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Evaluation of Infrared Brake Screening Technology: Final Report

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16. Abstract

This report documents the results of a field evaluation of the InfraRed Inspection System (IRISystem). The objective of the evaluation was to determine the effectiveness of the IRISystem in enhancing the screening of commercial motor vehicles (CMVs) in real time at the roadside for problematic conditions, primarily malfunctioning brakes. Four states - Georgia, Kentucky, North Carolina and Tennessee - participated in the evaluation for one year.

CMVs were screened by IRISystem while in queue at scale sites and subsequently subjected to a CVSA Level 1 (L1) inspection. A limited number of vehicles with no apparent problematic conditions were also inspected as a control group for the study. Fifty-nine percent of the vehicles screened by the IRISystem as problematic were placed out of service (OOS) in the Level 1 inspection, mostly for brake violations (nearly 80%). The percentage of vehicles placed OOS after IRISystem screening (59%) exceeded the effectiveness criterion of 50% defined by the State of Kentucky in this program for the vehicle-by-vehicle analysis.

The percentage of CMVs placed out of service with brake problems increased by a factor of 2.5 after using the IRISystem to screen vehicles for inspection. Additional considerations (training requirements, set up requirements, advantages, and limitations) are also reported herein.

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Abbreviations

3-S2	Combination vehicle including a 3-axle tractor and a 2-axle trailer
CFR	Code of Federal Regulations
CMV	Commercial Motor Vehicle
CVSA	Commercial Vehicle Safety Alliance
DOT	Department of Transportation
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FMCSR	Federal Motor Carrier Safety Regulation
FMVSS	Federal Motor Vehicle Safety Standard
IRISystem	InfraRed Inspection System
L1	Level 1
MCSAP	Motor Carrier Safety Assistance Program
NHTSA	National Highway Traffic Safety Administration
OMCS	Office of Motor Carrier Safety
OOS	Out Of Service
PBBT	Performance-Based Brake Tester

Definitions

Blind vehicle	A vehicle selected for a Level 1 inspection even though the IRISystem did NOT identified potential problems.
Defective brake	A brake found to have a FMCSR defect by the Level 1 inspection or, A brake that can not meet a minimum torque output.
Defective vehicle	A vehicle for which the Level 1 inspection reported one or more violations to safety regulations.
False positive	*Wheel-by-wheel*: one or more defect(s) (FMCSR violation(s)) were found on a wheel previously judged normal by the IRISystem operator, *Vehicle-by-vehicle*: a vehicle judged as blind, non-problematic by the IRISystem operator was placed OOS during the level 1 inspection.
False negative	*Wheel-by-wheel*: no defect (or FMCSR violation) was found on a wheel previously judged problematic by the IRISystem operator, *Vehicle-by-vehicle*: a vehicle judged as problematic by the IRISystem operator was NOT placed OOS during the level 1 inspection.
Normal brake	A brake, which according to the IRISystem operator, does not appear hotter or colder than the other brakes on the vehicle.
OOS vehicle	A vehicle for which FMCSR defect(s) meet one or more CVSA-defined out-of-service criteria, (i.e. the vehicle presents an imminent hazard).
Problematic brake	A brake, which according to the IRISystem operator, appears significantly colder or hotter than the other brakes on the vehicle.
Problematic vehicle	A vehicle selected for a Level 1 inspection and for which the IRISystem identified one or more potential problems.

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Executive Summary

Introduction

The InfraRed Inspection System (IRISystem) was evaluated in a field study to determine the effectiveness of this new technology for enhancing the screening of commercial motor vehicles (CMVs) for subsequent inspection.

The IRISystem is housed in a mobile van and can be positioned in a roadside inspection facility where commercial motor vehicles are applying their brakes to enter the facility. The IRISystem camera creates an infrared image of the CMV showing the relative temperature of wheels on the vehicle as the operator tracks the vehicle with the camera controls. After the CMV's brakes have been applied, a functional brake appears bright white, indicating that it is "hot." A non-functioning brake appears dark, or "cold."

Scope and Objectives

The objective of the evaluation was to determine the effectiveness of the IRISystem in enhancing the screening of CMVs in real-time at the roadside. The IRISystem was evaluated as a means to:

- Detect problematic CMV conditions--mainly brake-related defects. The IRISystem results were compared directly with roadside inspection results (on a wheel-by-wheel and vehicle-by-vehicle basis) and,
- Improve the existing screening methods. The roadside inspection results obtained after IRISystem screening were compared with roadside inspection results obtained after current screening (SafetyNet data).

Description of the program

Four states participated in the evaluation over the course of one year: Kentucky, Georgia, North Carolina and Tennessee. In this project, CMVs were screened by the IRISystem operator, and subsequently subjected to a CVSA Level 1 (L1) inspection. The IRISystem was set up at selected locations where CMVs could be readily screened and inspected, primarily while at scale sites on highways.

Results

Summary of data collected

Nearly 400 CMVs were inspected following IRISystem screening by the four states in one year. To improve the objectivity of the study, 62 vehicles with no apparent problems ("blind" vehicles) according to the IRISystem operator were selected also for a Level 1 inspection. These blind, non-problematic vehicles (per IRISystem screening results) represented 16% of the total population of CMVs tested in the evaluation.

Approximately 10% of the wheels screened by the IRISystem (399 out of 3769) were identified as problematic and cold, and about 1% of the wheels screened by the IRISystem (44 out of 3769) were identified as problematic and hot.

Most of the problems identified during the IRISystem screening were located on the trailer wheels located on the far side of the CMV (with respect to the IRISystem van). Wheel covers on the near-side wheels tended to obscure the infrared image, whereas the far-side wheels were easier to evaluate because of a better line of sight to the back of the wheel and slightly more viewing time as the CMV passed in front of the IRISystem van. The presence of brake defects or deficiencies was a good indicator that other repairs were needed on the CMV.

Identification of Out-Of-Service CMVs (Vehicle-by-vehicle Analysis)

For all participating states, fifty-nine percent (194 out of 330) of vehicles screened by IRISystem as problematic were subsequently placed OOS in the Level 1 inspection. Seventy-nine percent (153 out of 194) of the screened OOS vehicles were placed OOS as a result of brake violations, among which 22% (42 out of 194) had brake and other OOS violations (for example, driver related violations). The percentage of blind, non-problematic vehicles placed OOS (false negatives) was 19% (12 out of 62).

The effectiveness criterion defined by Kentucky was 50% for the vehicle-by-vehicle analysis (meaning 50% of the vehicles screened as problematic should be confirmed as defective by the Level 1 inspections). The effectiveness criterion defined by Kentucky was met in all four states.

IRISystem as a screening device:
Does the IRISystem improve the current screening method?

The results of the evaluation were compared to SafetyNet data for the four participating states from 1997 to 1999. The percentage of vehicles placed OOS after IRISystem screening (59%) was significantly greater than the percentage of vehicles placed OOS after the current screening methods (27%), or more than twice as effective. The percentage of vehicles with brake violations also increased by a factor of 2.5, from 34% with current screening to 84% with IRISystem screening.

IRISystem as a screening device:
Other considerations

Training - One-half to one day of training was necessary. Officers who had previous experience with the IRISystem were valuable to the training sessions as they were able to share their experience directly with new trainees.

Skill level requirements - The IRISystem is an operator-friendly device and relatively easy to learn and to use. Prior experience with infrared imaging or the joystick control configuration of the camera helped some operators collect data more quickly and

more accurately than less experienced operators. Effectiveness in screening increased with practice.

Owner's manual/supportive documentation - The owner's manual was detailed and included all documentation needed to operate the IRISystem. However, the manual would benefit from the inclusion of photographs of typical problems detected with the IRISystem.

Set up locations - The IRISystem van should be set up with the center of the camera range roughly perpendicular to the direction of the traffic flow so the operator can track vehicles easily with an unobstructed view of the wheels. The IRISystem was typically set up at scale sites. The CMVs screened were traveling at speeds less than 10 mph (16 km/hr), although experienced operators were able to screen vehicles at speeds up to about 35-40 mph (56-64 km/hr).

Set up and shut down times - The IRISystem can be set up or shut down rapidly.

Mainline screening (speeds greater than 55 mph (88.5 km/hr)) - Although mainline screening was attempted with the IRISystem, no useful results were obtained. Officers indicated that mainline screening was not practical because of the difficulty in identifying the target vehicle, the inability to observe all wheels on a CMV traveling at highway speeds, the difficulty of intercepting the target CMV downstream, and overall safety concerns.

Identification of problems other than brake-related - In the field evaluation, flat tires were frequently identified with the IRISystem. Although possible with the system, no hot brakes (indicative of dragging brakes), exhaust leaks, or frame cracks were identified during the program.

Conclusions

The IRISystem can be used effectively to screen commercial vehicles for inspection of brake-related problems. This study found that:

- Sixty-eight to seventy-six percent (68% to 76%) of the wheels identified as problematic by the IRISystem, whether for brakes, flat tires, under-inflated tires, hot bearings, or other problems, were confirmed as defective by the Level 1 inspections. Most of these were brake-related defects.
- The effectiveness criterion defined by the State of Kentucky in this program for a vehicle-by-vehicle analysis was exceeded. The effectiveness criterion was that 50% of the vehicles screened as problematic by the IRISystem should be confirmed as defective by the Level 1 inspections. In this study, 59% of the vehicles screened by the IRISystem were placed out of service after Level 1 inspections. Nearly 80% of those vehicles were placed out of service for brake violations.
- The percentage of vehicles placed out of service with brake problems increased by a factor of 2.5 after using the IRISystem to screen vehicles for inspection.

For effective use, the IRISystem should be placed at inspection sites, such as scales, where commercial vehicles must apply their brakes to enter the facility. Vehicles are typically screened at speeds under 10 mph (16 km/hr), although vehicles moving at speeds up to about 35 mph (56 km/hr) can be screened by experienced operators. The IRISystem should be located such that the operator has an unobstructed view of the vehicle's wheels, and provisions can be made to identify and detain the vehicle for subsequent inspection.

Additional benefits of the IRISystem include:

- The IRISystem is a mobile device and can be used at various scale sites or other suitable inspection locations,
- The IRISystem is operator-friendly and relatively easy to learn and use,
- The infrared technology enables the IRISystem to be operated at normal roadside temperatures during both day and night, and
- The IRISystem can detect other vehicle problems such as flat tires, under-inflated tires, and hot bearings in addition to brake-related problems.

1. Introduction

1.1 Background

From 1997 to 1999, over 450,000 roadside inspections[1] of commercial motor vehicles (CMVs) were conducted in the states of Georgia, Kentucky, North Carolina and Tennessee. On average, approximately 22% of the vehicles inspected were placed out of service (OOS), and 19% had brake-related violations[2]. These inspections covered only a small percentage of the CMVs traveling on US highways. Traditionally, the selection of CMVs to be subjected to roadside inspections has been either random, based on the experience of the inspectors with the maintenance history of fleets, or based on past inspection results[3].

The InfraRed Inspection System (IRISystem) was evaluated in a field study to determine the effectiveness of this new technology for enhancing the screening of commercial motor vehicles for subsequent inspection.

The IRISystem is housed in a mobile van, as shown in Appendix A (Figure A-1), and can be positioned in a roadside inspection facility where CMVs are applying their brakes to enter the facility (Figure A-3). The IRISystem camera creates a live infrared image[4] of the CMV (Figure A-4, bottom) showing the relative temperature of wheels on the vehicle as the operator tracks the vehicle with the camera controls.

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[1] North American Standard Critical Item Inspection Procedure, 1996, CVSA; also at: http://www.cvsa.org/Inspections_Procedures/inspection_procedures.html

[2] SAFETYNET for GA, KY, NC and TN, all inspection levels, 1997 to 1999.

[3] A new system, SAFER, is under implementation, where a summary of previous inspection results assists the inspectors in the selection of vehicles to be inspected.

[4] The primary source of infrared radiation is heat. Even objects that we think of as being very cold, like an ice cube, emit infrared radiation. The warmer the object, the more infrared radiation it emits. An infrared camera reads thermal radiation, therefore detects temperature differences. Since heat is generated at the pad/drum interface during normal braking, infrared technology can be used to monitor brake systems.

A color image of the CMV is also available to the operator to identify the vehicle more easily (Figure A-4, top). Inside the van, the IRISystem operator views and interprets[5] the image on a monitor (Figure A-2). After the CMV's brakes have been applied, a functional brake appears bright white, indicating that it is "hot." A non-functional brake appears dark, or "cold" (Figures A-5 and A-6). In practice, the operator then selects the vehicle for inspection.

1.2 Scope and Objectives

The objectives of the evaluation were to determine the effectiveness of the IRISystem in enhancing the screening of CMVs in real-time at the roadside. The IRISystem was evaluated as a means to:

- Detect problematic CMV conditions--mainly brake-related defects. The IRISystem results were compared directly with roadside inspection results (on a wheel-by-wheel and vehicle-by-vehicle basis) and,
- Improve the existing screening methods. The roadside inspection results obtained after IRISystem screening were compared with roadside inspection results obtained after current screening (SafetyNet data).

Two types of analyses were performed on the IRISystem screening results: a wheel-by-wheel analysis and a vehicle-by-vehicle analysis. In the wheel-by-wheel analysis, the IRISystem results for each individual wheel were compared to Level 1 inspection results for the same wheel. In the vehicle-by-vehicle analysis, the results of the IRISystem screening (CMV problematic or not) and the Level 1 inspection (CMV

[5] The operator compares the relative temperature images of the brake systems on the vehicle's wheels. If all brakes are functioning identically (either normally or abnormally), the temperatures will be identical, and the infrared image will not show differences. Typically, a functional brake appears white or "hot", and a non-functional brake appears dark or "cold." However, a malfunctioning brake theoretically could also be whiter than a functional brake if it is dragging and causing excessive heat to be generated at the brake pad surface.

placed OOS or not) were compared. The specific location of the problematic wheels and defects were not correlated in the vehicle-by-vehicle analysis.

2. Description of the program

2.1 Participating States

Four states participated in the evaluation over the course of one year (June 1, 1999 to May 31, 2000): Kentucky, lead State for the program, Georgia, North Carolina and Tennessee.

2.2 Evaluation Plan

CMVs were screened by the IRISystem, and subsequently subjected to a full Level 1 CVSA inspection[6] by an inspector with no prior knowledge of the results of the IRISystem screening.

The IRISystem was set up at selected locations where CMVs could be readily screened and inspected, primarily while at scale sites on highways where the vehicles had to apply their brakes to enter the facility. Vehicles were typically screened at speeds under 10 mph (16 km/hr), although vehicles moving at speeds up to about 35-40 mph (56-64 km/hr) could be screened by experienced operators. A limited number of vehicles (62) with no apparent problems were also selected for Level 1 inspection to ensure that the Level 1 inspector was not biased towards finding a problem because the CMV had been selected by the IRISystem. The objectivity of the inspectors was a crucial element for the evaluation. In this report, the vehicles with no apparent problems according to the IRISystem screening are referred to as "blind, non-problematic vehicles."

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[6] The CVSA defines six levels of inspections: North American Standard Inspection (Level I), Walk-Around Driver/Vehicle Inspection (Level II), Driver-Only Inspection (Level III), Special Inspections (Level IV), Vehicle-Only Inspection (Level V), and Enhanced NAS Inspection for Radioactive Shipments (Level VI).
The Level 1 inspection includes examination of driver's license, medical examiner's certificate and waiver, if applicable, alcohol and drugs, driver's record of duty status as required, hours of service, seat belt, vehicle inspection report, brake system, coupling devices, exhaust system, frame, fuel system, turn signals, brake lamps, tail lamps, head lamps, lamps on projecting loads, safe loading, steering mechanism, suspension, tires, van and open-top trailer bodies, wheels and rims, windshield wipers, emergency exits on buses and hazardous materials requirements, as applicable.

Vehicles, for which the IRISystem detected a potential problem, are referred to as "problematic vehicles." In contrast, vehicles for which violations to safety regulations were found during the Level 1 inspection are referred to as "defective vehicles."

The effectiveness criterion defined by Kentucky was fifty percent (meaning 50% of the vehicles screened as problematic should be confirmed as defective by the Level 1 inspections). With the current screening methods, 19% of the vehicles inspected in Kentucky were placed OOS and 28% had brake violations[7]. Details of the evaluation plan can be found in Appendix B.

2.3 Data Collection Protocol

At least two inspectors were needed for data collection: one for the IRISystem and one for Level 1 inspections. Vehicles were selected for a Level 1 inspection by the IRISystem operator. Upon completion of the screening, the IRISystem operator filled out the IRISystem screening report (Appendix C), and printed the IRISystem photographs of the selected vehicle together with an indication of the suspected problem area (Appendix A, Figures A-5 and A-6). A wheel was judged as being either problematic or normal. A problematic wheel or brake appeared, according to the IRISystem operator, significantly colder or hotter than the other wheels or brakes on the vehicle. A normal wheel (or brake) did not, according to the IRISystem operator, appear hotter or colder than the other wheels (or brakes) on the vehicle. The Level 1 inspection was performed by one or more other inspectors with no prior knowledge of the IRISystem screening results. The Level 1 inspector identified vehicle or driver defects in the CVSA report, as required by Level 1 inspections (Appendix D). The IRISystem screening report, the IRISystem photograph(s), and the Level 1 inspection report were stapled together for further analysis. The data collection protocol used throughout the evaluation is included in Appendix E. Subsequently, the results were reviewed and entered in a spreadsheet by the evaluation team for further analysis.

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[7] SAFETYNET data, all inspection levels, 1997 to 1999.

False positives were defined as follows (see Table 1). For the wheel-by-wheel analysis, no defect (or FMCSR violation) was found on a wheel previously judged problematic by the IRISystem operator. For the vehicle-by-vehicle analysis, a vehicle judged as problematic by the IRISystem operator was not placed OOS during the Level 1 inspection.

False negatives were defined as follows. For the wheel-by-wheel analysis, at least one defect (or FMCSR violation) was found on a wheel previously judged normal by the IRISystem operator. For the vehicle-by-vehicle analysis, a vehicle judged as blind, non-problematic by the IRISystem operator was placed OOS during the Level 1 inspection.

Table 1. False positive and false negative cases in the wheel-by-wheel and vehicle-by-vehicle analyses.

	Wheel-by-wheel analysis	**Vehicle-by-vehicle analysis**
False positive	IRISystem: Problematic wheel or brake Level 1: No defect found on the *same* wheel	IRISystem: Problematic vehicle (any wheel) Level 1: Vehicle not placed OOS
False negative	IRISystem: Normal wheel or brake Level 1: At least one defect found on the *same* wheel	IRISystem: Blind, non-problematic vehicle Level 1: Vehicle placed OOS

3. Results

3.1 Summary of Data Collected

Table 2. Summary of data collected

	All states
Number of CMVs inspected	392
Percentage of blind, non-problematic CMVs	*16%*
Percentage of 3-S2†† CMVs	*88%*
Percentage of loaded 3-S2 CMVs	*70%*
Number of days in use (for evaluation purposes)	77
Percentage of problematic (cold) wheels †	*11%*
Percentage of problematic (hot) wheels †	*1%*
Average No. of IRISystem-identified problems per 3-S2	1.3

† As identified by the IRISystem operator †† 3-axle tractor, 2-axle trailer combination

As shown in Table 2, nearly 400 CMVs were inspected following IRISystem screening by the four states in one year. On average, 16% of the inspected vehicles were blind, non-problematic vehicles to serve as a control group. Eighty-eight percent of the CMVs included in this study were 3-S2 tractor-trailer combinations. Other types of CMVs inspected included bobtail tractors, straight 2 or 3-axle trucks, other tractor-trailer combinations (e.g. mobile home trailers). Approximately 70% of the CMVs inspected were loaded vehicles.

For the evaluation, the IRISystem was in use for a total of 77 days. The total number of CMVs inspected per day was not limited by the IRISystem but rather by the number of inspectors available and by the requirement for Level 1 inspections[8].

Approximately 10% of the wheels screened by the IRISystem were identified as problematic and cold, and about 1% of the wheels screened by the IRISystem were identified as problematic and hot. The average number of problematic wheels identified per CMV by the IRISystem operator was 1.3, indicating that the operator typically identified and reported 1 to 2 problematic wheels. Some wheels may not have been visible to the operator. In this evaluation, when a wheel was not visible to the operator, it was assumed to be problem-free or "normal." The number of wheels that could not be assessed visually with the IRISystem is unknown.

Set-up locations were chosen by the individual states. In general, the IRISystem van was set up at scale sites on highways (Appendix A, Figure A-3). Other locations included state roads near a port of entry in Georgia. Appendix F shows typical set-ups for the IRISystem. The maximum speed of CMVs screened was 35-40 mph (56-64 km/hr), and the average screening speed was about 10 mph (16 km/hr). Although mainline screening (speeds greater than 55 mph (88.5 km/hr)) was attempted with the IRISystem, no useful results were obtained. Officers indicated that mainline screening was not practical because of the difficulty in identifying the target vehicle, the inability to observe all wheels on a CMV traveling at highway speeds[9], the difficulty of intercepting the target CMV downstream, and overall safety concerns.

To view the heat output of the brakes on the near-side wheels of the vehicle properly, the IRISystem camera was positioned nearly perpendicular to the traffic flow (Appendix A, Figure A-5). Near-side wheels were more difficult to assess than far-side wheels. Wheel covers on the near-side wheels tended to obscure the infrared image of

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[8] The IRISystem screening was completed typically in several minutes while the Level 1 inspection required up to one hour (when multiple violations of safety regulations were found). To keep the evaluation objective, the IRISystem operator did not conduct the Level 1 inspections. In future screening use, CVSA inspections of a level other than Level 1 could be conducted at the inspector's discretion to optimize the inspectors' time.

[9] At highway speeds, the time that the near-side wheels are visible to the operator is too brief for the operator to detect a problem.

the wheels, and the near-side wheels passed through the camera range more quickly than the far-side wheels (Appendix A, Figure A-6). On average, the majority of problems identified during the IRISystem screening were located on the trailer wheels on the far side of the CMV with respect to the IRISystem van (Figure 1). However, this result was dependent on the operator, as shown in Appendix G where figures similar to Figure 1 are included for each state.

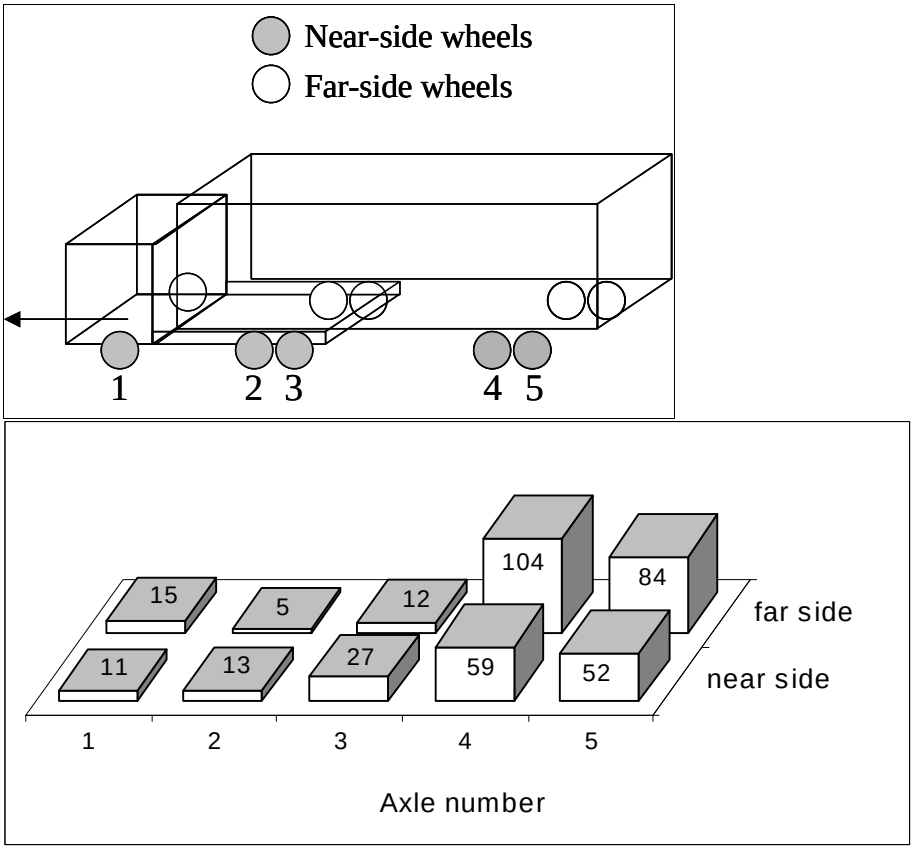

Figure 1. Number of problematic wheels identified by IRISystem as a function of wheel location on a 3-S2 CMV. The data are for all states. The arrow indicates the direction of the vehicle. The schematic illustrates the near-side and far-side wheel location as well as the axle numbers.

The presence of brake defects or deficiencies was a good indicator that other repairs on the CMV were needed, and led to additional violations. Figure 2 illustrates the average number of FMCSR violations reported for the CMVs screened with the IRISystem. Violations were grouped into one of two categories: non-wheel-specific violations and wheel-specific violations. Each of these categories of violations was

further sub-divided into brake-related and other violations. Typical examples for each of these types of violations are listed in Table 3. As shown on Figure 2, additional violations were discovered for most vehicles, whether blind or problematic. Plots similar to Figure 2 are included in Appendix H for each state.

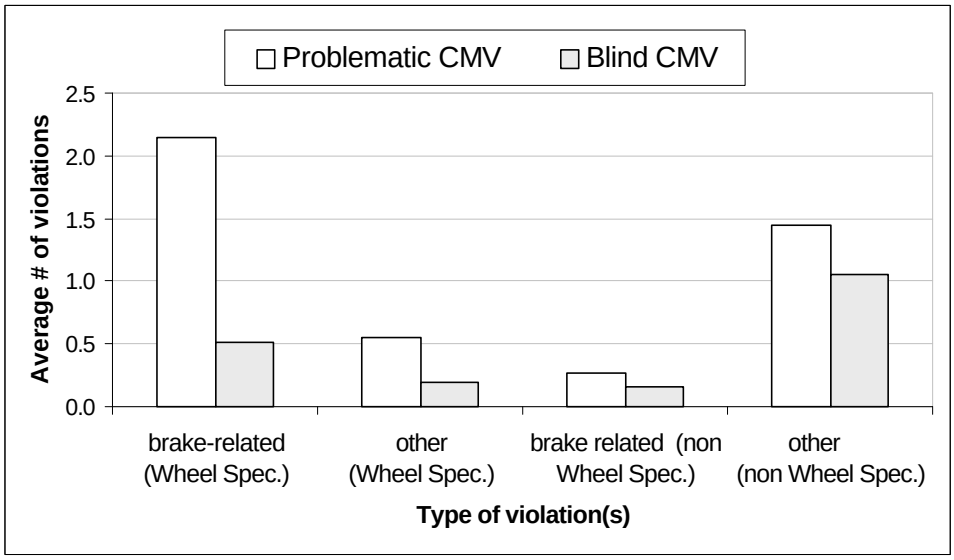

Figure 2. Average number of FMCSR violations reported in Level 1 inspections for CMVs screened with the IRISystem.

Table 3. Examples of FMCSR violations

Types of violations	Brake-related	Other (non brake-related)
Wheel-specific	• Readjustment limit exceeded [396.3(a)1]* • Cracked, loose or missing lining [393.47]*	• Tire violation, e.g. side wall is cut, worn or damaged to the extent that the ply cord is exposed [393.75(a)]*
Non-wheel-specific	• Any brake hose violation, e.g. hose with audible air leak.	• Any driver violation

* Section in Title 49 of the Code of Federal Regulations

3.2 Wheel-by-wheel analysis: Identification of problematic wheels. Comparison of the IRISystem screening results with the CVSA inspections results.

The IRISystem operator identified each wheel of the screened CMV as normal or problematic. If problematic, the operator specified "cold" or "hot" (Appendix E). Table 4 lists the percentage of agreement between the IRISystem screening results and the Level 1 inspection results for all wheels screened by the IRISystem. Figure 3 illustrates these results graphically. Similar results are included in Appendix I for each state. As listed in Table 5, two types of comparisons were conducted for the IRISystem-identified cold wheels. First, the percentage of agreement between IRISystem results and Level 1 Inspection results were assessed by seeking correlation between cold wheels and wheel-specific FMCSR violations, whether brake-related or not (Table 3). Second, the correlation between IRISystem cold wheels and brake-related FMCSR violations, whether wheel-specific or not (Table 3), was investigated.

Table 4. Percentage agreement between the IRISystem screening results and the Level 1 inspection results. State-specific results are included in Appendix I.

IRISystem diagnostic		**All states**
Normal wheels	# of wheels (% total)	3326 (88%)
	% agreement †	***85%***
	% disagreement †	*15% ***
Cold Wheels	# of wheels (% total)	399 (11%)
	% agreement †, 1 *(% disagreement* †,1*)*	***68%*** *(32% *)*
	% agreement †, 2 *(% disagreement* †,2*)*	**76%** *(24% *)*
Hot Wheels	# of wheels (% total)	44 (1%)
	% agreement † *(% disagreement* †*)*	***68%*** *(32% *)*
Total # wheels		3769

† Between IRISystem screening results and Level 1 inspection results
1 Level 1 inspection identified one or more wheel-specific defect, whether brake-related or not (Table 5).
2 Level 1 inspection identified one or more brake-related defect, whether wheel specific or not (Table 5).
* False positives ** False negatives

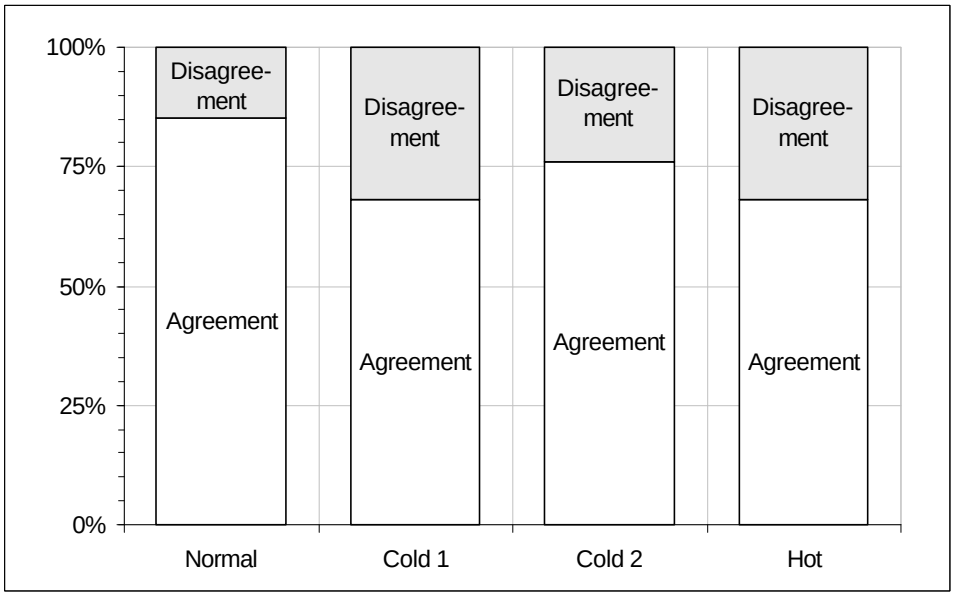

Figure 3. Percentage of agreement between IRISystem screening results and Level 1 inspection results.

Table 5. Correlation between IRISystem and Level 1 inspection results

Types of correlation	IRISystem diagnostic	FMCSR violations	Legend in Figure 3
1	Cold wheels	Wheel-specific violations (brake-related or not)	Cold 1
2	Cold wheels	Brake-related violations (wheel-specific or not)	Cold 2

<u>Wheels identified as normal by the IRISystem operator</u>

Eighty-five percent of the wheels identified as normal by the IRISystem operator were violation-free in the Level 1 inspection (the inspector did not find any FMCSR violation at the same wheel location).

The disagreement between the IRISystem and the Level 1 inspection results was due in part to (1) the assumption that a wheel not visible to the IRISystem operator was normal, and (2) the preventative nature of some Level 1 inspection violations. For

example, chafing or rubbing brake hoses could indicate a future problem that may not affect the vehicle's braking capability at the time of the inspection.

Wheels identified as problematic by the IRISystem operator

Approximately 12% of the total number of wheels screened were identified as problematic by the IRISystem operators in the field evaluation. Most of these (90%) were cold problematic wheels. A cold problematic wheel was typically a wheel with no braking action, whereas hot problematic wheels may be caused by hot bearings, flat tires or dragging brakes.

Cold wheels

Sixty-eight percent of the cold problematic wheels also had one or more wheel-specific violations, whether brake-related or not. This percentage increased to 76% for brake-related violations, whether wheel-specific or not.

The mismatch between the IRISystem and the Level 1 inspection results was not surprising because these techniques are based on different principles. The IRISystem provided a relative rather than an absolute assessment of brake system performance on a vehicle through a visual indication of the heat generated by braking forces. For example, the following disagreement was observed frequently during the evaluation. A brake, which appeared cold in the IRISystem screening, passed the inspection when its adjustment was nearly at the limit. This brake may have had less braking action than the other brakes and appeared colder.

Disagreement between the IRISystem screening and the Level 1 inspection results may also occur for exempt vehicles. For example, the IRISystem screening accurately detected cold wheels on mobile home trailers because the trailers were not equipped with brakes. Another discrepancy can occur if a tractor drops a trailer, which it has been pulling all night, and picks up another trailer that has been parked overnight. The tractor brakes may then appear hotter than the trailer brakes.

Hot wheels

The Level 1 inspection showed that 68% of the IRISystem-identified hot problematic wheels had a wheel-specific violation. Only one-third of the hot problematic wheels, for which the IRISystem and the inspection results matched, were brake related. The most common cause for an IRISystem-identified hot problematic wheel was a flat tire, which can be identified readily by an inspector without the use of the IRISystem technology. Theoretically, the IRISystem identify dragging brakes, which cause excessive heat. However, no dragging brakes were identified in this field evaluation.

In all four states, the effectiveness criterion defined by Kentucky (see page 4) was met. This result was consistent with earlier studies using a drive-over array of infrared sensors where infrared technology was shown to be effective in identifying inoperative and significantly misadjusted brakes[10].

Effect of vehicle loading

It was anticipated that the IRISystem would be more effective as the vehicle loading increased. However, the effect of loading could not be determined conclusively from the study data. The gross vehicle weights of the CMVs were not collected, only whether the CMVs were loaded or empty. The percentage agreement between the IRISystem screening and Level 1 inspection results was:

- for normal wheels: 86% loaded versus 88% empty.
- for cold wheels: 68% loaded versus 67% empty.

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[10] S. J. Shaffer and P. A. Gaydos, 1998, "Development, Evaluation and Application of Performance-Based Brake Testing Technologies," Final report, FHWA-MC-98-048, pp. 8-35 to 8-43. http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/8mn01!.pdf

3.3 Vehicle-by-vehicle analysis: Identification of Out-Of-Service CMVs. Comparison of the IRISystem screening results with the FMCSR inspections results.

In normal use of the IRISystem for screening brakes, i.e. not in the context of an evaluation, only problematic vehicles would be subjected to inspections. Therefore, this section presents results separately for problematic vehicles and blind, non-problematic vehicles.

For all of the participating states, 59% of vehicles on average screened by IRISystem as problematic were placed OOS in the subsequent Level 1 inspection (Table 6 and Figure 4b). Seventy-nine percent of the screened vehicles, which were placed OOS, were placed OOS as a result of brake violations, among which 22% had brake and other OOS violations (for example, driver related violations). Twenty-one percent of the problematic vehicles were placed OOS because of other-than-brake violations only.

As shown in Table 6 and Figure 4(a), the percentage of blind, non-problematic vehicles placed OOS was 19% (false negatives), considerably less than for the problematic vehicles. Two-thirds (2/3) of the blind, non-problematic CMVs were placed OOS as a result of brake violations and one-third (1/3) as a result of other-than-brake violations.

Table 6. Percentage of CMVs placed OOS after IRISystem screening

	Not placed OOS	**Placed OOS**			
		Any criteria	*Brake violation(s) only* ††	*Brake and other violation(s)* ††	*Other-than-brake violation(s)* ††
All CMVs (392)	47% (186)	53% (206)	*57% (118 / 206)*	*21% (43 / 206)*	*22% (45 / 206)*
Blind, non-problematic CMVs (62)	81% (50)	**19%** * (12)	*58% (7 / 12)*	*8% (1 / 12)*	*33% (4 / 12)*
Problematic CMVs (330)	41% ** (136)	**59%** (194)	***57%*** *(111 / 194)*	***22%*** *(42 / 194)*	***21%*** *(41 / 194)*

† Problematic vehicles only †† Percentage of OOS vehicles only.
* false negatives ** false positives

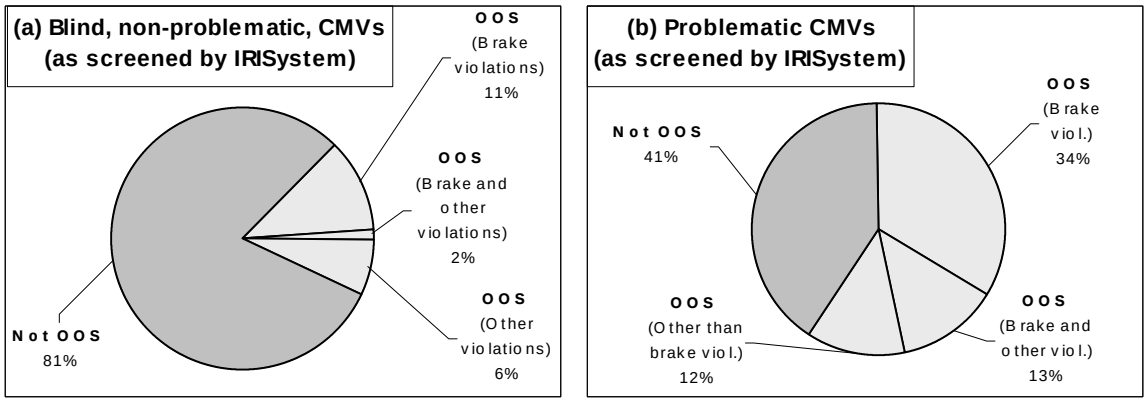

Figure 4. Percentage of CMVs placed OOS in all four states after IRISystem screening (a) blind, non-problematic vehicles and (b) problematic vehicles. These plots only include CMVs placed OOS in the Level 1 inspection. Some CMVs screened by IRISystem were not subsequently placed OOS.

Results for the individual states can be found in Appendix J.

On average for all four of the states, IRISystem identified the OOS violations on 74% of the CMVs placed OOS. This means that, for 74% of the CMVs placed OOS, the IRISystem-identified defects led to OOS in the subsequent Level 1 inspection. The vehicles missed by IRISystem were placed OOS due to other causes (for example, driver violations).

3.4 IRISystem as A Brake Screening Device

3.4.1 Does the IRISystem improve the current screening method?

SAFETYNET is a state level information management system for motor carrier safety, which operates in every state. It captures interstate and intrastate driver/vehicle inspection data, accident data, carrier compliance reviews, enforcement data, and carrier identification data.

The results of the evaluation were compared to SafetyNet data for the four participating states from 1997 to 1999, as shown in Figure 5.

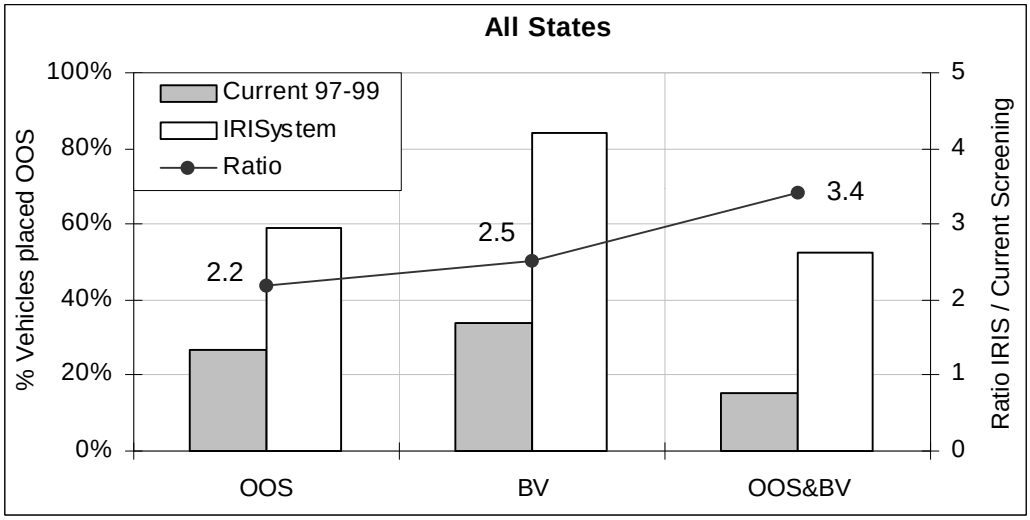

Figure 5. Comparison of IRISystem Results (no blind vehicles) with SAFETYNET data (current screening methods) for out-of-service (OOS) vehicles and brake violations (BV).

Figure 5 shows, the percentage of vehicles for all four states subjected to a Level 1 inspection that:

- were placed OOS ("OOS"),
- had brake violations ("BV"), and
- were placed OOS and had brake violations ("OOS & BV").

The brake violations reported are not necessarily OOS violations. For the IRISystem screening, the data are for the total number of vehicles for which the

IRISystem identified problematic wheels. The results for current screening methods (1997 through 1999 SAFETYNET data) and after IRISystem screening are compared. The ratio of the percentage of CMVs placed OOS after IRISystem screening divided by the percentage of CMVs placed OOS after current screening is also plotted on Figure 5. Results for each state are included in Appendix K.

As seen in Figure 5, the percentage of vehicles placed OOS after IRISystem screening (59%) was significantly greater than the percentage of vehicles placed OOS using current screening methods (27%), or more than twice as effective. The percentage of vehicles with brake violations also increased by a factor of 2.5, from 34% with current screening to 84% with IRISystem screening. Finally, the percentage of CMVs placed OOS with BV was much greater after using IRISystem screening (by a factor of 3.4).

3.4.2 Logistics considerations

Training requirements

One-half day to one day of training was necessary. During the field evaluation, an experienced operator presented to an audience who had already received and presumably reviewed the owner's manual, the basic principles of infrared imaging, the components of the IRISystem and its basic principles of operation. In particular, the set up, operation, shut down, and maintenance operations were explained. Following the formal training, trainees practiced operating the IRISystem. Level 1 inspections were not conducted during the IRISystem training.

- Officers who had previous experience with the IRISystem were valuable to the training sessions, as they were able to share their experience directly with the new trainees.
- More emphasis during training should be placed on the possibility of hot problematic brakes (e.g. dragging overheating brakes or dry wheel bearings). Only a small percentage of hot wheels were detected in this evaluation, perhaps as a result of lack of training of the inspectors, rather than a low occurrence of the defect.

Skill level requirements

Differences were observed in the performance of the system as a function of operator. Prior experience with infrared imaging or with the joystick control configuration of the camera helped some operators collect data more quickly and more accurately.

Owner's manual/supportive documentation

The owner's manual includes all documentation needed to operate the IRISystem. However, photographs of typical problems detected with the IRISystem should be added to the manual to help new operators identify problematic wheels. Also, information should be included to guide operators when visibility is limited (for example, by certain wheel designs or dust covers).

Set up locations

The IRISystem van should be set up such that the center of the camera range is perpendicular to the direction of the traffic flow. The IRISystem was typically set up at scale sites on US highways. The CMVs screened were traveling at maximum speeds of 35-40 mph (56-64 km/hr), though usually less than 10 mph (16 km/hr). The scale sites were chosen for several reasons:

- The CMVs were applying their brakes in order to enter the facility,
- The CMVs were traveling at low speed making observation easier,
- Inspections could be conducted near the IRISystem van, facilitating the interception of the CMVs with identified problems, and
- The IRISystem van could be set up in a safe environment for the inspectors and the CMV operators.

Set up and shut down times

The IRISystem can be set up or shut down rapidly.

Maintenance costs and effort requirements

Maintenance costs and effort requirements were not available for this study.

3.4.3 Performance considerations

Mainline screening

Mainline screening tests (speeds greater than 55 mph (88.5 km/hr)) were attempted as part of the evaluation. However, all of the IRISystem operators indicated that it was too difficult to identify the target vehicle and to observe all wheels on a CMV traveling at highway speeds. Also, intercepting the vehicle downstream would require significant efforts of coordination and present safety concerns for the IRISystem operator, the Level 1 inspector, and the CMV operator. The IRISystem van should be set up far enough away from moving traffic to ensure the safety of the operators and to permit sufficient time for observation of the vehicle being screened. The distance required between the CMV and the IRISystem van increases with the speed of the vehicle being screened.

Identification of problems other than brake-related

The IRISystem is capable of identifying problems other than brake-related defects, such as under-inflated tires, wheel bearings, cracks in the frame, or exhaust leaks. In the field evaluation, flat tires were frequently identified with the IRISystem. This can be valuable for inspection of inner tires, which may not always be seen using current screening methods. Some cases of tires with high tread wear were seen as well as a couple of hot wheel bearings. No hot brakes (indicative of a dragging brake) were identified. The majority of the problematic wheels reported by the IRISystem operator were cold brakes (90%).

4. Conclusions

The IRISystem can be used effectively to screen commercial vehicles for inspection of brake-related problems. This study found that:

- Sixty-eight to seventy-six percent (68% to 76%) of the wheels identified as problematic by the IRISystem, whether for brakes, flat tires, under-inflated tires, hot bearings, or other problems, were confirmed as defective by the Level 1 inspections. Most of these were brake-related defects.
- The effectiveness criterion defined by the State of Kentucky in this program for a vehicle-by-vehicle analysis was exceeded. The effectiveness criterion was that 50% of the vehicles screened as problematic by the IRISystem should be confirmed as defective by the Level 1 inspections. In this study, 59% of the vehicles screened by the IRISystem were placed out of service after Level 1 inspections. Nearly 80% of those vehicles were placed out of service for brake violations.
- The percentage of vehicles placed out of service with brake problems increased by a factor of 2.5 after using the IRISystem to screen vehicles for inspection.

For effective use, the IRISystem should be placed at inspection sites, such as scales, where commercial vehicles must apply their brakes to enter the facility. Vehicles are typically screened at speeds under 10 mph (16 km/hr), although vehicles moving at speeds up to about 35-40 mph (56-64 km/hr) can be screened by experienced operators. The IRISystem should be located such that the operator has an unobstructed view of the vehicle's wheels, and provisions can be made to identify and detain the vehicle for subsequent inspection.

Additional benefits of the IRISystem include:

- The IRISystem is a mobile device and can be used at various scale sites or other suitable inspection locations,
- The IRISystem is operator-friendly and relatively easy to learn and use,
- The infrared technology enables the IRISystem to be operated at normal roadside temperatures during both day and night, and
- The IRISystem can detect other vehicle problems such as flat tires, under-inflated tires, and hot bearings in addition to brake-related problems.