Research Report
KTC-15-19/MTIC7-14-1F
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Evaluation of Thermal Imaging Technology for Commercial Vehicle Screening

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Kentucky Transportation Center
176 Oliver H. Raymond Building
Lexington, KY 40506-0281
(859) 257-4513
fax (859) 257-1815

www.ktc.uky.edu

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Evaluation of Thermal Imaging Technology for Commercial Vehicle Screening

Authors

Jennifer R. Walton, P.E.
ITS Program Manager

Mark S. Spellman
Research Investigator

and

Joseph D. Crabtree, Ph.D., P.E.
Director

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

in Cooperation with

Kentucky Transportation Cabinet
Commonwealth of Kentucky

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Federal Highway Administration
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16. Abstract

Brake and tire violations are common problems identified through commercial vehicle inspections. Identifying and correcting these types of problems before a crash occurs can produce significant safety benefits. Thermal imaging technology can be used by commercial vehicle enforcement to screen vehicles as they approach a weigh station to determine if they may have flat tires and inoperable brakes. The vehicles do not have to be stopped at a weigh station to be screened. Kentucky currently has three stations outfitted with thermal imaging technology. The objectives of this study were to evaluate the benefits of using the thermal imaging cameras to identify brake and tire problems and to develop recommendations for how enforcement personnel can receive the most benefits from this technology. The data presented in this report include: 1) a summary of previous research, 2) evaluations of the technology, 3) on-site data collection at a Kentucky weigh station, 4) an interview with one of Kentucky's primary users of the technology, and 5) an analysis of Kentucky inspection data, specifically, brake and tire violations and vehicle out-of-service (OOS) rates. A Federal Motor Carrier Safety Administration (FMCSA) evaluation concluded that the OOS rate for vehicles pinpointed via thermal imaging camera systems was 59 percent, whereas the OOS rate for conventional inspection was only 19 percent. Facilities with a thermal imaging system recorded a higher percentage of tire and brake violations per inspection as well as a higher vehicle out-of-service (VOOS) rate than facilities without a thermal imaging camera. However, the effectiveness of thermal imaging technology was significantly influenced by whether law enforcement embraced it as well as by inspectors' proficiency operating the systems. This study recommends that enforcement staff who can access thermal imaging technology receive periodic training on its operation, then graduate to a practicum that lets them use the technology under expert supervision. Promotional materials that highlight the value of thermal imaging technologies should be distributed to all Kentucky enforcement personnel. In addition, methods and enforcement mechanisms should be identified so that personnel can be held accountable for using the technology.

17. Key Words Thermal image camera, infrared, commercial vehicle enforcement, inoperable brake, flat tire, OOS		**18. Distribution Statement**	
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Executive Summary

Driver error is the most common factor that contributes to crashes involving large trucks. The condition of brakes and tires is another major factor; a 2012 study found that approximately 35 percent of all the large trucks involved in injury crashes or fatal crashes in the U.S. had brake or tire problems. Brake and tire violations account for over 30 percent of all vehicle violations spotted during weigh station inspections. In 2014, there were 2.3 million commercial vehicle inspections conducted nationwide, resulting in nearly four million cited vehicle violations. Identifying and correcting these types of violations before a crash occurs can produce significant safety benefits.

The Kentucky State Police's Division of Commercial Vehicle Enforcement (KSP-CVE) is the agency primarily responsible for monitoring commercial vehicles on Kentucky's roadways. The division enforces all commercial-vehicle-related laws and regulations. There are 135 officers and inspectors on staff at KSP-CVE, but they can only inspect approximately one percent of the 3.5 million commercial vehicles passing through Kentucky's 14 inspection facilities each year. Three inspection facilities (Simpson, London northbound, and Kenton) are equipped with thermal imaging cameras on the weigh station ramp. These cameras are used to identify real-time safety problems related to tires and brakes.

The objective of this study was to evaluate the benefits of using the thermal imaging cameras to identify brake and tire problems. The Kentucky Transportation Center (KTC) also developed recommendations for how enforcement personnel can receive the most benefits from thermal imaging technology. The data presented in this report include: 1) a summary of previous research, 2) evaluations of the technology, 3) on-site data collection at one Kentucky weigh station, 4) an interview with one of Kentucky's primary users of the technology, and 5) an analysis of Kentucky inspection data, specifically, brake and tire violations and vehicle out-of-service rates. Thermal imaging cameras have immense value for identifying unsafe vehicles with tire and brake violations. The vehicles do not have to be stopped at a weigh station to be screened, allowing KSP-CVE to only remove those vehicles from service that have safety deficiencies.

A Federal Motor Carrier Safety Administration (FMCSA) evaluation concluded that the out-of-service (OOS) rate for vehicles pinpointed using thermal imaging camera systems was 59 percent, whereas the OOS rate for conventional inspection was only 19 percent. Analysis of Kentucky inspection data revealed that facilities with a thermal imaging system recorded a higher percentage of tire and brake violations per inspection as well as a higher vehicle out-of-service (VOOS) rate than facilities without a thermal imaging camera. However, the effectiveness of thermal imaging technology was significantly influenced by the level of acceptance of the technology by law enforcement personnel as well as by the inspectors' proficiency in operating these systems.

This study recommends that enforcement personnel who can access thermal imaging technology receive periodic training (initial and refresher) on its operation. Training should include an instructional session that provides an overview of the system's use, then graduate to a practicum that lets students utilize the technology under an expert trainer's supervision. Promotional materials that highlight the value of thermal imaging technologies should be distributed to all

Kentucky commercial vehicle enforcement personnel. In addition, methods and enforcement mechanisms should be identified so that personnel can be held accountable for using the technology. If thermal imaging is adopted, these steps will improve the quality of inspections and the rate at which inspectors spot violations.

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1. Introduction

In 2012, the National Highway Traffic Safety Administration (NHTSA) recorded 333,000 crashes that involved large trucks (a large truck has a gross vehicle weight rating greater than 10,000 pounds). These crashes resulted in 104,000 injuries and 3,921 fatalities.[1] The Federal Motor Carrier Safety Administration's (FMCSA) Large Truck Crash Causation Study[2] (LTCCS) examined 967 crashes involving large trucks and passenger vehicles. This sample was chosen from 120,000 crashes that caused injuries and fatalities over a 33-month period. The study examined pre-crash data and analyzed the condition of the drivers, the vehicles, the roadway, and weather. The LTCCS found that the most common factor leading to crashes involving large trucks were errors on the part of either the truck driver or the passenger car driver. However, the study also found that approximately 35 percent of all the large trucks involved in fatal or injury crashes had brake or tire problems.

FMCSA has the mandate of reducing the number and severity of crashes involving large trucks or busses. Performing more commercial vehicle inspections and compliance reviews can decrease the number of crashes.[2] In 2014, 2,341,228 vehicle inspections were conducted nationwide, which revealed 3,979,859 vehicle violations. Of those violations, approximately 21 percent were brake-related violations, while 10 percent were tire-related violations. Considered together, brake and tire violations accounted for over 30 percent of all vehicle violations identified during commercial vehicle inspections. Significant safety benefits will be realized if violations are identified and corrected before a crash occurs.

The Kentucky State Police's Division of Commercial Vehicle Enforcement (KSP-CVE) is the agency primarily responsible for monitoring commercial vehicles on Kentucky's roadways; the division enforces all laws and regulations related to commercial vehicles. KSP-CVE has 153 employees, including sworn law enforcement officers, inspectors, and civilian administrative staff. Sworn officers include both road officers and supervisors. Table 1 summarizes the breakdown of staffing by officer, inspector, and administrative staff.

[1] National Highway Traffic Safety Administration. Traffic Safety Facts: 2012 Data, Table 1. http://www-nrd.nhtsa.dot.gov/Pubs/811868.pdf

[2] Federal Motor Carrier Safety Administration, Office of Research and Analysis. July 2007. The Large Truck Crash Causation Study—Analysis Brief. Publication No. FMCSA-RRA-07-017. http://www.fmcsa.dot.gov/safety/research-and-analysis/large-truck-crash-causation-study-analysis-brief

Table 1. Number of KSP-CVE Employees

Type of Employee	Number of Employees
Sworn Officers	**108**
Supervisors	31
Road Officers	77
Inspectors	**27**
Administrative Staff	**18**
Total Employees	**153**

KSP-CVE enforces the safety, licensing, and registration of commercial vehicles. These activities are performed by officers and inspectors at Kentucky's 14 inspection facilities and at roadside. In addition to the inspection facilities, KSP-CVE officers patrol over 27,500 centerline miles of state-maintained roadways.[3]

In 2013, nearly 3.5 million trucks passed through Kentucky's inspection facilities. While the vast majority of these trucks were weighed, only about one percent were inspected, due to limited resources. This is typical of most weigh stations and inspection facilities in North America. Thus, enforcement personnel must make judicious decisions about which vehicles they choose to inspect. KSP-CVE officers and inspectors select vehicles based on a number of criteria, including visible indicators of a vehicle problem, previous experience with (or knowledge of) the company or vehicle, random selection, or by use of available screening technologies. Technologies are available that allow enforcement to focus on high-risk or non-compliant carriers, which maximizes the benefit of enforcement activities. Kentucky has the following screening technologies available to KSP-CVE officers and inspectors at inspection facilities:

- **Kentucky Automated Truck Screening (KATS)**, an optical character recognition (OCR) system that uses a license plate reader (LPR), USDOT number reader, and scene camera to capture data on each vehicle, decode identifying information, and then utilize that information to check credentials, registration, and safety history on the company and vehicle.
- **Automated Licensing and Taxation System (ALTS)**, a mainframe system that 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.
- **Commercial Vehicle Information Exchange Window (CVIEW),** a database accessed through the officers' and inspectors' inspection system that provides a pass, warn, or fail status for each motor carrier keyed into the system based on safety, credential, and registration information.

[3] Kentucky Transportation Cabinet, Division of Planning. April 1, 2015. State Primary Road System Mileage Report. http://transportation.ky.gov/Planning/Documents/sprslist.pdf

- **Ramp WIM, Sorting and Tracking System**, a system composed of weigh-in-motion (WIM) scales, static scales, loops for tracking vehicles throughout the facility, and related computer systems, which sorts vehicles based upon their weight.
- **Thermal Imaging Camera**, an infrared camera that is utilized by staff to detect the heat from the tires and brakes on commercial vehicles passing through the weigh station.

Of these technologies, only the thermal imaging camera provides information on possible real-time safety problems with the vehicle. This system can identify low or flat tires and can reveal a cold brake, which indicates it is not functioning properly. If no detectable heat emanates from the braking system, it suggests a failure, while a flat or low tire will generate a different thermal signature compared to a properly inflated tire. Figure 1 displays an image taken from a thermal camera, showing two axles from a commercial vehicle. On one axle, bright white shines through the wheel's hub, while the other hub is dark. The dark axle indicates an absence of heat, very likely due to a non-functioning brake.

Figure 1. Thermal Imaging Displaying an Inoperable Brake

Background and History

A thermal imaging camera was first installed in August of 2005 on I-75 northbound at the Laurel County inspection facility as part of the Integrated Safety and Security Enforcement System (ISSES). ISSES incorporated a suite of technologies aimed at identifying safety and security issues at weigh stations. The technologies included with the ISSES installation were a radiation detection system, an infrared brake monitoring system, and a license plate reader and USDOT number reader with optical character recognition. ISSES was also installed in 2006 at the Simpson County inspection facility on I-65 northbound as well as at the Kenton County inspection facility on I-75 southbound. Figure 2 depicts the ISSES installation on the weigh station ramp at the Laurel County northbound facility.

Figure 2. ISSES Equipment at Laurel NB

The ISSES technology that has proven most beneficial for enforcement is the thermal imaging camera. The radiation detection equipment performed well, but the vast majority of radiation alarms sounded for legitimate shipments of radioactive material. Over time, these radiation alarms became more of a nuisance than a help. The LPR and USDOTR reader technologies also functioned well, but there were significant performance issues with the overall system integration and user interface software for ISSES. As a result, the LPR and USDOTR technologies were never connected with a database to enable real-time screening for enforcement purposes. The thermal camera, however, showed potential for identifying inoperable brakes and flat tires. The technology helped remove the guesswork from selecting vehicles for inspection by providing visual evidence of a potential safety issue.

Lacking the funding to continue maintenance (coupled with the aforementioned integration and software issues), in fall of 2009 the ISSES equipment was turned off at all three facilities. However, the thermal imaging technology remained operational and is still in use. Despite proof that the thermal imaging cameras will accurately detect brake and tire deficiencies, not all of the enforcement staff have used the equipment. The amount of use varies greatly by location. Usage depends on the officers/inspectors' preferences as well as on the different levels of training and experience with the equipment. Personnel at the Simpson County facility have embraced the technology and use it regularly, while personnel at the other two stations have used the technology much less frequently. As a result, personnel at those stations have seen their familiarity and competence with the system deteriorate over time. Lightning strikes also plagued all three systems, resulting in significant downtime for the equipment in Laurel and Kenton counties. In the spring of 2014, the Kentucky Transportation Cabinet, with help from the Kentucky Transportation Center (KTC), repaired all three systems, using Commercial Vehicle Information Systems and Networks (CVISN) funding.

Objectives

The objectives of this study were to: (1) evaluate the benefits of using the thermal imaging cameras to identify brake and tire problems and (2) develop recommendations for how enforcement personnel can get the most from this technology.

Methodology

Internet databases and websites were searched to identify previous research that evaluated thermal imaging cameras. Next, data were collected on-site at the Simpson County I-65 northbound facility. Research staff observed the equipment's operation, interviewed the primary user, and collected inspection data related to the use of the thermal imaging cameras. Lastly, research staff acquired historical inspection data (provided by KSP-CVE) from all 14 of Kentucky's inspection facilities to compare the performance of stations that had thermal imaging cameras to those stations without such cameras.

2. Previous Research and Evaluations of Thermal Imaging Technology

In December of 2000, FMCSA published the final report describing the evaluation of Infrared Brake Screening Technology. The assessment was conducted for FMCSA by the Battelle Memorial Institute, and it provided an in-depth analysis of the field performance of thermal imaging technology. The study evaluated the performance of the Infrared Inspection System (IRIS) in four participating states: Georgia, Kentucky, North Carolina, and Tennessee. During the course of the evaluation, 3,769 wheels were screened using IRIS. Of these, 399 (about 10 percent) were flagged as problematically cold (indicating an apparent non-functioning brake), while 44 (about 1 percent) were identified as problematically hot. Ultimately, 330 vehicles were identified as problematic and flagged for inspection. An additional 62 vehicles without apparent problems (based on IRIS screening) were also directed to inspection to establish a blind control group. For vehicles identified as problematic by the IRIS screening, 59% were placed out-of-service (OOS). Seventy-nine percent of those were placed out-of-service due to a brake violation. Of the vehicles placed out-of-service, 22 percent had both a brake OOS violation and some other type of OOS violation. In comparison, vehicles in the blind control group had an OOS percentage of 19 percent.[4]

Kentucky conducted its own evaluation of the thermal imaging cameras in 2007 as part of a study that measured the value of Kentucky's commercial vehicle enforcement activities.[5] Researchers collected data at one location for two days. A third day of data collection took place at a different location. Staffing constraints limited the number of trucks that were inspected. Over the three days, Level 1 inspections were conducted on 38 trucks that the system identified as having brake problems. Twenty-six of those trucks (68 percent) were found to have the brake problem that the system had indicated. A total of 86 violations were found on the 38 trucks that were inspected. Of these, 56 were brake violations. Ten of the trucks (26 percent) were placed OOS. A key finding of this evaluation was that the technology's effectiveness depended heavily on the user's skill level and experience. On days when the system was operated by personnel with minimal training and experience, the OOS rate ranged from 10 percent to 16 percent. On the day when the system was monitored by a trained, experienced user (i.e., a representative of the technology vendor), the OOS rate was 67 percent.

[4] U.S. Department of Transportation, Federal Highway Administration. December 2000. Evaluation of Infrared Brake Screening Technology: Final Report. Report Number DOT-MC-01-007. http://ntl.bts.gov/lib/17000/17100/17174/PB2001100010.pdf

[5] Kentucky Transportation Center, College of Engineering, University of Kentucky. January 2008. Measuring the Value of Kentucky Vehicle Enforcement Activities. Report Number KTC-08-03/SPR332-07-1F. http://www.ktc.uky.edu/projects/measuring-the-value-of-kentucky-vehicle-enforcement-activities/

3. 2015 On-Site Data Collection

On Thursday April 2, 2015, KTC research staff observed enforcement personnel at the Simpson County inspection facility on I-65 northbound. Simpson County, Laurel County northbound, and Kenton County inspection facilities possess thermal imaging equipment, but Simpson County was chosen because the enforcement personnel use the technology more frequently than the personnel at the other two locations. The Station Commander identified one of the station's inspectors as the primary — and most proficient — user of the thermal imaging camera. On the date of the observation, the primary user was absent in the morning, so the thermal imaging camera was operated by two of the station's officers. The primary user arrived in the early afternoon and became the primary equipment operator. Typically, one officer/inspector would use the thermal imaging camera to identify vehicles with potential problems, and the other officer/inspector would be tasked with investigating further. Enforcement personnel had other responsibilities that required their attention during this time, so the equipment was not operated continuously during the observation period.

When an officer or inspector continuously monitored the camera, they would typically identify a vehicle for inspection every five to fifteen minutes. Both of the officers using the system in the morning adopted a similar process — they would monitor the camera and identify potential vehicle problems. Once a problem had been spotted, they directed the vehicle to stop, quickly examined the potential problem, and then either held it for inspection or released it. The officer's decision to hold or release a vehicle hinged on what the officer observed after the vehicle had been stopped. Enforcement personnel looked for brake or tire problems. On the day KTC researchers observed at the facility, all of the identified problems were tire-related. A MCSAP Level 2 inspection was conducted for each vehicle that was identified through this screening process, since the potential problem with each vehicle was a flat tire and could be verified with a walk-around inspection. A MCSAP Level 1 inspection would have been conducted if an inoperable brake had been identified.

During the observation, ten vehicles were stopped for further investigation. Of these, two had their tires checked and were released. The thermal imaging camera flagged one tire on each vehicle as having low air pressure. However, air pressure readings did not indicate the tires were flat. In each case, the driver was notified of the issue and allowed to proceed. Staff conducted Level 2 inspections on the remaining eight vehicles, and all of those vehicles were placed OOS due to a flat tire. Under the North American Standard Out-Of-Service Criteria, a flat tire must be repaired before the vehicle can resume operation. So, during this observation period, 80 percent of the vehicles identified as problematic by the thermal imaging system were placed OOS after an inspection.

4. Interview with the Primary User of the Technology

Because the Simpson County facility's Station Commander identified one inspector as the most proficient user of the thermal imaging technology, KTC researchers felt he could provide valuable insights for the system evaluation. After the day's inspections had been completed, the primary user was asked to talk about his typical daily operations with the thermal imaging camera. He estimated that he spends about 80 percent of his time monitoring the camera equipment and inspecting vehicles identified by the system as having potential brake and tire issues. Many vehicles he inspects personally, however, he also turns vehicles over to other inspectors and officers for inspection. At times, other staff members will monitor the camera as well, but he is the primary user. He has not received formal training on the equipment. His training was informal; he was shown how to use the equipment by another inspector. The more he operated the equipment, the more proficient he became at spotting problems. He noted that the data collected during the observation period was representative of a typical day of operation with the thermal imaging camera, with one exception — most days will see a mix of brake issues and tire issues, not just flat tires. The OOS rate is sometimes less than it was during the observation period (80 percent), since a vehicle must either have: 1) two or more brakes inoperable, or 2) one brake inoperable on the steering axle for the vehicle to be placed OOS. Even when the system functions perfectly and detects a non-functioning brake, that vehicle will not necessarily be placed OOS.

Building on the in-person observations, six months of inspection data (July 1 through December 31, 2014) from the primary user's operation of the thermal imaging equipment were gathered. During this period, the primary user performed 330 inspections, with a 43 percent vehicle out-of-service (VOOS) rate. This is more than double the national average (20.2 percent) and the state average (19.9 percent) for fiscal year 2014.[6] The primary user credited the thermal imaging camera for this high VOOS rate.

[6] Federal Motor Carrier Safety Administration. Safety Programs and Program Effectiveness, FY 2014 Data. Analysis and Information Online. http://ai.fmcsa.dot.gov/SafetyProgram/Home.aspx

5. Comparison of Inspection Data from Various Weigh Stations

To further analyze the impacts of the thermal imaging equipment, data were collected from 14 of Kentucky's inspection facilities over a nine-month period, April 1 through December 31, 2014. This period was selected because the thermal imaging cameras were repaired and brought back into service immediately prior to April 1, 2014. Data for this period reflected the characteristic use of the thermal imaging cameras for screening purposes at three locations: Simpson County, Laurel County northbound, and Kenton County. Although some of the other facilities use other types of technology for screening purposes, the thermal cameras are the only screening systems that can identify real-time safety issues related to tires and brakes. As such, increased numbers of brake and tire violations would be expected at the three stations with thermal camera technology. These types of violations could also be expected to lead to higher-than-average VOOS rates.

Figure 3 shows the total number of inspections performed at each weigh station over the study period. Staffing and hours of operation had the most significant impacts on these numbers. In general, the most inspections were performed at locations with the highest numbers of officers and inspectors. For example, Rowan County is a small facility with relatively light traffic, but four inspectors work at that location on a regular basis, whereas most facilities only have two inspectors on hand. Other facilities with a high number of inspections include Simpson, Scott, and Laurel northbound, each of which has higher staffing numbers than other facilities.

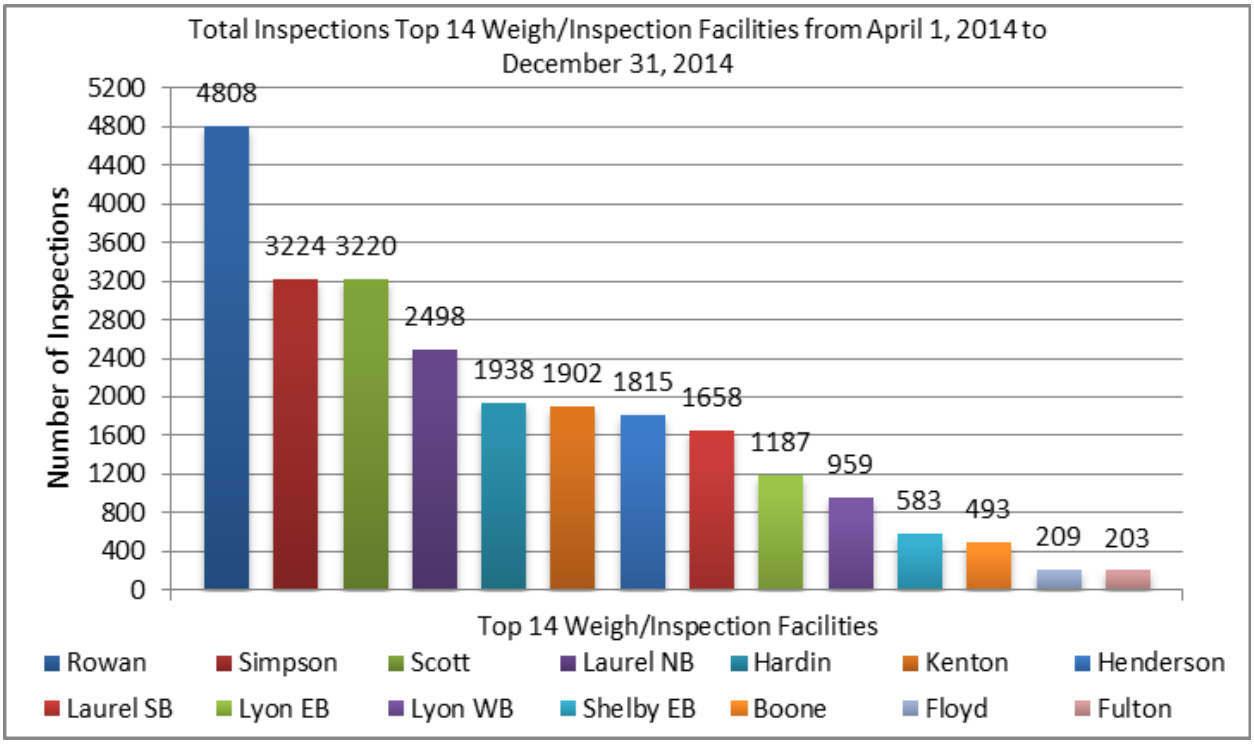

Figure 3. Number of Inspections at Inspection Facilities (April 1 - December 31, 2014)

Data related to inspections, violations, and OOS rates were examined for each location. Table 2 lists the following information:

- Total number of Level 1 and Level 2 vehicle inspections
- Number of vehicles placed OOS
- Total number of vehicle OOS violations (one vehicle may have multiple OOS violations)
- The average number of vehicle OOS violations per vehicle inspection
- Vehicle OOS rate for each facility

As with total inspections, Rowan County conducted the most vehicle inspections (3,894), followed by Simpson County (2,974) and Scott County (2,612). Simpson County also placed the most vehicles OOS (1,127), followed by Rowan County (610). Simpson County also identified the most vehicle OOS violations (1,499), again followed by Rowan County (799). With respect to the average number of vehicle OOS violations per vehicle inspection, Simpson County, again, led the state (0.504), followed by Kenton and Boone Counties (0.450 and 0.441, respectively). For vehicle OOS rate, Simpson County once again had the highest percentage (37.9 percent), followed by Boone County (29.4 percent) and Kenton County (29.2 percent). By comparison, in fiscal year 2014, the statewide vehicle OOS rate for all inspections (at facilities and roadside) was 19.9 percent. For the data displayed in Table 2, Simpson, Boone, Kenton, Henderson, and Lyon (EB) Counties all had vehicle OOS rates above the state average.

Table 2. Vehicle Inspections, Violations, and OOS Rates for Each Facility

Facility	Total Vehicle Inspections (Level 1 or 2)	Vehicles OOS	Vehicle OOS Violations	Avg. Vehicle OOS Violations / Vehicle Inspection	Vehicle OOS Rate
Boone	347	102	153	0.441	29.4%
Floyd	170	6	8	0.047	3.5%
Fulton	140	13	14	0.100	9.3%
Hardin	1704	313	425	0.249	18.4%
Henderson	1637	423	612	0.374	25.8%
Kenton	1705	498	768	0.450	29.2%
Laurel NB	1860	239	342	0.184	12.9%
Laurel SB	1221	152	276	0.226	12.5%
Lyon EB	978	196	312	0.319	20.0%
Lyon WB	791	106	143	0.181	13.4%
Rowan	3894	610	799	0.205	15.7%
Scott	2612	213	285	0.109	8.2%
Shelby EB	484	35	53	0.110	7.2%
Simpson	2974	1127	1499	0.504	37.9%

Table 3 summarizes the same data as Table 2, but compares the performance of facilities without a thermal imaging camera to those with a thermal imaging camera. Facilities without a thermal

imagining camera averaged 0.224 vehicle OOS violations per vehicle inspection, compared to 0.339 OOS violations per vehicle inspection for facilities with a thermal imaging camera. Similarly, facilities without a thermal imaging camera had a 15.8 percent vehicle OOS rate — significantly below national and statewide averages. Conversely, facilities with a thermal imaging camera recorded a 28.5 percent vehicle OOS rate — significantly above national and statewide averages.

Table 3. Vehicle Inspections, Violations, and OOS Rates: Comparing Facilities without Thermal Imaging to those with Thermal Imaging

Facility	Total Vehicle Inspections (Level 1 or 2)	Vehicles OOS	Vehicle OOS Violations	Vehicle OOS Violations / Vehicle Inspection	Vehicle OOS Rate
Facilities without Thermal Imaging	**13494**	**2134**	**3027**	**0.224**	**15.8%**
Boone	347	102	153	0.441	29.4%
Floyd	170	6	8	0.047	3.5%
Fulton	140	13	14	0.100	9.3%
Hardin	1704	313	425	0.249	18.4%
Henderson	1637	423	612	0.374	25.8%
Laurel SB	1221	152	276	0.226	12.5%
Lyon EB	978	196	312	0.319	20.0%
Lyon WB	791	106	143	0.181	13.4%
Rowan	3894	610	799	0.205	15.7%
Scott	2612	213	285	0.109	8.2%
Shelby EB	484	35	53	0.110	7.2%
Facilities with Thermal Imaging	**6539**	**1864**	**2609**	**0.399**	**28.5%**
Kenton	1705	498	768	0.450	29.2%
Laurel NB	1860	239	342	0.184	12.9%
Simpson	2974	1127	1499	0.504	37.9%

Table 4 and Table 5 present data on tire violations. Table 4 includes the following data:

- Number of inspections
- Number of tire violations
- Number of OOS tire violations
- Average number of tire violations per inspection
- Percentage of tire violations that were OOS violations

The number of inspections performed at each location influenced the number of tire violations and OOS tire violations recorded. However, the average number of tire violations per inspection is a good indicator to compare all facilities irrespective of their staffing levels and the number of inspections conducted. The data showed that Simpson County had the highest number of tire

violations per inspection (0.279), followed closely by Kenton County (0.240) and Boone County (0.197). For the percentage of tire violations classified as OOS violations, Simpson County logged the highest percentage (91.3 percent), followed by Henderson (82.5 percent) and Rowan (57.6 percent) Counties.

Table 4. Tire-Related Violations and Rates for Each Facility

Facility	Total Inspections	Tire Violations	OOS Tire Violations	Avg. Tire Viol. per Inspection	Percentage of Tire Violations that were OOS Violations
Boone	493	97	42	0.197	43.3%
Fulton	203	7	2	0.035	28.6%
Hardin	1938	109	56	0.056	51.4%
Henderson	1815	40	33	0.022	82.5%
Kenton	1902	457	252	0.240	55.1%
Laurel NB	2498	99	43	0.040	43.4%
Laurel SB	1658	33	13	0.020	39.4%
Lyon EB	1187	40	17	0.034	42.5%
Lyon WB	959	25	10	0.026	40.0%
Rowan	4808	212	122	0.044	57.6%
Scott	3220	132	52	0.041	39.4%
Shelby EB	583	20	4	0.034	20.0%
Simpson	3224	898	820	0.279	91.3%
Floyd	209	2	1	0.010	50.0%

Table 5 provides the same information as Table 4, but compares facilities with a thermal imaging camera to facilities without a thermal imaging camera. Facilities without a thermal imaging camera had an average number of tire violations per inspection of 0.042, while facilities with a thermal imaging camera recorded more than four times as many violations per inspection (0.191). For facilities without thermal imaging cameras, tire OOS violations accounted for 49.1 percent of the tire violations, compared to 76.7 percent at facilities with a thermal imaging camera.

Table 5. Tire-Related Violations and Rates: Comparing Facilities without Thermal Imaging to those with Thermal Imaging

Facility	Total Inspections	Tire Violations	OOS Tire Violations	Avg. Tire Violations Per Inspection	Percentage of Tire Violations That Were OOS Violations
Facilities without thermal imaging	**17073**	**717**	**352**	**0.0420**	**49.09%**
Boone	493	97	42	0.1968	43.30%
Fulton	203	7	2	0.0345	28.57%
Hardin	1938	109	56	0.0562	51.38%
Henderson	1815	40	33	0.0220	82.50%
Laurel SB	1658	33	13	0.0199	39.39%
Lyon EB	1187	40	17	0.0337	42.50%
Lyon WB	959	25	10	0.0261	40.00%
Rowan	4808	212	122	0.0441	57.55%
Scott	3220	132	52	0.0410	39.39%
Shelby EB	583	20	4	0.0343	20.00%
Floyd	209	2	1	0.0096	50.00%
Facilities with thermal imaging	**7624**	**1454**	**1115**	**0.1907**	**76.69%**
Kenton	1902	457	252	0.2403	55.14%
Laurel NB	2498	99	43	0.0396	43.43%
Simpson	3224	898	820	0.2785	91.31%

Table 6 and **Error! Reference source not found.** present data specifically on brake violations. Table 6 summarizes the following data:

- Number of inspections
- Number of brake violations
- Number of OOS brake violations
- Average number of brake violations per inspection
- Each facility's percentage of brake violations that were OOS violations

Again, the numbers of brake violations and OOS brake violations were influenced by the number of inspections performed at each location. Henderson County had the highest number of brake violations per inspection (0.490), followed by Kenton County (0.425), Lyon County EB (0.388), and Boone County (0.381). Shelby County logged the highest percentage of brake violations that were OOS violations (46.7 percent), followed by Floyd County (33.3 percent), but it is critical to note that both of these facilities recorded very few brake violations. When analysis is restricted to stations with at least 100 brake violations, the Kenton County facility had the highest percentage

(32.6 percent), followed closely by Laurel County NB (31.5 percent) and Rowan County (29.6 percent).

Table 6. Brake-Related Violations and Rates for Each Facility

Facility	Total Inspections	Brake Violations	OOS Brake Violations	Avg. Brake Viol. per Inspection	Percentage of Brake Violations that were OOS Violations
Boone	493	188	51	0.381	27.1%
Fulton	203	16	2	0.079	12.5%
Hardin	1938	513	144	0.265	28.1%
Henderson	1815	890	260	0.490	29.2%
Kenton	1902	808	263	0.425	32.6%
Laurel NB	2498	346	109	0.139	31.5%
Laurel SB	1658	352	92	0.212	26.1%
Lyon EB	1187	460	135	0.388	29.4%
Lyon WB	959	276	52	0.288	18.8%
Rowan	4808	808	239	0.168	29.6%
Scott	3220	288	70	0.089	24.3%
Shelby EB	583	30	14	0.052	46.7%
Simpson	3224	1165	311	0.361	26.7%
Floyd	209	3	1	0.014	33.3%

Error! Reference source not found. provides the same information as Table 6, but compares facilities with a thermal imaging camera to those facilities lacking a thermal imaging camera. At facilities without a thermal imaging camera, the average number of brake violation per inspection was 0.224. In contrast, this rate was 36 percent higher at facilities with a thermal imaging camera (0.304). At facilities without thermal imaging cameras, 27.7 percent of the brake violations resulted in an OOS. Facilities with a thermal imaging camera had a slightly higher proportion of brake violations leading to an OOS (29.5 percent).

Table 7. Brake-Related Violations and Rates: Comparing Facilities without Thermal Imaging to those with Thermal Imaging

Facility	Total Inspections	Brake Violations	OOS Brake Violations	Avg. Brake Viol. per Inspection	Percentage of Brake OOS out of all Brake Violations
Facilities without thermal imaging	**17073**	**3824**	**1060**	**0.224**	**27.7%**
Boone	493	188	51	0.381	27.1%
Fulton	203	16	2	0.079	12.5%
Hardin	1938	513	144	0.265	28.1%
Henderson	1815	890	260	0.490	29.2%
Laurel SB	1658	352	92	0.212	26.1%
Lyon EB	1187	460	135	0.388	29.4%
Lyon WB	959	276	52	0.288	18.8%
Rowan	4808	808	239	0.168	29.6%
Scott	3220	288	70	0.089	24.3%
Shelby EB	583	30	14	0.052	46.7%
Floyd	209	3	1	0.014	33.3%
Facilities with thermal imaging	**7624**	**2319**	**683**	**0.304**	**29.5%**
Kenton	1902	808	263	0.425	32.6%
Laurel NB	2498	346	109	0.139	31.5%
Simpson	3224	1165	311	0.361	26.7%

6. Conclusions & Recommendations

KTC's evaluation demonstrated that thermal imaging technology can be extremely effective and highly valuable for detecting commercial vehicle brake and tire violations, with the net result of removing unsafe vehicles from roadways. The 2000 FMCSA study found that the OOS rate for vehicles identified by the system (59%) differed significantly from the control group (19%). The inspection results for the technology's primary user in Simpson County, Kentucky (43 percent vehicle OOS rate over a six-month period) were impressive. There was also a significant difference in the overall vehicle OOS rate logged at stations with thermal imaging technology compared to stations lacking the technology. Because thermal imaging was effective at identifying unsafe vehicles and removing them from service (until the safety deficiencies were corrected), the technology is unquestionably valuable.

Whether thermal imaging technology functions effectively as an enforcement tool was contingent upon two factors. The first was the skill and experience level of the person using the technology. Results from this study, as well as from previous research, confirmed that observed OOS rates varied widely, from a low of 10 percent to a high of 80 percent. The technology being used was virtually identical in each evaluation, so the wide variation in OOS rates was primarily due to the differences in operator skill level.

The second critical factor that affected whether thermal imaging technology was effective was its level of use. If enforcement personnel are not comfortable using the equipment, or if attempts to use it have produced unimpressive results, they may let the technology sit unused while they rely on other methods to select trucks for inspection. This reason partially accounted for why facilities with identical technology had strikingly different inspection results. Over KTC's evaluation period, the three study locations with thermal imaging technology had vehicle OOS rates of 13 percent, 30 percent, and 38 percent. Since they all possessed the same technology, the data likely reflected differences in how (and how much) the technology was used.

To maximize the value of thermal imaging technology for identifying commercial vehicle safety violations, the following actions are recommended:

1. Provide periodic training (initial and refresher) to all enforcement personnel who have access to and are tasked with operating thermal imaging technology. This training should provide:
    - Instructions for using the technology
    - Opportunities to practice using the technology while being observed by trained experts, with feedback given on operational practices
    - Promotional materials that describe the technology's value and the importance of using it
2. Identify and adopt methods to hold enforcement personnel accountable for implementing this technology to improve inspection efficiency. This accountability could take the form of incentives for using it (e.g., awards, contests, recognitions) or disincentives for neglecting to use it.

It is recommended that the above actions be taken before installing thermal imaging equipment at additional sites. It would not be prudent to install the technology at additional sites only to see it poorly implemented or used sparingly.