Transportation Research Synthesis

Local Road Research Board
Minnesota Department of Transportation
651-366-3780
www.lrrb.org

TRS2005

October 30, 2020

REMOTE SENSING IN MAINTENANCE WORK

Prepared by SRF Consulting Group: Nicole Bitzan, Michael Marti, Mark Gallagher and Darwin Dahlgren from GoodPointe Technology/Zoom Information Systems

Safety is a key value within MnDOT Culture, for the general public and its workers. As MnDOT works within its right-of-way (ROW), that safety concern extends to the safety needs of maintenance staff in field work, as well as those of the unsheltered homeless population, who may camp on MnDOT's ROW. Therefore, MnDOT seeks to evaluate various remote sensing tools in the industry in order to help ensure safety and identify:

- Objects and artifacts left in encampments that pose a risk to maintenance.
- People who may be impaired or not awake and therefore, undetected and not visible in tall grasses along the ROW.
- Number of people within encampments and their locations before MnDOT staff/consultants enter.

Figure 1. Maintenance work within homeless camp within the ROW

SRF Consulting Group worked with MnDOT in identifying specific uses for the remote sensing tools, a list of potential tools was generated, MnDOT reviewed and then developed a short list of five tools which SRF then conducted a detailed investigation on a short list of five remote sensing tools identified. This TRS presents the findings including information on tool applications and details for MnDOT's specific application including pros and cons of each.

Technical Advisory Panel

Peter Morey, Unsheltered Encampment Coordination Team,
Metro District Maintenance

Leif Halverson, Management Analyst (Project Coordinator)
MnDOT Office of Research

Brian Duffee, Unsheltered Encampment Coordinator – Metro Maintenance
Northwest Region TPS2
Metro District Maintenance & Operations

Colin Lee, Photogrammetric Mapping Supervisor,
Office of Land Management

Dewayne Jones, Northwest Region Superintendent, Metro District Maintenance

Jennifer Wells, MnDOT State Bridge Inspection Engineer,
MnDOT Bridge Office

Katrina Gilmore, UAS Program Administrator,
Office of Aeronautics

Rodney Carter, Engineering Specialist,
MnDOT Bridge Office

Sheila Johnson, Maintenance Operations Engineer, Metro District Maintenance

The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by MnDOT and the Local Road Research Board. This TRS does not represent the conclusions of the authors, MnDOT or LRRB.

Background

MnDOT staff identified multiple safety concerns affecting their maintenance staff and the unsheltered homeless population, prompting an evaluation of remote sensing tools to use during maintenance activities. The primary concerns were: Identifying objects left in an existing or abandoned encampment and ensuring the camps were vacated.

Examples MnDOT cited include:

- Instances in the past where staff have run over propane tanks concealed within the high grass. Although no tanks have exploded, the risk grows as the number of encampments on MnDOT's ROW increases. Further, at a conference in Seattle in Fall of 2019, it was reported that in some west coast encampments, inhabitants placed hidden traps upon vacating the camps. Thus, the importance to equip staff with tools to identify threats.
- Mowing and clearing concern when people, who may be impaired or sleeping along the ROW obscured by tall grasses, are not visible to maintenance staff. Unfortunately, in 2019 an Oregon DOT maintenance employee was mowing along the ROW and killed a man who was asleep and not visible in the tall grass.
- Periodically, MnDOT staff/consultants need to enter homeless encampments to post "notice of removal" signs, conduct maintenance, etc. Prior to entering, the camps must be assessed for safety for both the inhabitants and the general public. Hence, it is desired to determine whether the encampments are still populated by remotely detecting occupancy (in or near tents) prior to entering.

To assist MnDOT in ensuring worker safety, this project evaluated several remote sensing tools via literature search, manufacturer interviews, and user input. This Transportation Research Synthesis (TRS) presents the findings of the five tools MnDOT identified as most relevant and affordable.

Data Collection

Information for this TRS was gathered in stages. Initially, after interviewing MnDOT to identify their specific needs/uses (tool parameters), a list of remote sensing tools was generated that met MnDOT's parameters (below); preliminary details were researched and reported on each (see Appendix A). In addition to the online research, inquiries on existing remote sensing tools used by defense agencies were also made.

Remote Sensing Tool Parameters (as defined by MnDOT TAP):

- Cost less than $20,000 per unit
- Remote Sensing Tool 1 (scanning encampments to check for occupancy)
    - working range of approximate 20 yards
    - mobile, lightweight, preferable less than 15-lbs
- Remote Sensing Tool 2 (attached to mower equipment to detect metal objects (propane tanks) and people both alive and deceased in tall grass
    - Mounted, can tie into onboard monitor,
    - relatively fast read

Using the tool parameters as a guide, twelve different, commercially available tools were identified that used a range of different detection technologies. Tools considered ranged from complete, self-contained "off-the-shelf" consumer products to sensor and components that would require customized integration to provide useful information. The characteristics of each tool was compiled into a summary table to facilitate comparisons of tools. The detailed list of twelve tools were sub-divided into three category types: infrared/thermal, polarized light, radar and other and included as Appendix A. A TAP meeting was then facilitated where MnDOT staff reviewed, evaluated and selected the top five remote sensing tools for more detailed information.

The following five tools were selected:

- FLIR ONE Pro (Infrared/Thermal)
- FLIR K1 (Infrared/Thermal)
- FLIR E95 (Infrared/Thermal)
- Phoenix 5.0P (Visible light/Polarization)
- Q130R (Radar)

For the five tools, additional details were collected to evaluate them for MnDOT's specific mowing/clearing applications. The additional information was specifically identified by MnDOT at a TAP meeting and via follow-up e-mails included:

- Description of MnDOT Application
- Pros/Cons
- Suggestions for MnDOT use
- Determination if others (military, law enforcement, others) have used for similar
- Handheld or mounted (vehicle, drone, etc.)
    - Mounting procedures and any issues
- Tool use in high vegetation
- Calibration needs and frequency
- Imagery and processing
- Maintenance
- Any legal opposition to the use of this tool in the public sphere

This additional information was collected through additional online research, reviews of application notes/white papers about the tools, and direct engagement with the manufacturers. This additional information, along with previously collect data/information, was summarized on fact sheets for each of the five tools.

Summary of Findings

Each of the five tools have pros and cons; no one tool (as sold off the shelf) immediately satisfies all the needs identified by the TAP. While there is overlap between the tools, each has a domain of detection that will perform better with some conditions/targets than others.

Infrared/Thermal detection and imaging solutions operate by detecting differences in radiated infrared energy from an object. These will work best for detecting live people, which are almost always a different temperature than their backgrounds. Infrared/Thermal detection will likely detect temperature differences of materials that are relatively infrared (IR) transparent. Further testing is recommended to confirm the range of capabilities. Detection of other objects (propane tanks, etc.) is also possible if they have some difference in temperature from their surroundings and are not fully obscured by infrared-opaque vegetation. As the temperature differences become smaller, the sophistication and sensitivity of the tool will become more important. Use of sleeping bags or even jackets reduce thermal loss and decrease the visible contrast in temperature. For other objects, size, composition, length of time for temperature to equalize and occlusion by vegetation will all affect the accuracy of detection. Customizing and calibrating methods and operational procedures will be needed to assist operators in identifying areas of interest when evaluating images.

Visible light/Polarization sensors operate by detecting differences in polarization of light reflected from different objects. A smooth, flat metal surface will have different and more uniform polarization than randomly reflected light from blades of grass or leaves. Detecting this difference can allow for identification of partially hidden objects, even if intentionally camouflaged. However, since the sensor operates using visible light, it will not penetrate any opaque material. Fully occluded objects cannot be detected. In addition, these tools are sold as sensor packages, which must be accessorized, programmed and integrated into a purpose-built tool. There are no off-the-shelf solutions using polarization detection.

Radar allows a degree of material penetration and simple integration into other systems, such as mower controllers. Since radar measures the strength of a returned radio signal, it can be programmed to discriminate between the "noise" of a ground reflection and the strong signal returned by a metal surface. Radars generally work poorly on "soft" surfaces such as bodies and are affected by the "aspect" or angle between the sensor and surface of a target. Properly configuring the radar sensor will be key to its reliable detection performance. While the tool itself is off-the-shelf and readily available, an evaluation will be required to identify the proper mounting locations, beam width and sensitivity parameters to determine if it will reliably detect objects in front of the mower blades. It is unlikely that radars will be suitable for identifying occupants at camps.

Based on the data collected, it seems likely that a two-device solution (person and object detectors) will be needed to satisfy the scenarios described by the Technical Advisory Panel. Prior to operational use, testing to determine the accuracy and limits of detection capabilities are understood and documented is recommended.

The five MnDOT selected remote sensing tools' further evaluation to include general availability, cost, application details, and details for MnDOT's specific applications follow this page. The costs provided for each tool is subject to change due to market and inventory conditions. Also, the mounting and integration of on-mower tools has not yet been determined. These details will affect deployment costs.

Next Steps

Through this TRS, details for each tool was gathered. It is important to understand that the equipment was not built for the specific MnDOT desired use. A detailed implementation testing plan should be put into a place to confirm that best equipment for this application.

FLIR ONE Pro

Figure 2. FLIR ONE Pro Tool

The FLIR ONE Pro operating ranges 32°F – 95°F and can detect temperatures from -4°F – 752°F. Typically, the tool is used for thermal imaging for home inspections, moisture detection, air leakage, HVAC, electrical panels, agriculture, DIY projects, and many other examples.

Cost - $399.99

Rental/Evaluation Options

Not available for this product.

For MnDOT Application

Under perfect conditions, the One Pro will detect a person at about 130 feet. However, the ability to detect a person (or a propane tank) using a thermal imager at a distance is a function of many conditions. Some of these are the lens field (FOV), the number of pixels, the ambient temperature (or the difference between the person and the surrounding temperature) and obstructions. Thermal cameras, like visible cameras can see as far as your eye can see in most cases. Optimal conditions exist with a cool background and a warmer human or object. Results will vary depending on the environmental conditions. The larger the temperature difference between the environment and the object, the more successful the tool will be. If a person is hidden either by a tent or otherwise obstructed in thick cover, it will be difficult to detect the outline of a person. These conditions will reduce the range considerably for the MNDOT application. If the ambient temperature is warmer, then the ability to "see evidence of a warm body" in the tent will be significantly diminished, if not impossible, due to highly reflective tent surfaces. However, there are reflectivity settings on the thermal cameras that can be set to partially mitigate reflectivity. With that being said, newer tents are designed to reflect heat to keep the inside of the tent cool. Further testing will be needed to verify the effective operating range under the variable conditions, which MnDOT faces. These and other factors will impact range and results of thermal cameras and will require defined operating procedures to effectively use the tool such as collecting data through screens and tent openings for a higher detection success rate.

Pros for MnDOT Application

The ONE Pro will detect objects at a distance with a temperature differential compared to the surroundings. The tool has a slightly larger field of view and weighs less in comparison to the FLIR K1 and E95. The high-resolution optical camera integration provides increased information for the operator to interpret more of the results compared to the K1. The ONE Pro also has a desirable thermal sensitivity of 70mK. Thermal sensitivity is similar to the image pixilation (noise) that you see in low light conditions of an optical camera. Therefore, the lower the thermal sensitivity, the less noise in a thermal image when the thermal differentiation is minimal.

Cons for MnDOT Application

At certain times of the day and depending on the distance, FOV and the thermal signature and extent of coverage of object(s) between the person and the camera, may make detection of a person more difficult. The ONE Pro's features will assist in the detection of people and other objects but does not offer as many features to be able to customize the detection to MNDOT's application. The ONE Pro also only offers one-hour of battery life. Although the battery life is better than the K1, it is 5 times less than the E95. If the time to reach the next camp is within the recharge time, then the ONE Pro could be used throughout the workday. Further, the ONE

Pro has a fixed focus, which means limited adjustments are available. Finally, the tool is not as rugged as the K1 or the E95 (or other Exx-series). However, with the lower replacement cost the ruggedness of the unit may not be as critical if a replacement camera is quickly available.

Suggestions/Modifications/Alternatives to the Tool to Better Meet MnDOT's Needs

The tool will be more successful if used under certain established conditions and following tested procedures. Testing of the thermal tools should be conducted with the goal of developing operational procedures for use of this equipment. The K1 and the Exx-series cameras may offer additional features to improve the applicability to MNDOT needs.

Tool Capabilities

Determine if others (military, law enforcement, others) have used for similar applications:	None
How can the tool be used? (Handheld or Mounted)	Handheld
For tools used while mowing, verify mounting procedures and any issues.	Not Applicable
How does the tool work in areas of high vegetation?	There needs to be a temperature differences between the object (in the vegetation) and the vegetation. This temperature difference is detected and presented on screen in color hues. If vegetation completely obscures the object, the detection may only be very small spots of color changes on the screen. In the high grass of the mowing operations the likelihood of an objects heat signature being completely obscured is less than in heavy broad leaf vegetation. In an encampment there may be occasions where the heavy vegetation (by design of the occupant) obscures the persons' visibility, that person may be difficult for the thermal camera to detect.
How often does calibration need to be performed (just once upon initial use, quarterly, upon every use, etc.)? Can calibration be done by user or does it require servicing?	Calibration occurs just once. Additional may be required due to (improper) usage. Calibration is performed by the OEM. The system comes with a calibration certificate. There are some user available calibrations on screen for situations and viewing preferences and calibration. These may include language, time, date, units etc. Additional viewing customization such as focus, temperature range, span and level, brightness and contrast, color palette will be needed to better position the camera to work in the conditions. There is a manual provided to accomplish these adjustments. The other calibration SOP is for the operator and would need to be developed by MNDOT or send the operator to FLIR ITC (certified training). Manual tuning of the shutter is not required. It occurs automatically.
Confirm that the tool's imagery is instant and does not require processing.	Confirmed.
What kind of maintenance does the tool require?	Proper use and storage.
Has there been any legal opposition to the use of this tool in the public sphere? *** The responses here are not to be considered a legal opinion.**	Some concerns around capturing images of people's faces (unmasked).

Additional FLIR ONE Pro Detailed Specifications

Overview	
Accuracy	±37°F or ±5%, typical Percent of the difference between ambient and scene temperature. Applicable 60 sec after start-up when the unit is within 59°F — 95°F and the scene is within 41°F — 248°F.
Non-Operating Temperature	-4°F — 140°F
Scene Dynamic Range	-4°F — 752°F
Spot Meter	Off °F. Resolution 0.1°F
Thermal Sensitivity/NETD	70 mK
Weight	36.5 g
Dimensions (H x W x D)	2.7 × 1.3 × 0.6 in
Phone	IOS and Android versions are available
App	
Adjustable MSX distance	0.3 m — Infinity
Battery charge monitor	0 — 100%
Capture modes	Video, Still image, Time lapse
File Formats	Still images – radiometric jpeg Video – MPEG-4 (MP4)
Palette	Gray (white hot), Hottest, Coldest, Iron, Rainbow, Rainbow HC, Arctic, Lava and Wheel
Video and Still Image Display/Capture	Saved as 1440 × 1080
Connections & Communications	
Charging	Female USB-C (5V/1A)
Video	Male USB-C
Compliance and Certifications	
Certifications	MFi (iOS version), RoHS, CE/FCC, CEC-BC, EN61233
Environmental & Approvals	
Emissivity Settings	Matte: 95%, Semi-Matte: 80%, Semi-Glossy: 60%, Glossy: 30%
Mechanical shock	Drop from 5.9 ft
Operating Temperature	32°F — 95°F, battery charging 32°F — 86°F
Imaging and Optical	
Focus and Frame Rate	Fixed 15 cm — Infinity, 8.7 Hz
HFOV/VFOV	55° ±1° / 43° ±1°
Shutter	Automatic/Manual
Thermal Resolution	160x120
Thermal Sensor	Pixel size 12 µm, 8 — 14 µm spectral range
Visual Resolution	1440 × 1080
Power	
Battery Charge Time	40 minutes
Battery Life	Approximately 1 hour

FLIR K1

The FLIR K1 operating ranges is 14°F to 194°F or 14°F to 239°F with flash light on and can detect temperatures in High Gain Mode from: 14°F to 284°F and Low Gain Mode from: 14°F to 752°F (at room temperature). The K1 is used by first responders, primarily fire departments, for fire control, detection, confirmation and search and rescue.

Figure 3. FLIR K1 Tool

Cost - $599

Rental/Evaluation Options

Not available for this product.

For MnDOT Application

Similar to the FLIR ONE Pro, the ability to detect a person (or a propane tank) using a thermal imager at a distance is a function of many conditions. Please refer to the operating parameter and capabilities as described in the ONE Pro description for those general conditions. The K1 is basically a ruggedized version of the thermal systems used in the ONE Pro with some upgrades in the ability to withstand higher operating temperatures and some higher and lower capabilities as is shown in the tool's specifications including in this report.

Pros for MnDOT Application

The K1 is a ruggedized unit and will resist damage. With a higher temperature differential compared to the surroundings, the K1 will have a greater thermal range. This thermal detection is better when used under the high temperature operating conditions identified below.

Cons for MnDOT Application

At certain times of the day and depending on the distance, FOV and the thermal signature and extent of coverage of object(s) between the person and the camera, may make detection of a person more difficult. While the thermal image resolution is the same as the ONE Pro, the sensitivity is not as desirable as the ONE Pro. The higher NETD 100mK number in the K1 means more pixilation (noise) in the image compared to the 70mK in the ONE Pro. For MNDOT application, sensitivity may be a very important feature to consider because the lower the number entails ease in understanding the image and identifying the objects in the IR image. Further, the lower optical camera resolutions of the K1 provides less information than the ONE Pro resolution for the operator to better interpret the results. Finally, the battery life is not as long in the K1 compared to the ONE Pro.

Suggestions/Modifications/Alternatives to the Tool to Better Meet MnDOT's Needs

The tool will be more successful if used under certain established conditions and following tested procedures. Testing of the thermal tools should be conducted with the goal of developing operational procedures for use of this equipment. If operational procedures are such that the K1 is suitable for the application, then the K1 would be recommended based on the ruggedness and relative low cost. However, the higher thermal sensitivity (100mK) and the shorter battery life of the K1 should also be considered.

Tool Capabilities

Determine if others (military, law enforcement, others) have used for similar applications:	None
How can the tool be used? (Handheld or Mounted)	Handheld, possible mounting on vehicle
For tools used while mowing, verify mounting procedures and any issues.	The K1 is rugged and may be mounted. A MnDOT staff member indicated that the new mowers have a smoother operation. The operators do not feel a lot of vibration. If that is the case it may be that drop height, shock rating, and vibration rating of the K1 (and the E95) is overkill. The ONE Pro may be usable in the mower operation. The K1 uses the Tripod Mounting UNC 1/4"-20 or compression grip on the handle could be used for mounting (A standard vehicle phone mount could be used for the ONE Pro. A pressure grip for the K1 would offer the same flexibility as the E95 (See E95 mounting procedures). However, the screen size and resolution of the K1 may not be suitable for the mowing application. Further testing would be needed. One possible mounting set up could be to mount a K1 on each side of the driver covering half of the drive path. The ONE Pro, if tested for mowing shock and vibration resistance, would offer the screen size of the phone and one unit may be applicable to the field of view needed for the mowing operations.
How does the tool work in areas of high vegetation?	There needs to be a temperature differences between the object (in the vegetation) and the vegetation. This temperature difference is detected and presented on screen in color hues. If vegetation completely obscures the object, the detection may only be very small spots of color changes on the screen. In the high grass of the mowing operations the likelihood of an objects heat signature being completely obscured is less. In an encampment there may be occasions where the heavy vegetation (by design of the occupant) obscures the person and that person may be difficult for the thermal camera to detect.
How often does calibration need to be performed (just once upon initial use, quarterly, upon every use, etc.)? Can calibration be done by user or does it require servicing?	Calibration occurs just once. Additional may be required due to (improper) usage. Calibration is performed by the OEM. The system comes with a calibration certificate. There are some user available calibrations on screen for situations and viewing preferences and calibration. These may include language, time, date, units etc. Additional viewing customization such as focus, temperature range, span and level, brightness and contrast, color palette will be needed to better position the camera to work in the conditions. There is a manual provided to accomplish these adjustments. The other calibration SOP is for the operator and would need to be developed by MNDOT or send the operator to FLIR ITC (certified training).
Confirm that the tool's imagery is instant and does not require processing.	Confirmed.
What kind of maintenance does the tool require?	Proper use and storage. The ruggedized K1 will offer considerably more protection from improper use than the ONE Pro.
Has there been any legal opposition to the use of this tool in the public sphere? *** The responses here are not to be considered a legal opinion.**	Some concerns around capturing images of people's faces (unmasked).

Additional FLIR K1 Detailed Specifications

Overview	
Accuracy	±9°F or ±5% in High Gain Mode, or ±18°F or ±10% in Low Gain Mode, for ambient temperatures of 50–95°F
Detector Type	Focal plane array, uncooled microbolometer
Field of View	57° × 44°
Focal Length	0.075 in.
IR Resolution	160 x 120 pixels
Multi Spectral Dynamic Imaging (MSX)	Yes
Object Temperature Range	High Gain Mode: –10°C to 140°C (14°F to 284°F) Low Gain Mode: 14°F to 752°F) (at room temperature)
Packaging Size	11.1 × 5.83 × 4.06 in
Thermal Sensitivity/NETD	<100 mK @ 86°F
Connections & Communications	
Interface	Update from PC devices over USB
Storage Media	Internal memory (3.9 GB)
USB	USB Type – C
Environmental	
Drop	6.6 ft
EMC	EN 61000-6-2:2005 (immunity) EN 61000-6-3:2011 (emission) FCC Title 47 part 15, subpart B
Encapsulation	IP 67 (IEC 60529)
Humidity (Operating and Storage)	0–90% RH (32°F– 98.6°F); 0–65% RH (98.6°F–113°F); 0–45% RH (113°F–131°F)
Magnetic fields	EN 61 000-4-8 Class 3
Operating Temperature Range	Up to 10 min. with flashlight on, 14°F to 194°F Up to 2 min. with flashlight on, 14°F to 239°F
Shock	25 g (IEC 60068-2-27)
Storage Temperature Range	–22°F to 131°F
Tripod Mounting	UNC 1/4"-20
Vibration	2 g (IEC 60068-2-6)
Flashlight	
Light Output	300 lumens
Flashlight	Bright LED flashlight
LED CCT	LED CCT
LED CRI	70
Beam Angle	20°

Imaging and Optical	
Built-in Digital Camera	320 × 240 pixels
Depth of Field	0.33 ft, infinity
Digital Camera FOV	71° × 56°, adapts to the IR lens
f-number	1.1
Focus	Fixed
Image Frequency	8.7 Hz
Image Modes	TI Basic (White-hot with isotherm), White-hot, Iron
Pitch	12 µm
Spatial resolution (IFOV)	6.22 mrad
Spectral Range	8–13 µm
Storage Capacity	Approx. 10,000 images
Measurement & Analysis	
Automatic Hot Detection	NA
Isotherm	Yellow coloring 150°C to 250°C, Orange coloring 250°C to 350°C, Red coloring >350°C
Spot Meter	Center spot
Meter Data	
Auto Range	NA
Camera size (L x W x H)	8.19 × 3.3 × 2.6 in
Camera weight incl battery	0.90 lb.
Display	2.4 in. backlit LCD, 320 × 240 pixels
Power	
Battery capacity	3000 mAh
Battery operating time	Approximately 5.5 hours in MSX mode; 3.8 hours with torchlight only
Battery Type	Li ion
Battery voltage	3.7 V
Charging system	Battery is charged inside the camera
Charging Temperature	32°F to 113°F
Charging Time	4 hours to 90%, 6 hours to 100%
Power Management	Adjustable
Safety [power supply]	Camera: IEC/EN 61010-1 Power supply: UL, CSA, CE, PSE, CCC, and SAA
Start Up Time	15 s
Start-up time from sleep mode	TBD
Material	
Material	PPSU Silicon rubber Aluminum, cast

FLIR E95

The FLIR E95 offers the ruggedness of the K1, a large screen size and many features that will aid in customizing the unit to the MNDOT application. It has and operating range of 5°F to 122°F and can detect slight temperatures variations from various ranges: –4 to 248°F, 32 to 1200°F, and 572 to 2732°F. The E95 offers additional settings and higher thermal (IR) and optical resolutions than both the FLIR K1 and the ONE Pro. The E95 likely provides more options and information to determine the type of partially obstructed objects MNDOT is attempting to detect at greater distances than the One Pro or K1. Where the One Pro may detect an unobstructed person at about 130 feet under good conditions the settings and the resolution of the E95 will better define the outline of the person and perform better under less than optimum conditions.

Figure 4. FLIR E95 Tool

The E95 is used in larger industrial scale operations for differential heat detection in many different operations. It is primarily used for excessive heat detection for machinery, wiring, and heat loss. First responders and the military may use the Exx-series for situational awareness, tracking and rescue. Additional discussions of other uses took place with staff at FLIR. However, they were anecdotal based.

Cost - $10,594 for the 240 lens ($500 to upgrade to 420 lens); the 240 lens may be too narrow FOV.

Rental/Evaluation Options

When performing a preliminary test, the E95 could be used under an arranged demonstration period for up to a week (7 business days) at a cost of $995 or for a month at a cost of $2,495. It may be possible to extend that demo period depending on the sales volume that MnDOT is looking to purchase. Contact FLIR to arrange terms.

For MnDOT Application

Like the ONE Pro and the K1, the ability to detect a person (or a propane tank) using a thermal imager at a distance is a function of many conditions. Please refer to the general description of thermal camera operating conditions under ONE Pro section. The E95 (or other Exx-series cameras) is ruggedized similar to the K1 (although not capable of running in as high of operating temperature) with enhanced capabilities and features above the ONE Pro and K1. The capabilities are highlighted in the tool's specifications including in this report. One of the more relevant features is the larger screen size, higher resolution and finer temperature differentiations. These features will improve the range results under similar conditions as the ONE Pro and K1.

Pros for MnDOT Application

The E95 provides higher accuracy than K1 and ONE Pro. The thermal resolution (IR) almost triples the K1 and ONE Pro. It is ruggedized similar to the K1 therefore, it can withstand some abuse that may occur in the regular mowing operations. The larger screen compared to the K1 and ONE Pro offers greater visibility for the operator and will be critical for the operator in interpreting the thermal images. Storage capability is double the size of the K1 (the One Pro has other settings for storage with the phone). Battery life is up to 5.5 hours, which is a significant improvement from the K1 and ONE Pro. One of the most critical features that may make the use of the E95 the best option is the 30mK thermal sensitivity (70mK for the ONE Pro and the 100mK for the K1). This feature allows the tool to work in conditions where the ONE Pro and K1 (less sensitive cameras) cannot. The sensitivity and the features like the exchange of lenses will provide MnDOT staff many options to find the ideal

focus point of the camera and identify objects in the IR image. Further, it will assist with determining a proper focal point for the encampments if detection from a 20-feet distance (as identified by MnDOT) is desired. Finally, the E95 offers Wi-Fi and Bluetooth connection (possible integration with OEM screens), voice recording over images, GPS tagging of images and many other features listed in the provided specifications. This unit is one of the most capable units FLIR offers under the price cap provided by MNDOT.

Cons for MnDOT Application

Like all thermal camera limitations, at certain times of the day and depending on the distance, FOV, the thermal signature and extent of coverage of object(s) between the person and the camera the detection of a person may be more difficult.

Suggestions/Modifications/Alternatives to the Tool to Better Meet MnDOT's Needs

The E95 is the top of the line Exx-series and offers an array of customized settings and object detection settings. In discussions with MNDOT staff, it was learned that integration with the current AVL screen was not available and that while the new mowers will have integrated screens interfacing with them was somewhat complicated. With no convenient way to currently integrate with the current AVL, it is recommended to use the E95 or explore the lower cost versions of the Exx-series. Depending on the results of the E95 testing, these lower costing Exx-series units could also be tested to determine the optimum performance versus price.

Based on the screens currently in the mowers (per preliminary investigation) and from all the discussion on process and procedure, the E screen size and the mounting options seemed to be the best fit. The Exx-series screen is approximately the same size as the current AVL system.

If the remote sensing system can integrate with the OEM screen in the future (or the AVL screen if still present in cab) then there are other FLIR systems (in addition to the Exx-series) and mounting options that are available. Would recommend the Vue Pro interfaced with the either the OEM screen if possible or an interface with a standard smart phone using COTS mounting systems for the phone similar to the One Pro, if that unit is not sufficient for the tasks as determined after testing.

Tool Capabilities

Determine if others (military, law enforcement, others) have used for similar applications:	None
How can the tool be used? (Handheld or Mounted)	Both
For tools used while mowing, verify mounting procedures and any issues.	The E95 is rugged and would perform while mowing. See drop height, shock & vibration, & encapsulation below). The options for mounting include the Tripod Mounting UNC 1/4"–20 identified in the spec sheet or possibly a gimbal mounted compression grip on the E95 handle. The compression grip would be attached to a FLIR available gimbal or third-party system. When in a new or unfamiliar area, the operator should further investigate on foot before proceeding. If an operator proceeds on foot, a detachable handheld tool would be more convenient. With a compression grip, the unit would be stable mounted, but could also be easily removed for a more detailed walking survey, as needed. With the tripod mount the unit would need to be unscrewed.
How does the tool work in areas of high vegetation?	There needs to be a temperature differences between the object (in the vegetation) and the vegetation. This temperature difference is detected and presented on screen in color hues. If vegetation completely obscures the object, the detection may only be very small spots of color changes on the screen. In the high grass of the mowing operations the likelihood of an objects heat signature being completely obscured is less. In an encampment there may be occasions where the heavy vegetation (by design of the occupant) obscures the person and that person may be difficult for the thermal camera to detect.
How often does calibration need to be performed (just once upon initial use, quarterly, upon every use, etc.)? Can calibration be done by user or does it require servicing?	Calibration occurs just once. Additional may be required due to (improper) usage. Calibration is performed by the OEM. The system comes with a calibration certificate. There are some user available calibrations on screen for situations and viewing preferences and calibration. These may include language, time, date, units etc. Additional viewing customization such as focus, temperature range, span and level, brightness and contrast, color palette will be needed to better position the camera to work in the conditions. There is a manual provided to accomplish these adjustments. The other calibration SOP is for the operator and would need to be developed by MNDOT or send the operator to FLIR ITC (certified training).
Confirm that the tool's imagery is instant and does not require processing.	Confirmed.
What kind of maintenance does the tool require?	Proper use and storage.
Has there been any legal opposition to the use of this tool in the public sphere? *** The responses here are not to be considered a legal opinion.**	Some concerns around capturing images of people's faces (unmasked).

Additional FLIR E95 Detailed Specifications

Overview	
Accuracy	±3.6°F or ±2% of reading for ambient temperature 59°F to 95°F and object temperature above 32°F
Alarm	Moisture alarm, insulation alarm, measurement alarms
Color alarm (isotherm)	Above/below/interval/condensation/insulation
Difference Temperature	Yes
Display Technology	IPS
Field of view (FOV)	42° x 32° (10 mm lens)
Housing material	PCABS with TPE, magnesium
IR Resolution	464 × 348 pixels
Laser	Class 2, 1.6–131 ft. ±1% of measured distance
Object Temperature Range	–4 to 248°F, 32–1200°F, 572–2732°F
Packaging Size	19.7 x 7.5 x 14.6 in.
Programmable Buttons	1
Resolution	640 × 480 pixels (VGA)
Screening	0.9°F accuracy @ 98.6°F with reference
Thermal Sensitivity/NETD	<30 mK, 42° @ +86°F
Warranty	http://www.flir.com/warranty/
Compass GPS	Yes; automatic GPS image tagging
Text	Text from predefined list or soft keyboard on touchscreen
Time Lapse [Infrared]	10 seconds to 24 hours (infrared)
Voice	60 seconds built-in microphone and speaker (and via Bluetooth) on still images and video
Weight & Dimensions (without lens)	2.2 lbs, 11.0 x 4.6 x 4.4 in
FLIR Screen-EST Mode	Yes
Sampling Average in Screen-EST Mode	Recommended temperature range: 86 to 113°F in stable room temperature
Accuracy [Drift] in Screen-EST Mode	Accuracy (drift): ±0.5°F
Compliance and Certifications	
NIST Certification	Yes

Connections & Communications	
Audio	Microphone and speaker for voice annotation of images
Charging	In camera (AC adapter or 12 V from a vehicle) or two-bay charger
Communication Interfaces	USB 2.0, Bluetooth, Wi-Fi
Interface	USB 2.0, Bluetooth, WiFi, DisplayPort
Remote Control	Using FLIR Tools (using USB cable), FLIR Tools Mobile (over Wi-Fi)
Storage Media	Removable SD card (8 GB)
USB	USB Type-C: data transfer/video/power
USB - Standard	USB 2.0 High Speed
Video Out	DisplayPort over USB Type-C
METERLiNK	Wireless connection (Bluetooth) to: FLIR meters with METERLiNK
WiFi	Peer to peer (ad hoc) or infrastructure (network
Setup Commands	Local adaptation of units, language, date and time formats
Environmental	
Drop	6.6 ft
EMC	ETSI EN 301 489-1 (radio), ETSI EN 301 489-17, EN 61000-6-2 (immunity), EN 61000-6-3 (emission), FCC 47 CFR Part 15 Class B (emission)
Emissivity Correction	Yes: variable from 0.01 to 1.0 or selected from materials list
Humidity (Operating and Storage)	IEC 60068-2-30/24 hours/95% relative humidity 77–104°F/two cycles
Operating Temperature Range	5°F to 122°F
Radio Spectrum	ETSI EN 300 328, FCC Part 15.249, RSS-247 Issue 2
Safety	EN/UL/CSA/PSE 60950-1
Storage Temperature Range	-40°F to 158°F
Tripod Mounting	UNC 1/4"–20
Shock & Vibration & Encapsulation	25 g / IEC 60068-2-27, 2 g / IEC 60068-2-6, IP 54 /IEC 60529; EN/UL/CSA/PSE 60950-1

Imaging and Optical	
Additional lenses	24°, 14°
Auto Rotation	Yes
Camera software update	Use PC software FLIR Tools
Color depth (bits)	24
Color palettes	Iron, Gray, Rainbow, Arctic, Lava, Rainbow HC
Detector Type and Pitch	Uncooled microbolometer, 17 µm
Digital Camera	5 MP, 53° x 41° FOV
Digital Zoom	1-4x continuous
f-number	1.1, 42°
Field of view match	Yes
Focal Length	0.39 in., 42°
Focus	Continuous, one-shot laser distance meter (LDM), one-shot contrast, manual
Gallery	Yes
Image Adjustment	Automatic, Automatic maximum, Automatic minimum, Manual
Image Frequency	30 Hz
Image Modes	Infrared, visual, MSX®, Picture-in-Picture
Image Sketch	Yes: on infrared images only
Infrared Image	Yes
Lens Identification	Automatic
Minimum Focus Distance	0.49 ft., 42°
Minimum Focus Distance with MSX	2.13 ft., 42°
Non-Radiometric IR or Visual Video	H.264 to memory card
Non-radiometric IR video streaming	H.264 or MPEG-4 over Wi-Fi MJPEG over UVC or Wi-Fi
Picture-in-Picture	Resizable and movable
Radiometric IR video recording	Real-time radiometric recording (.csq)
Radiometric IR video streaming	Over UVC
Spatial resolution (IFOV)	1.66 mrad/pixel, 42°
Spectral Range	7.5 - 14.0 µm
Viewfinder	No
Focus Distance	Lens Dependent
Focus Length	Lens Dependent
MSX	Embosses visual details on full resolution thermal image; Non-Radiometric IR & Visual Video Recording; H.264 to memory card
Sketch	From touchscreen
UltraMax	Super-resolution process quadruples pixel count, activated in FLIR Tools+
Viewing Angle	80°
Visual Video Streaming	Yes

Measurement & Analysis	
Area	1 in live mode
Area measurement information	Yes
Languages	21
Measurement Corrections	Yes
Measurement Presets	No measurement, center spot, hot spot, cold spot, User Preset 1, User Preset 2
Reference Temperature	Yes
Spot Meter	3 in live mode
Automatic hot & cold detection	Auto-maximum/minimum markers within area
Meter Data	
Cover Glass Material	Dragontrail®
Display	4", 640 x 480 optically bonded PCAP touchscreen, with 400 cd/m2 surface brightness
Power	
Battery Life (Operating)	> 2.5 hours at 68°F and typical use
Battery operating time	Approx. 2.5 hours at 77°F ambient temperature and typical use
Battery size (L x W x H)	5.9 × 1.8 × 2.2 in.
Battery Type	Li-ion battery, charged in camera or on separate charger
Battery voltage	3.6 V
Battery weight	4.9 oz.
Charging Temperature	+32°F to +113°F
Charging Time (using two-bay charger)	2.5 hours to 90% capacity with charging status indicated by LEDs
External Power Operation	AC adapter 90–260 V AC, 50/60 Hz, or 12 V from a vehicle (cable with standard plug—optional)
Power Management	Automatic shut-down and sleep mode
Shipping Information	
Packaging	Infrared camera with lens, battery (2 ea), battery charger with power supply, front lens and light protection, straps (hand and wrist), lanyards, lens caps (front and rear), lens cleaning cloth, 15 W3 A power supply, printed documentation, 8 GB SD card, Torx screwdriver, cables (USB 2.0 A to USB Type-C,USB Type-C to HDMI, USB Type-C to USB Type-C)
Storage Media	
Image File Format	Standard radiometric JPEG, measurement data included

Phoenix 5.0 MP (PHX050S-P/Q)

The Phoenix 5.0 MP operating ranges is 14 to +133°F for the sensor, however other tools, (lens, processor, etc.) will have to be added. Since this is a visible light camera, range is largely dependent on the size of the object detected.

Cost - $1,950, additional components are needed to create a working detector system.

Rental/Evaluation Options

Unknown

For MnDOT Application

The tool is a camera with four separate polarization filters. It can supply image data with any of these filters engaged to isolate a specific polarization of light. An object with a flat or smooth surface will reflect light with a different polarization than foliage/vegetation. This difference can be detected with an image processor and drivers alerted through and alarm or image display. The processing of image data and displays are created by customers – not provided by the camera.

Figure 5. Phoenix 5.0 MP Tool

Pros for MnDOT Application

Polarization analysis can detect even intentionally camouflaged objects in vegetation.

Cons for MnDOT Application

Will not detect fully occluded people or objects, lens must be kept clean, camera only, detection system must be developed and built by MnDOT.

Suggestions/Modifications/Alternatives to the Tool to Better Meet MnDOT's Needs

This tool is a sensor/processor module. An appropriate housing, lens and mounting system is needed to attach the Phoenix 5.0 MP to a mower and integrate it with driver alert or other systems.

Tool Capabilities

Determine if others (military, law enforcement, others) have used for similar applications:	Detector of camouflaged vehicles in foliage is listed as an application, but the camera works in visible light, so will not be able to detect people within tents or completely occluded objects.
How can the tool be used? (Handheld or Mounted)	Mounted on a vehicle since it must connect to an external processor and power.
For tool used while mowing, verify mounting procedures and any issues.	Supplier provides imaging module only. Design of housing, mounts, lens system, etc. will be custom for the application. Since it uses a lens to focus visible light, mounting must consider keeping lens clean and unobstructed.
How does the tool work in areas of high vegetation?	The camera works by detecting differences in polarization of reflected light. Vegetation will reflect with a different polarization than a flat surface and this difference can be detected.
How often does calibration need to be performed (just once upon initial use, quarterly, upon every use, etc.)? Can calibration be done by user or does it require servicing?	Since this is a custom application of the camera module, calibration/set up procedures are unknown.
Confirm that the tool's imagery is instant and does not require processing.	The camera module provides "raw" data to a customer's external system. Managing and displaying imagery is the role of the external system, which would be developed for the mower application.
What kind of maintenance does the tool require?	Lens systems must be kept clean and free from obstruction. A separate washer system may be the best way to accomplish this.
Has there been any legal opposition to the use of this tool in the public sphere? *** The responses here are not to be considered a legal opinion.**	Unknown.

Additional Detailed Specifications

Overview	
Detector Type	Color or monochrome CMOS visible light sensor with 4-way polarizing filter
Field of View	Dependent on lens (C and NF mounts available)
Resolution	2448 x 2048 pixels, 5.0 MP
Packaging Size (sensor only)	24 x 24 x 27.35 mm
Weight	30 g
Connections & Communications	
Interfaces	1000BASE-T RJ45, GPIO (8 pin), 1 opto-isolated input, 1 opto-isolated output, 2 non-isolated input/output
Environmental	
Drop	Dependent on housing
Humidity (Operating and Storage)	Operating – 20%-80% non-condensing
Operating Temperature Range	14 to 131°F
Shock	DIN EN 60068-2-27
Storage Temperature Range	–22°F to 131°F
Tripod Mounting	UNC 1/4"-20
Vibration	DIN EN 60068-2-64
Imaging and Optical	
Built-in Digital Camera	2448 x 2048 px
Depth of Field	Dependent on lens
Digital Camera FOV	Dependent on lens
f-number	Dependent on lens
Focus	Dependent on lens
Image Frequency	24 FPS
Image Modes	Horizontal and vertical binning, decimation, ROI, horizontal and vertical flip
Pitch	12 µm
Storage Capacity	128 MB buffer
Power	
Input Voltage	POE (48 VDC nominal) or 12- 24VDC external
Power consumption	3.1W via PoE, 2.5W when powered externally

Q130R

The Q130R (Banner Engineering) operating ranges is -40 to +149F Detection distance is 1-24 meters/1-40 meters for the sensor. Two models are available (9076 and 2450) data for each is given below.

Figure 6. Banner Engineering Q130R

Cost - $645 to $895

Rental/Evaluation Options

No rental options. However, a reduced price "evaluation" purchase (65% off) may be available. Please contact Banner Engineering for more information.

For MnDOT Application

The Q130R is a radar. It will send a pulse of RF energy out and sense reflection of that energy from a target. The tool's internal processor allows for tuning of the distance and strength of the detected reflection to discriminate objects & reject unwanted detections. A simple on/off output from the detector can then be connected to a device that alerts the driver of presence.

Pros for MnDOT Application

The Q130R is simple to install, rugged, reliable and relatively inexpensive.

Cons for MnDOT Application

The Q130R does not have a history for this application. It must be tested, and calibration parameters determined. Mounting methods and hardware will be customized for this application. There may not be a set of calibration parameters that provides reliable detection performance.

Suggestions/Modifications/Alternatives to the Tool to Better Meet MnDOT's Needs

The tool itself provides a simple on/off output. The method of alerting the driver must be determined. If there are other warning indicators used by MnDOT to avoid collisions, etc., consider adapting these to the mower application. After further discussion with Banner Engineering, a good testing program to determine mounting locations and sensor calibrations for the mowers is necessary.

Tool Capabilities

Determine if others (military, law enforcement, others) have used for similar applications:	Tool provides object detection only (radar requires high reflectivity of RF energy). Typically, this tool is used to detect the presence of metallic objects (vehicles or other items). It has been used on moving platforms (mining dump trucks) for collision avoidance. However, the mower application will require validation as it has not been used in this specific environment.
How can the tool be used? (Handheld or Mounted)	Mounted on a vehicle.
For tools used while mowing, verify mounting procedures and any issues.	The distance and angle to the detection area in front of the mower should remain constant. Tool outputs will be connected to an external visual or audible indicator for the driver. Mining applications are very dusty/dirty and involve intense vibration. Tool is IP67 rated to prevent liquid and dust ingress. Mounting method will require design specific to the mower.
How does the tool work in areas of high vegetation?	Unknown. Performance will require testing/validation.
How often does calibration need to be performed (just once upon initial use, quarterly, upon every use, etc.)? Can calibration be done by user or does it require servicing?	If the position of the sensor relative to the target area does not change (i.e. two feet below and four feet ahead of sensor mounting position), calibration should only be necessary at set-up. Calibration is through manufacturer-provided software.
Confirm that the tool's imagery is instant and does not require processing.	This tool does not produce imagery
What kind of maintenance does the tool require?	Inspection of the connection to power and driver indicators should be the only maintenance required for the tool. Inspection of the mounting hardware to ensure that aspect on the target area has not changed and should also be part of mower maintenance
Has there been any legal opposition to the use of this tool in the public sphere? *** The responses here are not to be considered a legal opinion.**	No.

Additional Detailed Specifications

Overview	
Detector Type	Frequency modulated continuous-wave (FMCW) radar
Range	9076 models: 3.3 ft to 78.7 ft 2450 models: 3.3 ft to 131.2 ft)
Beam Angle	90 X 76 degrees (9076); 24 X 50 degrees (2450)
Response Time	50 milliseconds minimum
Packaging Size (sensor only)	1.97 X 6.71 X 3.57 in
Weight	~ 1 pound
Connections & Communications	
Interfaces	Two Bipolar NPN/PNP outputs
Configurations	Switch point (distance). Hysteresis, Signal strength, Output settings, Response time/delay
Environmental	
Drop	Dependent on housing
Humidity (Operating and Storage)	Operating – 5%-95% non-condensing
Operating Temperature Range	-40 to +149 F
Shock	IEC 60947-5-2
Storage Temperature Range	-40 to +149 F
Vibration	IEC 60947-5-2
Power	
Input Voltage	10- 30 VDC
Power consumption	1.2W, 50mA @ 24VDC

Appendix A – Complete List of Reviewed Remote Sensing Tools

Thermal – Thermal/Visible (Detects through temperature variation)

Collect fine temperature differential data. With high-resolution systems, image is like a digital optical camera. Thermal cameras lose sharpness quickly at farther distances. Can be combined with optical images for contrast.

Type (thermal, magnetic, etc.)	What it can Detect	Tool Name	Manufacture	Range	Limitations	Size/Weight	Approx Cost
Thermal with MSX	Variations in temperature in total darkness, through smoke, and other undesirable elements, detects temp variations. <100 mK (0.1C) Thermal Sensitivity @ 30°C (86°F)	Flir K1 There are many models (This is base 1st responder model) basically the same as the K2 without the device higher heat resistance.	Flir	20 yards may be their max operating distance?	Ruggedized handheld stick figured design with pistol grip so may not be perceived as a camera by some. No alarm so Operator must look at display. 5-hr hour battery life; charges via standard USB port. Easy operation including with a gloved hand and comes with built-in multi-setting flashlight *Unique function – MSX (FLIRs Thermal and Visual image overlay) This screen resolution for the K1 (and K2) is less than other systems but the integrated MSX optical overlays provide sharp optical capture. Overlaid on the 160x120 pixel screen provides much richer picture than pixels would indicate. Captures still images with trigger pull and can save up to 10,000 sets of radiometric thermal and visual images for reporting. Upgrading to more expensive models add greater sensitivity with extended temperature ranges. The basic look and feel are the same as the K1 but can increase the ability to detect minute heat differences. Similar models can cost as much as $2,000 or more.	11’× 6’×4”	$599
Thermal with MSX	Variations in temperature Same as above but <150mK (0.15C) Thermal Sensitivity Range: 4F-752F	FLIR One Pro	Flir	15 yards effective	Phone attachment with adjustable height connector (works with protective cases). Looks like a camera. No audible alarm but has a high temperature color alarm (could make items such as propane tanks standout because of the air void.) Built in optical camera (1440x1080p) and Thermal camera (160x120p) where optical and thermal cameras use same focal point (thermal and optical images are interlaced). 1-hr battery life; charges separately from USBC to USBA cable. Does not use phone	2’x1.5”x6” .4 lbs	$399

Type (thermal, magnetic, etc.)	**What it can Detect**	**Tool Name**	**Manufacture**	**Range**	**Limitations**	**Size/Weight**	**Approx Cost**
					battery (Flir C2 or C3 are similar but less resolution systems but fully functional cameras and have two hours if longer life needed. 9Hz refresh rate; Auto focus only; Record video on phone/tablet		
Thermal (pair with phone camera)	Variations in temperature <70mK (0.07C) Thermal Sensitivity	SEEK Compact Pro	SEEK	15 yards effective	15Hz refresh rate (big help for smooth visual movement in the field of view. Auto focus but Option for manual focus Uses phone camera	2”x1.25”.6” .3 lbs	$395
Thermal/Visible	Variations in temperature + Visible Light	HT A2	HT Instrument	N/A	No alarm functions. Screen may be difficult to read in direct sunlight w/o a sunshade/hood. Operator must look at display.	5.5” x 3.1” ~0.5 lbs	$520
Thermal	Variations in temperature	M12	Milwaukee (2258-21)	N/A	No alarm functions. Looks like a gun. Operator must look at display.	9” x 3.25” ~0.6 lbs	$500

Thermal Industrial Grade Cameras

More testing is required to determine if the higher sensitivity is needed. For example, detects the difference between the outside fabric temperature of a dark colored tent and the body inside the tent

Type (thermal, magnetic, etc.)	**What it can Detect**	**Tool Name**	**Manufacture**	**Range**	**Limitations**	**Size/Weight**	**Approx Cost**
Thermal with MSX™	Industrial Thermal Cameras <30mK (0.03C) Thermal Sensitivity Range: 4F-2732F	E95	Flir	Can use different lenses to maximize range >20 yds	Thermal IR Resolutions of 464 x 348; 30Hz Frame rate (higher frame rate provides smoother picture for operator to analyze). 4 in x 4 in Screen, Brilliant display (Seen better in sun) Touch screen; Ultramax tool increases resolution by 4 times (928x696) Laser assisted auto-focus; IR optical image interlacing (MSX); Built in WiFi can remotely view screen; 2 batteries with recharging station can run 8 hrs. HDMI output to second in cab screen Audible alarm settings	7lbs	$9995
Thermal with IR Fusion™	Industrial Thermal Cameras <30mK (0.03C) Thermal Sensitivity Range: 4F-2192F	**Ti450**	FLUKE	Same	Thermal IR Resolutions of 320x240; 60 Hz frame rate (video camera level higher frame rate provides smoother picture for operator to analyze); 3.5”x3” touch screen; clean menu structure Fluke SmartView reporting software; Super resolution 640x480; Laser assisted auto-focus IR optical image interlacing (IR Fusion); Audible alarms	Several pounds	$8500

Radar (Detects Metal Objects)

Very good at penetrating through thick brush and partially buried metal objects at great distances.

Type (thermal, magnetic, etc.)	**What it can Detect**	**Tool Name**	**Manufacture**	**Range**	**Limitations**	**Size/Weight**	**Approx Cost**
Radar uses Frequency Modulated Continuous Wave (FMCW) technology.	Metals, other dielectric materials (not people)	Q130R	Banner Engineering	140’	Has wide field of detection. Must be tuned to limit weak reflections. Sensor settings can be set for distance, sensitivity and output configuration. Works best when perpendicular to target. Models are available with 90°x76° or 24°x50° beam patterns. Not effected by ambient weather conditions and vibrations. Will need to check for dead zones and reliable detection of smaller metal objects.	6.7” x 3.5” ~1 lbs	$800

Polarized Cameras

Analyzes an object polarized spectral property emitted

Type (thermal, magnetic, etc.)	**What it can Detect**	**Tool Name**	**Manufacture**	**Range**	**Limitations**	**Size/Weight**	**Approx Cost**
Linear polarization camera	Detect the tanks hidden in the grass	Phoenix 5.0 MP	Lucid				$2,000
Polarization camera	Captures clean images; detects tiny objects	GigE 3CCD	Fluxdata		Pricey. Depends on desired configurations; can obtain via loan for $2500		$45-75K

Additional Detection Tools

Able to detect devices (users' phone) through Bluetooth

Type (thermal, magnetic, etc.)	**What it can Detect**	**Tool Name**	**Manufacture**	**Range**	**Limitations**	**Size/Weight**	**Approx Cost**
RF Analyzer	Active Bluetooth or Wi Fi adapters	Bluetooth Tracker	Ellisys	20'	Will be a custom application. Can indicate presence of a cell phone will BT or WiFi active, but nothing else.	3"x3"; 0.2 lbs (plus, other hardware)	$200 (plus, other hardware)
Metal Detector: Pulse Induction	Metals, some cavities (not people)	SPARK	MFT	300'	Very good at locating metal objects of various sizes and buried up to certain depths Must sweep to find direction. Must calibrate/adjust. No alarm output. May be better at handling wet conditions.	14" x 6"	$1,600

Appendix B – Contact Information

Banner Engineering Corp.

Chris Graber, Area Sales Manager - MNDAK
9714 10th Avenue North,
Minneapolis, MN 55441
(P) 763-593-3917 (C) 612-251-5462
cgraber@bannerengineering.com

FLIR Systems, Inc

Customer Service
9 Townsend W,
Nashua, NH 03063
(P) 603-324-7716

Lucid Vision Labs

Sales Headquarters
130-13200 Delf Place,
Richmond B.C.
Canada, V6V 2A2
(P) 833-465-8243
sales@thinklucid.com