Smart Infrared Inspection System Field Operational Test

U.S. Department of Transportation
Federal Motor Carrier Safety Administration

April 2014

FOREWORD

One of the main goals of the Commercial Motor Vehicle Roadside Technology Corridor (CMVRTC) is to support and evaluate the use of innovative technologies that improve commercial truck and bus safety. The Smart Infrared Inspection System (SIRIS) was the first technology to be tested and evaluated in the CMVRTC throughout its entire existence.

From the first SIRIS prototype in 2007 until now, SIRIS has proven to be a valuable asset to the commercial motor vehicle (CMV) community by accurately identifying vehicles that should be inspected by a trained CMV inspector.

Throughout this report data is presented that supports the use of SIRIS, or a similar device, at inspection stations across the country. In the future, when States install these devices, trooper productivity will increase, and the number of defective CMVs removed from the highways will increase, ultimately saving lives.

NOTICE

QUALITY ASSURANCE STATEMENT

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16. Abstract

The Smart InfraRed Inspection System (SIRIS) is a tool designed to assist inspectors in determining which vehicles passing through the system are in need of further inspection by measuring the thermal data from the wheel components. As a vehicle enters the system, infrared cameras installed on the road measure temperatures of the brakes, tires, and wheel bearings on both wheel ends of commercial motor vehicles (CMVs) in motion. This thermal data is then presented on a user-friendly interface to enforcement personnel in the inspection station. Vehicles that are suspected to have a violation are automatically alerted to the enforcement staff.

The main goal of the SIRIS field operational test (FOT) was to collect data to evaluate the performance of the prototype system and to determine the viability of such a system being used for CMV enforcement.

Overall, the enforcement personnel who have used SIRIS for screening purposes have indicated that SIRIS has the potential to be an effective tool. With improvements in detection algorithms and stability, the system will be beneficial to the CMV enforcement community and will increase overall trooper productivity by accurately identifying a higher percentage of potentially dangerous CMVs for inspection.

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Commercial motor vehicle, crash avoidance, SIRIS, screening, enforcement	**No restrictions**

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Unclassified	**Unclassified**	**46**	

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SI* (MODERN METRIC) CONVERSION FACTORS

TABLE OF APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	Millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
mi	miles	1.61	Kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME	1000 L shall be shown in m^3	
fl oz	fluid ounces	29.57	Milliliters	mL
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		MASS		
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE	Temperature is in exact degrees	
°F	Fahrenheit	5 × (F-32) ÷ 9 or (F-32) ÷ 1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	Lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		Force and Pressure or Stress		
lbf	poundforce	4.45	Newtons	N
lbf/in^2	poundforce per square inch	6.89	Kilopascals	kPa

TABLE OF APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
Mm	millimeters	0.039	inches	in
M	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2000 lb)	T
		TEMPERATURE	Temperature is in exact degrees	
°C	Celsius	1.8c + 32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		Force & Pressure Or Stress		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.(Revised March 2003, Section 508-accessible version September 2009)

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

CMV	commercial motor vehicle
CMVRTC	Commercial Motor Vehicle Roadside Technology Corridor
FMCSA	Federal Motor Carrier Safety Administration
FOT	field operational test
GUI	graphical user interface
IEM	International Electronic Machine
IS	inspection station
NAS	North American Standard
OOS	out of service
ORNL	Oak Ridge National Laboratory
PBBT	Performance-based Brake Tester
ROI	region of interest
SIRIS	Smart InfraRed Inspection System
TDOS	Tennessee Department of Safety
TDOT	Tennessee Department of Transportation

EXECUTIVE SUMMARY

The Smart InfraRed Inspection System (SIRIS) is a tool designed to assist inspectors in determining which vehicles passing through SIRIS are in need of further inspection. This is accomplished by measuring thermal data from the wheel components. As a commercial motor vehicle (CMV) travels through the system, infrared cameras mounted on the roadside measure temperatures of the brakes, tires, and wheel bearings on both wheel ends of the vehicle. This thermal data is analyzed by SIRIS internally before being presented to enforcement personnel on a user-friendly interface inside the inspection station. Vehicles that are suspected to have a defect are automatically alerted to the enforcement staff.

The main goal of the SIRIS field operational test (FOT) was to collect data to evaluate the performance of the prototype system and to determine the viability of such a system for use in CMV enforcement. From March 2010 to September 2010, researchers facilitated the SIRIS FOT at the Greene County Inspection Station (IS) in Greeneville, Tennessee. During the course of the FOT, 413 CMVs were given a North American Standard (NAS) Level-1 inspection. Of those 413 CMVs, 384 were subjected to a SIRIS screening. A total of 36 (9.38 percent) of the vehicles screened by SIRIS were flagged by the system as having one or more thermal issues, with brake issues making up 33 (91.67 percent) of those. Of the 36 vehicles flagged as having thermal issues, 31 (86.11 percent) were found to have a violation and 30 (83.33 percent) were placed out-of-service (OOS).

With improvements in detection algorithms and stability, the system will be beneficial to the CMV enforcement community and increase overall trooper productivity by accurately identifying a higher percentage of CMVs to be placed OOS with minimal error.

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1. INTRODUCTION

In 2006, International Electronic Machines Corporation (IEM), with support from the U.S. Department of Transportation (USDOT), the Federal Motor Carrier Safety Administration (FMCSA) and the New York State Energy Research and Development Authority, began to develop the Smart Infrared Inspection System (SIRIS) to address many limitations of current thermal prescreening programs.

SIRIS is a tool designed to assist inspectors in determining which commercial motor vehicles (CMVs) passing through the SIRIS system are in need of further inspection. SIRIS collects thermal data from the wheel components and flags anomalies based on temperature differences which indicate possible vehicle deficiencies such as dragging or inoperative brakes, underinflated tires, and wheel bearing failures. As a CMV enters the system, infrared cameras mounted at the roadside measure temperatures of the brakes, tires, and wheel bearings on both wheel ends of the CMV in motion. This thermal data is analyzed internally before being presented to enforcement personnel on a user-friendly interface inside the inspection station (IS). The enforcement staff is automatically alerted to CMVs that are suspected to have a defect.

During the summer of 2007, a first-generation prototype version of the system was deployed at the Greene County, Tennessee, CMV IS within the Commercial Motor Vehicle Roadside Technology Corridor (CMVRTC) for proof-of-concept testing. The SIRIS prototype consisted of roadway components that collected thermal data on brakes, tires, and bearings by infrared cameras while the vehicle was in motion. The ability to screen vehicles in motion allowed for seamless integration into the IS without interfering with normal operation. The prototype also automatically alerted enforcement personnel of any potential defect on a user interface located inside the IS.

Out of that effort, IEM made adjustments to the system configuration. In 2008, IEM made additional modifications to the overall SIRIS configuration. Based on these modifications, a second generation of the SIRIS prototype was deployed for data collection and verification purposes at inspection sites in New York and New Jersey. The data obtained from these sites was analyzed by the University of Michigan Transportation Research Institute with the goal of generating a set of statistically-based procedures for automatic vehicle evaluation. Initial analysis resulted in a procedure that, when applied to actual Level-1 data, allowed SIRIS to accurately identify nearly 65 percent of the vehicles with brake problems, with a very low false positive rate.

In late April 2009, IEM returned its prototype SIRIS to the Greene County site for a 3-week system test and demonstration. For this demonstration, SIRIS used its intelligent imaging evaluation capability. Employing a set of empirically-derived procedures from earlier work in Tennessee, New York, and New Jersey, SIRIS automatically evaluated each CMV as it passed by, and, via a combined audio and visual alert, notified the inspectors at the CMV IS of possible issues with scanned vehicles. Inspectors were taught how to use the SIRIS software to access more detailed thermal information to decide which vehicles required inspection. Of the approximately 2,500 vehicles that were evaluated by SIRIS during the April 2009 testing, 232 (about 9 percent) were flagged as having possible issues with brakes, tires, or bearings. While not conducting a controlled test program during the three-week period, inspectors at the weigh station did conduct 29 Level-1 inspections on vehicles flagged by SIRIS. Of those vehicles inspected, 22 (76 percent) had relevant violations found and 17 (59 percent) were placed out-of-service (OOS)—mostly for brake-related issues. The 3-week program culminated in a day-long demonstration on May 7 to a number of key individuals from the Tennessee Departments of Safety (TDOS) and Transportation (TDOT), the Kentucky Transportation Center of the University of Kentucky, FMCSA, and the research team. During the demonstration, four vehicles were flagged and inspected; three of those were placed OOS, and the fourth had a non-functional brake but was not placed OOS. During the demonstration, each of those vehicles was also tested on the Performance-based Brake Tester (PBBT) with results consistent with those generated by SIRIS.

After the April 2009 testing, SIRIS was tested by the research team at the Greene County IS for a 15-day period during July and August 2009. During the testing, SIRIS operated completely autonomously, evaluating vehicles as they passed through the ramp to the pit scale. The system then alerted inspectors when a thermal anomaly was encountered with a vehicle's brakes, tires, or wheel-end bearings. SIRIS evaluated a total of 4,373 CMVs during this pilot testing. A total of 359 (8.2 percent) of those evaluated were flagged for 1 or more thermal issues, with brakes comprising the largest portion of problems. The majority of CMVs flagged by SIRIS were then given a PBBT test and a NAS Level-1 or NAS Level-2 inspection. This resulted in a total of 275 Level-1 and PBBT inspections and 30 Level-2 inspections being performed. For these 305 vehicle inspections, 193 vehicles were placed OOS for safety issues and an additional 41 inspected vehicles were found to have safety defects that were noted but did not meet OOS criteria. These results are shown in Table 1 and Table 2.

Table 1. Summary of SIRIS test results, 2009.

Test	Result	Percentage
Total Vehicles Scanned by SIRIS	4,373	–
Total Vehicles Flagged by SIRIS	359	8.2%
Flagged for Brakes	328	–
Flagged for Tires	29	–
Flagged for Bearings	2	–
Total Vehicles Subjected to Inspection	305	–
Total Vehicles Placed OOS for Reason Directly Related to SIRIS Flag	193	63.3%
Total Vehicles With Any Flaws Found	234	76.7%

Table 2. Detailed summary of SIRIS flags, 2009.

Type of Flaw Detected	Inspections	OOS	Related Issue or Violation	No Violations Found
Brakes	274	174 63.5%	33 12.0%	67 24.5%
Tires	29	18 62.1%	8 27.6%	3 10.3%
Bearings	2	1 50.0%	– –	1 50.0%
Total	**305**	**193** **63.3%**	**41** **13.4%**	**71** **23.3%**

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2. FIELD OPERATIONAL TEST

The FOT was conducted at the Greene County IS, located on I-81 South in Greeneville, Tennessee, for a period of 7 months (from March 2010 through September 2010).

2.1 DATA COLLECTION

In order to conduct an unbiased evaluation of the SIRIS technology, a test plan was created for enforcement personnel to follow during the FOT. During February 2010, pre-FOT testing was conducted in order to familiarize inspection staff with the test plan and to confirm that the procedures in the test plan were feasible.

Enforcement personnel were asked to perform five inspections during their shifts. This number was chosen to allow for thoroughness of the inspections and record keeping. It was understood that this number of inspections would not be met during all shifts due to circumstances out of the officer's control (e.g. vehicle condition, carrier OOS orders, driver arrest, system downtime due to hardware malfunction, and/or weather).

All inspection data was collected in paper format at the inspection station, and electronic data from the ASPEN inspection reports, sanitized of all personally identifiable driver information, was also received from TDOS in Nashville. This data was processed using data analysis software developed by the research team's laboratory.

2.1.1 Selection of Test Vehicles

To provide a representative sample of all vehicles traveling on I-81 South during the test period, vehicles were selected according to a strict procedure. The plan allowed for all vehicles on the mainline to be sampled (including electronic screening participants) while recognizing and mitigating the risk for significant backup from the pit scale. The procedure was outlined as follows:

1. Turn off electronic screening (set to 100 percent) and divert all CMVs to the high-speed bypass lane (so that the vehicles in this lane will be representative of the mainline).
2. Wait at least 1 minute so the stream of vehicles in the high-speed bypass lane is representative of all vehicles on the mainline. The pit scale lane should be empty before proceeding to Step 3.
3. Divert four consecutive vehicles to the pit scale (diverting these vehicles into the path of the SIRIS system).
4. Divert remaining vehicles back to the high-speed bypass lane and turn electronic screening back on (previous setting), returning all scale facilities to normal operations.
5. Select the fourth vehicle in the queue for the pit scale for inspection under this FOT, regardless of the type of vehicle. This vehicle must be inspected to the fullest extent possible. If the vehicle cannot be placed on the PBBT or inspection pit, conduct as thorough an inspection as possible and note the areas that could not be inspected on the log sheet.

2.1.2 Inspection of Vehicle

Once the vehicle was selected and driver information was checked, the enforcement personnel directed the vehicle to the inspection pit to perform a Level-1 inspection. To keep the evaluation process unbiased, the enforcement personnel performing the Level-1 inspection were not permitted to look at any SIRIS data prior to conducting the inspection. After completing a thorough inspection, the vehicle was directed to pull onto the PBBT. A PBBT test was performed last so that the inspector would not be knowledgeable of any possible brake defects that would be identified by the PBBT.

After these inspections were complete, the inspector recorded all inspection numbers, times and general vehicle information on the log sheet provided (see Appendix A). Normal enforcement protocol was followed regarding any vehicle and/or driver found to have OOS defects.

2.2 TEST EQUIPMENT

2.2.1 SIRIS

The tested version of SIRIS included the following components:

- Two thermal infrared cameras, one on either side of the lane.
- One visible camera.
- One vehicle presence detection sensor.
- Wheel triggers.
- Roadside electronics for system control and power management.
- Cross-lane cabling for remote camera system.
- Fiber cable from roadside to in-scale-house computer.
- Computer system and monitor.
- SIRIS software to evaluate vehicles and to make notification when vehicles with the following conditions were detected:
  - Unusually cool brakes.
  - Overheated brakes.
  - Overheated tires.
  - Overheated wheel bearings.

The roadside SIRIS components are shown in Figure 1 and Figure 2.

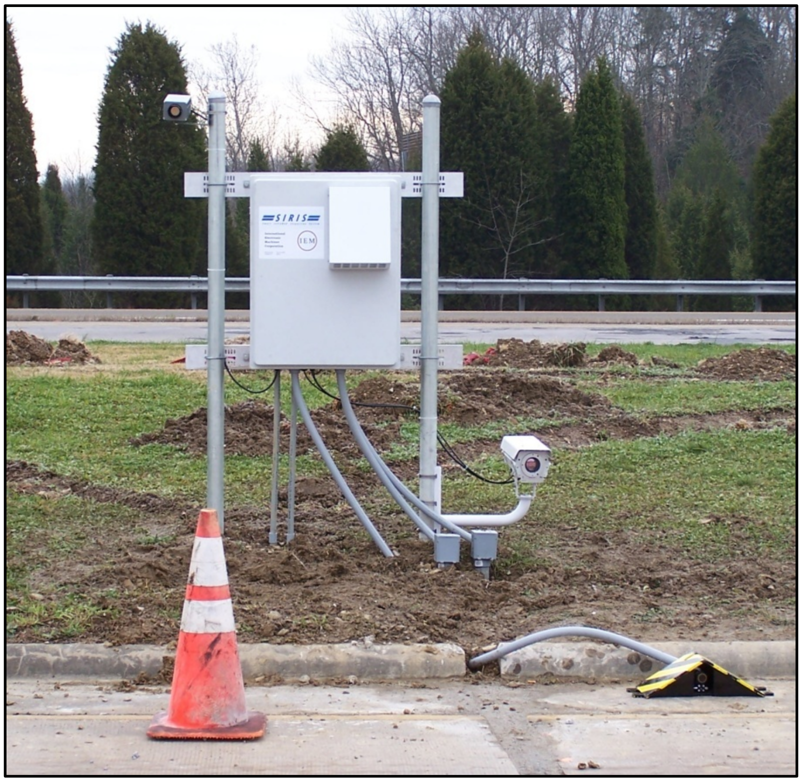

Figure 1. Photo. Driver's side components of the SIRIS system.

Figure 2. Photo. Passenger side components of the SIRIS system.

The SIRIS system was located on the entrance ramp to the pit scale as shown in Figure 3. This location is approximately 200 feet from the IS building, allowing for wide-load vehicles exiting from the parking area to turn back onto the pit scale without the danger of damaging the SIRIS equipment.

Figure 3. Photo. Location of SIRIS system.

2.2.2 Performance-based Brake Tester

PBBTs are devices that can evaluate the current brake efficiency of a vehicle by measuring brake forces developed as the vehicle engages in a braking event while stationed on the device. Since the Greene County IS has an in-ground roller dynamometer PBBT (see Figure 4), testing was also conducted to determine if any correlation existed between SIRIS flags and a PBBT inspection.

Figure 4. Photo. PBBT, located at Greene County Inspection Station.

3. ANALYSIS OF FOT DATA

The main goal of the SIRIS FOT was to collect data to evaluate the performance of this prototype system and to determine the viability of such a system for use in CMV enforcement. Using a typical NAS Level-1 inspection as the "ground truth," the collected SIRIS data was evaluated for accuracy in predicting whether a vehicle would have a potential violation or be placed OOS. The violations that were considered to be SIRIS-related or "detectable" by SIRIS are listed in Appendix B.

The reliability of SIRIS is related to the quality of the image and individual temperature regions (i.e. tire, brake, and bearing). These temperature regions are referred to as regions of interest (ROIs). If the ROI is off-center (see Figure 5) or not detected at all (see Figure 6), the temperatures from those regions are not usable; therefore, wheel-ends with ROI problems were not included in the analysis.

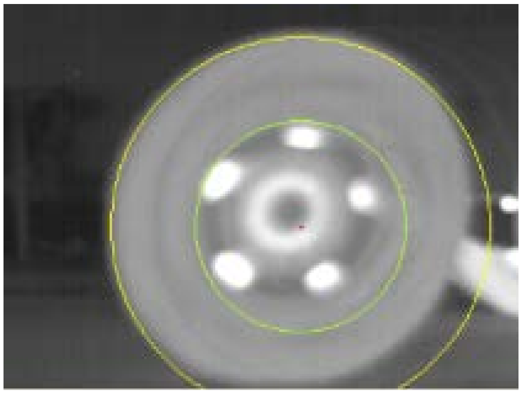

Figure 5. Image. Wheel-end with ROI problems.

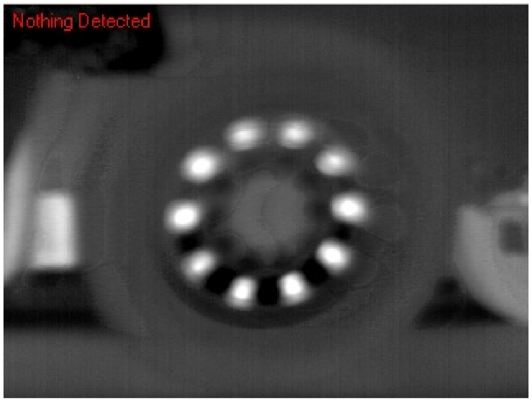

Figure 6. Image. Wheel-end with no ROI detected.

Typically, ROI problems are caused by speeding vehicles, obstructed camera views, and hardware malfunctions. Table 3 shows the percentage of all wheel ends that had ROI problems associated with them.

Table 3. Percentage of ROI problems per axle.

Axle	Percentage of ROI
Axle 1 (Left)	3.63%
Axle 2 (Left)	4.12%
Axle 3 (Left)	2.48%
Axle 4 (Left)	2.99%
Axle 5 (Left)	9.11%
Axle 1 (Right)	9.93%
Axle 2 (Right)	5.81%
Axle 3 (Right)	3.22%
Axle 4 (Right)	4.73%
Axle 5 (Right)	10.89%

3.1 SIRIS FLAG ANALYSIS

During the test period, 413 vehicles were randomly selected from the mainline and 384 were scanned by SIRIS. The 29 vehicles that were not scanned by SIRIS because of system malfunction or downtime were still given a Level-1 inspection and PBBT. As shown in Table 4, 36 of the vehicles that were selected were flagged by SIRIS as possibly having a brake or tire violation (in no case did SIRIS flag for both brake and tire). All 36 of those vehicles were subjected to a Level-1 inspection resulting in 30 (83.3 percent) vehicles being placed OOS for a related violation, and 31 (86.11 percent) of the total vehicles having a flaw of some type relative to brakes, tires, or wheel bearings.

Table 4. Summary of SIRIS FOT results.

Test	Result	Percentage
Total Vehicles Scanned by SIRIS	384	–
Total Vehicles Flagged by SIRIS	36	9.38%
Flagged for Brakes	33	–
Flagged for Tires	3	–
Flagged for Bearings	0	–
Total Vehicles Subjected to Inspection	36	–
Total Vehicles Placed OOS for Reason Directly Related to SIRIS Flag	30	83.33%
Total Vehicles with Any Flaws Found	31	86.11%

Table 5 shows a more detailed breakdown of the SIRIS flags. Most of the flags were brake-related and had a false-positive rate of 15.2 percent and an 84.8-percent success rate in identifying a related violation on the vehicle. When a tire was flagged by SIRIS as having a potential violation, the resulting Level-1 inspection placed the vehicle OOS 100 percent of the time. In this particular evaluation, the sample size was relatively small. Thus, definite conclusions about tire flags cannot be made; however, from previous testing it can be inferred that the success rate on tire flags would be approximately the same, if not better than brake flags. Overall, SIRIS had an 86.11 percent positive flag rate (as shown in Table 4).

Table 5. Detailed summary of SIRIS flags.

Type of Flaw Detected	Inspections	OOS	Related Issue or Violation	Nothing Found
Brakes	33	27 81.8%	1 3.0%	5 15.2%
Tires	3	3 100%	–	–
Bearings	0	–	–	–
Total	**36**	**30** **83.33%**	**1** **2.78%**	**5** **13.89%**

It is helpful for enforcement personnel in the field to know that a vehicle flagged by SIRIS would be very likely to have an associated violation. This allows officers to focus their time on vehicles with brake violations. Brake problems are the most common vehicle-associated factor in large truck crashes (at approximately 29 percent), thus focusing more time on brake violations would likely have an effect on the number of CMVs involved in accidents.[(1)] Table 6 shows the OOS rate and violation rate of test vehicles based on the amount of SIRIS flags that occurred on the inspected vehicle. Vehicles with one or two flags were placed OOS 83.3 percent of the time. Vehicles in the field that are flagged by SIRIS are very likely to be placed OOS if inspected by enforcement personnel.

Table 6. Summary of results per number of SIRIS flags.

No. Flags	No.	OOS Rate	Mean Brake Violation Rate	Mean Tire Violation Rate	Mean Bearing Violation Rate
1	16	81%	2.7500	1.0625	0.0000
2	14	85%	3.0000	0.4286	0.0000
3	3	100%	7.6667	1.3333	0.6667
4	2	50%	2.0000	0.0000	0.0000
5+	1	100%	4.0000	4.0000	0.0000

3.2 INSPECTION CORRELATION

Correlation data shown in Table 7 and Table 8 only include brake-related results. Tire and bearing data was not statistically significant, with only three total flags, and thus was not included in the tables shown below. These findings show that if SIRIS were to be used as anything other than a screening tool, it would not be able to reliably place vehicles OOS without a PBBT or Level-1 Inspection.

Table 7. SIRIS—Level-1 correlation results.

Flag	Pass, No Brake Defects	Pass, with Defects Detected	Fail
Flagged	1.30% 5	0.26% 1	7.03% 27
Not Flagged	30.73% 118	4.17% 16	56.51% 217

Table 8. SIRIS—PBBT correlation results.

Flag	Pass	Fail
Flagged	5.25% 19	3.31% 12
Not Flagged	67.13% 243	24.31% 88

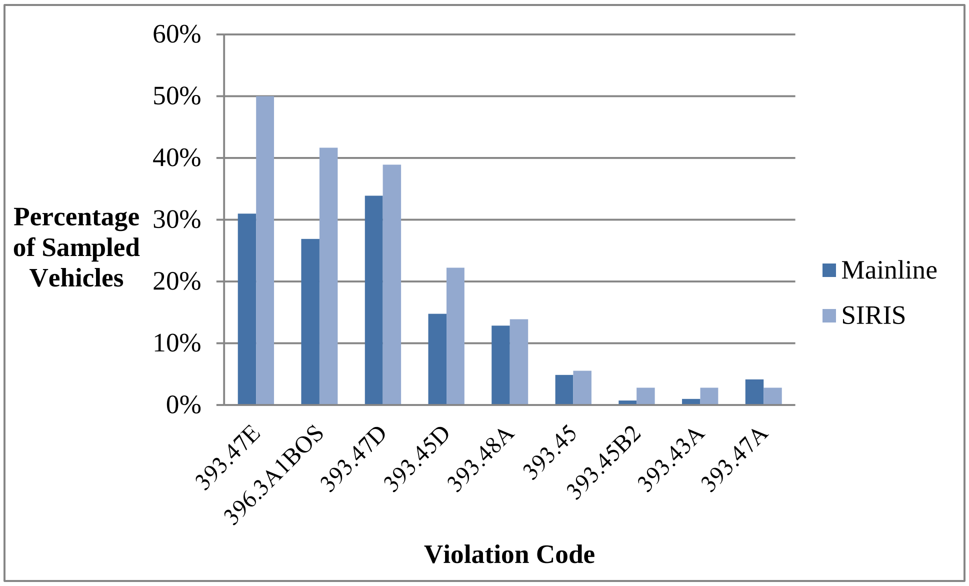

Figure 7. Brake violation correlation.

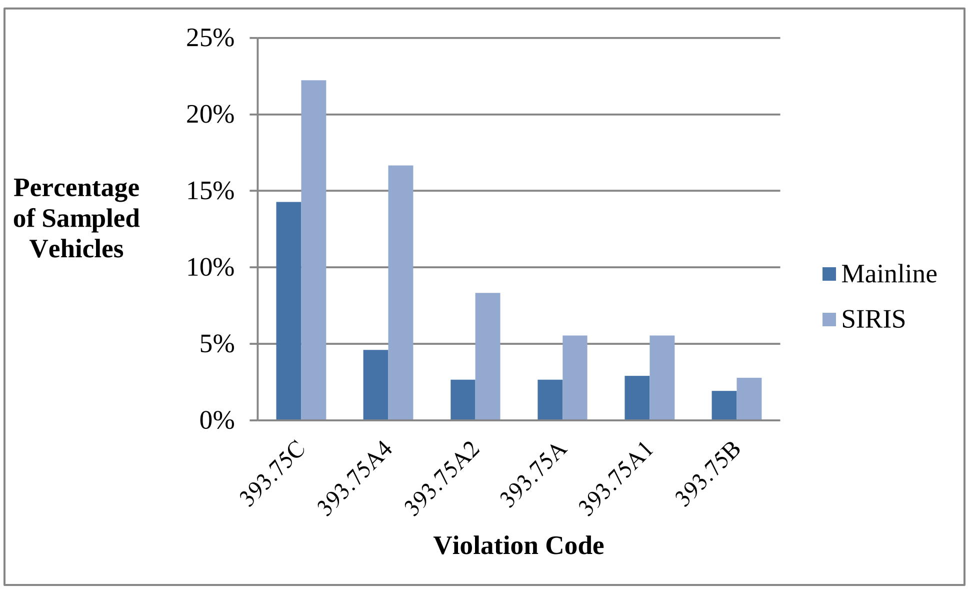

Figure 8. Tire violation correlation.

3.3 COMMON VIOLATIONS OF SIRIS FLAGGED VEHICLES

Vehicles that were flagged by SIRIS as having a possible violation typically had similar violations found during the Level-1 inspection. Since SIRIS uses ambient temperature and ROI temperatures to determine whether a wheel-end needs to be inspected, a detected brake flag would not necessarily mean a brake violation, but could be a sign of another possible vehicle defect that prevents the brake from performing optimally (e.g., flat tire shifted weight causing brake to exert more force to stop). The violations listed in the tables in the next subsections are shown in order of decreasing frequency in the inspected vehicles that were flagged by SIRIS.

3.3.1 Brake Violations

Table 9 shows the most common brake violations of all the SIRIS vehicles that were flagged. It is clear that the majority of the brake violations found were due to insufficient brake linings and out-of-adjustment brakes.

Table 9. Brake violations of vehicles flagged by SIRIS.

Violation Code	Number of Vehicles	Number of Wheel Ends	Description of Violation
393.47E	18	50	Clamp or Roto-type brake out-of-adjustment
396.3A1BOS	15	15	Brakes did not meet 20% criteria
393.47D	14	31	Insufficient brake linings
393.45D	8	8	Brake connections with leaks or constrictions
393.48A	5	7	Inoperative or defective brakes
393.45	2	2	Brake tubing and hose adequacy; emergency line to trailer outer layer peeled
393.45B2	1	1	Brake hose or tubing chafing and/or kinking
393.43A	1	1	No or improper tractor protection valve
393.47A	1	2	Inadequate brakes for safe stopping

3.3.2 Tire Violations

Of the vehicles flagged by SIRIS, very few tire violations were found as compared to brake violations. Table 10 shows the tire violations of vehicles flagged by SIRIS.

Table 10. Tire violations of vehicles flagged by SIRIS.

Violation Code	Number of Vehicles	Number of Wheel Ends	Description of Violation
393.75C	8	15	Tire – other: tread depth less than 2/32 of inch
393.75A4	6	8	Tire – cut: exposing ply and/or belt material
393.75A2	3	3	Tire – tread and/or sidewall separation
393.75A	2	2	Flat tire or fabric exposed
393.75A1	2	2	Tire – ply or belt material exposed
393.75B	1	1	Tire – front tread depth less than 4/32 of inch

3.3.3 Bearing Violations

As shown in Table 11, there was only one vehicle which had a bearing violation and no SIRIS bearing violations. Based on the number of vehicles flagged, this is not a significant finding.

Table 11. Bearing violations of vehicles flagged by SIRIS.

Violation Code	Number of Vehicles	Number Wheel of Ends	Description of Violation
393.209D	1	2	Steering system components worn, welded, or missing

3.3.4 Driver Violations

As shown below in Table 12, for the vehicles flagged by SIRIS, there was no correlation between vehicles with violations and drivers' violations.

Table 12. Driver violations of vehicles flagged by SIRIS.

Violation Code	Number Of Drivers	Description of Violation
391.11B4	4	Using a physically unqualified driver
392.16	4	Failing to use seat belt while operating CMV
395.8E	3	False report of drivers Record of Duty Status
392.5A	1	Driver consuming an intoxicating beverage within 4 hours
395.8	1	Record of Duty Status violation (general/form and manner)
392.2	1	Local laws (general)
392.60A	1	Unauthorized passenger on board CMV
395.3A2/R	1	14-hour rule violation (Property)
395.8A	1	No driver's Record of Duty Status
392.2W	1	Size and weight
395.8F1	1	Drivers Record of Duty Status not current
395.3A1/R	1	11-hour rule violation (Property)
391.45B	1	Expired medical examiner's certificate

3.3.5 Miscellaneous Vehicle Violations

Similar to the driver violations, the miscellaneous violations shown in Table 13 have no correlation with the vehicles flagged by SIRIS.

Table 13. Miscellaneous violations of vehicles flagged by SIRIS.

Violation Code	Number of Vehicles	Total Occurrences	Description of Violation
393.9TS	5	8	Inoperative turn signal
396.7	5	6	Unsafe operations forbidden
393.53B	3	3	CMV manufactured after 10/19/94 has an automatic airbrake adjustment system that fails to compensate for wear
396.17C	2	2	Operating a CMV without periodic inspection
392.9A	1	1	Failing to secure load
393.25F	1	1	Stop lamp violations

Violation	Number of	Total	Description of Violation
393.207A	1	1	Axle positioning parts defective/missing
393.95A	1	1	No/discharged/unsecured fire extinguisher
393.201A	1	1	Frame cracked/loose/sagging/broken
393.9	1	1	Inoperable required lamp
396.5B	1	1	Oil and/or grease leak
393.76	1	1	Sleeper berth requirement violations
392.2RG	1	1	State vehicle registration or license plate violation
392.2FT	1	1	State or International Fuel Tax violation
393.60C	1	1	Damaged or discolored windshield
393.104B	1	1	Damaged securement system/tie-downs
392.2IRP	1	1	International Registration Plan apportioned tag or registration violation
393.9H	1	1	Inoperable head lamps
392.2WC	1	1	Wheel (mud) flaps missing or defective
393.100A	1	1	No or improper load securement
392.60A	1	1	Unauthorized passenger on board CMV
393.9T	1	1	Inoperable tail lamp
392.2	1	1	Local laws (general)
393.7	1	1	Fifth wheel
392.2W	1	1	Size and weight
393.43	1	1	No or improper breakaway or emergency braking
385.325C	1	1	Operating in interstate commerce on or after the operational OOS order date
392.2DIM	1	1	Dimension violation

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4. LESSONS LEARNED

4.1 SIRIS FUNCTIONALITY ISSUES

During the course of the FOT, there were 12 recorded instances where SIRIS became inoperable or performed in a manner that made it unusable by IS personnel. Research team staff and inspection personnel were asked to keep track of any problems with SIRIS by logging them onto the “SIRIS Problem Log Sheet” (Appendix C). Not all problems were logged due to the busy nature of the IS. However, most of the recorded problems were similar in nature and were easily corrected with a system reboot. There was a period of time where SIRIS was nonfunctioning due to a hardware malfunction; no testing was performed during this time. The situation was resolved in a timely manner by IEM and did not negatively affect the FOT data collection period.

The major problem with SIRIS throughout the FOT was the effect of weather on the image quality and functionality of the system. Whenever there was cold weather, the incidence of false positive flags increased dramatically based on anecdotal evidence from the troopers and research team staff, especially related to tires. When there was heavy precipitation, the image quality was reduced, which caused fewer flagged vehicles to be observed and the system would randomly take pictures even if no vehicle was present. It should be noted that enforcement personnel typically do not inspect vehicles in harsh weather, thus, weather anomalies did not negatively affect the results during the FOT. The troopers also noted on the log sheets downtime of the system due to power surges during storms or unexpected malfunctions during normal use.

Another issue with SIRIS was related to the software and/or hardware inside the IS. Occasionally, the SIRIS graphical user interface (GUI) would lock up and not inspect vehicles until the power to the cameras was cycled or the computer was rebooted. This occurred on a regular basis during the FOT. It was noted that this phenomenon typically occurred after a vehicle passed too quickly through SIRIS.

4.2 TROOPER FEEDBACK

At the end of the evaluation, enforcement personnel familiar with SIRIS were asked questions (see Appendix D) regarding the functionality of SIRIS, and how they envisioned SIRIS being used in the future. The research team received five completed questionnaires (responses to questionnaires are shown in Appendix E).

In general, SIRIS was believed to have great potential in the enforcement community relative to increased productivity when used as a screening tool. However, all of the troopers agreed that in its current condition, SIRIS was not ready for national deployment because of instability and inaccuracy in flagging vehicles with potential defects. Many of the troopers were concerned with the level of downtime for SIRIS and the number of times the cameras had to be reset in order for vehicles to be detected.

Many troopers would like the detection rate to be higher (at the time of the FOT, the detection rate was around 10 percent), and when a vehicle is flagged, they want to absolutely be certain that it will have a violation or be placed OOS. Also, due to the amount of false alarms, troopers mentioned that in some cases the SIRIS alarms were not as helpful as the actual temperatures on the SIRIS GUI in determining if a vehicle needed to be inspected. In these situations, the troopers used their experience with SIRIS to determine whether or not a vehicle should be pulled in for inspection following an alert.

While it would be impossible to flag every single vehicle with a possible defect, the likelihood of a vehicle having a defect if flagged cannot be overlooked. Since not all vehicles can be inspected due to limited resources, using SIRIS as a screening tool to determine if a vehicle should be inspected is a great improvement over the traditional method of choosing vehicles.

5. CONCLUSIONS

The SIRIS device developed and tested during this project proved to be a viable screening tool for the detection of vehicles with brake defects when one excludes the stability and operational issues encountered during the data collection period. This was borne out by the data analysis (81.8 percent of the vehicles flagged by SIRIS were placed OOS for brakes) and by testimonies from the Tennessee Highway Patrol staff who used the device on a day-to-day basis. Additionally, for the small sample of tire data, it appears that SIRIS may be an effective screening tool for dangerously overheated tires due to pressure or loading issues.

While the vehicle defect and OOS statistics for the vehicles flagged by SIRIS are impressive, the automated nature of the SIRIS system bridges the gap between being just another time-consuming enforcement tool and a viable screening system for use in low-speed applications. The use of SIRIS in high-speed applications would not be desirable because in order to assess brake functionality thermally, the vehicle's brakes would need to be applied before the thermal scan is completed. Ideally, the system would be placed directly in front of a pit scale to take full advantage of the braking event. However, at the Greene County IS this was not physically possible because of lane width.

The overall value to enforcement of the current SIRIS system is limited to a large degree by the documented instability and operational issues believed to be caused by power fluctuation, inclement weather, and SIRIS's sensitivity to vehicles traveling at speeds greater than the thermal system can accurately detect. The latter issue could be corrected by the deploying site with proper machine placement and speed control signage.

From a qualitative standpoint, the SIRIS device, if deployed, could focus the limited resources of commercial vehicle inspection agencies to inspect vehicles with a high probability of having a brake or tire defect. From a quantitative standpoint, the inability of the current SIRIS device to remain operational within the ramp-side environment precludes its value to enforcement. Work must be done to overcome the stability and operational issues with the overall system for SIRIS to become a viable mainstream tool. These stability and operational issues should not overshadow the fact that the current optical system and decision-making algorithm have produced results that could clearly have a positive effect on the OOS rates of commercial vehicles and the related crash rate.

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6. NEXT STEPS

Upon demonstration of the effectiveness and accuracy of SIRIS in detecting potential safety issues with brakes, tires, and wheel hubs in this FOT, it is anticipated that States will begin to implement this type of technology at fixed and mobile inspection sites. At fixed sites, SIRIS-like systems can be permanently installed on the off ramp, and portable systems developed during the FOT can be used at mobile sites. These options will provide States with flexibility when deploying the system in areas of interest, such as motorcoach parking lots at large events, toll booths, and noted bypass routes.

Funding for these systems will likely be obtained through the Agency's Commercial Vehicle Information Systems and Networks Program. To assure that these systems attain a similar level of accuracy and effectiveness (as was achieved in the FOT), FMCSA will develop and publish testing and performance requirements. This will provide States with guidelines for making funding decisions as more manufacturers begin to offer the systems.

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APPENDIX A: MAINLINE BRAKE ASSESSMENT CORRELATION LOG SHEET

In order to make this test unbiased, please make sure that the **SIRIS monitor and sound are turned off**, and the results are not used or collected until after the Level-1 Inspection and PBBT. Please also take measures to ensure **proper times for tests are recorded**. The target number of inspections for an 8-hour shift is five (5) (or three [3] for a 4-hour shift). It is understood that the target number of inspections may not be reached due to complications arising from a given inspection. If the target number of inspections cannot be reached in a given shift, please note the extenuating circumstance(s)**. Note: Care and thoroughness of inspection and supporting paperwork are far more important than the number of inspections performed (for the purposes of this research and the overtime grant).**

This log sheet is to be used for randomly-selected vehicles ONLY.

Tractor Description Color: ____________ Ownership/Operation ☐ Independent owner/operator ☐ Company-owned ☐ Leased	Date	
	Time	
	License Plate	
	Make	
Trailer Description Color: ____________ Ownership/Operation ☐ Company-owned ☐ Leased ☐ Drop-and-hook	Model year	
	Mileage	
	Other information	

1. Print vehicle weigh ticket and record GVW	
2. Perform a Level-1 inspection and record the report number	
3. Perform PBBT test and record test number (see printout)	
4. Print out SIRIS inspection and record the inspection number	
5. Identify axle ends with SIRIS ROI problems	
6. Check tires for problems such as mismatched tire heights, low pressure, etc. ☐ None found ☐ Yes, problem(s) described below:	
7. Comments	

Attach the following documents and place in the ORNL wall pocket:

- Weigh ticket
- Level-1 inspection report
- PBBT results
- SIRIS printout

APPENDIX B: VIOLATIONS ASSOCIATED WITH SIRIS

Reg Code	Type	Notes
393.44	B	NO/DEFECTIVE BUS FRONT BRAKE LINE PROTECTION
393.45	B	BRAKE TUBING AND HOSE ADEQUACY
393.40	B	INADEQUATE BRAKE SYSTEM ON A CMV
393.41	B	NO/DEFECTIVE PARKING BRAKE SYSTEM ON CMV
393.42	B	NO BRAKES AS REQUIRED
393.42A	B	NO BRAKES ON ALL WHEELS AS REQUIRED
393.42B	B	NO/DEFECTIVE FRONT WHEEL BRAKES AS REQ
393.43	B	NO/IMPROPER BREAKAWAY/EMERG BRAKING
393.43A	B	NO/IMPROPER TRACTOR PROTECTION VALVE
393.43D	B	NO/DEFECTIVE AUTOMATIC TRAILER BRAKE
393.45	B	BRAKE TUBING AIR HOSE ADEQUACY
393.45B2	B	BRAKE HOSE/TUBING CHAFFING/KINKING
393.45B3	B	BRAKE HOSE/TUBE CONTACT EXHAUST SYSTEM
393.45D	B	BRAKE HOSE/TUBE CONNECTION
393.45D	B	BRAKE CONNECTIONS WITH LEAKS/CONSTRICT
393.47	B	INADEQUATE BRAKE LINING FOR SAFE STOPPING
393.47A	B	INADEQUATE BRAKES FOR STOPPING
393.47D	B	INSUFFICIENT BRAKE LININGS
393.47E	B	CLAMP OR ROTO TYPE BRAKE OUT-OF-ADJUSTMENT
393.48A	B	INOPERATIVE/DEFECTIVE BRAKES
393.48B1	B	DEFECTIVE BRAKE LIMITING DEVICE
393.50	B	INADEQUATE RESERVOIR, AIR/VACUUM BRAKES
393.50A	B	FAIL TO HAVE SUFFICIENT AIR/VACUUM RESERVE
393.50B	B	FAIL TO EQUIP VEH-PREVENT RES AIR/VAC LEAK
393.50C	B	NO MEANS TO ENSURE OPERABLE CHECK VALVE
393.51	B	NO/DEFECTIVE BRAKE WARNING DEVICE
393.75	T	TIRES/TUBES (GENERAL)
393.75A	T	FLAT TIRE OR FABRIC EXPOSED
393.75A1	T	TIRE-PLY OR BELT MATERIAL EXPOSED
393.75A2	T	TIRE-TREAD/SIDEWALL SEPERATION
393.75A3	T	TIRE-FLAT/AUDIBLE AIR LEAK
393.75A4	T	TIRE-CUT EXPOSING PLY/BELT MATERIAL
393.75B	T	TIRE-FRONT TREAD DEPTH LESS THAN 4/32 INCH
393.75C	T	TIRE-OTHER TREAD DEPTH LESS THAN 2/32 INCH
393.75D	T	TIRE-BUS REGROOVED/RECAP ON FRONT WHEEL
393.75E	T	TIRE-REGROOV ON FRNT OF TRUCK/TRUCK/TRAC
393.75F	T	TIRE-LOAD WEIGHT RATING/UNDER INFLATED
393.75F2	T	TIRE-UNDER-INFLATED
393.75F4	T	FLAT TIRE
393.209D	R	LOOSE BEARING
396.3A1B	B	BRAKES (GENERAL)
396.3A1BA	B	BRAKE-OUT OF ADJUSTMENT
396.3A1BC	B	BRAKE-AIR COMPRESSOR VIOLATION
396.3A1BD	B	BRAKE-DEFECTIVE BRAKE DRUM

Reg Code	Type	Notes
396.3A1BH	B	BRAKE-HOSE/TUBE DAMAGE/LEAKING
396.3A1BL	B	BRAKE-RESERVE SYSTEM PRESSURE LOSS

APPENDIX C: SIRIS PROBLEM LOG SHEET

This log sheet is to be used when any problem with SIRIS occurs such as weather related issues, detection issues, or any other issues that cause the system to not function properly.

Date		Time	
Trooper (in case of additional questions concerning SIRIS issue)			
Describe the issue with SIRIS:			
Action(s) performed to resolve issue:			

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APPENDIX D: SIRIS FIELD OPERATIONAL TEST QUESTIONNAIRE

The purpose of this questionnaire is to get a sense of the overall end-user acceptance of SIRIS. Answers and comments will be anonymously included in the Final Report.

1. Briefly describe your experience working with SIRIS.

2. How effective has SIRIS been in screening vehicles for inspection? Briefly explain why or why not.

3. What changes (if any) would you make to the SIRIS system including the way the information is displayed on the user screen?

4. Do you believe that a system such as SIRIS is ready for national deployment? Explain.

5. How would you envision a system as such SIRIS being used in your operations if it were a permanent device?

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APPENDIX E: TENNESSEE HIGHWAY PATROL QUESTIONNAIRE ANSWERS

1. Briefly describe your experience working with SIRIS.

a. Have used on multiple occasions as overtime grant – collection of data etc.
b. Have used on multiple occasions – grant overtime, etc. grant research etc.
c. Interaction at the Greene Co. Scales. I have spent more time working on it than working with it.
d. Use it every day that it works.
e. SIRIS has been installed at our facility. I have conducted numerous inspections based on the SIRIS indicators.

2. How effective has SIRIS been in screening vehicles for inspection? Briefly explain why or why not.

a. Very small percentage of accuracy. Very sound in theory and idea, however I believe it needs to be greatly fine-tuned.
b. Detect a potential lack of performance, needs more stability, application method has signs of impairment. I have multiple concerns into the testing of the program, over "screening" versus "inspecting" vehicles have become a hot topic.
c. Somewhat…you have to learn to ignore the alarm and read the temperatures yourself and take more things like weight of load into consideration.
d. Is a good screening tool when you learn to draw your own judgments from the alerts.
e. About 20% defects indicated have been found during my inspections, however the machine has proven to be very environmentally sensitive to rain and temperature differences. I have also had a lot of difficulty in keeping the computer and cameras operating.

3. What changes (if any) would you make to the SIRIS system including the way the information is displayed on the user screen?

a. None – The design & display of information is very good (just the accuracy).
b. None. Just look at its operational policies to ensure that it has provided appropriate guidance to enforcement personnel so that they are able to make uniform decisions throughout.
c. I would make it more reliable and consistent so trooper could depend on it to work. The parameters would be reworked for a more accurate defect rate when alarm is obtained.
d. Make the unit more robust. No so sensitive to weather. Screen display is great when working. More work is needed to stop false alarms.
e. Display is OK.

4. Do you believe that a system such as SIRIS is ready for national deployment? Explain.

a. No – At this point I believe it takes more time to screen SIRIS than it does to walkout side & screen the vehicle personally.
b. Yes. Truly it's a rewarding experience and reinforces your belief that the alliance is headed in the right direction. I encourage others to get involved and take on responsibility. You will learn a lot, have a greater appreciation for SIRIS, and want to contribute to furthering its mission.
c. No. Too much time spent keeping system up and running. Disconnected socket, no picture, and showing 15 axles when truck only has 5 or showing two when truck has 5.
d. Not reliable enough at this time.

e. No. The system is unreliable. It won't stay operational and continuously needs to be reset. Ambient temperature makes it fair weather only device. It also has too many false positives.

5. How would you envision a system as such SIRIS being used in your operations if it were a permanent device?

a. At present it is an OK tool. If SIRIS was more accurate and dependable, it would be a great tool. [If] It could determine 100% of the vehicles we would check or inspect. Bottom line – If it was more accurate it would be invaluable. As it is, I believe a quick walk around the vehicle is more beneficial.
b. I envision the smart infrared inspection system (SIRIS) as [it] saves time for the inspectors and increases inspector productivity. I would benefit greatly because (SIRIS) has the potential to automatically target unsafe trucks and buses for further inspection by roadside/scale complex thus reducing the likelihood of these vehicles being involved in crashes and vehicle fires. Knowing I had a system like (SIRIS) would have potential to save hundreds of staff hours by identifying unsafe vehicles for inspection.
c. It has potential of being a great screening tool. It could help you spend your time checking trucks that need to be checked. It seems to be in a really early stage of development
d. Great screening tool.
e. The idea of temperature relating to vehicle defects is a sound theory if you have a reliable and efficient method of determination. This would allow for more time to be spent with problem vehicles and less time with good ones resulting in more unsafe operators being removed from service.

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1 U.S. Department of Transportation, Federal Motor Carrier Safety Administration, Report to Congress on the Large Truck Crash Causation Study. March 2006.

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