologies in-ramp and mainline

In this case the project team's goal was to quantify the impact of having a compliance screening system on the mainline versus inside the weigh station on the number of vehicles that are detected for violations. The objective of this use case was to measure and compare the impact of systems like KATS or LPRs which are installed on the ramp of the weigh stations to similar compliance systems like Drivewyze, PrePass, and NCPass that offer similar capabilities to the previous system but in the mainline, allowing compliant vehicles to by-pass the station without having to break or stop to be inspected. However, it is important to note that, although these applications are most commonly seen on weigh station ramps, LPR systems with OCR technology can be used and have been used successfully in mainline applications for screening purposes.

- **Response variables:**
    - *Numbers of trucks that exit the weigh station without inspection*: These are trucks that enter the weigh station and exit without being pulled for inspection.
    - *Number of trucks that exit the weigh station with inspection and with violation*: These are the trucks that enter the weigh station and are found to have violations after being pulled for inspection.

- *Number of trucks that by-pass the weigh station*: These are the trucks that never enter the weigh station.
- **Factors:**
  - *Deployment of an In-Ramp Compliance Screening System (CS In-Ramp)*
  - *Deployment of a Mainline Compliance Screening System (CS Mainline)*
- **Levels:**
  - *ON – Where the Mainline/In-Ramp systems are operational*
  - *OFF – Where the Mainline/In-Ramp systems are not operational*
- **Treatments:**
  - *The experimental design used in this project is a $2^k$ factorial, where K is the number of factors and 2 is the number of levels. For this case, the number of factors is 2, leading to $2^2$= 4 treatments.*
- **Replications:**
  - *The number of replications used in the case was 50 per treatment. Having a large number of replications would provide a higher level of confidence in the results.*
  - *In this particular case running 50 replications for each of the treatments would provide results that are almost within a 99.8% confidence interval of the real value.*
- **Specific assumptions:**
  - *The level for technology adoption for Mainline Compliance Screening systems is set at 15%*
  - *The percentage level for random pulls for the Mainline Compliance Screening system which is equivalent to a By-Passing system is set at 25%.*

In order to have a better understanding of the different scenarios (combinations) that will be depicted in this use case, Figure 40 shows a graphical representation of all the treatments that will be analyzed in this case. This will include one scenario with no compliance screening systems, one scenario with both mainline and in-ramp screening systems, and two additional scenarios each with one of the systems. This may help on the interpretation of the tables containing the outcomes of each of the use cases.

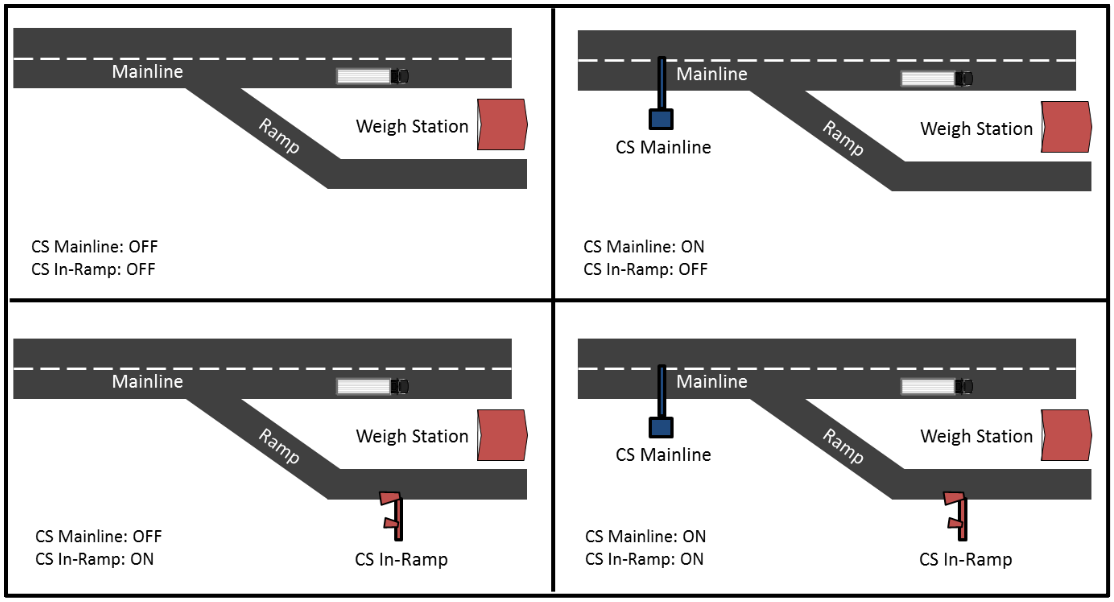


***Figure 40. Use Case #1 Graphic Representation of Weigh Station Scenarios***

*Source: Productivity Apex, Inc.*

***Use Case #1 Results***

The results of this case as shown in Table 33 show that deploying the compliance screening technologies whether on the ramp or outside the ramp has an effect on the number of vehicles that exit the station without inspection. This number decreases when any of the systems are active as evident by the Marginal Means for the two systems; both are lower when the systems are ON. However, the results also show that the impact of the mainline system is insignificant when the in-ramp compliance screening system is ON, assuming both systems have the same capability for detecting the same type of violations.

**Table 33. Use Case #1 Trucks that exit the weigh station without inspection**

| Trucks that exit the weigh station without inspection | | CS Mainline | | Marginal Mean for CS In-Ramp |
|---|---|---|---|---|
| | | OFF | ON | |
| CS In-Ramp | OFF | 2672 | 1551.96 | 2111.98 |
| | ON | 1987.96 | 1534.48 | 1761.22 |
| Marginal Mean for CS Mainline | | 2329.98 | 1543.22 | |

*Source: Productivity Apex, Inc.*

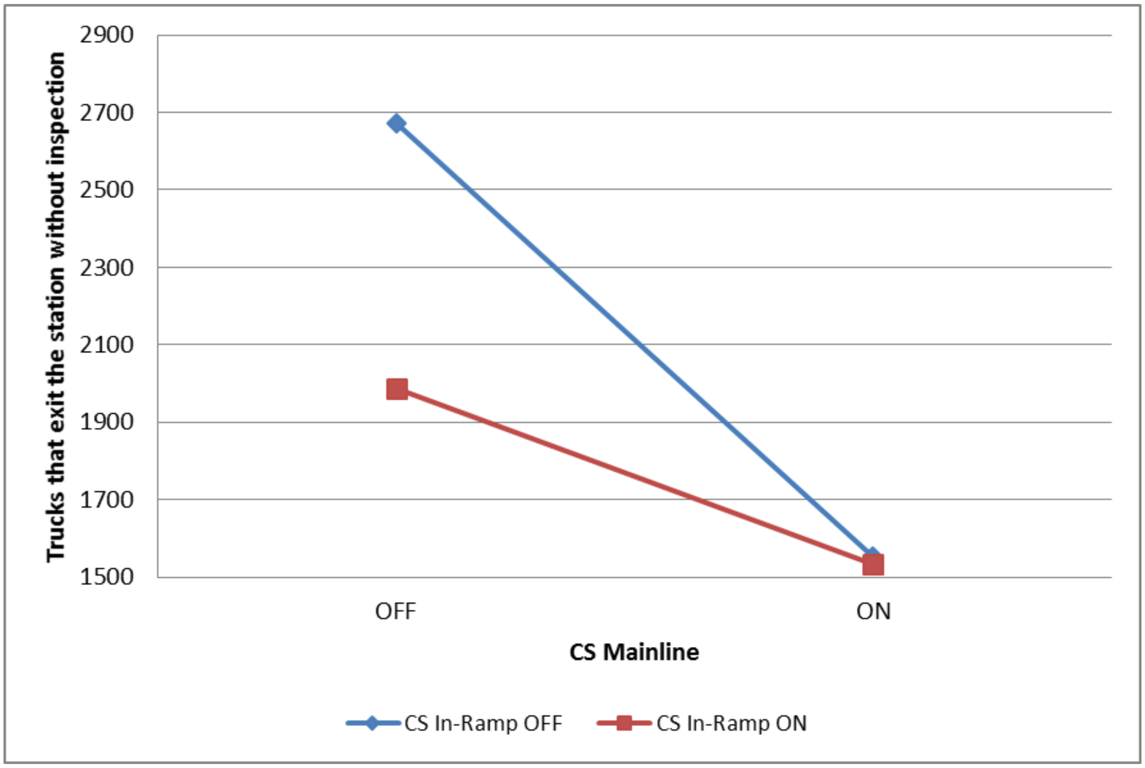


***Figure 41. Line graph of means from Table 33***

*Source: Productivity Apex, Inc.*

The results of this case also show that having an In-Ramp or mainline Compliance Screening significantly increases the number of vehicles identified with violations, as observed in Table 34 below. There is no significant difference shown between the effectiveness of the two systems because of the assumption made in the model. However, the mainline system will have additional benefits such as improved productivity of the weigh station as mostly those vehicles with violation will be sent to the station for further inspection.

**Table 34. Use Case #1 Trucks that exit the weigh station with inspection with violation**

| Trucks that exit the station with inspection with violation | | CS Mainline | | Marginal Mean for CS In-Ramp |
|---|---|---|---|---|
| | | OFF | ON | |
| CS In-Ramp | OFF | 113.24 | 745.24 | 429.24 |
| | ON | 752.46 | 739.66 | 746.06 |
| Marginal Mean for CS Mainline | | 432.85 | 742.45 | |

*Source: Productivity Apex, Inc.*

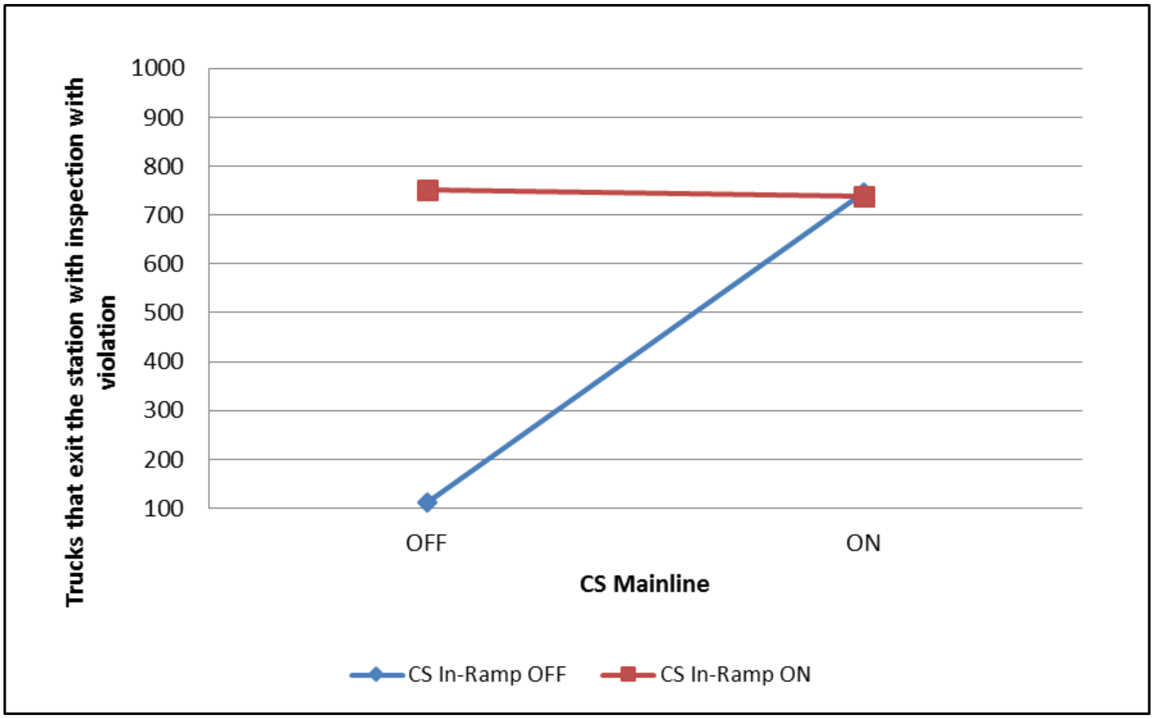


***Figure 42. Line graph of means from Table 34***

*Souce: Productivity Apex, Inc.*

Finally, results also show that the only factor that affects the number of vehicles that by-pass the weigh station is the mainline screening technology, as depicted in Table 35. Vehicles will only by-pass the weigh station if the mainline screening is active; otherwise no vehicles by-pass the weigh station.

**Table 35. Use Case #1 Trucks that by-pass the weigh station**

| Trucks that By-Pass Weigh Station | | CS Mainline | | Marginal Mean for CS In-Ramp |
|---|---|---|---|---|
| | | OFF | ON | |
| CS In-Ramp | OFF | 0 | 450.8 | 225.4 |
| | ON | 0 | 451.66 | 225.83 |
| Marginal Mean for CS Mainline | | 0 | 451.23 | |

*Source: Productivity Apex, Inc.*

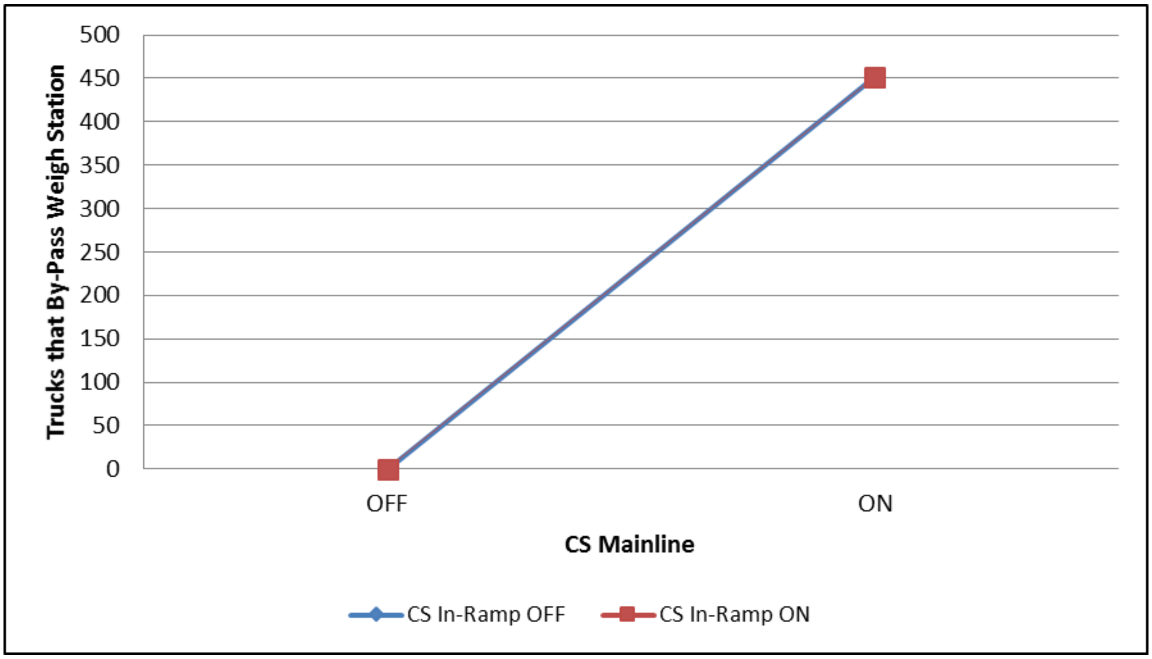


***Figure 43. Line graph of means from Table 35***

*Source: Productivity Apex, Inc.*

***Use Case #1 Findings***

The findings of this simulation show that having a Compliance Screening System in the mainline allows capturing almost the same number of violators compared to having it in-ramp; however, it helps to filter out those vehicles with lower probability of violations allowing them to bypass the station. This could increase the efficiency of the weigh station by making the inspections more productive given that there is a higher probability of finding violations on those vehicles that are sent into the weigh station when the mainline technology is active. It is also important to consider that mainline technologies, differently than in-ramp systems, allow screening vehicles at highway speed, not only minimizing delays and improving efficiencies; but also potentially reducing the environmental impact that decelerating or fully stopping commercial motor vehicles has.

## Use Case #2: Impact of technology adoption for bypassing technology and random pull levels

In this use case the project team's goal was to quantify the effect that technology adoptions made by trucking companies and random pulls would have on weigh station operations. The objective is to measure and compare the number of trucks that flow through the weigh station when changing the percentage of vehicles that have adopted bypass technology, and how is this affected at the same time by having different setup levels for truck's random pull in the system.

- **Response variables:**
  - *Numbers of trucks that exit the weigh station without inspection*
  - *Number of trucks that exit the weigh station with inspection with violation*

    - *Number of trucks that by-pass the weigh station*
- **Factors:**
    - *Percentage of population using By-Pass technology*
    - *Percentage of By-Pass Random Pulls*
- **Levels**:
    - *Percentage of population using By-Pass technology: The first level is set at 15% which was based on current observation by enforcement officials in KY and the second level was 60% which was selected assuming a scenario where wider acceptance is implemented by the trucking community. Additionally, it was found that Florida has a 60% of the population using this technology.*
    - *Percentage of By-Pass Random Pulls: The two values selected were 10% and 25%. Even though the default value in these systems is 5%, these range represented some of the most common lower and upper levels used.*
- **Treatments:**
    - *The experimental design will once again have $2^2$= 4 treatments.*
- **Replications:**
    - *The number of replications used in the case was 50 per treatment. Having a large number of replications would provide a higher confidence in the results.*
    - *In this particular case running 50 replications for each of the treatments would provide results that are almost within a 99.8% confidence interval of the real value.*
- **Specific assumptions:**
    - *There were no specific assumptions for this case other than the general assumptions made above for the analysis.*

***Use Case #2 Results***

The graph below in Figure 44 shows that both the By-Pass technology adoption level and the percentage of Random Pulls for By-Pass systems have a significant effect on the number of vehicles that exit the stations without inspection. When analyzing the Marginal Means for both factors, in Table 36, it is evident that as the by-pass adoption level increases, the number of vehicles that exit the stations without inspection is reduced leading to increased efficiency of the weigh station. However, the data shows that this number increases as the Random Pull level increases.

**Table 36. Use Case #2 Trucks that exit the weigh station without inspection**

| Trucks that exit the station without inspection | | Adoption Level 15% | Adoption Level 60% | Marginal Mean for Random Pull |
|---|---|---|---|---|
| Random Pull | 10% | 1722.44 | 860.16 | 1291.3 |
| | 25% | 1778.26 | 1087.86 | 1433.06 |
| Marginal Mean for Adoption Level | | 1750.35 | 974.01 | |

*Source: Productivity Apex, Inc.*

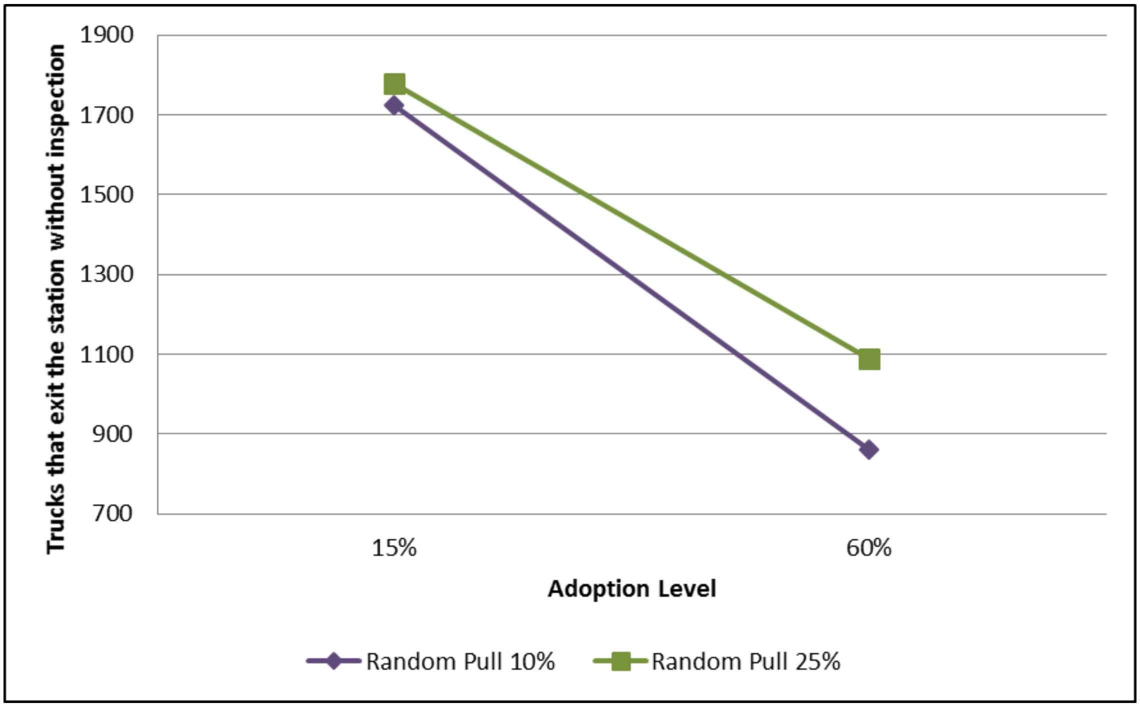


***Figure 44. Line graph of means from Table 36***

*Source: Productivity Apex, Inc.*

Results also show that both the increase in the adoption level of By-Pass technology and the percentage of random pulls have no significant effect on the number of vehicles found with violations, as it can be observed in Figure 45. Although this statement may be valid when comparing both technologies, it is also important to take into consideration the assumptions that may be playing a significant role in these results. The first assumption is that all technologies are 100% percent accurate; this means there is no possibility that the by-pass technology or mainline WIM will fail to detect a violation while a similar in-ramp technology (like the in-ramp WIM and compliance screening) detects a violation after a random pull. The second assumption is that there is no inspector discretion for pulling a vehicle for inspection; this means there is no possibility of any vehicle being randomly pulled for inspection by an inspector while passing by the ramp, hence found a violation not detected by the system. The third assumption that could be impacting these results is that the compliance screening systems, both mainline (By-Pass technology) and in-ramp (e.g.: KATZ, LPR's with OCR technology), have the same capability for detecting the same type of violations; this eliminates the possibility of a truck being detected any other violation, once randomly pulled and in the ramp, that has not been previously detected by the by-pass technology.

**Table 37. Use Case #2 Trucks that exit the weigh station with inspection with violation**

| Trucks that exit the station with inspection with violation | | Adoption Level 15% | Adoption Level 60% | Marginal Mean for Random Pull |
|---|---|---|---|---|
| Random Pull | 10% | 745.1 | 754.84 | 749.97 |
| | 25% | 751.88 | 748.68 | 750.28 |
| Marginal Mean for Adoption Level | | 748.49 | 751.76 | |

*Source: Productivity Apex, Inc.*

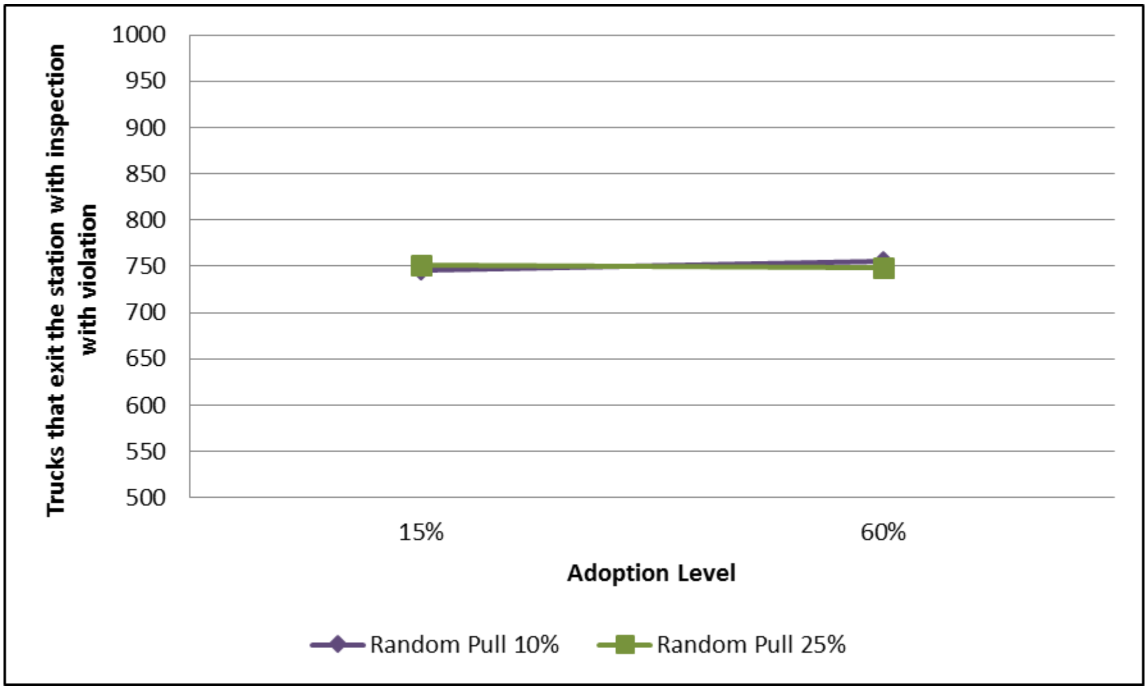


***Figure 45. Line graph of means from Table 37***

*Source: Productivity Apex, Inc.*

This final graph in Figure 46 shows that the number of vehicles bypassing the weigh station increases as the Adoption Level for the by-passing technology rises. This is evident when observing the Marginal Means for Adoption Level. However, the opposite trend can be observed for the percentage of Random Pull; the number of vehicles by-passing the station is reduced as the level of Random Pull increases, as depicted in Table 38.

**Table 38. Use Case #2 Trucks that by-pass the weigh station**

| Trucks that By-Pass Weigh Station | | Adoption Level 15% | Adoption Level 60% | Marginal Mean for Random Pull |
|---|---|---|---|---|
| Random Pull | 10% | 284.94 | 1137.44 | 711.19 |
| | 25% | 227.14 | 894.02 | 560.58 |
| Marginal Mean for Adoption Level | | 256.04 | 1015.73 | |

*Source: Productivity Apex, Inc.*

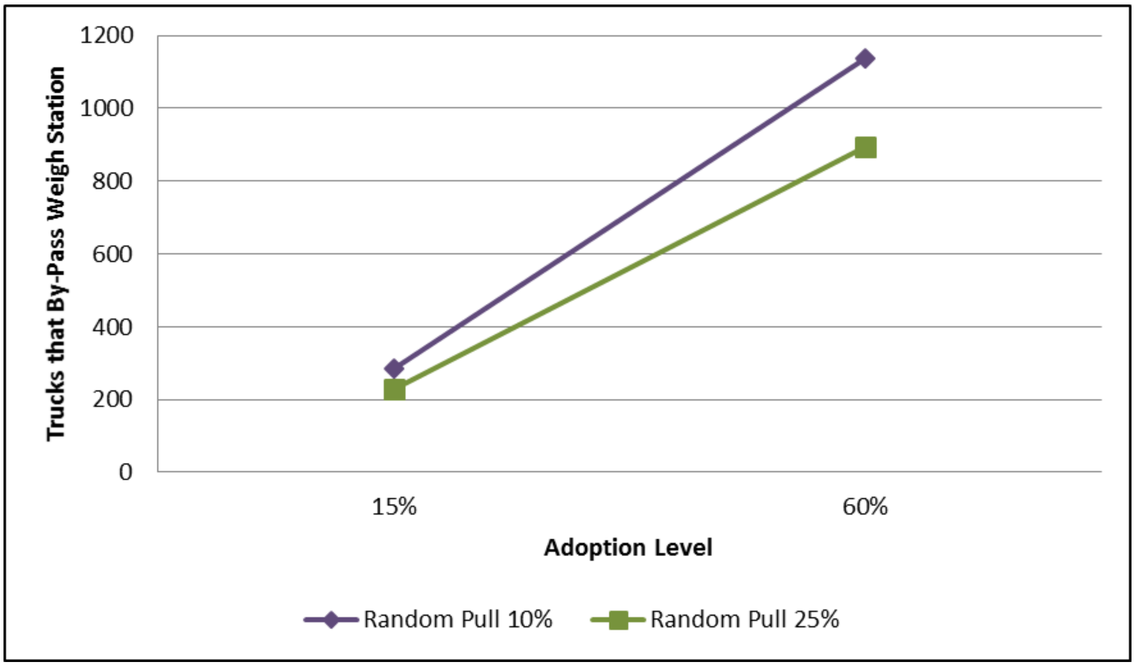


***Figure 46. Line graph of means from Table 38***

*Source: Productivity Apex, Inc.*

***Use Case #2 Findings***

The findings in this case show that the two response variables most affected by the change in the adoption level of bypassing technology and the random pull levels are the number of trucks that bypass the weigh station and the number of trucks that exit the weight station without being inspected. This makes intuitive sense given that a larger portion of the population using the system would allow for more trucks to bypass the weigh station. Also, as expected, the impact of changing the random pull levels is smaller when the adoption level of the technology is low. Additionally, it was interesting to find out that these two variables didn't have a major impact on the number of vehicles found with violations. However, it made sense when considering the assumptions for this case; in real life it is likely that there would have been some differences in this number at least when changing the levels of random pull, given that as of today pre-screening or by-pass technology are not able to detect potential violations due to mechanical or visual problems.

# Findings

The purpose of this study was to capture the potential impacts of SRI-like technologies on the safety, operational efficiency, and freight mobility in the nation's corridors. The team was able to successfully perform an impact assessment of these systems using statistical analysis, surveys, and modeling and simulation with the data provided by the five selected sites.

Some of the sites in this study showed that SRI-like technologies provided great improvements in weigh station productivity and efficiency. Lyon and Mount Airy were excellent examples of how integrated systems comprised of license plate readers and USDOT number readers with Optical Character Recognition technology installed at the weigh station' ramps, increased considerably the proportion and average number of inspections with violations. In Simpson, on the other hand, driver behavior may have played a role in the decrease of violations found per inspection. Nonetheless, enforcement personnel generally agreed that these systems have improved their ability to identify violations.

Safety and compliance are other factors significantly affected by smart roadside technologies. The analyses showed that e-screening technologies like KATS and WIM with ALPR increased the number of out of service violations detected at enforcement sites. This translates into benefits for the trucking industry by removing non-compliant and unsafe trucks from roadways, providing a much safer environment for all users of the entire transportation infrastructure. Additionally, many of the survey's respondents in this study acknowledged that although systems like these may be geared toward improving compliance with required fees and payments and enhanced record's screening, many of the vehicles stopped for paperwork issues are also found to have safety violations after inspection.

Moreover, the increased revenue observed in all sites where these technologies were deployed was unexpected, in some locations more than doubling the rate from the previous periods before the systems deployment.

The SRI Prototype also demonstrated that integration across multiple systems from different vendors is possible and could be beneficial for day-to-day commercial vehicle inspections and screening operations. One of the most common requests from enforcement personnel was to try to unify all systems into a single interface with a single credential for accessing it. They mentioned that having multiple systems disconnected from each other caused delays and confusion when performing a vehicle screening or updating carrier's records after inspections are performed.

Additionally, the SRI Prototype, albeit limited in its testing, demonstrates how DSRC technology can be used in commercial vehicle enforcement operations. Although the deployment faced challenges, mostly in the software used by both the OBU and the RSU, the technology would allow for a smoother operation, facilitating its deployment once those challenges are overcome.

The study, through the use of modeling and simulation, also showed that while the deployment of WIM sensors and automated compliance screening systems on stations' ramps may improve the flow of trucks, deploying these technologies on the mainline at highway speed would bring the highest benefits. Enforcement officials state that electronic screening systems are currently focusing mostly on carriers' records screening; however, they agree that further improvements would be achieved once other levels of screening could be deployed in the mainline. Implementations like this would bring potential environmental benefits and safety improvements, in addition to the reduction in congestion and traffic flow that it could generate.

User adoption is also an important factor in the implementation of smart roadside systems. Specifically, most of the mainline systems that exist nowadays require carriers or drivers to sign up to use the service and to carry hardware on the truck. The output of this simulation shows the importance of user adoption for mainline screening systems and how different rates in adoption increase the rate of by-passes, without negatively affecting the proportion of detected violations. Additionally, considering the assumptions made in this particular use case, for example 100% technology accuracy the simulation results indicated that using random pulling rates between 10% and 25%, although it may seem as a good solution for catching those potential violators not detected by the by-pass systems, has little effect on the number of additional violators found.

Overall, a larger scale deployment of SRI-like systems would enable a more thorough assessment of the effects on the region. However, deployments of similar systems made throughout the country have shown the benefits that technologies like these may bring to different areas.

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# APPENDIX A. Abbreviations and Acronyms

| | |
|---|---|
| **AADT** | Annual Average Daily Traffic |
| **ALPR** | Automated License Plate Reader |
| **ALTS** | Automated Licensing and Taxation System |
| **CDLIS** | Commercial Driver's License Information System |
| **CME** | Certified Medical Examiners |
| **CMV** | Commercial Motor Vehicle |
| **CS** | Compliance Screening |
| **CVE** | Commercial Vehicle Enforcement |
| **CVIEW** | Commercial Vehicle Information Exchange Window |
| **CVISN** | Commercial Vehicle Information Systems and Networks |
| **DOOS** | Driver Out of Service |
| **DOTR** | USDOT Number Reader |
| **DOT** | Department of Transportation |
| **E-TIX** | Electronic Traffic Information Exchange |
| **FHWA** | Federal Highway Administration |
| **FMCSA** | Federal Motor Carrier Safety Administration |
| **FOOS** | Federal Out of Service |
| **FUELTACS** | Fuel Tax Compliance System |
| **IFTA** | International Fuel Tax Agreement License |
| **IR** | Infrared (camera) |
| **ISS** | Inspection Selection System |
| **KATS** | Kentucky Automated Truck Screening |
| **KIT** | Kentucky Intrastate Tax License |
| **KY HIRE** | Kentucky-for-Hire Program |
| **KYU** | Kentucky Highway Use License |
| **LEIN** | Law Enforcement Information Network |
| **LPR** | License Plate Reader |
| **METERS** | Maryland Electronic Telecommunications Enforcement Resource System |
| **OCR** | Optical Character Recognition |
| **OOS** | Out of Service |

| | |
|---|---|
| **OST** | Office of the Secretary of Transportation |
| **PRISM** | Performance and Registration Information Systems Management |
| **SAFER** | Safety And Fitness Electronic Records system |
| **SRI** | Smart Roadside Initiative |
| **UCR** | Unified Carrier Registration |
| **USDOT** | United States Department of Transportation |
| **VOOS** | Vehicle Out of Service |
| **WIM** | Weigh-In-Motion |

# APPENDIX B. Inspection Standards

FMCSA's primary mission is to reduce crashes, injuries, and fatalities involving large trucks and buses on the Nation's highways. This is accomplished through a coordinated effort of Federal, State, and industry organizations to reduce fatalities, injuries, property damage and hazardous materials incidents. For this, FMCSA implements safety and compliance programs through a national network of fifty-two field offices, including the District of Columbia and Puerto Rico.

## North American Standard Inspection Levels

One of the objectives of deploying technologies in a weigh station is the ability for determining in an instant the likeliness of a truck having a specific type of violations. Each type of technology helps officers and inspectors to focus on a specific violation category, which in turn help to determine the type of inspection to perform on the vehicle or driver.

USDOT inspections are conducted in order to make sure that parts and accessories of the CMV are in good working order and/or that driver and carrier credentials are valid and up to date. There are seven levels of this safety analysis, which simply refers to the methods that will be employed during the assessment of a vehicle and/or the driver. Table 39 defines the seven inspection levels.

**Table 39. North American Standard Inspection Levels**

| Category | Name | Description |
|---|---|---|
| **Level I** | North American Standard Inspection | An inspection that includes examination of driver's license; medical examiner's certificate and Skill Performance Evaluation (SPE) Certificate (if applicable); alcohol and drugs; driver's record of duty status as required; hours of service; seat belt; vehicle inspection report(s) (if applicable); brake systems; coupling devices; exhaust systems; frames; fuel systems; lighting devices (headlamps, tail lamps, stop lamps, turn signals and lamps/flags on projecting loads); securement of cargo; steering mechanisms; suspensions; tires; van and open-top trailer bodies; wheels, rims and hubs; windshield wipers; emergency exits and/or electrical cables and systems in engine and battery compartments (buses), and HM/DG requirements as applicable. HM/DG required inspection items will be inspected by certified HM/DG inspectors. |

| Category | Name | Description |
|---|---|---|
| **Level II** | Walk-Around Driver/Vehicle Inspection | An examination that includes each of the items specified under the North American Standard Level II Walk-Around Driver/Vehicle Inspection Procedure. As a minimum, Level II inspections must include examination of: driver's license; medical examiner's certificate and Skill Performance Evaluation (SPE) Certificate (if applicable); alcohol and drugs; driver's record of duty status as required; hours of service; seat belt; vehicle inspection report(s) (if applicable); brake systems; coupling devices; exhaust systems; frames; fuel systems; lighting devices (headlamps, tail lamps, stop lamps, turn signals and lamps/flags on projecting loads); securement of cargo; steering mechanisms; suspensions; tires; van and open-top trailer bodies; wheels, rims and hubs; windshield wipers; emergency exits and/or electrical cables and systems in engine and battery compartments (buses), and HM/DG requirements as applicable. HM/DG required inspection items will be inspected by certified HM/DG inspectors. It is contemplated that the walk-around driver/vehicle inspection will include only those items, which can be inspected without physically getting under the vehicle. |
| **Level III** | Driver/Credential Inspection | An examination that includes those items specified under the North American Standard Level III Driver/Credential Inspection Procedure. As a minimum, Level III inspections must include, where required and/or applicable, examination of the driver's license; medical examiner's certificate and Skill Performance Evaluation (SPE) Certificate; driver's record of duty status; hours of service; seat belt; vehicle inspection report(s); and HM/DG requirements. Those items not indicated in the North American Standard Level III Driver/Credential Inspection Procedure shall not be included on a Level III inspection. |
| **Level IV** | Special Inspections | Inspections under this heading typically include a one-time examination of a particular item. These examinations are normally made in support of a study or to verify or refute a suspected trend. |
| **Level V** | Vehicle-Only Inspection | An inspection that includes each of the vehicle inspection items specified under the North American Standard Inspection (Level I), without a driver present, conducted at any location. |
| **Level VI** | North American Standard Inspection for Transuranic Waste and Highway Route Controlled Quantities (HRCQ) of Radioactive Material | An inspection for select radiological shipments, which include inspection procedures, enhancements to the North American Standard Level I inspection, radiological requirements, and the *North American Standard Out-of-Service Criteria for Transuranic Waste and Highway Route Controlled Quantities (HRCQ) of Radioactive Material*.<br>As of January 1, 2005, all vehicles and carriers transporting highway route controlled quantities (HRCQ) of radioactive material are regulated by the U.S. Department of Transportation and required to pass the North American Standard Level VI Inspection.<br>Previously, U.S. Department of Energy (DOE) voluntarily complied with the North American Standard Level VI Inspection Program requirements.<br>Select radiological shipments include highway route controlled quantities (HRCQ) of radioactive material as defined by Title 49 CFR Section 173.403. And, because only a small fraction of transuranic is HRCQ, DOE has decided to include its transuranic waste shipments in the North American Standard Level VI Inspection Program. |

| Category | Name | Description |
|---|---|---|
| **Level VII** | Jurisdictional Mandated Commercial Vehicle Inspection | An inspection that is a jurisdictional mandated inspection program that does not meet the requirements of any other level of inspection. An example will include inspection programs such as, but not limited to: school buses; limousines; taxis; shared ride; hotel courtesy shuttles, and other intrastate/intraprovincial operations. These inspections may be conducted by CVSA-certified inspectors, other designated government employees or jurisdiction approved contractors. Inspector training requirements shall be determined by each jurisdiction. No CVSA decal shall be issued for a Level VII inspection but a jurisdiction-specific decal may be applied. |

*Source: Retrieved from http://www.cvsa.org/programs/nas_levels.php#a1*

It is also one of the federal government's duties and objectives to preserve the Nation's infrastructure and to keep trucks and buses moving efficiently as well as ensuring the safety, productivity, and mobility of freight commerce. For this, states need to ensure that commercial motor vehicles comply with federal weight standards. The FHWA is responsible for certifying state compliance with Federal standards.

The organization in charge of overseeing the state enforcement of heavy truck and bus weight standards is The National Vehicle Size and Weight Team, which is part of the Federal Highway Administration's (FHWA's) Office of Freight Management and Operations. Staff in each of FHWA's 52 Division Offices provides one-on-one support to individual states, the District of Columbia, and Puerto Rico.

## Commercial Vehicle Weight Standards

National weight standards apply to commercial vehicle operations on the Interstate Highway System, an approximately 40,000-mile system of limited access, divided highways that spans the nation. Off the Interstate Highway System, states may set their own commercial vehicle weight standards. The United States Department of Transportation (USDOT) requires that commercial motor vehicles (CMV) with a gross vehicle weight rating of more than 10,001 pounds undergo an inspection every year.

Federal commercial vehicle maximum standards on the Interstate Highway System are:

| | |
|---|---|
| Single Axle: | 20,000 pounds |
| Tandem Axle: | 34,000 pounds |
| Gross Vehicle Weight: | 80,000 pounds |

***Bridge Formula Weights.***

The bridge formula was introduced in 1975 to reduce the risk of damage to highway bridges by requiring more axles, or a longer wheelbase, to compensate for increased vehicle weight. The formula may require a lower gross vehicle weight, depending on the number and spacing of the axles in the combination vehicle.

# APPPENDIX C. Survey Questions

## Kentucky CVE

1. Have you used the KATS system to perform commercial vehicle inspections?

2. To what degree has KATS improved your ability to identify commercial vehicle violations?
   a) Significantly Improved
   b) Slightly Improved
   c) Not Improved at all
   d) Made it worse
   e) Don't Know

3. How is this technology helping you (or not) identify vehicle violations?

4. Which types of violations specifically have become easier to detect using KATS? (You can select more than one)
   a) Overweight
   b) Unsafe Driving
   c) Hours of Service
   d) Driver Fitness
   e) Controlled Substances
   f) Vehicle Maintenance
   g) Hazardous Materials
   h) Others (Please specify)

5. To what degree has KATS has impacted the safety of individual truck drivers?
   a) Very Positively
   b) Positively
   c) No Impact
   d) Negatively
   e) Very Negatively
   f) Don't Know

6. Please explain your answer

7. To what degree do you believe KATS has impacted safety conditions in this corridor?
   a) Very Positively
   b) Positively
   c) No Impact
   d) Negatively
   e) Very Negatively
   f) Don't Know

8. Please explain your answer

9. Have you noticed a change in driver behavior during inspections after implementing KATS? (Example: Have you noticed drivers are more cautious with their trucks, logs, or the way they drive since the implementation of the technology, or any other behavior?)

a) Yes
b) No

10. If yes, how has it changed? Why do you think this has happened?

11. Do you think KATS has changed drivers' attitude towards inspections? (Example: they like this technology because it filters out complying trucks and drivers and saves them time, or they feel safer on the road, etc.?
    a) Yes
    b) No

12. If yes, how has it changed? Why do you think this has happened?

## Maryland and Michigan CVE

1. Have you used the SRI Dashboard system to perform commercial vehicle inspections?

2. To what degree has the SRI Dashboard improved your ability to identify commercial vehicle violations?
    a) Significantly Improved
    b) Slightly Improved
    c) Not Improved at all
    d) Made it worse
    e) Don't Know

3. How is this technology helping you (or not) identify vehicle violations?

4. Which types of violations specifically have become easier to detect using the SRI Dashboard? (You can select more than one)
    a) Overweight
    b) Unsafe Driving
    c) Hours of Service
    d) Driver Fitness
    e) Controlled Substances
    f) Vehicle Maintenance
    g) Hazardous Materials
    h) Others (Please specify)

5. To what degree do you believe has SRI Dashboard has impacted the safety of individual truck drivers?
    a) Very Positively
    b) Positively
    c) No Impact
    d) Negatively
    e) Very Negatively
    f) Don't Know

6. Please explain your answer

7. To what degree do you believe SRI Dashboard has impacted safety conditions in this corridor?
    a) Very Positively

b) Positively
c) No Impact
d) Negatively
e) Very Negatively
f) Don't Know

8. Please explain your answer

9. Have you noticed a change in driver behavior during inspections after implementing SRI Dashboard? (Example: Have you noticed drivers are more cautious with their trucks, logs, or the way they drive since the implementation of the technology, or any other behavior?)
   a) Yes
   b) No

10. If yes, how has it changed? Why do you think this has happened?

11. Do you think SRI Dashboard has changed drivers' attitude towards inspections? (Example: they like this technology because it filters out complying trucks and drivers and saves them time, or they feel safer on the road, etc.?
    a) Yes
    b) No

12. If yes, how has it changed? Why do you think this has happened?

## North Carolina CVE

1. Have you used the ALPR system to perform commercial vehicle inspections?

2. To what degree has the ALPR improved your ability to identify commercial vehicle violations?
   a) Significantly Improved
   b) Slightly Improved
   c) Not Improved at all
   d) Made it worse
   e) Don't Know

3. How is this technology helping you (or not) identify vehicle violations?

4. Which types of violations specifically have become easier to detect using the ALPR? (You can select more than one)
   a) Overweight
   b) Unsafe Driving
   c) Hours of Service
   d) Driver Fitness
   e) Controlled Substances
   f) Vehicle Maintenance
   g) Hazardous Materials
   h) Others (Please specify)

5. To what degree has the ALPR has impacted the safety of individual truck drivers?
   a) Very Positively
   b) Positively

   c) No Impact
   d) Negatively
   e) Very Negatively
   f) Don't Know

6. Please explain your answer

7. To what degree do you believe the ALPR has impacted safety conditions in this corridor?
   a) Very Positively
   b) Positively
   c) No Impact
   d) Negatively
   e) Very Negatively
   f) Don't Know

8. Please explain your answer

9. Have you noticed a change in driver behavior during inspections after implementing the ALPR? (Example: Have you noticed drivers are more cautious with their trucks, logs, or the way they drive since the implementation of the technology, or any other behavior?)
   a) Yes
   b) No

10. If yes, how has it changed? Why do you think this has happened?

11. Do you think the ALPR has changed drivers' attitude towards inspections? (Example: they like this technology because it filters out complying trucks and drivers and saves them time, or they feel safer on the road, etc.?
    a) Yes
    b) No

12. If yes, how has it changed? Why do you think this has happened?

## Kentucky Carriers

1. Have you heard of KATS before taking this survey?
   a) Yes
   b) No

2. Has the implementation of the Kentucky Automated Trucking Screening (KATS) had an impact on your daily operations?
   a) Yes
   b) No

3. If yes, what kind of impact has it had?

4. Has the implementation of KATS changed your or your drivers' behavior while at work? (Example: Are you more cautious with having all your truck permits in order, keep your HOS logs updated, or any other behavior?)
   a) Yes
   b) No

5. If yes, how has it changed?

6. Has KATS changed your or your drivers' attitude towards inspections? (Example: do you like this technology because it filters out complying trucks and drivers and saves you time, do you feel safer on the road, or any reason why perhaps you would not like it?
   a) Yes
   b) No

7. If yes, how has it changed?

## Maryland and Michigan Carriers

1. Have you heard of the SRI Dashboard or Application before taking this survey?
   a) Yes
   b) No

2. Has the implementation of the SRI Dashboard or Application had an impact on your daily operations?
   a) Yes
   b) No

3. If yes, what kind of impact has it had?

4. Has the implementation of the SRI Dashboard/App has changed your or your drivers' behavior while at work? (Example: Are you more cautious with having all your truck permits in order, keep your HOS logs updated, or any other behavior?)
   a) Yes
   b) No

5. If yes, how has it changed?

6. Has the SRI Dashboard/App changed your or your drivers' attitude towards inspections? (Example: do you like this technology because it filters out complying trucks and drivers and saves you time, do you feel safer on the road, or any reason why perhaps you would not like it?
   a) Yes
   b) No

7. If yes, how has it changed?

## North Carolina Carriers

1. Have you heard of the ALPR before taking this survey?
   a) Yes
   b) No

2. Has the implementation of the ALPR had an impact on your daily operations?
   a) Yes
   b) No

3. If yes, what kind of impact has it had?

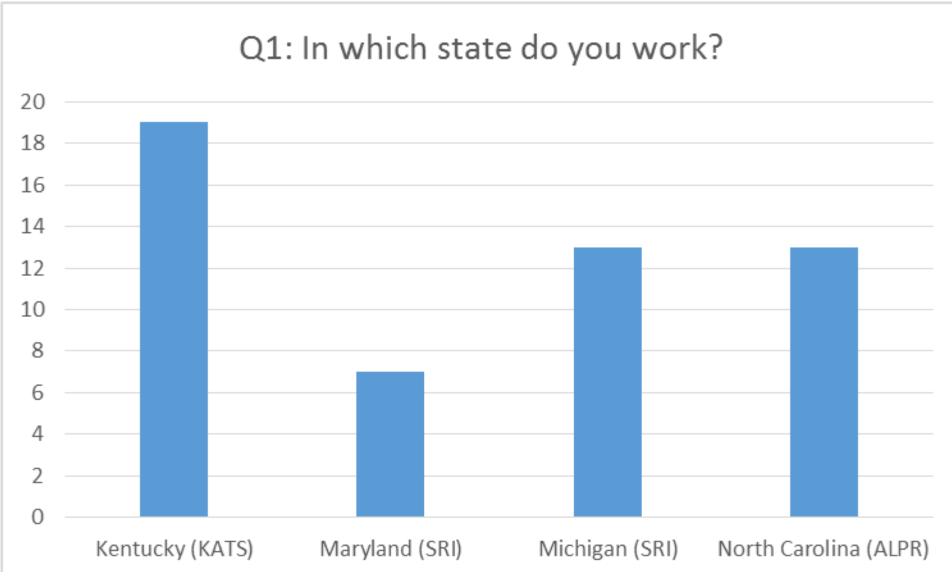
4. Do you feel the implementation of the ALPR changed your or your drivers' behavior while at work? (Example: Are you more cautious with having all your truck permits in order, keep your HOS logs updated, or any other behavior?)
   a) Yes
   b) No

5. If yes, how has it changed?

6. Has the ALPR changed your or your drivers' attitude towards inspections? (Example: do you like this technology because it filters out complying trucks and drivers and saves you time, do you feel safer on the road, or any reason why perhaps you would not like it?
   a) Yes
   b) No

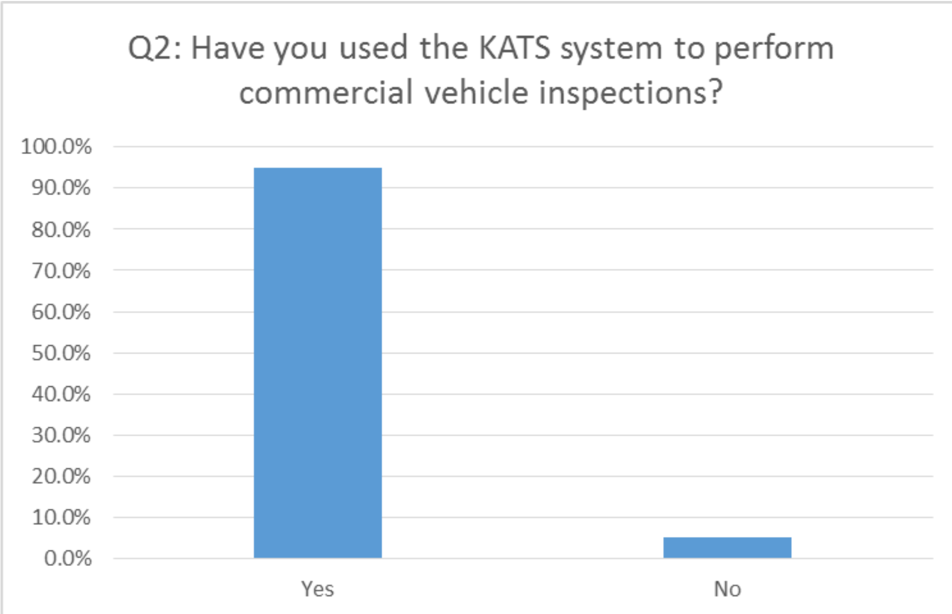
7. If yes, how has it changed?

# APPENDIX D. Survey Results




*Source: Productivity Apex, Inc*

## Kentucky CVE

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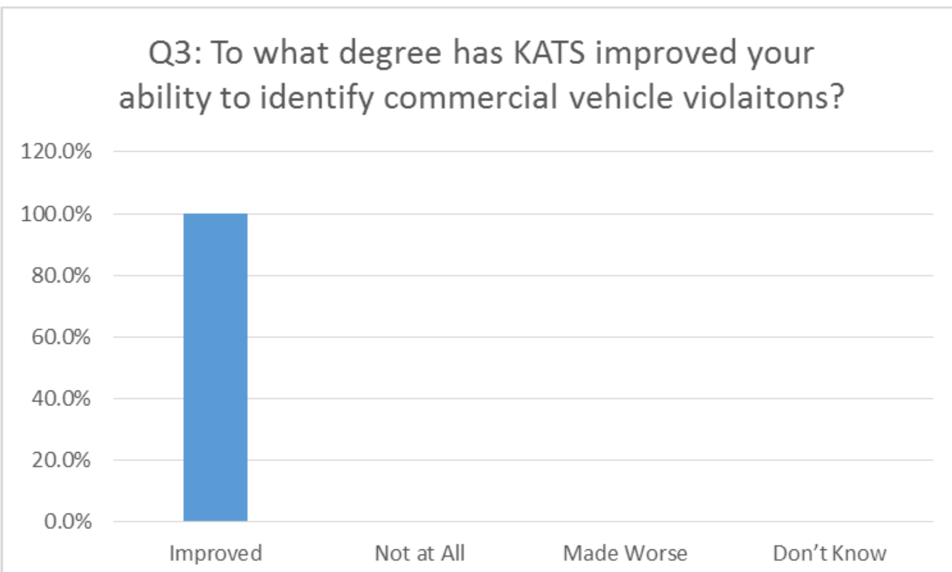


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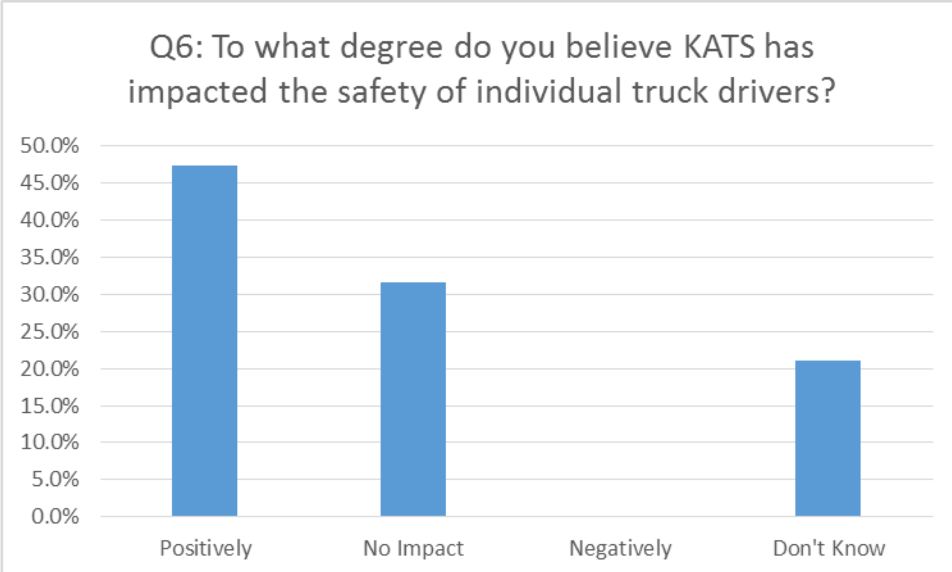


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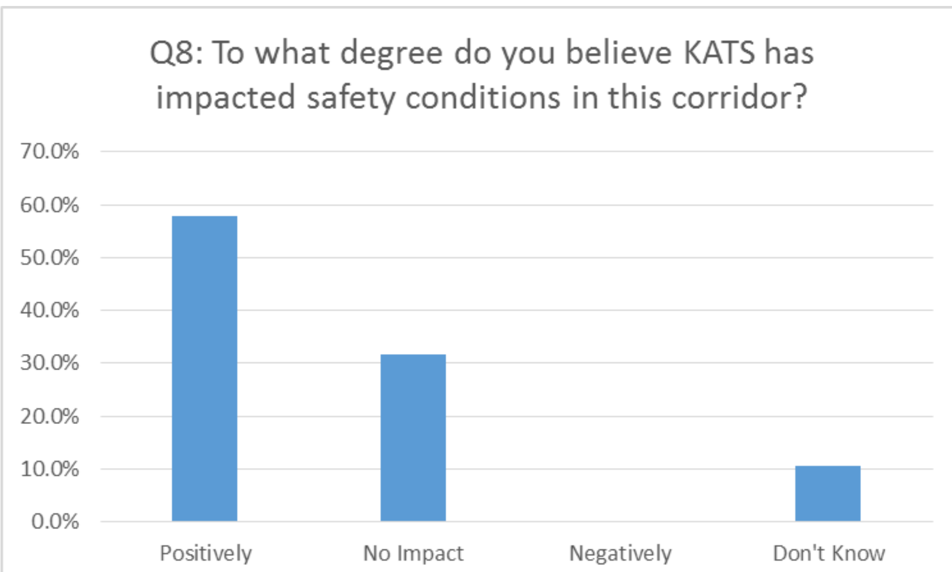


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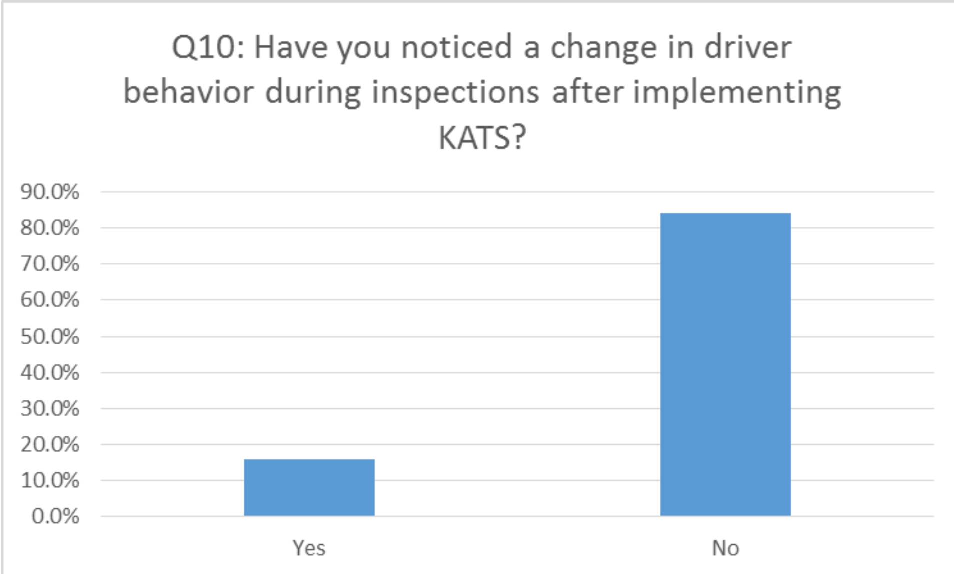


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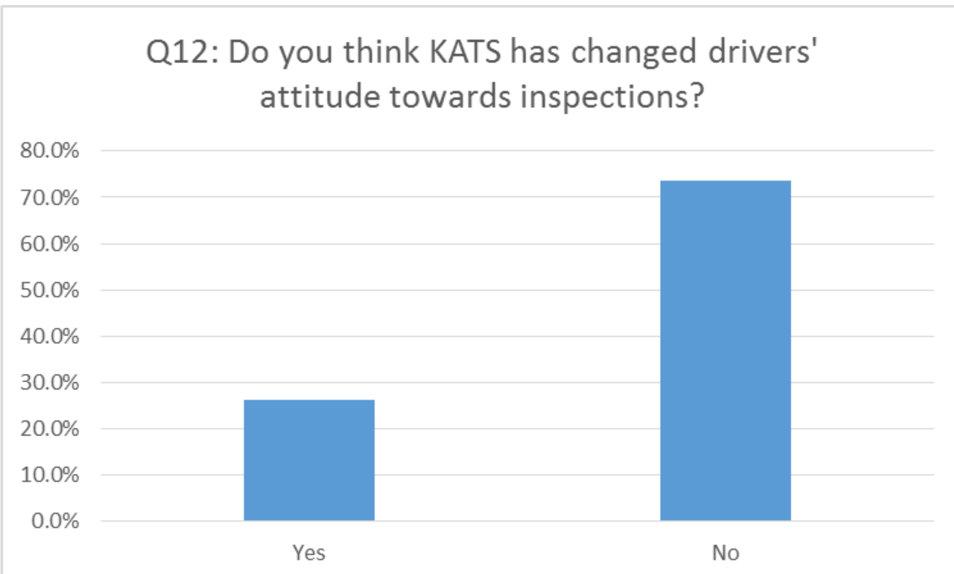


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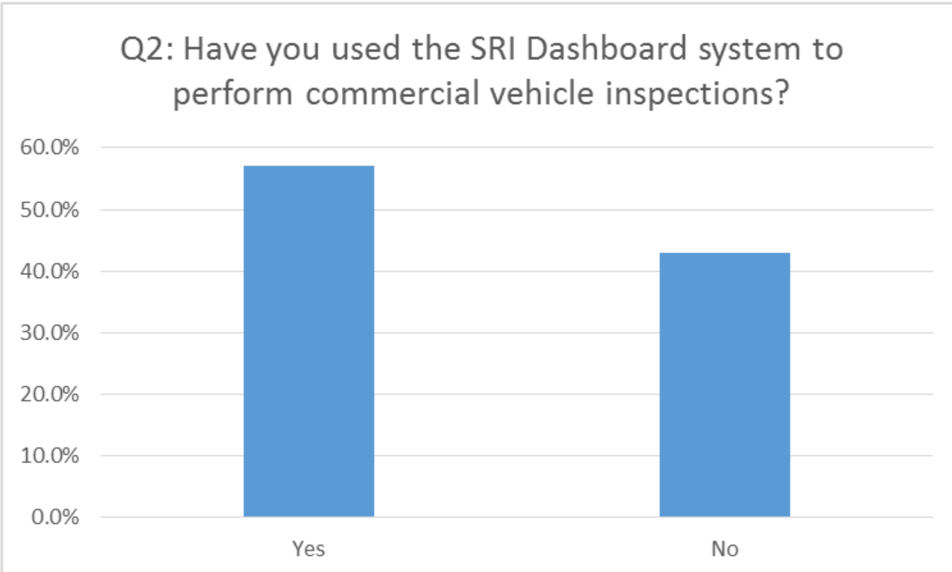
## Maryland CVE

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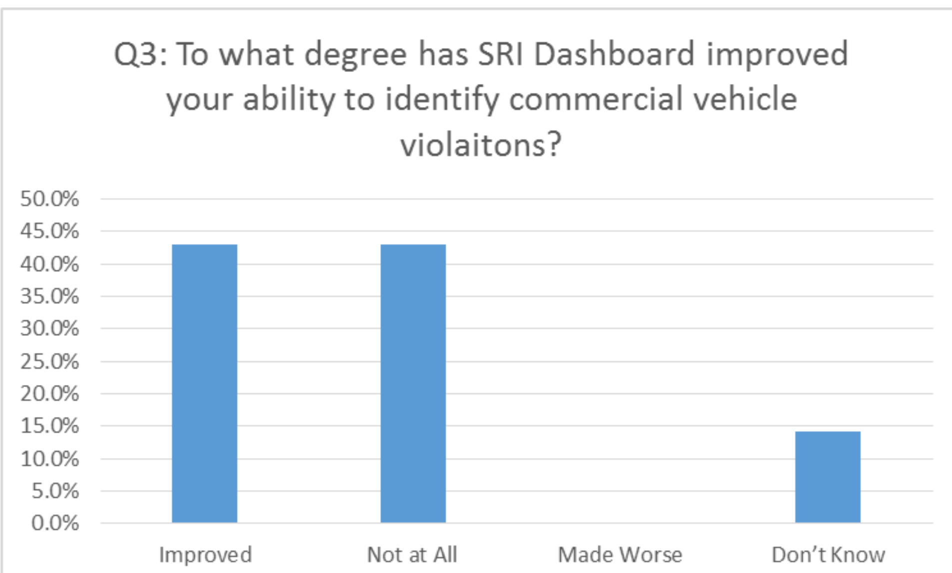


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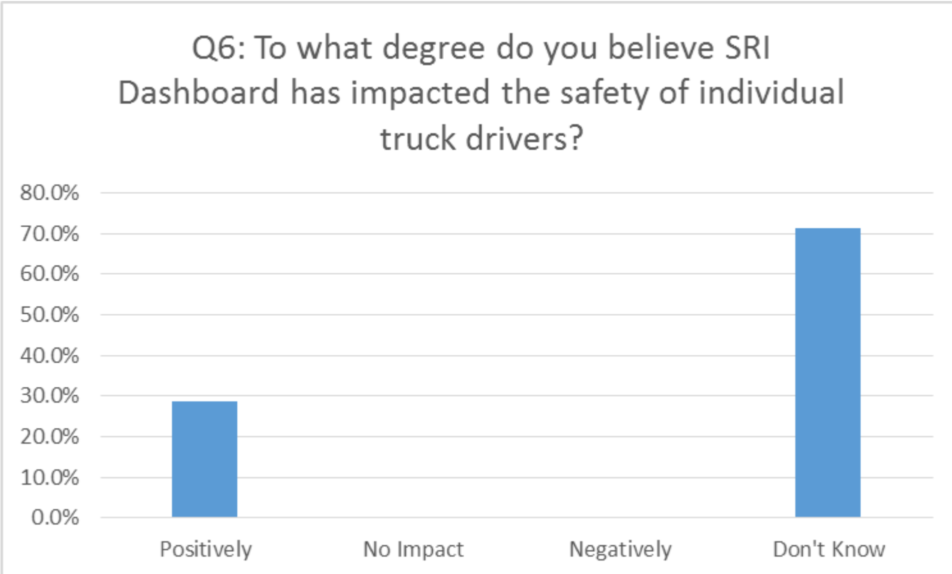


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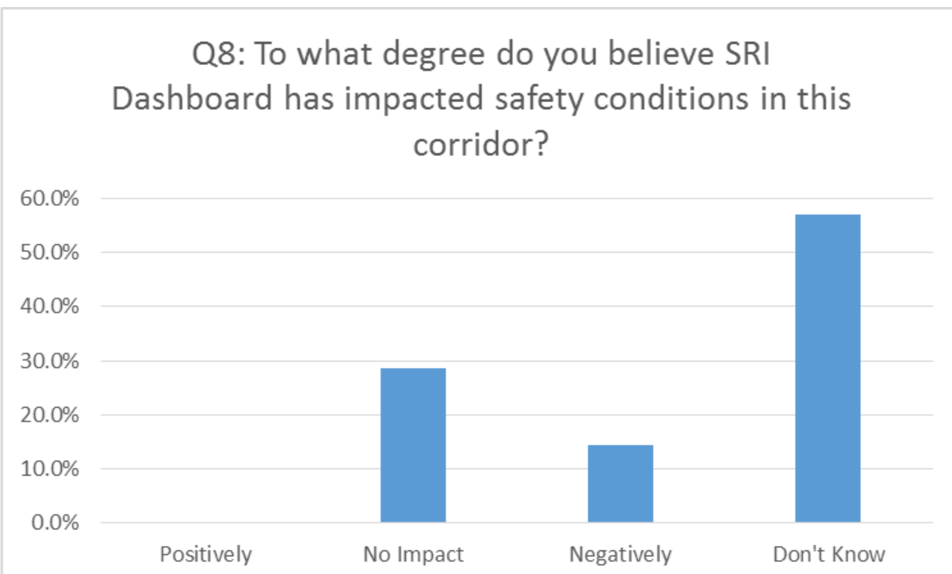


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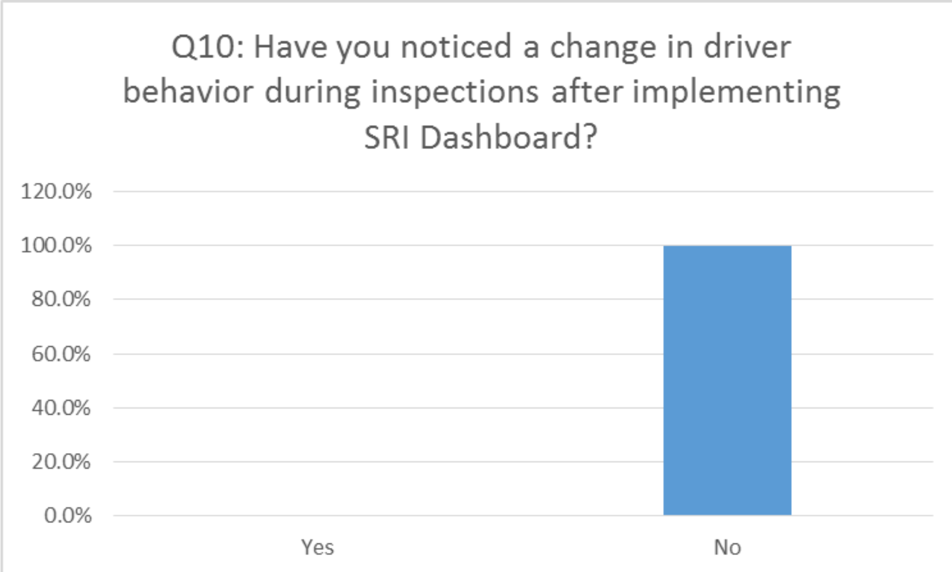


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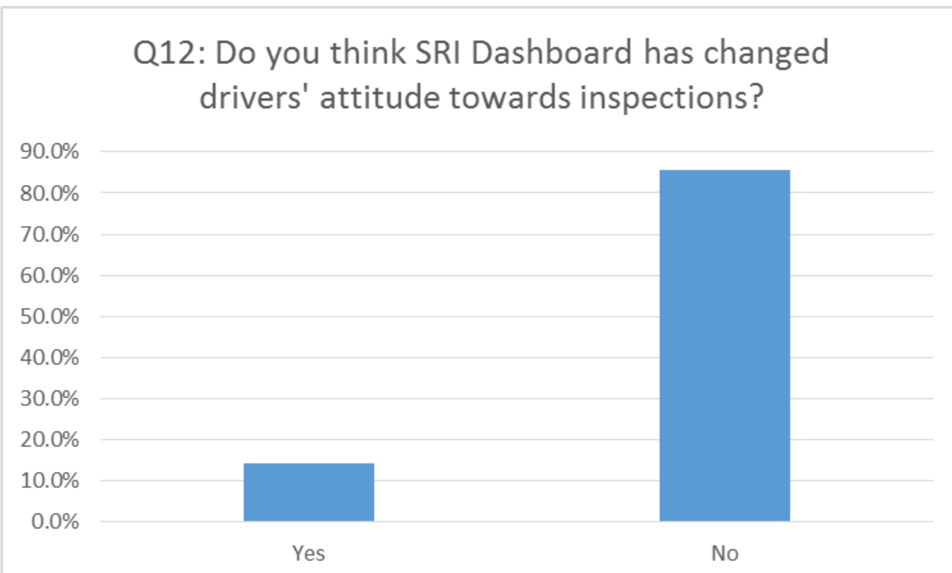


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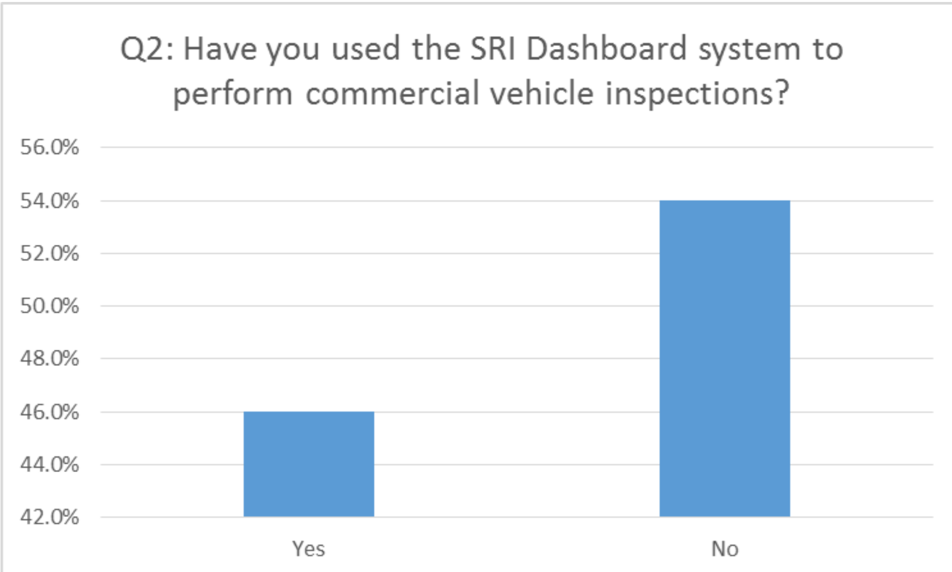
## Michigan CVE

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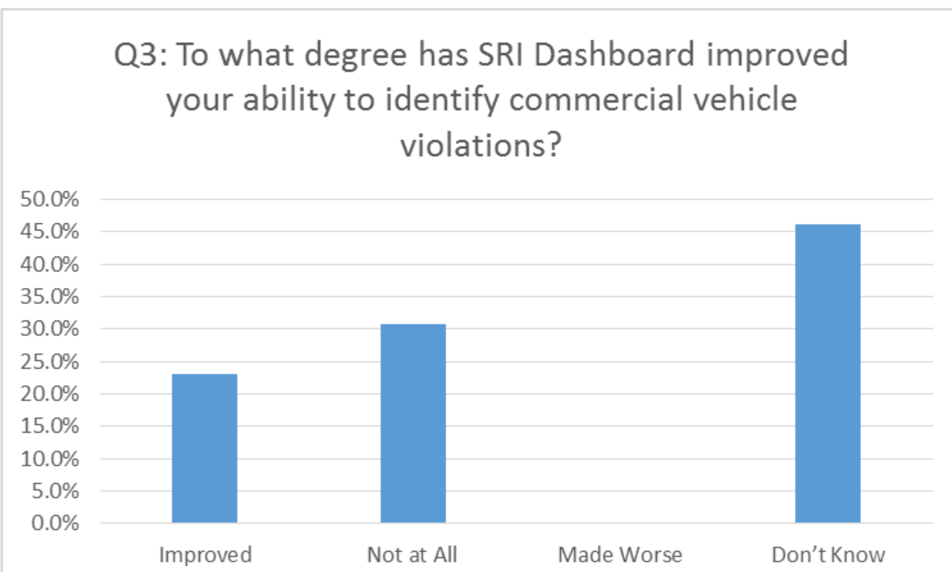


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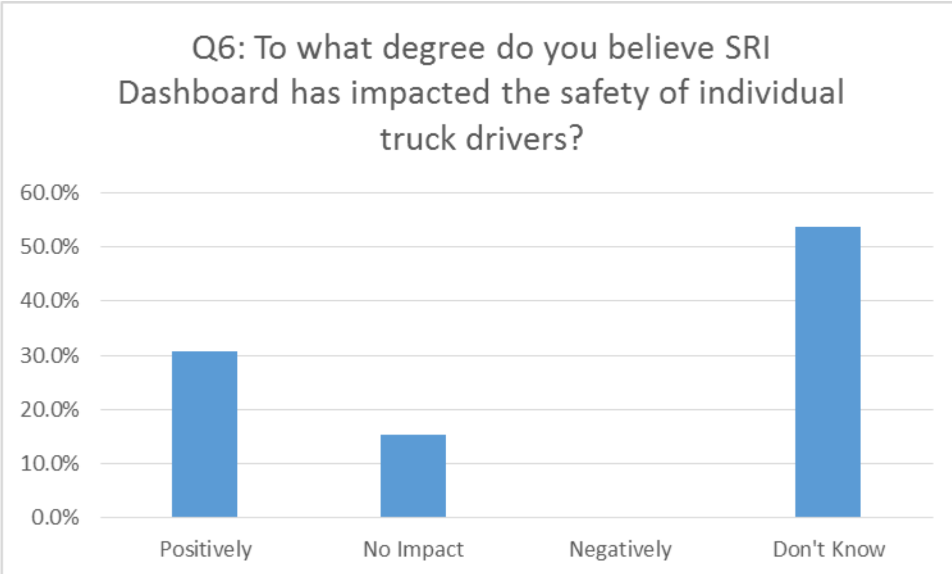


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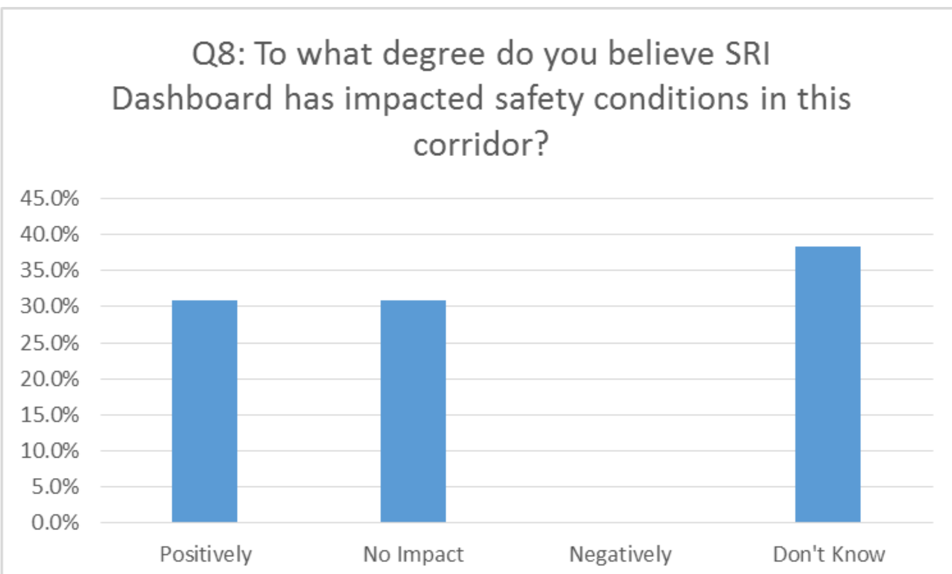


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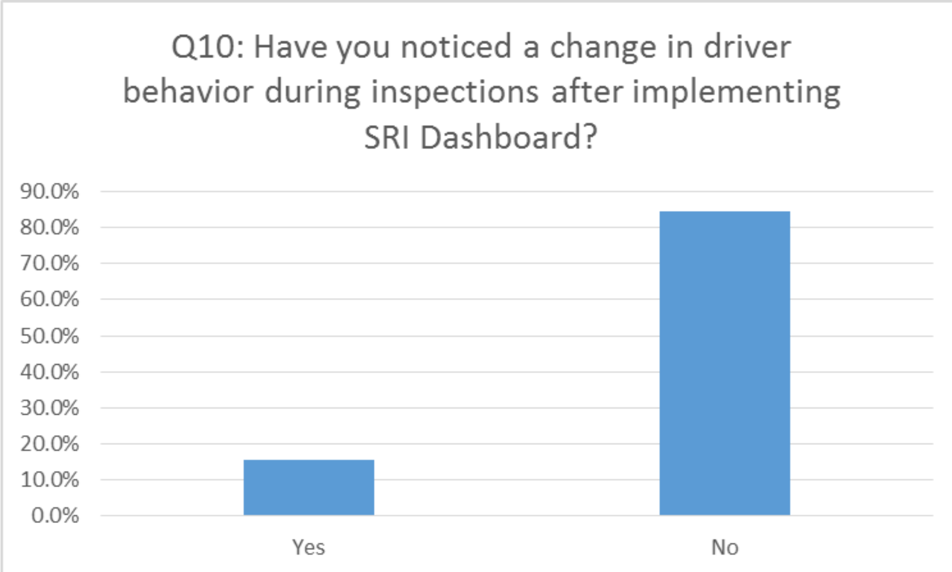


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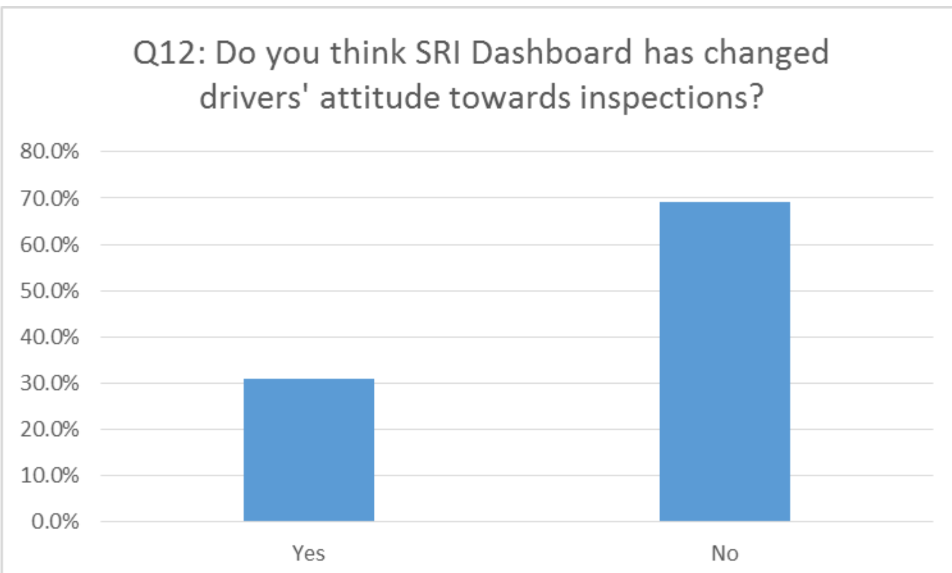
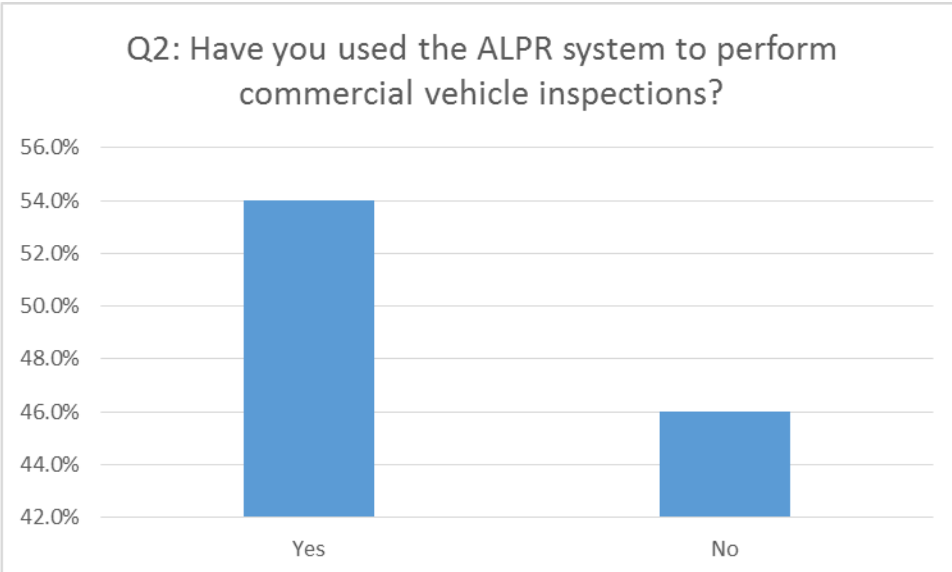



*Source: Productivity Apex, Inc*

## North Carolina CVE

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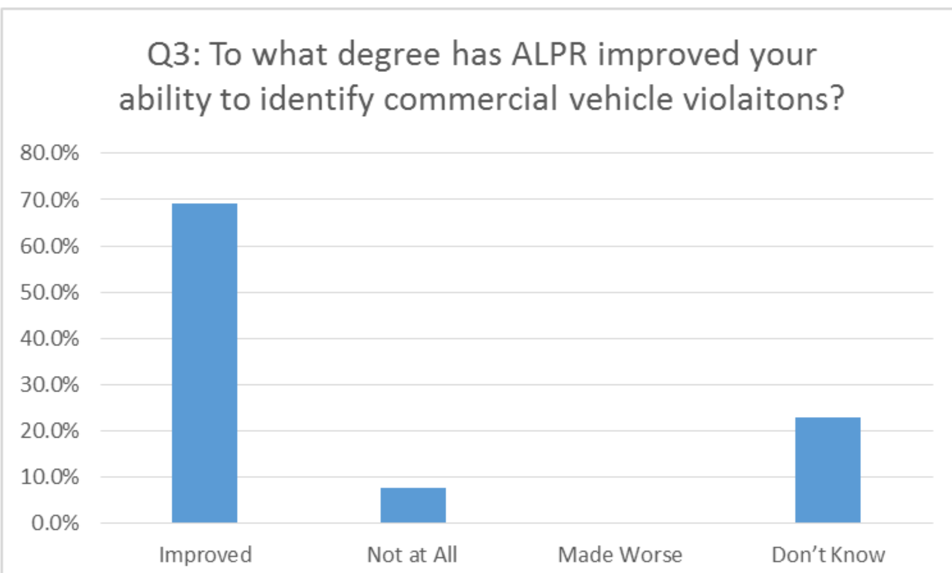


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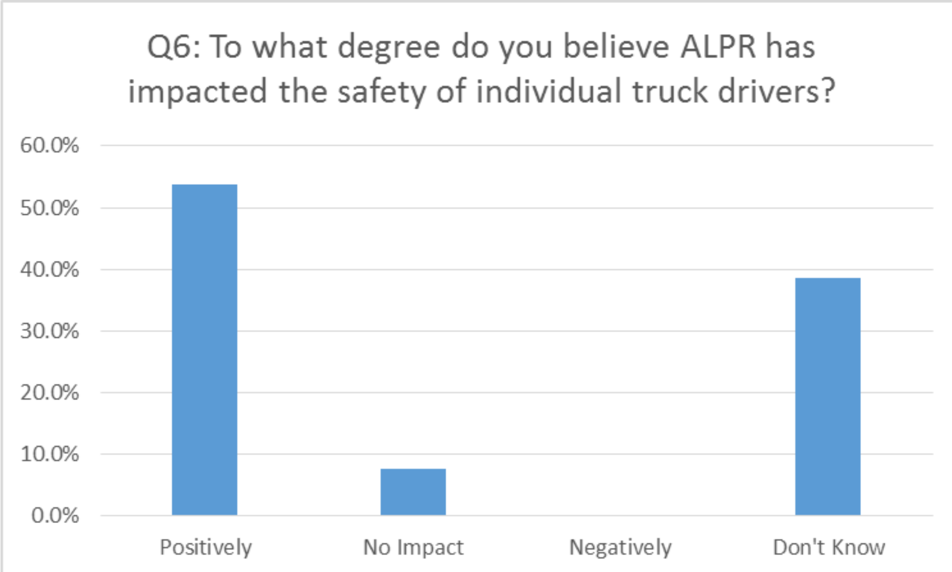


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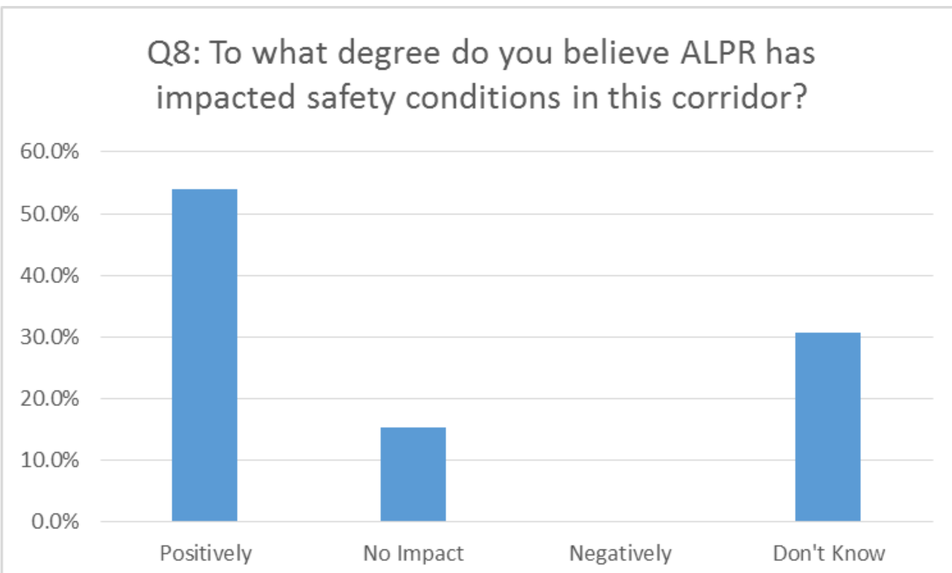


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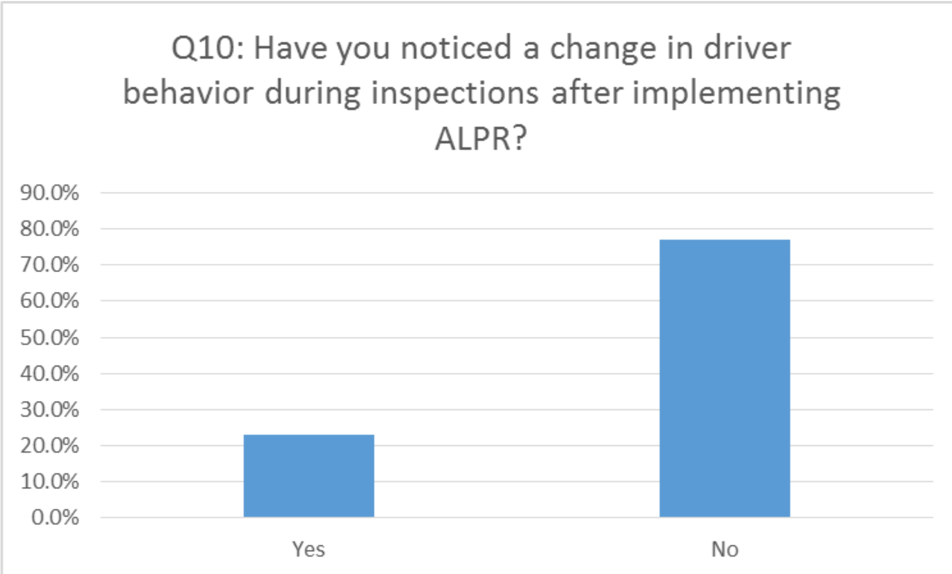


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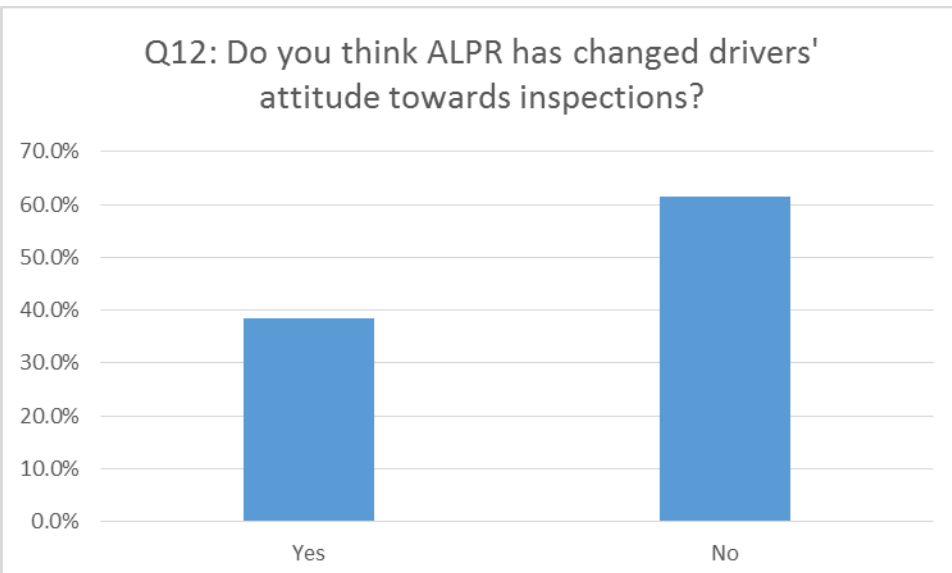


*Source: Productivity Apex, Inc*

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