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Synthesis: Commercial Air-Coupled Ground Penetrating Radar Systems to Be Used for Pavement Evaluations in Texas

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16. Abstract

This study examines the potential of air-coupled Ground Penetrating Radar (AC-GPR) systems to overcome limitations in the Texas Department of Transportation's (TxDOT) current pavement evaluation practices. The research integrates a comprehensive literature review, a statewide survey of TxDOT districts on GPR usage and barriers, and a technical assessment of commercially available AC-GPR platforms, including systems from GSSI, Kontur, IDS GeoRadar, and ImpulseRadar. Evaluation criteria included operational features, frequency ranges, data formats, and compatibility with TxDOT's PaveCheck software. Findings indicate that the GSSI RoadScan system offers the most practical solution for near-term implementation due to its widespread adoption and training support, though proprietary data conversion is required for PaveCheck integration. Recommendations include deploying the GSSI 2 GHz horn antenna and SIR 30 control unit, alongside modernizing PaveCheck to ensure future compatibility. The study also identifies opportunities for advancing pavement monitoring through 3D GPR technologies and AI-assisted data processing, aiming to improve efficiency and support long-term infrastructure management.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The findings, opinions, and conclusions expressed in this document are those of the authors and do not necessarily reflect the official policies or positions of TxDOT or FHWA. This report does not constitute a standard, specification, or regulation.

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The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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Special thanks are extended to pavement engineers and staff from TxDOT's districts for their participation in the statewide survey and for sharing their expertise and operational insights regarding air-coupled GPR usage. Their contributions were essential in shaping the findings and recommendations of this report.

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BACKGROUND

Ground Penetrating Radar (GPR) is a widely used non-destructive evaluation (NDE) technology for assessing pavement layer thickness, detecting subsurface anomalies, and supporting pavement design and maintenance decisions. The air-coupled GPR actively used in TxDOT has proven to be invaluable non-destructive testing (NDT) equipment to evaluate in-situ pavement conditions since the early 2000s. TxDOT currently employs an air-coupled GPR system integrated with the PaveCheck software for these evaluations. However, the existing system faces increasing limitations due to aging hardware, outdated software, limited availability of replacement parts, federal restrictions on acquiring high-frequency antennas, data format compatibility issues, gaps in staff training, and rising maintenance costs.

To address these challenges, TxDOT initiated this project to identify and recommend a modern, vehicle-mounted air-coupled GPR system that better aligns with current and future pavement evaluation needs. The objective was to evaluate commercially available GPR systems in terms of technical performance, compatibility with existing workflows, long-term cost-effectiveness, and ease of use across TxDOT districts—while requiring minimal disruption to current operations and offering scalability for future advancements in data processing and analysis.

PROJECT TASK

This project's tasks included the following:

Task 1: Conduct Project Management and Research Coordination

Task 2: Literature review to condense current practices and significant findings

Task 3: Interview preparation usage requirements and purposes of the current GPR system

Task 4: Investigate GPR Equipment and Software

Task 5: Preliminary SWOT analysis and review of available GPR

Task 6: Investigate the data formats of the new system for PaveCheck

Task 7: Evaluate GPR system selection criteria

Task 8: Evaluate suitability of available new GPR system

Task 9: Develop draft recommendations and implementation guidance for the new GPR system

Task 10: Finalize review and recommendations

DELIVERABLES

Table 1 includes the Key deliverables from this project.

Table 1: Key deliverables from this project

Task #	Task Description	Deliverables
1	Conduct Project Management and Research Coordination	
2	Literature Review to Condense Current Practices and Significant Findings	TM-2
3	Interview Preparation Usage Requirements and Purposes of The Current GPR System	TM-3
4	Investigate GPR Equipment and Software	TM-4
5	Preliminary Analysis and Review of Available GPR	TM-5
6	Investigate the Data Formats of new System for Pavecheck	TM-6
7	Evaluate GPR System Selection Criteria	TM-7
8	Evaluate Suitability of Available New GPR System	TM-8
9	Develop Draft Recommendations and Implementation Guidance for New GPR System	TM-9
10	Implementation Guidance	P-1
1	Research Report	R1
1	Project Summary Report	PSR

RESEARCH APPROACH

To achieve the objective stated earlier, a series of research tasks were performed. The following subsections summarize each of the primary tasks.

1. Literature Review to Condense Current Practices and Significant Findings

As part of Task 2, the research team conducted an extensive literature review to identify the modern practices and significant findings related to GPR technology. The review focused on the existing GPR practices implemented across Texas and other states, alongside ongoing research, to determine the applicability of these findings to the Receiving Agency's specific needs for pavement evaluation as well as potential new avenues for GPR usage. The detailed explanations of the tasks performed are as follows:

1.1. Common Applications of GPR

GPR is a versatile non-destructive evaluation technology widely adopted by various DOT for infrastructure assessment and maintenance. By using electromagnetic wave pulses, GPR enables efficient subsurface exploration without the need for invasive procedures, making it an essential tool in modern engineering applications. Some of the common uses of GPR are listed below.

1.1.1. Pavement Evaluation

GPR is extensively used to evaluate pavement thickness, detect voids, and analyze density variations, ensuring efficient and precise assessments of road infrastructure. For example, in California, GPR is used for inspecting pavement, crack detection and determining asphalt [1]. Figure 1 shows Caltrans' current GPR setups for scanning pavement. Washington employs GPR integrated with distance measuring instruments (DMI) and GPS systems to assess density variations in newly constructed asphalt pavements.

Figure 1: Caltrans Ground Penetrating Radar Setups for pavement evaluation [2]

1.1.2. Bridge Deck Inspection

GPR is a valuable tool for evaluating bridge decks, finding rebar corrosion, detecting delamination, assessing deterioration, and identifying moisture intrusion. In Virginia, GPR is deployed to detect delamination, assess overlay debonding, and determine rebar placement accuracy [1]. Colorado applies GPR for evaluating overlay conditions and identifying delamination in bridge decks, aiding maintenance and rehabilitation efforts [1]. Nebraska DOT uses GPR to evaluate suspect areas on bridge decks. Figure 2 shows the Nebraska Department of Transportation (NDOT) air-coupled GPR system to evaluate bridge decks [1].

Figure 2: NDOT air-coupled GPR system for bridge deck inspection [1]

1.1.3. Utility Mapping:

The ability of GPR to locate underground utilities and measure cover depth has made it indispensable for utility mapping projects. California also utilizes GPR to locate subsurface utilities and ensure proper cover depth during milling operations, preventing equipment damage [1]. Similarly, Oregon uses GPR for utility mapping, as well as verifying rebar placement and depth during bridge inspections, ensuring safety and construction accuracy [1]. Figure 3 shows the aerial photo overlayed with location of utilities found using GPR technology.

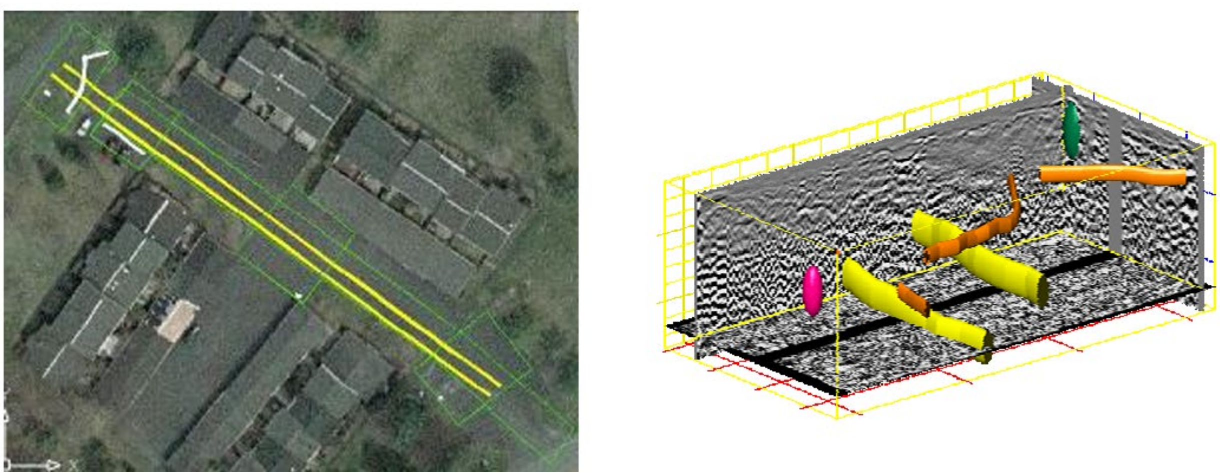


Figure 3: Aerial photo overlayed with location of utilities found (Left) and 3D view of a section showing the mapped utilities (Right)[3]

1.1.4. Tunnel Inspections:

In tunnel inspections, GPR is employed to identify moisture-related anomalies and assess structural conditions. For example, Louisiana conducts inspections of tunnel liners using high-speed GPR to detect moisture and evaluate overall structural conditions [1]. Pennsylvania combines GPR with infrared thermography (IR) and traditional inspection methods to detect deterioration in concrete tunnel linings, offering a comprehensive view of tunnel conditions as shown in Figure 4 [1].

Figure 4: PennDOT is using a van-mounted GPR system to inspect tunnel walls [1].

1.1.5. Geotechnical Applications

GPR is also utilized in geotechnical investigations to analyze subsurface conditions, detect voids, and evaluate soil layers as shown in Figure 5. South Dakota employs ground-coupled GPR systems to study subsurface features such as ground water tables [4].

Figure 5: GPR system used for geotechnical investigation (trenchlesstechnology.com)

1.2. Overview of GPR Usage

The Performing Agency found that many states use GPR for a variety of applications in infrastructure evaluation, such as pavement assessments, bridge inspections, and utility mapping. These practices showcase the versatility and effectiveness of GPR technology. Table 2 provides a summary of GPR applications across various states.

Table 2. Overview of statewide GPR applications

State	Usage of GPR in Pavement Evaluation	Comments
California [1,4][4]	• Road: Determining asphalt thickness for concrete overlay, moisture detection, locating subsurface crack • Road: Measuring cover depth prior to milling operations to avoid equipment damage • Bridge: Bridge deck inspection, checking rebar placement	Caltrans utilizes a combined method of GPRs and other traditional NDE methods such as hammer sounding to perform pavement evaluations. They comment on the increased need for training and experience for the effective use of GPR techniques.
Colorado [1][4][5]	• Bridge: Evaluating potential damaged areas on bridge decks due to chloride contamination, rebar corrosion, moisture. • Road: Used to find damage within the roadways like voids, stripping sinkholes, and changes in subsurface conditions, determining pavement layer thickness	CDOT primarily uses GPR on bridge decks with overlays but does not plan for any new NDE technology investigations.
New Mexico [1][6]	• Bridge: Checking for correct rebar placement when unexpected cracking occurs • Road: Determining pavement layer thickness • Road: Used to ensure road projects don't impact Native American burial sites	NMDOT finds that GPR offers value when applied as an additional evaluation method alongside traditional methods such as chain dragging.

Oregon [1]	• Bridge: Checking for correct rebar placement and depth • Bridge: Supporting identification of coring locations for concrete chloride testing • Road: Drainage system inspections to ensure the proper functioning of roadway water management systems	Due to the difficulty in interpreting NDE data ODOT finds the use of GPR not necessary. They state that the creation of more universal references and standards would increase the value of GPR.
Pennsylvania [1]	• Road: Detecting deterioration under asphalt • Road: Measuring asphalt thickness • Road: Used to detect potential sinkhole formations • Bridge: Measuring rebar cover depth	PennDOT comments on the cost and time needed too process NDE data as one of the few faults with GPR.
Minnesota[7] (www.prweb.com)	• Road: Measure moisture fluctuations in the unbound aggregate layers • Road: Evaluates asphalt overlay thickness, pavement conditions and layers for maintenance scheduling • Bridge: Detecting concrete deterioration, rebar-level delamination, rebar cover depth.	MNDOT recommends further investigation of utilizing 3D-GPR and other NDE tools in relation to stripping and moisture susceptibility.
Indiana [1][8]	• Bridge: Detects where chlorides have transferred onto bridge decks • Road: used to evaluate pavement thickness, detecting voids, moisture, subgrade evaluation	INDOT has found that even though they are able to perform NDE studies themselves, the use of consultants provides more insightful results.
Louisiana [1][9]	• Bridge: Used to inspect bridge decks and joints, assess concrete deterioration, and detect delamination • Road: Used in high-risk areas of sinkholes	LADOTD has increased its use of GPR as an NDE method due to having the third highest bridge deck area. Previous NDE methods such as chain dragging is deemed as an aging technology. Interest in the increasing speed of GPR

	• Road: Pavement moisture damage detection, layer thickness measurement, subsurface anomaly detection	processing has positively impacted the perception of GPR as a main NDE technique.
Iowa [1][10][11]	• Bridge: Inspection of bridge decks and deck joints, detecting rebar location, detection corrosion damage in rebar • Road: Detect pavement layer thickness, moisture detection, detection of defects such as voids, stripping	Iowa DOT has partaken in some GPR NDE usage, but they do not deem it as enough of a return-on-investment to fully switch to an automated NDE technique. They still use manual sounding methods primarily.
Nebraska [1][12]	• Bridge: used for evaluation of bridge decks for repair work estimation, detecting voids, delamination, corrosion detection, moisture detection	NDOT finds use in GPR as an NDE technique as it can be used to estimate damage of asphalt overlay on bridge decks
Washington state [3]	• Road: Used for pavement evaluation and density measurement, finding underground utilities	WSDOT found that GPR is a promising tool for evaluating pavement density but has limitations when applied to thicker asphalt pavements.
Virginia [1][14]	• Bridge: Used for evaluating bridge decks and checking rebar placement within the new decks, detection voids. • Tunnel: Evaluating suspect tunnel liners and evaluating tunnel roadways • Road: Used for determining pavement layer thickness, dielectric constant, Quality Control in pavement construction	VDOT primarily uses manual inspection techniques such as chain-dragging and sounding, but it has resorted to the use of more advanced techniques that can be performed without shutting down traffic lanes or potentially risking VDOT workers.
New York [4]	• Road: Used for pavement thickness assessment, void detection, moisture	NYSDOT identifies a need for faster and safer NDT methods such as GPR

	content analysis, and underground utility mapping • Bridge: Used for bridge deck inspection, detecting delamination	due to the reduction in lane closers and exposer to high-speed traffic by NYSDOT workers.
New Jersey [5][17]	• Road: Used for determining pavement Layer thickness, detecting voids, locating underground utilities • Bridge: Evaluate bridge decks for delamination	NJDOT found that GPR is good at predicting pavement types and thickness, but not as reliable for predicting base and sub-base materials.
Connecticut[4]	• Bridge: Used to evaluate bridge deck conditions • Road: Pavement layer thickness evaluation	GPR was used sparingly, and it was performed by an outside contractor.
Illinois[17]	• Road: Pavement layer thickness and condition • Bridge: used for bridge deck condition surveys for delamination and steel depth	GPR was found to be an accurate tool for determining pavement thickness and condition.
Florida [4][18]	• Road: Used to find underground utilities before construction of roadways, detecting subsurface layer thickness, utility and sinkhole location • Road: Used in areas that could be exposed to water and potential underground erosion • Bridge: Used for bridge deck survey for determining delamination, cover depth, voids	FDOT found that there is moderate interest in establishing an NDT certification program to improve technician competence in QA and QC testing
Kentucky [16]	• Road: Pavement layer thickness, detecting voids, moisture • Bridge: Determining rebar cover depth	It was determined that the use of GPR for pavement thickness analysis was promising, but caution was to be

		exercised for concrete pavement analysis
Missouri [5]	• Bridge: Used to estimate bridge deck deterioration, correct placement of dowel bar, used to inspect the condition of drainage pipes and culverts to identify blockages, voids, or failures • Road: Used for determining pavement layer thickness, sinkhole, voids, geotechnical application such as sinkhole, buried objects	GPR was found to be highly repeatable and could be used as a good tool for QC in road construction and repair.

1.3. Other State DOT Practices

1.3.1. Minnesota Department of Transportation (MDOT)[19]

MDOT conducted a study to develop a procedure for assessing pavement thickness using a 3D GPR system. The study aimed to reduce the reliance on coring while ensuring precise measurements of asphalt layer thickness using data collected from 3D GPR.

MDOT utilized a 3D GPR system integrated into the RoadDoctor vehicle as shown in Figure 6. The vehicle was equipped with an array of 11 transmitting and 11 receiving antennas as shown in Figure 7. The initial data processing was carried out using the 3D GPR Examiner Software, while advanced analysis was facilitated through custom FORTRAN code. This integrated approach ensured efficient and accurate evaluations, demonstrating the potential of 3D GPR systems in enhancing pavement assessment processes as shown in Figure 8.

Figure 6: Vehicle mounted with 3D GPR system[19]

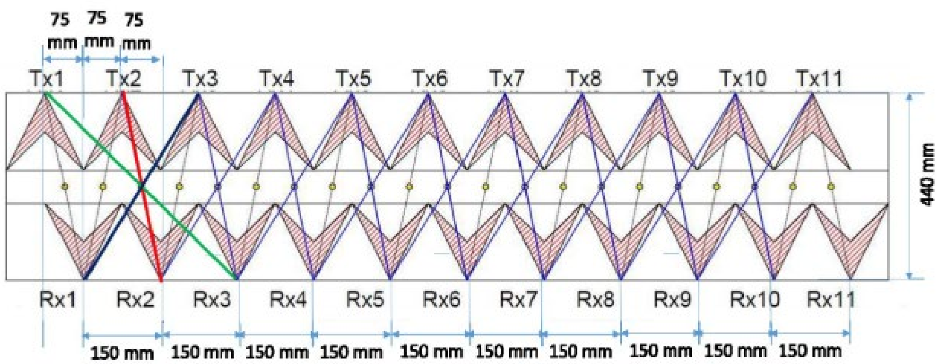


Figure 7: 3D GPR array system[19]

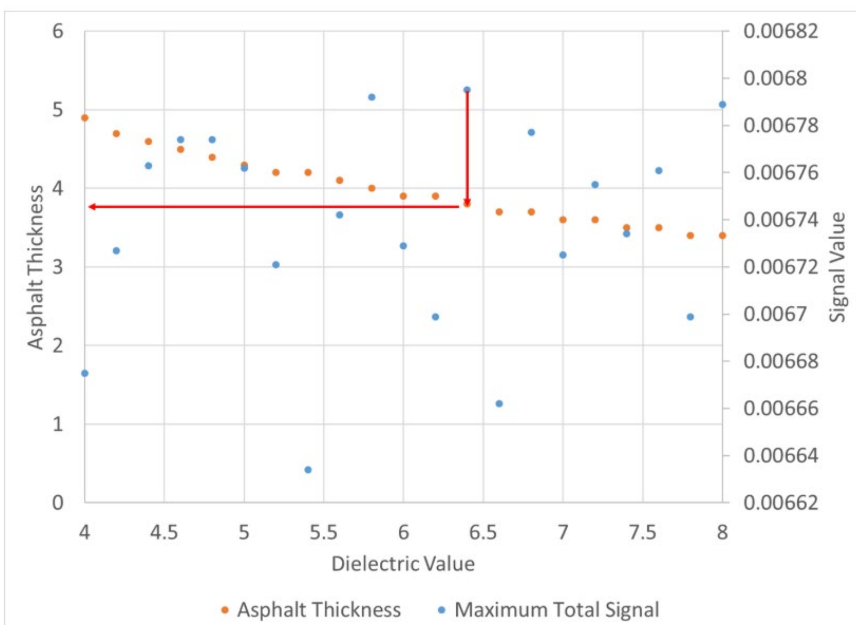
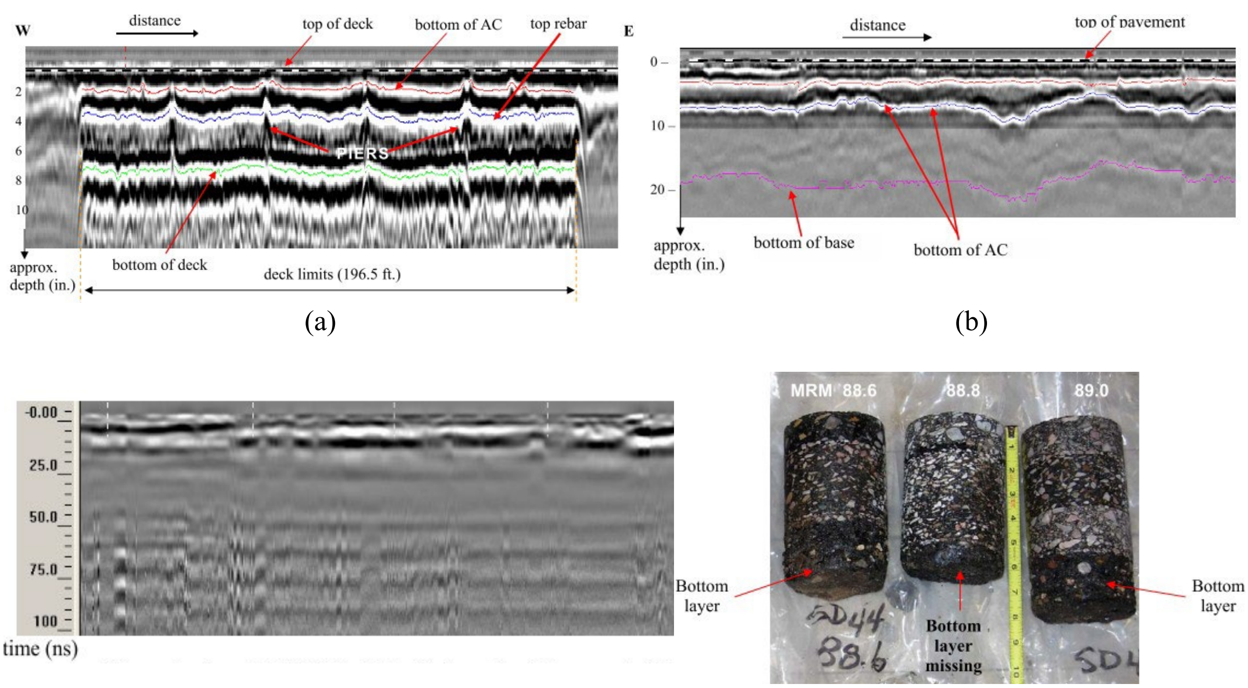


Figure 8: Asphalt thickness for various values of dielectric constant of asphalt[19]

1.3.2. South Dakota Department of Transportation (SDOT) [4]

SDOT investigated the effectiveness of GPR in evaluating pavements, detecting bridge deck damage, and conducting geotechnical studies. The study utilized the GSSI SIR-20 system equipped with 1 GHz and 2 GHz horn antennas for bridge deck and pavement surveys as shown in
Figure 9. For geotechnical investigations, a portable SIR-3000 unit equipped with 200 MHz and 400 MHz ground-coupled antennas was used. Signal processing was performed using software like WinDECAR® to analyze dielectric properties, rebar depth, and concrete attenuation as shown in Figure 10. The study showcased GPR as a reliable tool for non-destructive evaluation across different use cases.

Figure 9: Horn antenna equipment field setup [4]



(a) (b)

(c) (d)

Figure 10: (a) GPR data output from pavement (b) GPR data output from bridge (c) GPR data output from fault survey (d) Core taken from the pavement[4]

1.3.3. Montana Department of Transportation (MDT)[17]

MDOT focuses on evaluating the feasibility of expanding its GPR program to enhance pavement evaluation applications. The study aimed to determine how GPR could improve data accuracy for measuring pavement thickness, performing quality assurance, and conducting network-level evaluations.

The MDT utilized a GSSI SIR-20 system with a 2.0 GHz horn antenna, integrated with Falling Weight Deflectometer (FWD) data for detailed pavement analysis as shown in Figure 11. The RADAN software was used to process GPR data, enabling accurate identification of pavement layers and calculation of their thicknesses.

Figure 11: GPR Vehicle of MDT[17]

1.3.4. Georgia Department of Transportation (GDOT)[20]

GDOT conducted a study to explore the use of Ground Penetrating Radar GPR for evaluating pavement layers and improving quality control, specifically in the context of Full-Depth Reclamation (FDR) projects. The study utilized a MALA ground-coupled GPR system equipped with a 1.2 GHz antenna, as shown in Figure 12. The GPR data was processed using RadExplorer software for visualization as shown in Figure 13. The findings highlighted the effectiveness of GPR in assessing pavement conditions for FDR Projects.

Figure 12: GPR equipment assembly[20]

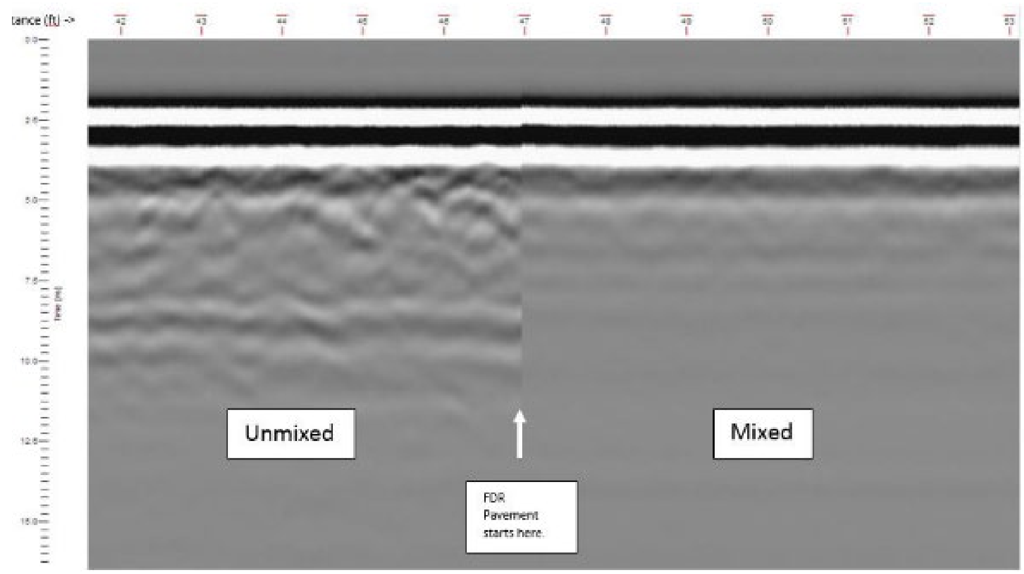


Figure 13: GPR output showing before and after FDR construction[20]

1.3.5. Colorado Department of Transportation (CDOT)[5]

CDOT focused on evaluating the use of GPR for assessing delamination and deterioration in bridge decks covered with asphalt overlays. The main objective was to develop a refined interpretation method for GPR data to accurately estimate delaminated areas, aiding in maintenance and repair decisions. Alongside GPR, other non-destructive testing methods, including visual inspection, chain drag, and rebound hammer, were utilized for comprehensive assessment as shown Figure 14.

The study utilized a GSSI SIR-20 GPR system with 2 GHz air-coupled antennas. The GPR analysis is carried out with GSSI's commercial software Radan 7. As shown in Figure 15, GPR technology effectively visualizes subsurface conditions, such as deterioration.

(a) (b) (c)

Figure 14: Nondestructive tests: (a) Air-coupled GPR (b) Rebound hammer (c) Marked areas and exposed rebars[5]

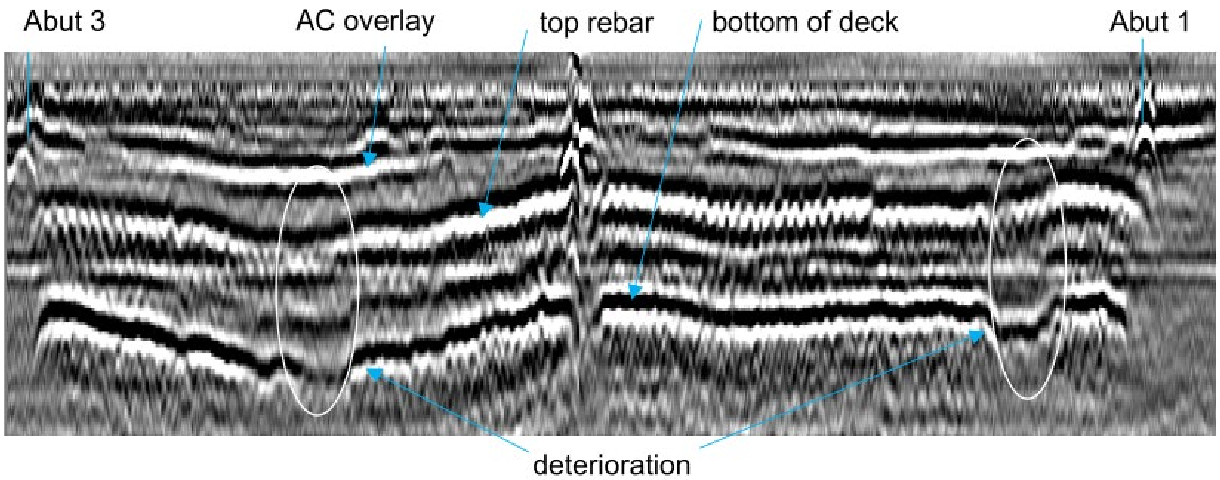


Figure 15: GPR B-scan showing evidence of deterioration on structure[5]

1.3.6. Washington State Department of Transportation (WSDOT)[21]

WSDOT evaluated the feasibility of using GPR to measure density variations in newly constructed asphalt pavements. The study aimed to determine how GPR can improve quality control by providing real-time data on pavement density, reducing the reliance on traditional core sampling methods, and enhancing the efficiency of paving operations.

The project employed a GSSI SIR-20 GPR system equipped with a 2.0 GHz horn antenna. A distance measuring instrument (DMI) and a GPS system were integrated into the setup to enhance spatial accuracy as shown in Figure 16. Data analysis was conducted using Infrasense's proprietary winDECAR® software, which can calculate dielectric constants, analyze density variations, and determine pavement thickness as shown in Figure 17.

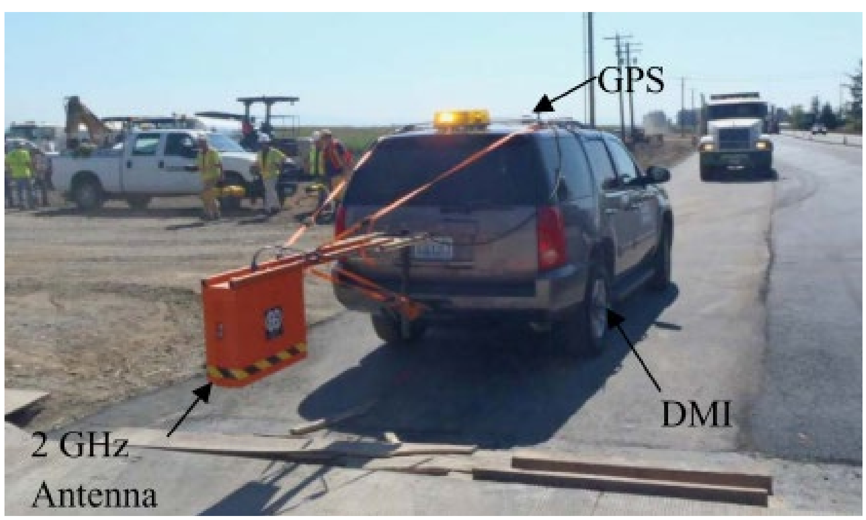


Figure 16: Vehicle mounted with GPR, DMI and GPS system[21]

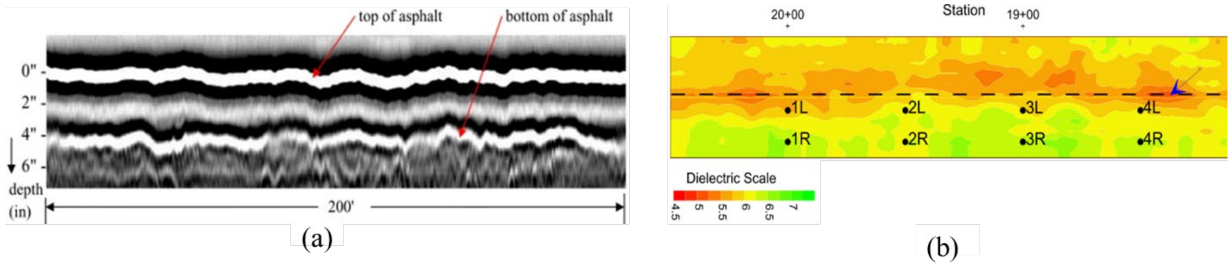


Figure 17: (a) GPR data output showing pavement thickness (b) Dielectric contour plot[21]

1.3.7. New York Department of Transportation (NYDOT)[22]

NYDOT explored the use of Ground Penetrating Radar (GPR) for applications such as pavement thickness assessment, void detection, moisture content analysis, and underground utility mapping. The study evaluated GPR's feasibility for both project-level and network-level applications, focusing on its ability to ensure efficient and reliable data collection for infrastructure management.

GSSI GPR systems with multi-channel configurations were employed to obtain detailed subsurface imaging and data acquisition as shown in Figure 18. Data interpretation and visualization were carried out using Road Doctor software by Roadscanners and proprietary software by UIT. These tools combined GPR data with video, GPS, and CAD mapping to provide comprehensive subsurface insights as shown in Figure 19.

Figure 18: Vehicle equipped with GPR[22]

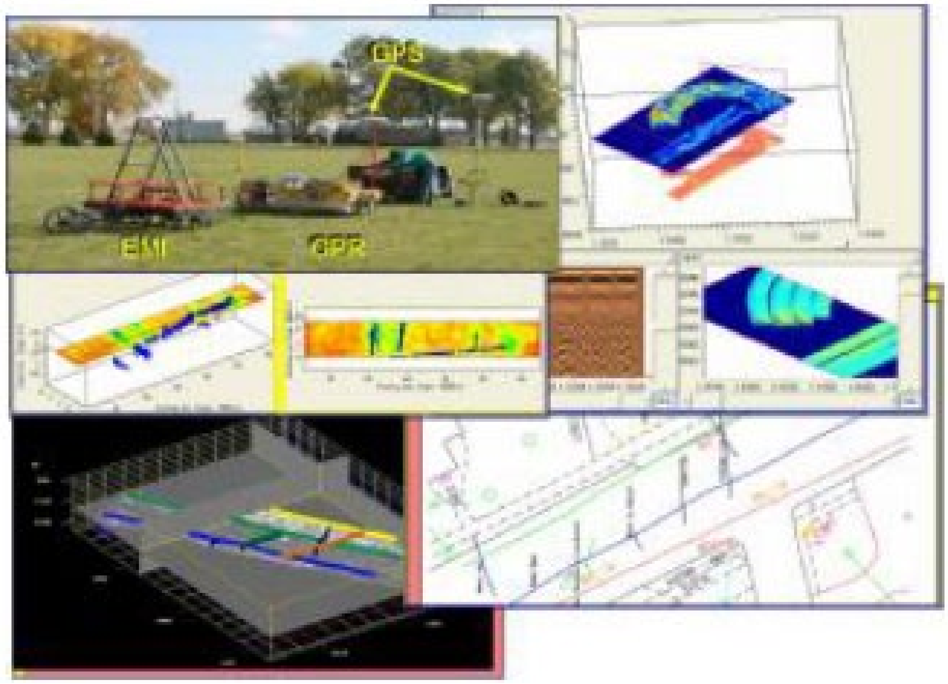
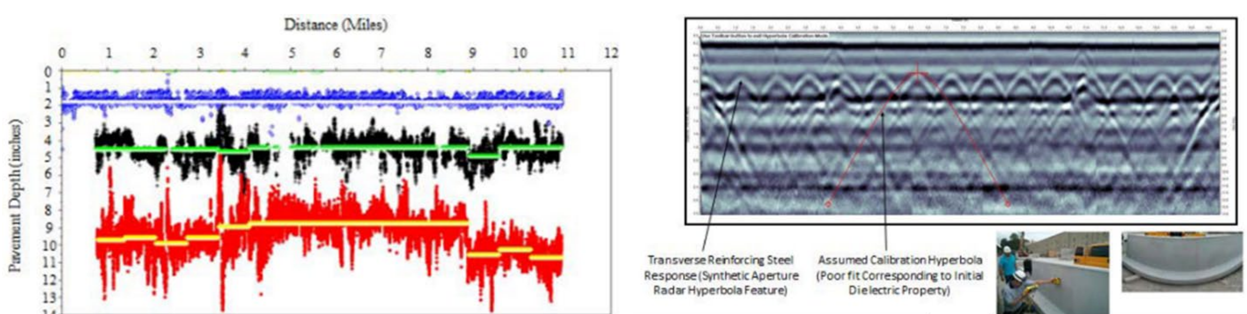


Figure 19: System for subsurface investigation that includes integrated hardware and software tools[22]

1.3.8. Maryland Department of Transportation (MDDOT)[23]

MDDOT explores the application of GPR for assessing critical infrastructure components like pavements, bridge decks, and precast concrete elements. The primary goal was to improve GPR data analysis techniques and utilize GPR for better decision-making and reduce maintenance costs.

Various GPR systems, such as GSSI SIR-20/SIR-30, Sensors & Software Conquest, Noggin, and US Radar systems, with antenna frequencies ranging from 250 MHz to 2.0 GHz were used for diverse applications like pavement thickness detection and bridge deck evaluation. Advanced techniques such as Multi-scale Pavement GPR Data Analysis (MPGA) were utilized for pavement thickness evaluation as shown in Figure 20.



(a) (b)

Figure 20: (a) Pavement data with MPGA Results (3 Layers) (b) GPR data B-scan[23]

1.4. Texas current application

1.4.1. Texas Transportation Institute (TTI)[24]

TTI utilizes GPR to identify subsurface conditions, such as moisture content, base thickness, and structural integrity, to guide the rehabilitation and maintenance of these roadways. They integrate GPR with other data sources such as core samples, visual inspection data, and geotechnical surveys to enhance decision-making in road design and maintenance.

TTI employed a GSSI SIR-10B system with a 1 GHz air-coupled antenna for road surface and subsurface assessments and a 200 MHz and 500 MHz ground-coupled antenna was used for deeper investigations into the subgrade layers as shown in Figure 21 .The COLORMAP system was used for processing air-launched GPR data as shown in Figure 22 and the Road Doctor was used for processing ground-coupled GPR data as shown in Figure 23.

Figure 21: Combined air-launched and ground-coupled used by TTI[24]

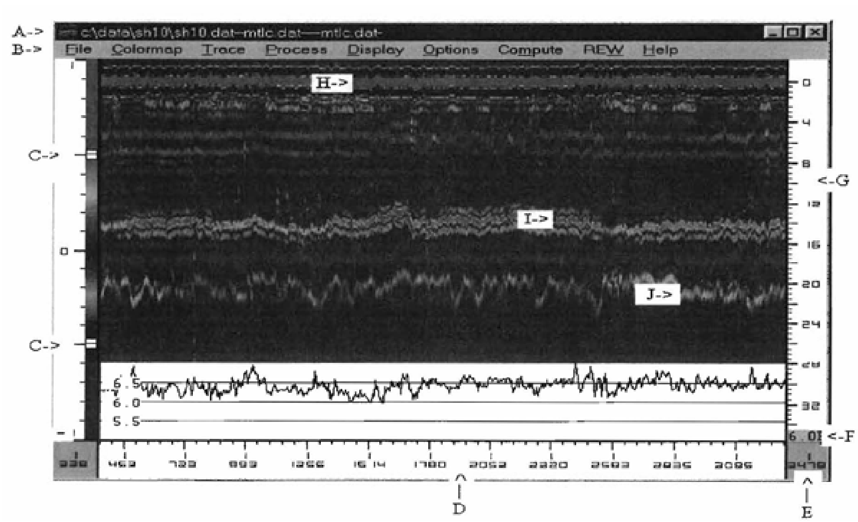


Figure 22: Display of hot-mix pavement using Colormap[24]

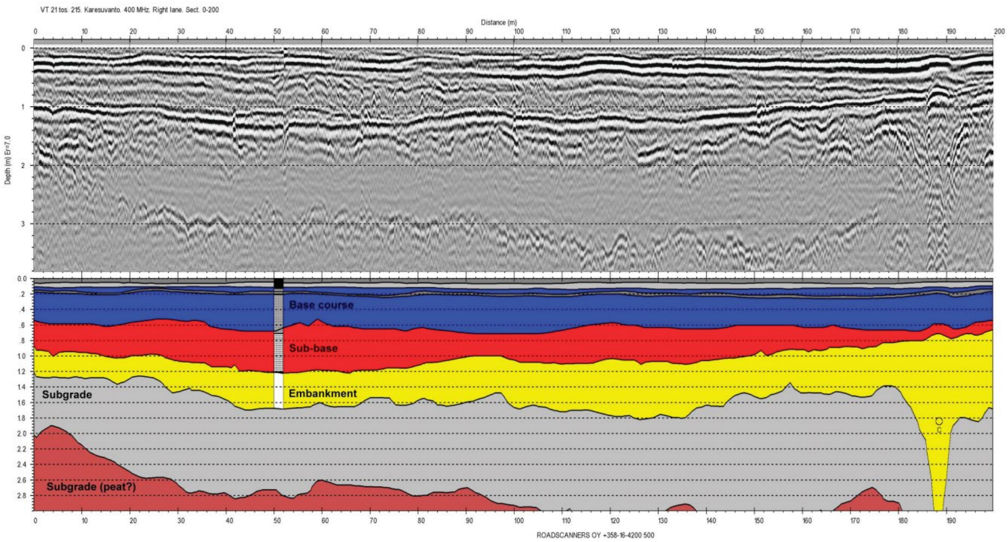


Figure 23: Road Doctor output showing subsurface layering[24]

1.4.2. Texas Department of Transportation (TXDOT)[25]

TXDOT focused on developing and implementing GPR systems to enhance its capabilities for network- and project-level pavement surveys. The primary goal was to create cost-effective, FCC-compliant GPR systems that can efficiently measure pavement layer thickness, detect voids, and assess subsurface conditions for better road maintenance and safety.

The study used ground-coupled GPR for deeper subsurface evaluations, such as base and utility detection as shown in Figure 24, and air-coupled GPR for high-speed pavement surveys, like layer thickness measurement and delamination detection as shown in Figure 25. The GPR TXDOT software was specially designed for this project to collect and process GPR as shown in Figure 26. The software automatically detects pavement layers, measures their thickness, detects faults and calculates material properties, making it easy and fast to analyze road conditions as shown in Figure 27.

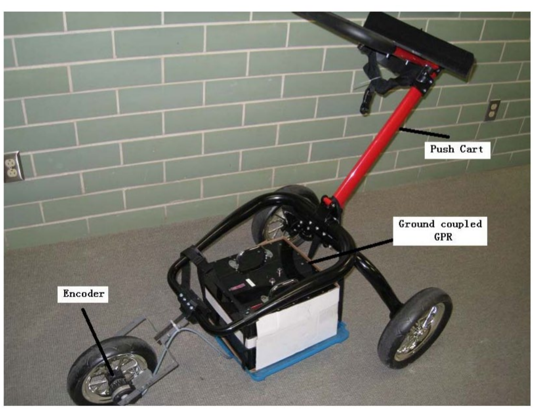


Figure 24: Ground-coupled GPR system[25]

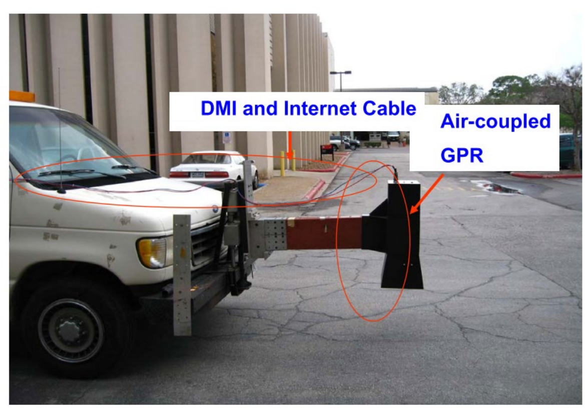


Figure 25: Air-coupled GPR system[25]

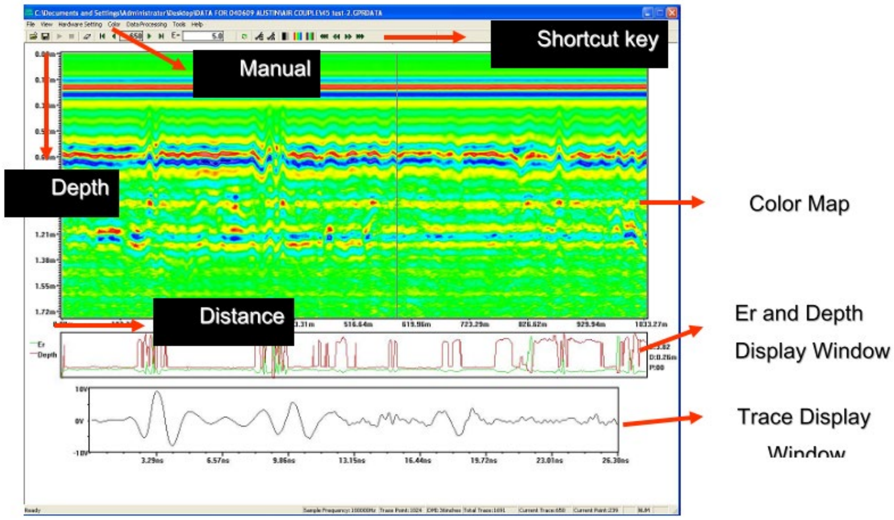


Figure 26: GPR TXDOT software layout[25]

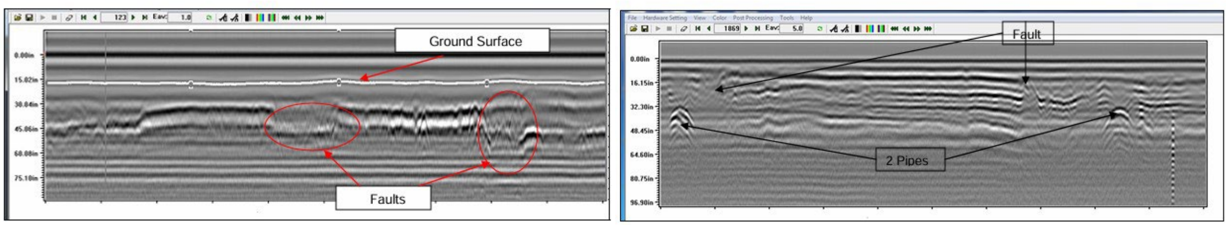


Figure 8, Base and sub-base evaluations by air coupled GPR.

(a) (b)

Figure 27: (a) Base and sub-base evaluation by air coupled GPR system (b) Faults detected by using the ground coupled GPR system[25]

1.4.3. Texas Transportation Institute (TTI) [26]

The purpose of this paper is to assess whether the PaveCheck system, developed by the Texas Transportation Institute (TTI), can be utilized for the comprehensive evaluation of pavement conditions. The system integrates Ground Penetrating Radar (GPR) data, Falling Weight Deflectometer (FWD) results, GPS mapping, and video imaging to provide a complete analysis of pavement health as shown in Figure 28. Figure 29 shows the GPR vehicle used for data collection, equipped with a 1 GHz Horn antenna, a GPS unit, and a digital camera, enabling real-time data acquisition as the vehicle travels along the pavement.

The PaveCheck software then processes this data, integrating multiple streams—GPR, FWD, GPS, and video—to generate actionable insights for pavement assessment. The software uses MODULUS 6 back-calculation algorithms to estimate the structural integrity and stiffness of pavement layers based on deflection data from the FWD test. PaveCheck also enables users to compare surface conditions (video images) with subsurface data (GPR results) offering a comprehensive view of pavement conditions, as illustrated in Figure 30.

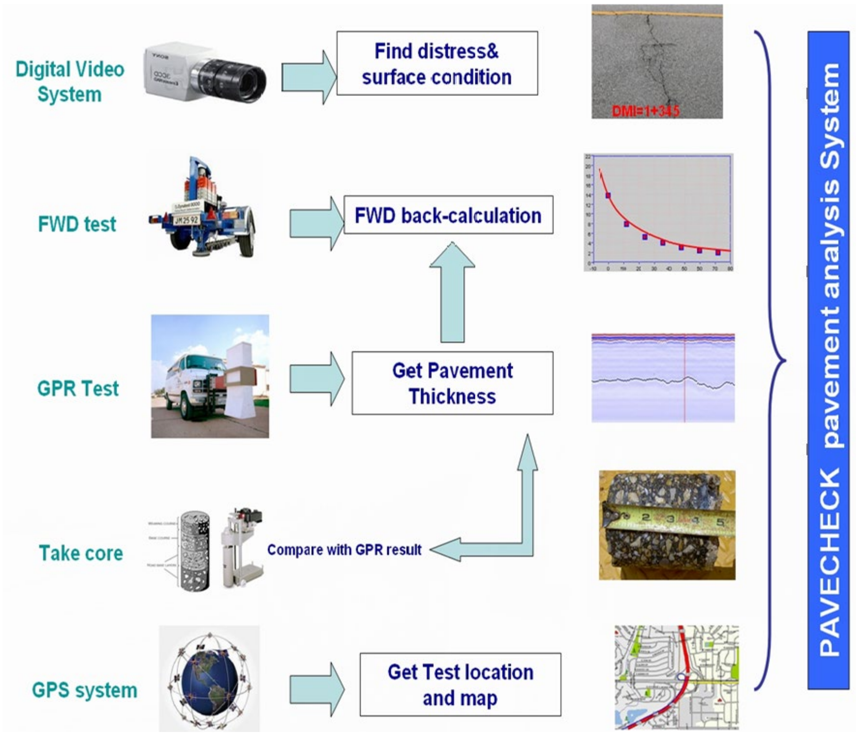


Figure 28: Elements of the PaveCheck System[26]

One of the key features of PaveCheck is its ability to generate GIS-compatible maps, making it easy for engineers to analyze roadway conditions. This is particularly useful for identifying problematic pavement sections and planning maintenance.

The PaveCheck interface, depicted in Figure 31, allows users to easily load and process the necessary project data, including typical GPR, FWD, GPS, and core data files. Figure 32 further demonstrates the system's ability to map the locations of all tested highways, helping to visualize the geographical scope of the data collection efforts.

Figure 29: GPR vehicle with GPS and video camera[26]

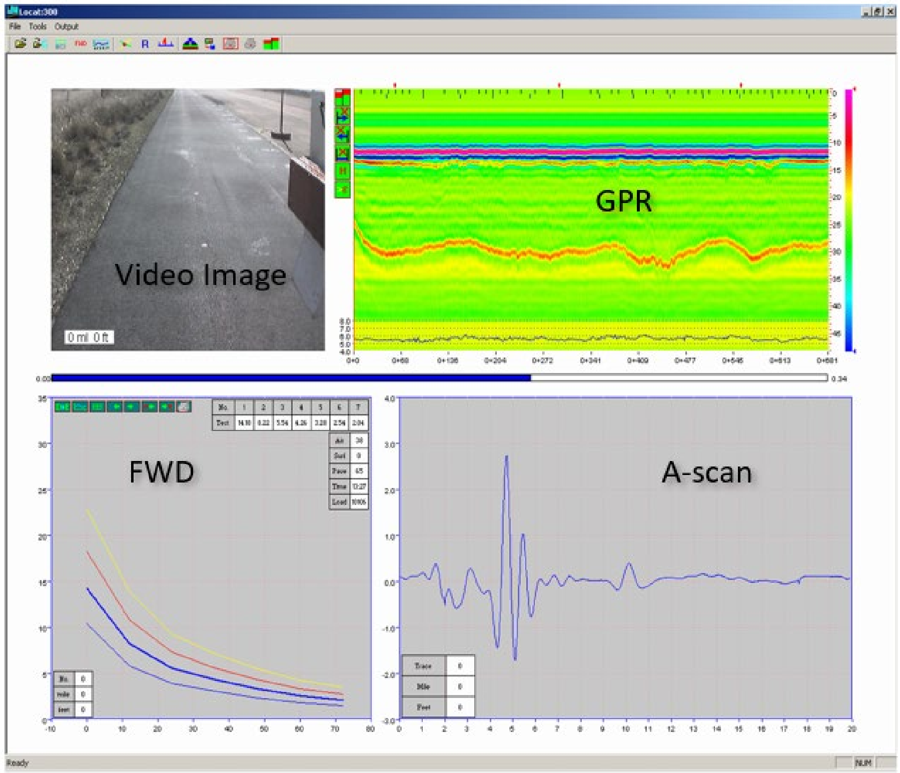


Figure 30: PaveCheck software showing combined FWD, GPR and video image[26]

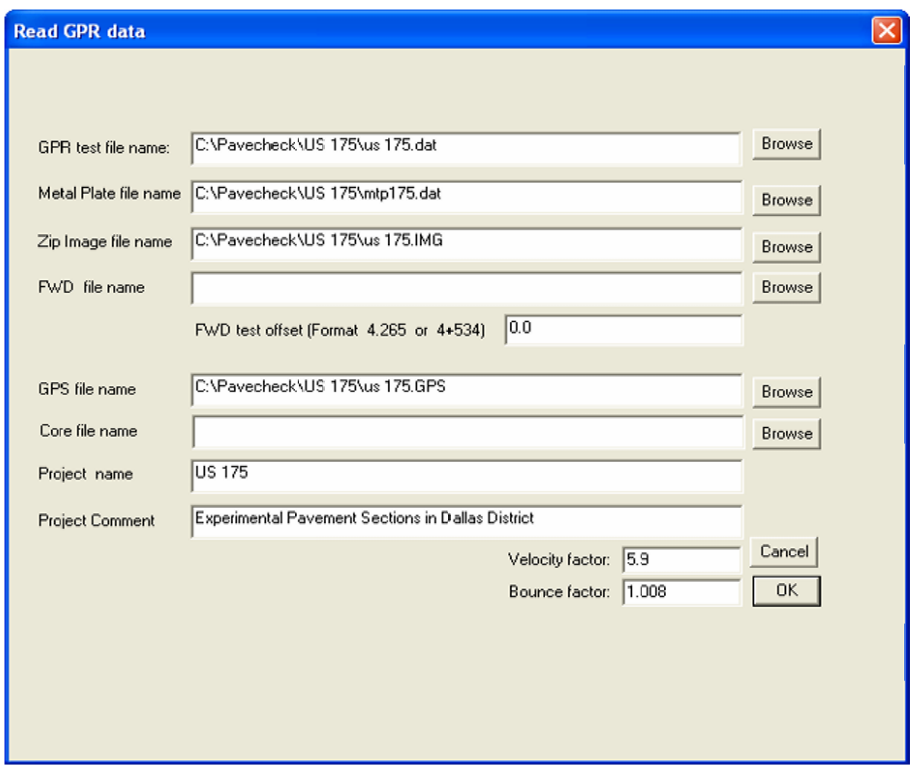


Figure 31: PaveCheck software interface showing the loading of typical data into the project file.[26]

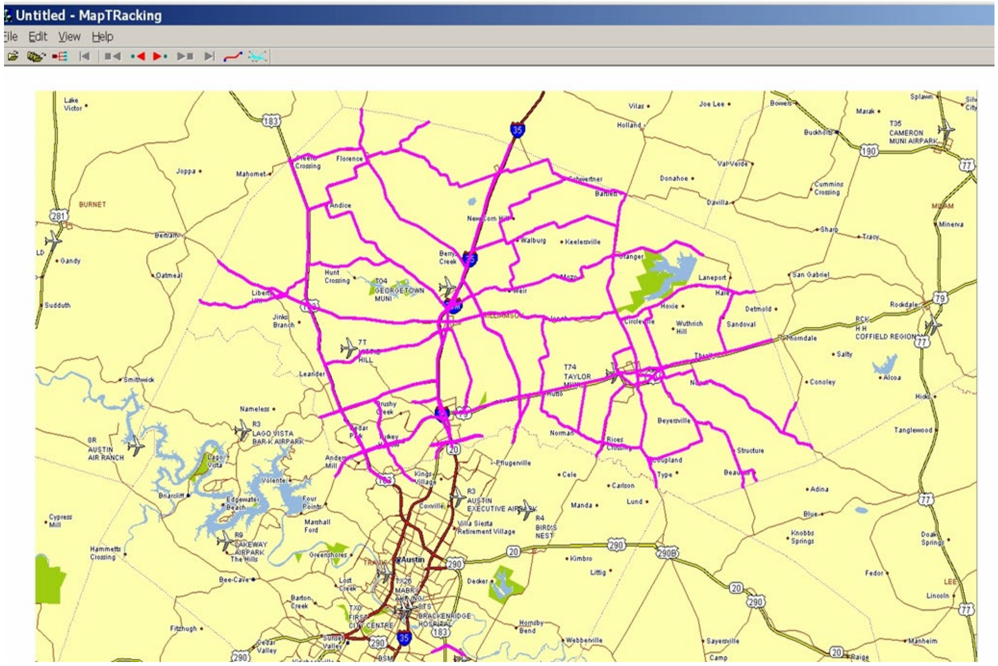


Figure 32: Map showing the location of all the tested highways (PaveCheck)[26]

1.4.4. Advanced Rapid Damage Assessment of Concrete Bridge Deck Leveraging Multi-Channel GPR in an Automated Double-Sided Bounce System[27]

The report focuses on the rapid characterization of internal and external concrete structures using an Automated Crack Evaluation (ACE) system as shown in Figure 33. The system integrates multiple data-gathering technologies to detect a range of pavement and bridge deck conditions without requiring lane closures as shown in Figure 34 and Figure 35.

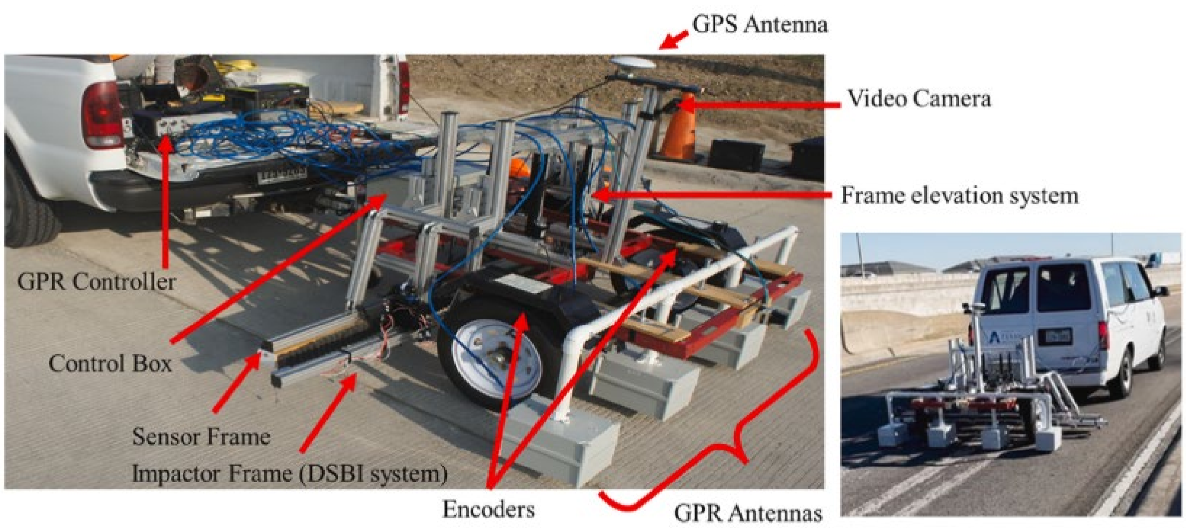


Figure 33. ACE System towed by a truck (left) and a van (right)[27]

The ACE system utilizes impact echo methods to evaluate potential cracking and delamination damage. The system operates using a double-sided bounce impacting (DSBI) system, which utilizes a hardened steel ball, flexible wire, and a high-RPM DC motor to generate high-energy impacts. This mechanism enables consistent impact signals with a high pulse repetition frequency (PRF). In conjunction with the DSBI system multiple air-coupled microelectromechanical system (MEMS) sensors are used for precise acoustic data collection. This allows for a frequency collection range of 100 Hz to 10 kHz.

In addition to impact echo, the system uses multi-channel GPR for detecting rebar corrosion and other internal damage within bridge decks and pavement. It is equipped with four GSSI 1600 MHz antennas connected to a SIR 30 multi-channel control unit, along with RTK GPS and video cameras for synchronized data acquisition and precise location mapping. Based on this configuration, collection of subsurface condition data can be performed without the need for stopping lanes of traffic. The report covers the study of two example bridges to test the data capturing capabilities of the ACE system, with Bridge A being an older bridge and Bridge B a newer bridge.

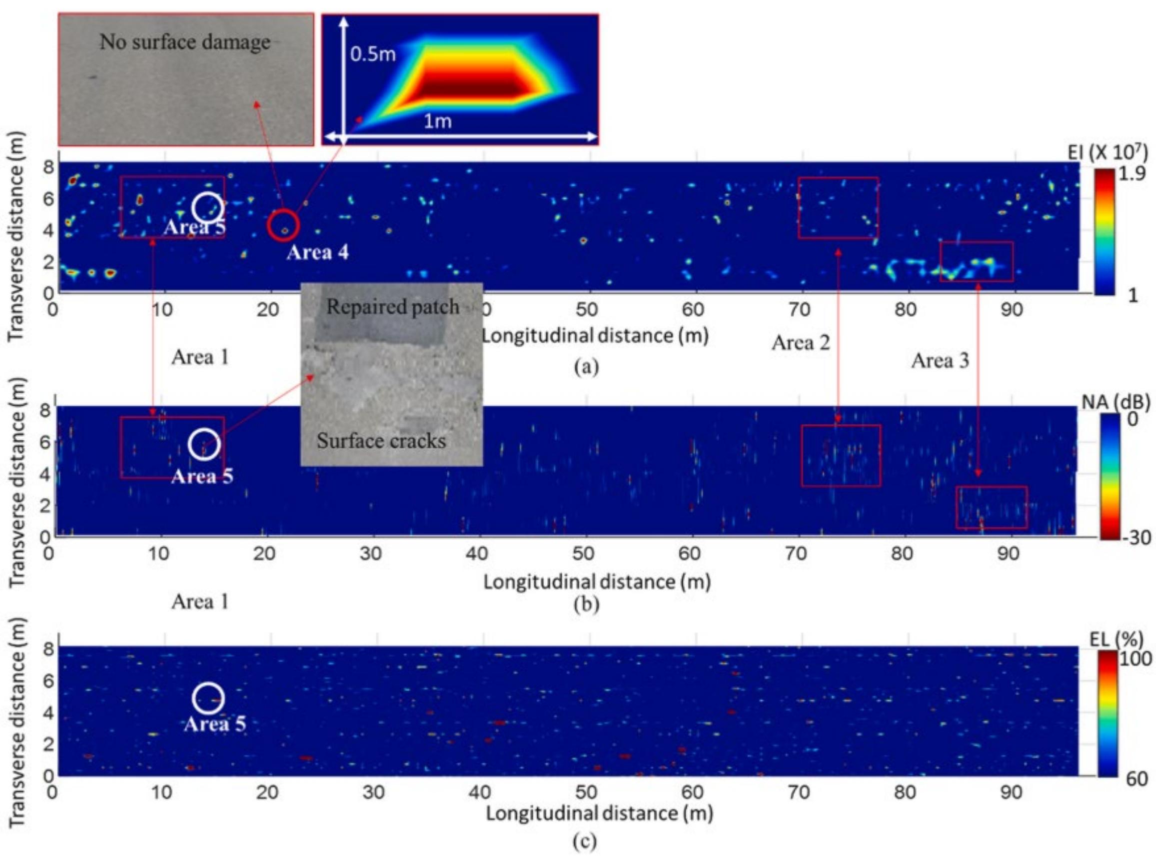


Figure 34. Top view of inspection results on Bridge A: (a) delamination map, (b) corrosion map, and (c) vertical crack map. Colormaps represent damage obtained from the ACE system[27]

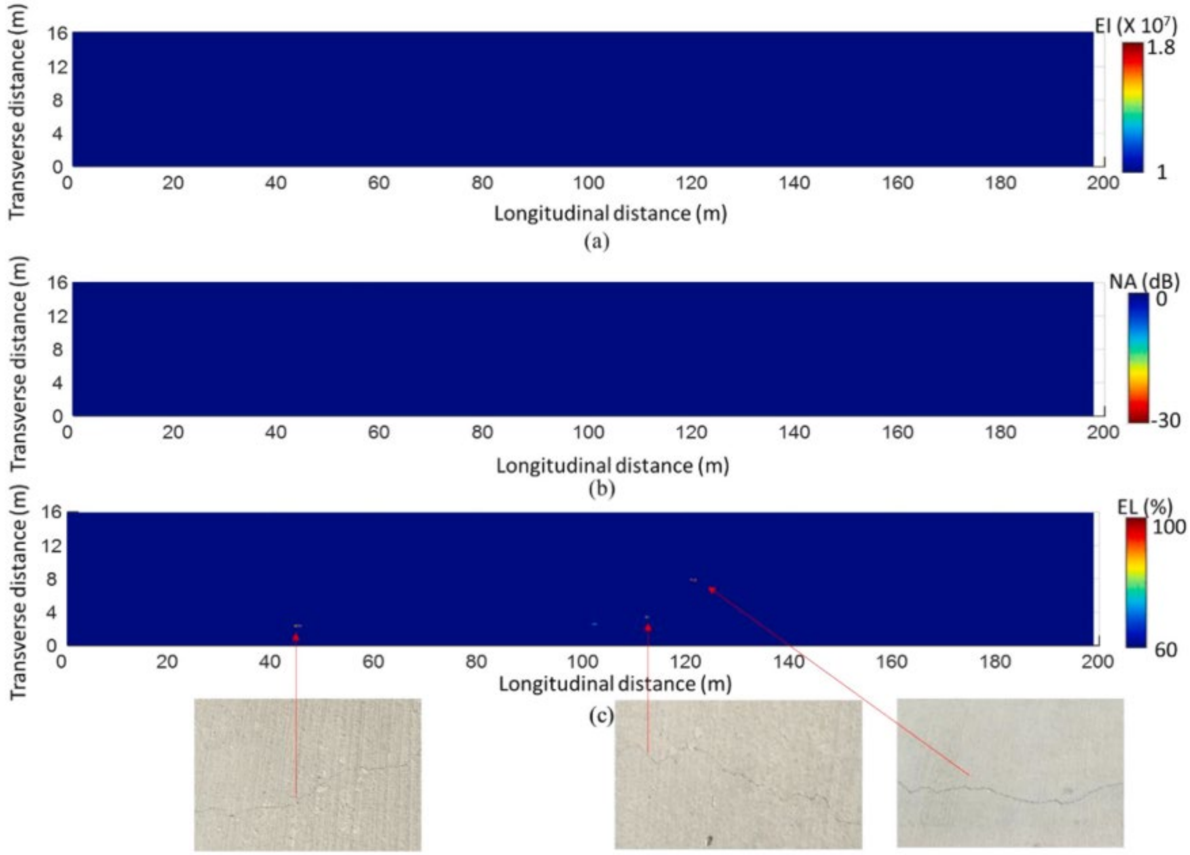


Figure 35. Inspection results of Bridge B: (a) delamination map, (b) corrosion map, and (c) vertical crack map. The inspection result indicates the bridge is in a minimal damage condition[27]

The findings indicate that the ACE system enables high-resolution, automated inspections with minimal human involvement. The combined use of DSBI and multi-channel GPR significantly reduces inspection time and safety risks. The system can be configured as either ground-coupled or air-coupled and supports integration with 3D GPR capabilities.

1.5. Research Study Literature Review

1.5.1. Corrosion assessment using ground penetrating radar in reinforced concrete structures [28]

The paper evaluates the potential of GPR for detecting corrosion in reinforced concrete structures. It reviews key factors that affect GPR signal interpretation, such as moisture content, chloride contamination, and rebar configuration. The paper further explores methodologies to improve the accuracy and efficiency of corrosion detection.

The paper highlights the use of ground-coupled and air-coupled antennas in GPR system (from GSSI and IDS) with frequencies ranging from 1.5 GHz to 2.6 GHz, suitable for detecting rebar and corrosion in concrete as shown in Figure 36. Data processing and interpretation were carried out using tools like

RADAN (from GSSI), GRED HD (from IDS), and Reflexw, which support both 2D and 3D visualization. Additionally, custom MATLAB scripts were also employed to overcome limitations in commercial software and enable enhanced data analysis as shown in Figure 37.

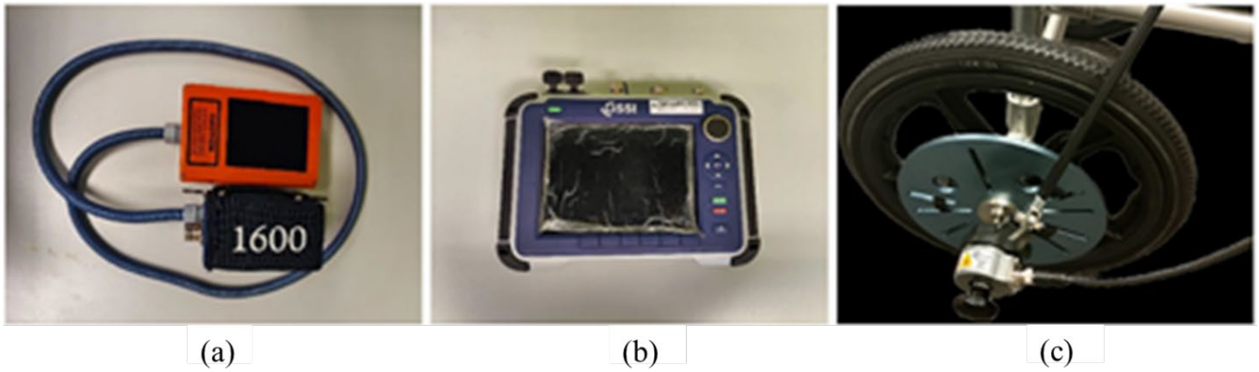


Figure 36: GPR system components (a) GPR antenna (b) Control unit (c) Distance Measurement Instrument[28]

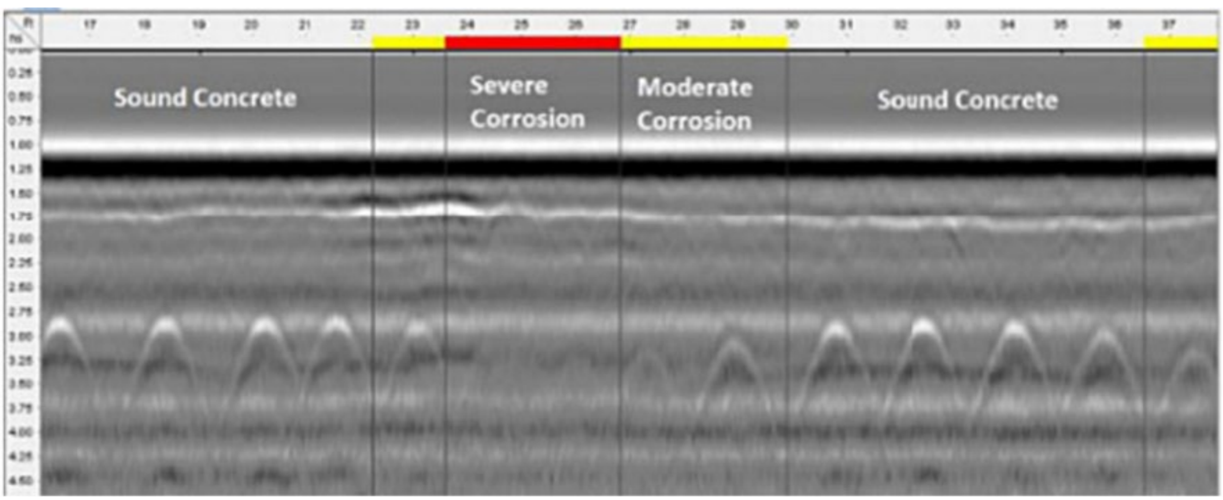


Figure 37: B-scan showing corrosion[28]

1.5.2. 3D Step Frequency GPR Asphalt Pavement Stripping Detection[29]

The paper discusses the application of 3D step frequency Ground Penetrating Radar (GPR) technology for detecting stripping (moisture damage) in asphalt pavements, a critical issue causing premature deterioration as shown in Figure 38. The case study was conducted at the National Center for Asphalt Technology (NCAT) test track where stripping zones (moisture-induced damage) were pre-constructed to provide a clear comparison between stripped and non-stripped locations.

The study used a step-frequency array GPR system with 21 antenna pairs as shown in Figure 39. Data collection was managed by a GeoScope Mk IV control unit with a dwell time of 7.52 μs per frequency step. The equipment was selected for its ability to provide high-resolution data for precise stripping detection.

Raw data was initially analyzed in waveform plots as shown in Figure 40. To enhance clarity and accuracy, advanced filtering techniques such as the Maximum Energy Ratio Method and High-Order Statistical Methods were applied. The study demonstrated the potential of advanced GPR techniques for accurately identifying asphalt stripping and improving pavement evaluation.

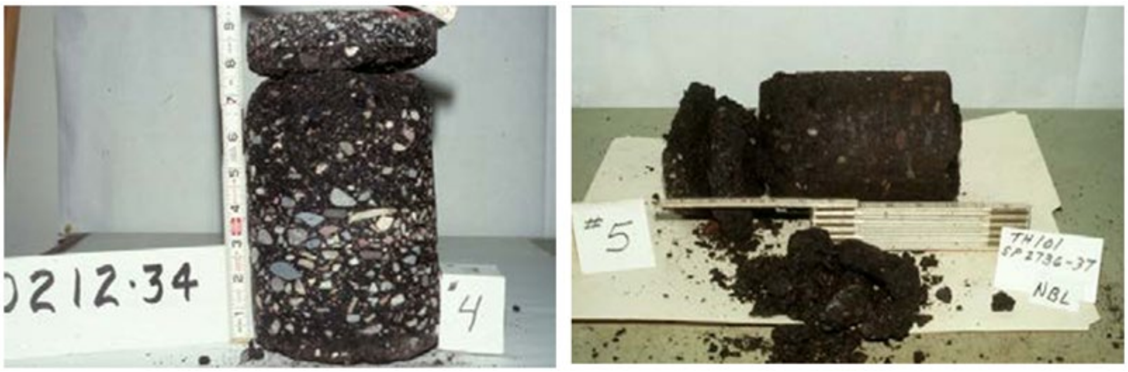


Figure 38: Stripping of Hot-Mixed Asphalt[29]

(a) (b)

Figure 39: (a) Vehicle mounted with 3D Radar antenna GPR system (b) Pavement containing stripped section[29]

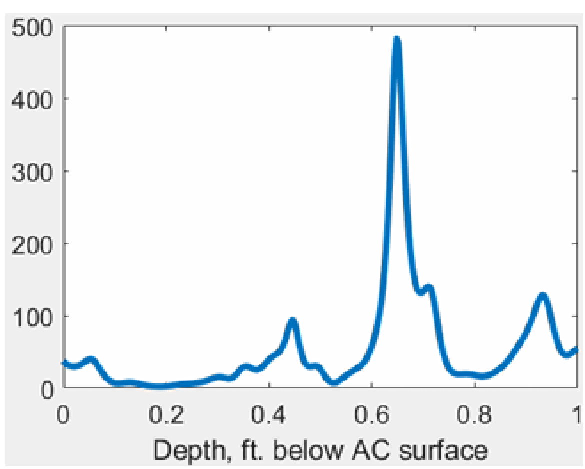


Figure 40: Energy ratio method results at a known interface with changing dielectric properties[29]

1.6. Significant Findings from Literature Review

1.6.1. Common Uses of GPR Across State DOTs

The literature review confirms that GPR is widely adopted by many states Departments of Transportation (DOTs) as a non-destructive evaluation (NDE) tool for a broad range of infrastructure applications. The most common uses include:

- Measuring pavement layer thickness and detecting subsurface defects such as voids and stripping.
- Assessing bridge decks for delamination, corrosion, and rebar placement.
- Mapping underground utilities to avoid damage during excavation.
- Evaluating tunnel linings for moisture intrusion and structural condition.
- Conducting geotechnical investigations, including moisture and layer characterization.

This widespread usage demonstrates GPR's versatility and value for both project-level diagnostics and network-level planning.

1.6.2. Preferred GPR Systems for Pavement Evaluation

Based on the literature reviewed in this study, air-coupled commercial GPR systems are generally preferred by state DOTs for pavement evaluation due to their ability to perform high-speed, continuous surveys without requiring lane closures. Among these, systems developed by GSSI (Geophysical Survey Systems, Inc.) are the most widely adopted by DOTs nationwide for pavement evaluation. DOTs in states such as Texas, South Dakota, Montana, Colorado, and Washington have used GSSI platforms (e.g., SIR-20, SIR-30, SIR-3000) extensively for pavement thickness measurement and base layer evaluation. Ground-coupled systems are also used, but primarily for deeper investigations or spot assessments rather than rapid surface profiling.

1.6.3. Commonly Used GPR Antenna Frequencies and Their Application

The literature review indicates that air-coupled antennas operating at 1 GHz and 2 GHz are the most commonly used by state DOTs for pavement evaluations. These frequencies are preferred for their ability to provide high-resolution data at roadway speeds without requiring lane closures. 1 GHz antennas are widely used for standard pavement thickness measurements and general surface layer evaluations.

2 GHz antennas are selected when finer resolution is needed to identify thin surface layers or detect near-surface defects such as delamination. For deeper pavement investigations, such as evaluating base or subgrade layers, DOTs frequently employ ground-coupled antennas in the 200–500 MHz range. These lower-frequency antennas provide greater penetration depth, though at reduced resolution. They are commonly used in slower-moving or stationary surveys where access and time are less restrictive. In

addition to pavement applications, the literature shows that bridge deck inspections often use 1.5–2.6 GHz antennas to detect delamination, rebar corrosion, and concrete deterioration near the surface.

Geotechnical investigations, such as identifying voids, groundwater tables, or buried features, typically use very low-frequency antennas (e.g., 100–400 MHz) to penetrate deeper into soil and substructure layers. Several DOTs also reported the use of multi-frequency antenna setups—combining high and low-frequency antennas during the same survey—to collect data across multiple depths in a single pass, improving efficiency and structural interpretation.

1.6.4. Software tools for GPR Data Processing and Analysis

According to the literature, the most commonly used software for GPR data analysis across DOTs includes:

RADAN (by GSSI): Most commonly used for both 2D and 3D processing, especially with GSSI equipment, for analyzing pavement thickness and subsurface layering.

Road Doctor (by Roadscanners): Used to combine GPR data with other sources like FWD, GPS, and video to support comprehensive pavement condition evaluation.

WinDECAR® (by Infrasense): Used for calculating dielectric constants and estimating layer thickness, especially in pavement density assessment projects.

GRED HD (by IDS GeoRadar) and Reflexw: Used in specialized or research-focused applications, particularly for corrosion assessment in reinforced concrete.

Custom MATLAB scripts: Custom scripts are sometimes used when commercial software doesn't meet specific needs or to automate batch processing tasks in advanced studies.

1.6.5. Additional key findings from literature

3D GPR systems, such as those used by Minnesota DOT and others, are emerging as powerful tools for capturing continuous volumetric pavement data, reducing the reliance on coring. Integrating GPR data with other non-destructive testing tools, such as FWD, GPS, core samples, and visual inspections, enhances the reliability and actionability of GPR results. Many DOTs emphasize the importance of technician training, as interpreting GPR data requires specialized skills and experience. There is a growing interest in **AI-assisted processing**, as noted in advanced studies involving stripping detection and corrosion analysis. Some DOTs (e.g., New Jersey and Oregon) note that GPR works well for surface layers but is less reliable for base and sub-base evaluation, especially in wet conditions. In such cases, they recommend combining GPR with core sampling or other NDE methods. States like Maryland and New York are exploring advanced GPR methods that combine 3D visualization, CAD mapping, and video overlays to support more comprehensive infrastructure evaluations.

2. Interview preparation usage requirements and purposes of the current GPR system

Task 3 focuses on designing and conducting preliminary interviews to assess how GPR is currently used across TxDOT districts, identify operational challenges, and gather input for future improvements. To support this, the Performing Agency developed a structured questionnaire informed by literature reviews, case studies, and survey questionnaire from other DOTs. The goal was to collect targeted feedback on the use of Air-Coupled Ground Penetrating Radar (AC-GPR), including perceived benefits, barriers, training needs, and potential areas for improvement.

The survey results will help inform the analysis of AC-GPR's role in supporting TxDOT's future use of GPR technology in pavement evaluations. By synthesizing this data, actionable recommendations will be developed to enhance AC-GPR's effectiveness, address its current challenges, and optimize its integration into TxDOT's pavement management strategies.

2.1. Literature Review of Survey Reports from Other State DOTs

2.1.1. Federal survey: Use of Non-Destructive Testing (NDT) Technologies for Highway Infrastructure Inspection[30]

This paper provides a comprehensive overview of NDT technologies used for highway infrastructure inspection during construction and maintenance. The study is based on survey responses from 50 state DOTs and provides insights into the commonly used NDT methods, their practical applications, and the challenges faced during implementation.

Figure 41 illustrates NDT technologies used for inspection during construction. Figure 42 displays typical NDT methods used during asset maintenance. Figure 43 summarizes the application of these technologies for maintenance. Figure 44 outlines the main challenges in implementing NDT methods for highway infrastructure inspection.

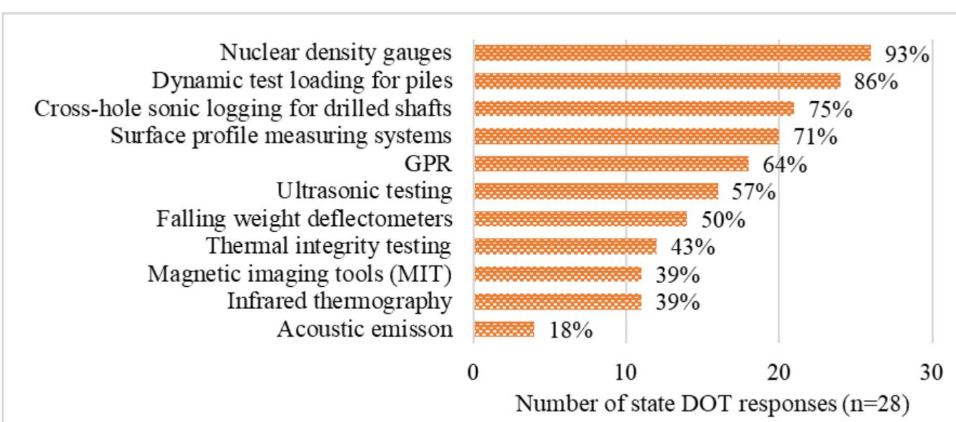


Figure 41: Types of NDT technologies used for highway infrastructure inspection during construction[30]

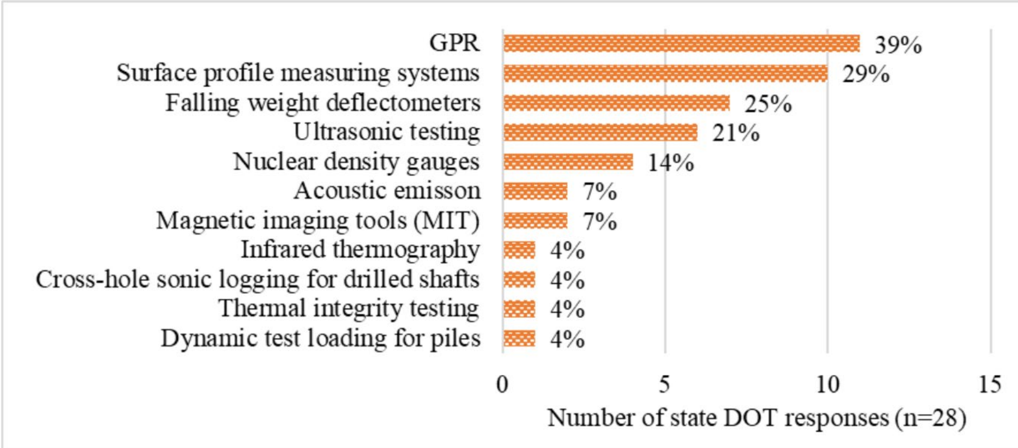


Figure 42: Types of NDT methods used for highway infrastructure inspection during maintenance of assets[30]

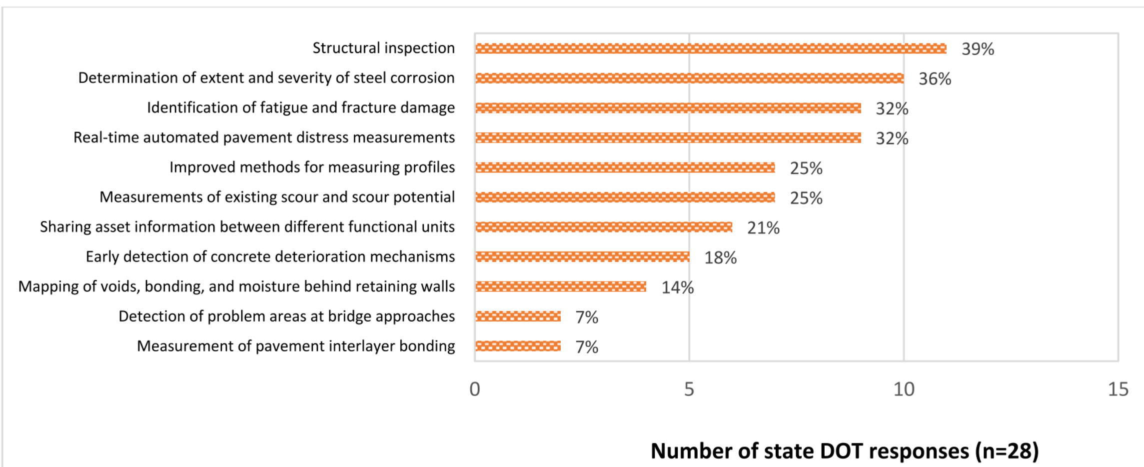


Figure 43: Application of NDT methods for highway infrastructure inspection during asset management[30]

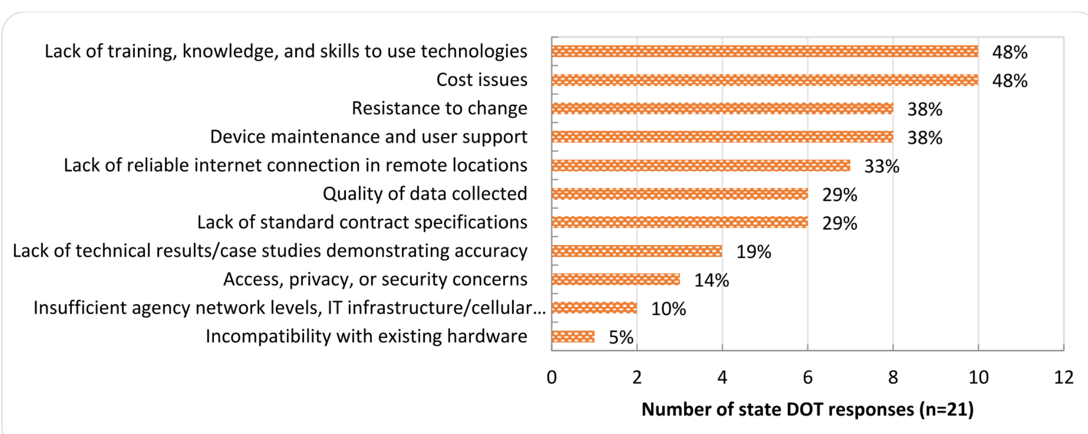


Figure 44: Challenges in NDT methods for highway infrastructure inspection[30]

2.1.2. MDT - Ground Penetrating Radar (GPR) Analysis: Phase 1[16]

The Montana Department of Transportation (MDT) conducted an evaluation of GPR to explore its feasibility for broader pavement analysis applications. The objectives established by the report were:

- Asses the feasibility of expanding GPR applications for pavement analysis
- Provide accurate pavement layer information for reconstruction and rehabilitation
- Explore potential of GPR in QA of new pavement thickness and density

Additionally, as part of the study a nationwide survey was performed to determine their experience with GPR and gauge the relevance of their experience to MDT's GPR goals.

The study found that GPR accuracy for measurements of pavement thickness within 2-10% of core values, with newly constructed pavements showcasing higher values. With the suitability of GPR in pavement use the study determined that GPR has potential uses in pavement design, rehabilitation, and network evaluations. This potential can be especially utilized when ensuring correct milling depths and detection of layer thickness variability. MDT recommended the use of field evaluations to verify the accuracy of GPR data, as well as implementing lower frequency antennas to improve depth penetration of GPR signals. The success of FPR as an NDT method allowed MDT to consider incorporating GPR into structural number calculations for design, network evaluations, and QA /QC of new pavements.

As for implementations of GPR methods, MDT suggests developing test matrices incorporating carious pavement types and environmental conditions. Alongside the matrices, representative test sites can be established and documented for validation of GPR data with coring samples. Table 3 summarizes the extent of GPR usage among various agencies, categorizing states by their level of adoption and application in pavement evaluation.

Table 3. Extent of GPR usage among agencies[16]

Usage of GPR in Pavement Evaluation	States
Extensive or Regular Use	Alaska, Florida, Indiana, Michigan, Minnesota, New Hampshire, Texas, and Wisconsin
Limited Use	Alabama, Colorado, Illinois, Kansas, Louisiana, Mississippi, Missouri, New Jersey, New Mexico, New York, North Dakota, Ohio, Oklahoma, Rhode Island, Utah, Virginia, and West Virginia
Initiating Use	Arizona, Hawaii, and Iowa
Does Not Use	Arkansas, Delaware, Georgia, Idaho, Maine, Nebraska, Nevada, North Carolina, Oregon, Pennsylvania, South Carolina, Tennessee, Washington, and Wyoming

Furthermore, state DOTs were asked if they see GPR expansion in the future for themselves and the results are as shown in Figure 45.

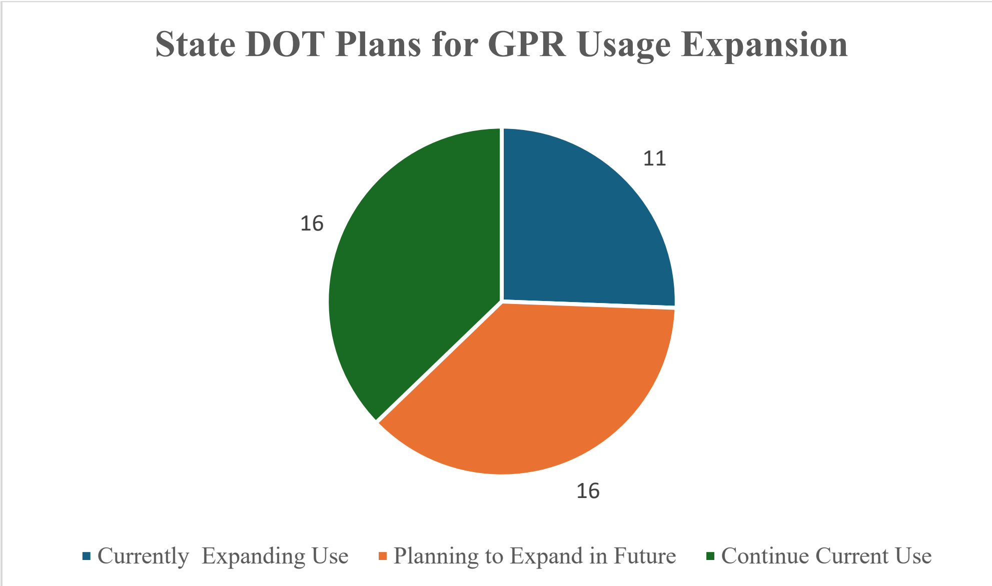


Figure 45: DOT's plans for expansion of GPR usage[16]

2.1.3. Feasibility of Using Ground Penetrating Radar (GPR) for Pavements, Utilities, and Bridges[31]

This report evaluates the feasibility of GPR as a primary method for NDT. The main objectives of this report are assessing GPR technology for transportation infrastructure, conducting a cost-benefit analysis for GPR application, as well as developing an implementation plan. The assessment found that the main applications of GPR as an NDT method were:

- Evaluating pavement thickness and bridge deck delamination detection
- Subgrade moisture analysis
- Detection of unknown subsurface conditions

The use of GPR introduced many advantages to previously used NDT methods as the nature of GPR testing allowed surveys to be performed quicker. The increased speed of surveying reduces the need to close traffic lanes, which also contributes to the cost-effective nature of GPR testing by reducing the need for traffic control measures. Though GPR testing creates many advantages, the complex nature of the equipment requires experienced operators to analyze the results.

A cost-benefit analysis was also performed which utilized GSSI equipment as the intended purchase for an NDT solution. The analysis provided the initial costs of acquiring the hardware and software packages (Figure 46) as well as upkeep costs due to maintenance and repair of equipment (Figure 47). Figure 48 provides a visual representation of the cost allocation for SDDOT in 2006 across various categories.

	Item	Cost	Total Cost
1	SIR-20 Data Collection and Control Unit	$30,000	
1	Model 4105 2 GHz Horn Antenna	$15,000	
1	Antenna Cable	$1,000	
1	Distance Measuring Unit	$5,000	
	Antenna Mounting Hardware	$2,000	
	Computer and Miscellaneous Hardware	$5,000	
	Vehicle	$30,000	
	Total Equipment Cost		**$88,000**
Software for GPR Data Analysis			
	Pavement Analysis Software	$20,000	
	Bridge Deck Analysis Software	$7,500	
	Total Software Cost		**$27,500**
Total Initial Costs of Equipment and Software			**$115,500**
EUAC of Equipment and Software			**$27,419**

Figure 46: Costs of Equipment and Software[31]

Training					
	Equipment & Data Collection		2 weeks	=$5,000	
	Data Analysis		4-8 weeks	=$10,000	
	SDDOT Personnel				
	Equipment & Data Collection	160 hours @	$20	=$3,200	
	Process	240 hours @	$20	=$4,800	
	overhead	0.5	$8,000	=$4,000	
	Total Training Cost				**$27,000**
Maintenance & Repair of Equipment					**$3,000**
	Annualized Training & M&R Cost				**$9,410**

Figure 47: Cost of Training, Maintenance, and Repair[31]

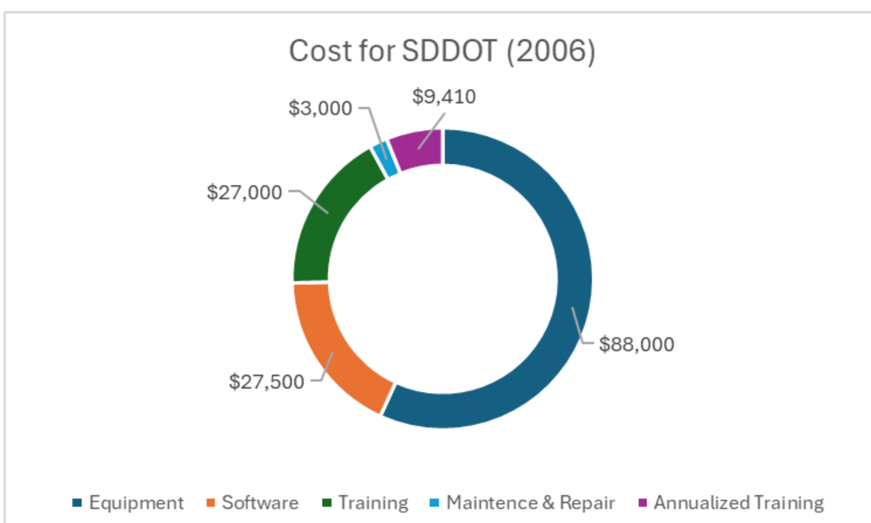


Figure 48: Cost for South Dakota to operate GPR[31]

Additionally, the cost of utilizing a GPR consultant to operate the NDT equipment was studied (Figure 49) as there was an expected delay in training of SDDOT operators. Figure 50 and Figure 51 further detail the weekly cost distribution for pavement and bridge deck analysis respectively.

Mobilization to SDDOT	$5,000	
Data Collection (equipment, personnel, expenses)	$2,200	per day
Data Analysis		
Bridge Decks	$250	per bridge
plus	$0.12	per square foot
Pavement Thickness (project level)	$250	per section
plus	$110	per lane mile

Figure 49 . Unit costs for consultant[31]

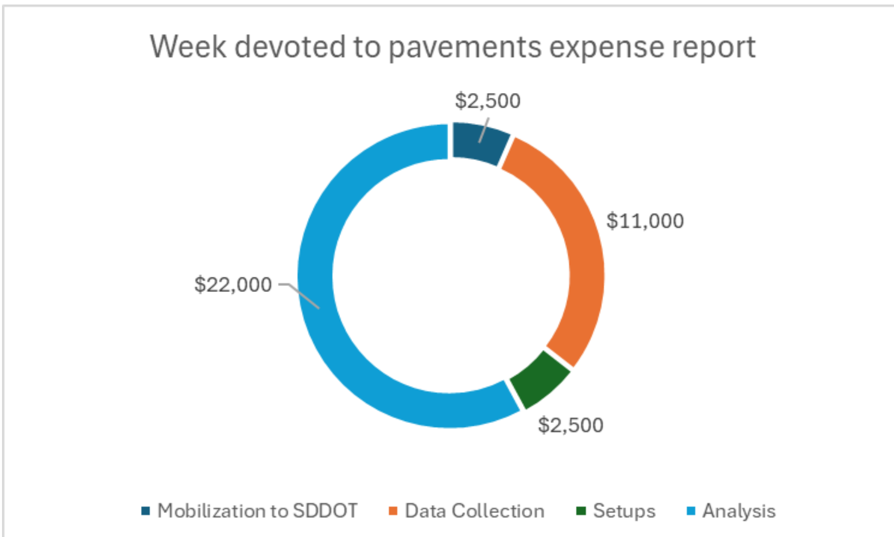


Figure 50 . Weekly cost forecast for South Dakota allocated towards pavement analysis[31]

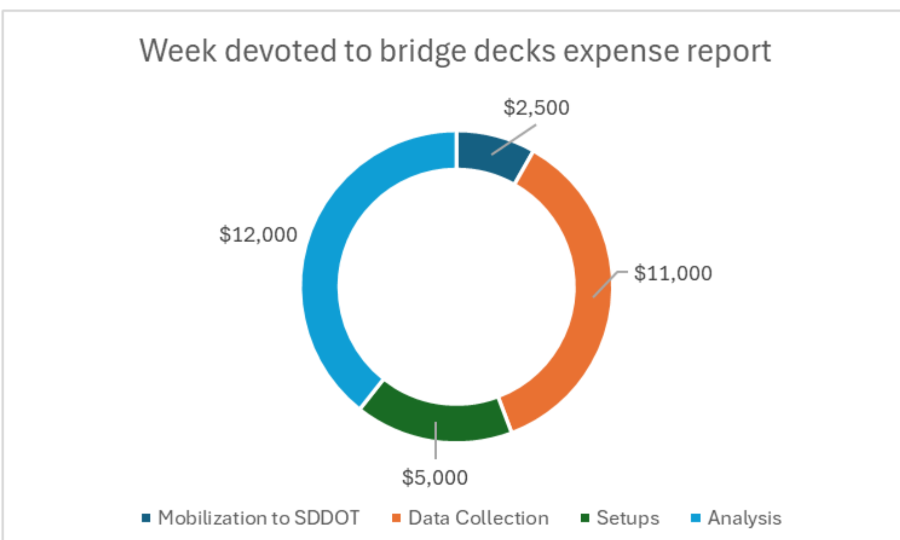


Figure 51 .Weekly cost forecast for South Dakota allocated towards bridge deck analysis[31]

The cost analysis concluded that there were high cost/benefit ratios, especially for pavement thickness QA and bridge deck evaluations as shown in Figure 52.

GPR APPLICATION SCENARIO	BENEFIT/COST RATIO
Thickness Evaluation for Pavement Rehab	34.4
Condition Evaluation for M&R of Bridge Decks	
Bare Concrete Decks	1.98
Overlaid Decks	8.9
Thickness Evaluation for QA of New Pavement	57-113

Figure 52. Summary of Benefit / Cost analyses[31]

SDDOT concludes the need for gradual adoption of GPR techniques with initial aid of consultant services. The proposed intent of GPR expansion is to focus the uses of GPR on proven success cases such as pavement thickness and bridge deck evaluations.

2.2. Survey Questionnaire

The Performing Agency reviewed numerous questionnaires from other DOTs survey to help design and structure their own questionnaire. The questions were designed to evaluate key aspects of GPR usage, including:

- Current GPR usage in districts, including applications and effectiveness.
- Challenges and advantages compared to other non-destructive evaluation methods.
- Potential for future expansion, including the use of advanced systems like 3D-GPR and artificial intelligence.
- Costs associated with GPR equipment, operation and training.
- The integration of GPR with supplementary NDT methods for enhanced accuracy.

After reviewing the questions provided by the Performing Agency, the Receiving Agency made several revisions to ensure the survey gathered more relevant and actionable data. These revisions aimed to:

- Clarify the questions for better understanding.
- Align the questions with TxDOT's operational goals.
- Ensure the questions provided clear, comprehensive answers to guide future decisions on GPR usage.

The revised questions were then used in the final survey distributed across the TxDOT districts. Below are the revised questions used in the survey.

1. To what extent is Air-Coupled Ground Penetrating Radar (AC-GPR) incorporated into the district's decision-making process regarding pavement evaluation?

a. Regularly used
b. Occasionally used (project-specific)
c. Standard part for routine pavement design/maintenance process
d. Not used (Skip to Q. 10)

2. How is AC-GPR data collected in your district? (Select all that apply)

a. District operated equipment
b. Division provided support
c. Consultant or IAC contract
d. Other (please specify)

3. If selected "other" for #2, please specify below:

4. What are the primary uses of AC-GPR data in your district? (Select all that apply)

a. Pavement design
b. Maintenance and rehabilitation
c. Emergency response (e.g., post-weather event subsurface damage)
d. Asset management
e. Other (please specify)

5. If selected "other" for #4, please specify below:

6. When AC-GPR is used, are other test methods commonly used alongside it? If so, which ones? (Select all that apply)

a. Falling Weight Deflectometer (FWD)
b. Dynamic Cone Penetrometer (DCP)
c. Ground-coupled GPR
d. Core sampling
e. Not applicable
f. Other (please specify)

7. If selected "other" for #6, please specify below:

8. How many personnel in your District are trained in interpreting AC-GPR data using TxDOT's GPR analysis software (PaveCheck)?

a. None
b. 1–2
c. 3–5
d. More than 5

9. How would you rate the usability of PaveCheck?

a. Very easy

b. Easy
c. Neutral
d. Difficult
e. Very difficult
f. Not familiar / not used

10. If your district does not use AC-GPR, what alternative methods are used for layer thickness and subsurface evaluation?

11. What are the main barriers to using AC-GPR more effectively in your district? (Select all that apply)

a. Limited equipment availability
b. Lack of trained personnel
c. Time constraints
d. Budget constraints
e. Data interpretation complexity
f. Maintenance/repair issues
g. Other (please specify)

12. If selected "other" for #11, please specify below:

13. Do you anticipate AC-GPR playing a larger role in your district's decision-making in the next 3–5 years?

a. Yes
b. No
c. Uncertain
d. Other (please explain)

14. If selected "other" for #13, please specify below:

15. What support would help your district the most to better utilize AC-GPR? (Rank top 2)

a. Increased access to equipment
b. Training on operators for data collection
c. Training on data interpretation (PaveCheck)
d. Better guidance documents
e. Other (please specify)

16. If selected "other" for #15, please specify below:

17. Do you have experience using other AC-GPR units and/or data other than our system?

a. No
b. Yes (please specify)

18. If selected "Yes" for #17, please specify below:

19. How did the other GPR system(s) perform relative to ours?

a. Satisfactory

b. Average

c. Unsatisfactory

20. Please share any examples where AC-GPR data significantly helped a project.

2.3. Survey Questionnaire Results

A survey was conducted with TxDOT district pavement engineers to assess their experience with Air-Coupled Ground Penetrating Radar (AC-GPR) and its integration into pavement evaluation processes. A total of 24 districts were contacted, with 9 responses received, representing a 37.5% response rate. The survey aimed to gather insights into the current usage of AC-GPR, types of pavements evaluated, and the primary applications for technology (such as pavement design, maintenance, and asset management). It also explored the operational barriers, including equipment access, data interpretation, training gaps, and software usability (e.g., PaveCheck). Additionally, the survey focused on the future role of AC-GPR, examining the support needed, such as increased access to equipment and training in data analysis. Responses were received via email. The full detail of the survey response is presented in Appendix A. A list of the survey questions and a general summary of the responses is presented below.

1. **To what extent is Air-Coupled Ground Penetrating Radar (AC-GPR) incorporated into the district's decision-making process regarding pavement evaluation?**

The use of AC-GPR for pavement evaluation varies across districts. While some districts use AC-GPR as a regular tool for routine pavement design and maintenance, others incorporate it only occasionally for project-specific evaluations. A few districts do not use AC-GPR in their decision-making process at all. The distribution of AC-GPR usage is represented in Figure 53, showing the breakdown of usage patterns.

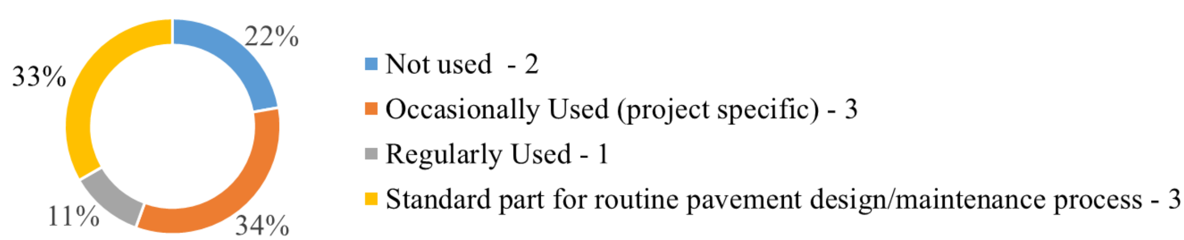


Figure 53: Usage of AC-GPR across Texas districts for pavement evaluation

2. **How is AC-GPR data collected in your district? (Select all that apply)**

The method of collecting AC-GPR data varies across districts. In many districts, Division-provided support is the primary method, while district-operated equipment is used in a few districts like El Paso and Fort Worth. Some districts, like Brownwood and Wichita Falls, use Consultants or IAC contracts for support. The distribution of data collection methods is shown in Figure 54, illustrating the varying approaches.

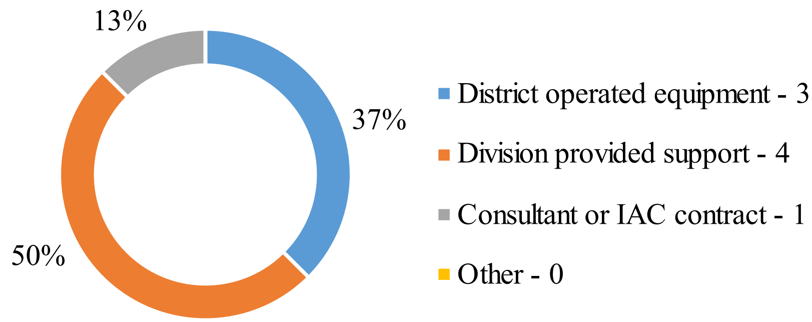


Figure 54: AC-GPR data collection methods across Texas districts

3. What are the primary uses of AC-GPR data in your district? (Select all that apply)

The primary uses of AC-GPR data across districts include pavement design and maintenance and rehabilitation, with most districts applying AC-GPR for these purposes. Some districts also use AC-GPR for other applications such as asset management. The distribution of these uses is shown in Figure 55, with 43% responses indicating pavement design and 43% indicating maintenance and rehabilitation as primary uses.

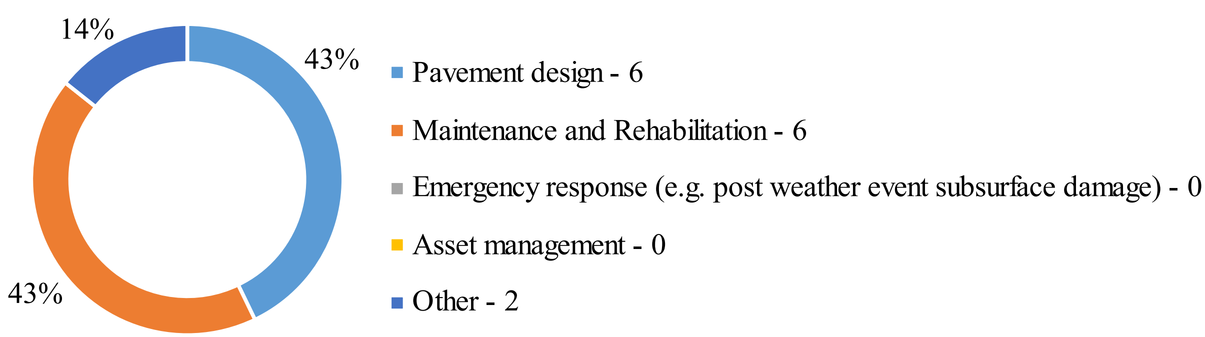


Figure 55: Primary Uses of AC-GPR Data across Texas districts

4. When AC-GPR is used, are other test methods commonly used alongside it? If so, which ones? (Select all that apply)

When AC-GPR is used, other test methods such as the Falling Weight Deflectometer (FWD) and Core sampling are commonly employed. Some districts also use the Dynamic Cone Penetrometer (DCP) alongside AC-GPR for additional pavement evaluation. Figure 56 illustrates the distribution of additional testing methods used in conjunction with AC-GPR, with 35% of districts using FWD, and 30% using Core sampling.

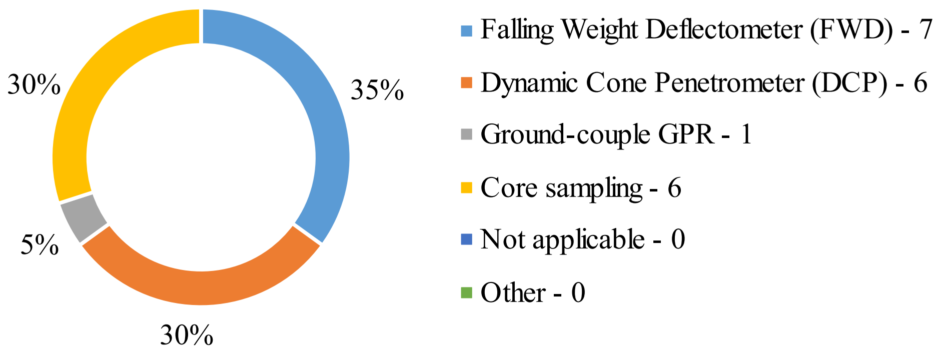


Figure 56: Common Test Methods Used Alongside AC-GPR

5. How many personnel in your District are trained in interpreting AC-GPR data using TxDOT's GPR analysis software (PaveCheck)?

The number of personnel trained in interpreting AC-GPR data using TxDOT's PaveCheck software varies across districts. The majority of districts have 1–2 personnel trained, while a few districts have no personnel trained or have 3–5 personnel trained. Figure 57 shows the distribution of personnel training levels, with 57% of districts reporting no trained personnel and 29% reporting 1–2 trained individuals.

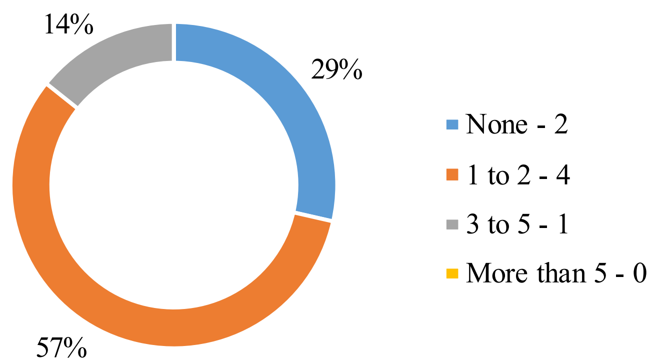


Figure 57: Personnel Trained in Interpreting AC-GPR Data Using PaveCheck

6. How would you rate the usability of PaveCheck?

The usability of PaveCheck was rated across various districts, with most districts finding it difficult to use, while others have neutral or no familiarity with the software. Figure 58 illustrates the usability ratings, showing that 29% of districts found it difficult, 28% found it neutral, and 14% found it very difficult.

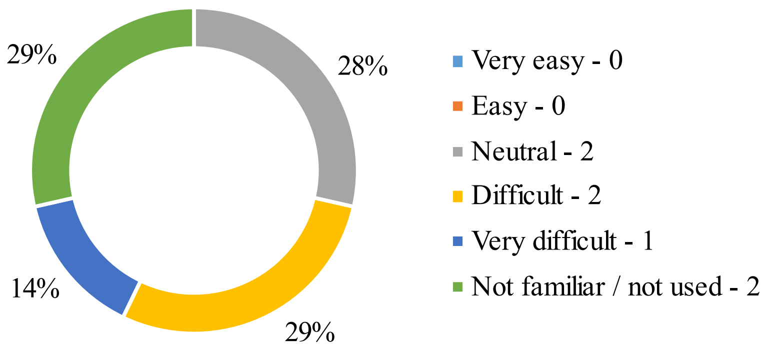


Figure 58: Usability rating of PaveCheck across Texas districts

7. **What are the main barriers to using AC-GPR more effectively in your district? (Select all that apply)**

The primary barriers to using AC-GPR more effectively in various districts include lack of trained personnel, limited equipment availability, and time constraints. Figure 59 shows the distribution of these barriers, with 31% of districts reporting lack of trained personnel and 31% citing limited equipment availability as the main challenges.

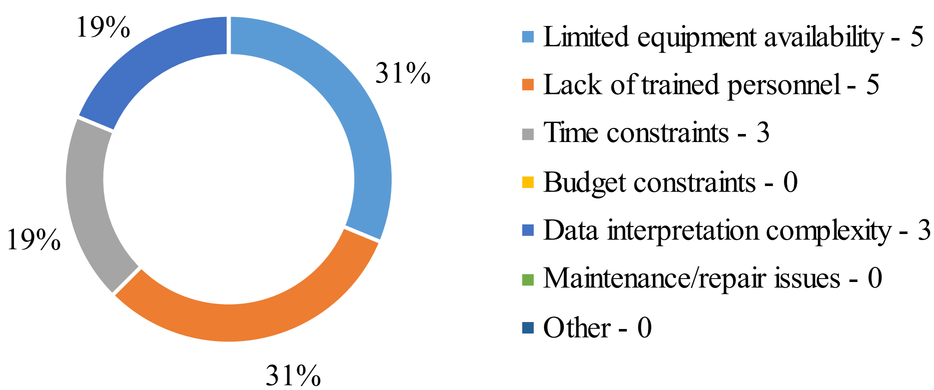


Figure 59: Barriers to effective use of AC-GPR across Texas districts

8. **Do you anticipate AC-GPR playing a larger role in your district's decision-making in the next 3–5 years?**

Most districts anticipate that AC-GPR will play a larger role in their decision-making over the next 3–5 years, with 67% of responses indicating "Yes". Figure 60 shows the distribution of responses, with 33% of districts uncertain about its future role, and none of the districts stating "No".

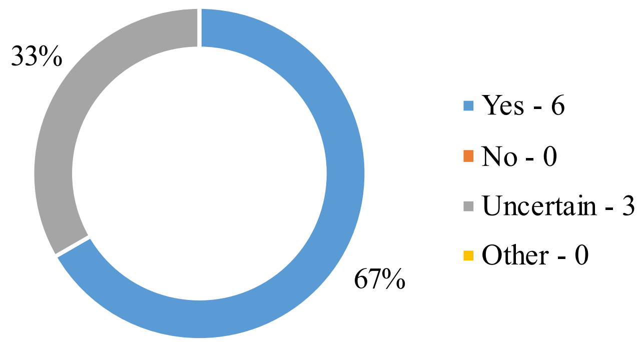


Figure 60: Anticipated Future Role of AC-GPR in District Decision-Making

9. What support would help your district the most to better utilize AC-GPR? (Rank top 2)

The main support required by districts to better utilize AC-GPR includes training on data interpretation (particularly with PaveCheck) and increased access to equipment. Figure 61 illustrates the distribution of responses, with 39% of districts requesting better guidance documents, and 28% highlighting the need for increased access to equipment.

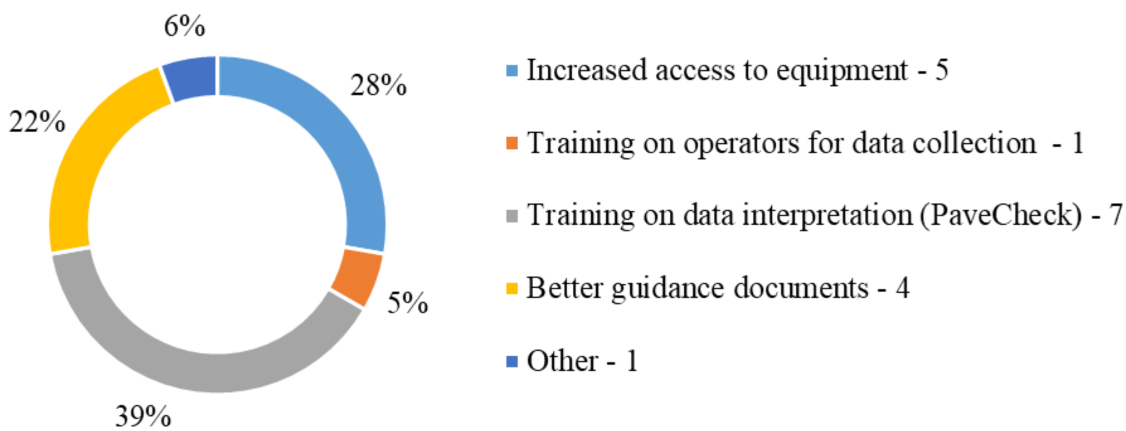


Figure 61: Support Needed to Better Utilize AC-GPR Across Texas Districts

2.4. Significant Findings from Survey Results

The survey results from 9 TxDOT district pavement engineers provide critical insights into the current use and future potential of Air-Coupled Ground Penetrating Radar (AC-GPR) in pavement evaluation. The findings reveal that 78% of districts currently utilize AC-GPR, with pavement design and maintenance/rehabilitation being the primary applications for the technology. However, challenges such as limited equipment availability, lack of trained personnel, and data interpretation complexity continue to affect the full utilization of AC-GPR.

Districts' operational use of AC-GPR varies, with some using it regularly as part of their standard operations, while others employ it on a project-specific basis. The survey also highlighted the frequent pairing of AC-

GPR with other test methods, such as the Falling Weight Deflectometer (FWD) and Core Sampling, underscoring the complementary role AC-GPR plays in pavement evaluation.

Data collection is mostly handled by district-operated equipment, although division-provided support and consultants are also utilized in some cases. Training needs were a recurring theme across the responses, with training on data interpretation (PaveCheck) being identified as the top priority. PaveCheck usability continues to be a challenge, as no district rated it as easy to use. The survey results also reveal a need for more user-friendly software and better guidance documents to facilitate the integration of GPR data into their pavement management systems.

When asked about the future role of AC-GPR, 67% of districts expect the technology to play a larger role in the next 3-5 years, indicating a strong belief in its potential despite the current barriers. The support needed most frequently included increased access to equipment and training in data analysis, which would help districts make more confident decisions using GPR data.

Although some districts have no prior experience with other GPR systems, AC-GPR's effectiveness in pavement evaluation is well acknowledged, and it is seen as a valuable tool for future projects. In conclusion, addressing the training gap, improving software usability, and ensuring consistent equipment access will be crucial for maximizing AC-GPR's effectiveness in TxDOT's pavement management program and fully realizing its potential for future pavement evaluations.

3. Investigating GPR Equipment and Software

As part of Task 4, the Performing Agency conducted a comprehensive analysis of existing GPR equipment and software to provide the Receiving Agency with multiple viable options for their operational needs. This analysis will focus on evaluating hardware capabilities and software performance — including core functionalities, data processing efficiency, and suitability for different GPR applications such as pavement evaluation, subsurface mapping, and structural analysis. By outlining the key characteristics and operational considerations of each hardware and software option, the Performing Agency aims to deliver actionable insights that will help the Receiving Agency select a solution aligned with their technical requirements, budget constraints, and long-term objectives for enhancing infrastructure evaluation.

3.1. Radar Frequency Policy

3.1.1. Federal Communications Commission (FCC) Regulation[32]

The FCC regulation addressed the use of outdated 1-GHz horn antennas primarily used in pavement applications, which became prominent in the 1990s with advancements in data interpretation.

- Implemented in 2002, the regulations targeted Ground Penetrating Radar (GPR) equipment operating within the radio frequency ranges of 960 MHz to 3.1 GHz, which interfered with cell phones and GPS receivers. This had a significant impact on the routine use of 1-GHz antennas for GPR pavement assessment. Consequently, some GPR manufacturers, like air-coupled 1-GHz Pulse Radar, ceased operations
- The FCC classifies GPR as “a field disturbance sensor designed for ground contact or within one-meter proximity for detecting buried objects or assessing ground properties”.
- Pre-regulation GPR devices can only be utilized by their registered owners, such as older Pulse Radar equipment operated by entities like TxDOT, Florida DOT, and consultants, provided they were duly registered with the FCC by October 15, 2002.
- Post-regulation, all GPR devices operating at 1 GHz or higher frequencies required FCC certification and licensing. Subsequently, GSSI updated their technology to meet FCC certification requirements, obtaining FCC approvals for new GPR equipment compliant with regulations, while still achieving up to 1 scan per foot at normal highway speeds.

Subsequently, both domestic and foreign companies have developed FCC-approved GPR equipment, including air-launched antennas. In conclusion, all current commercial GPR equipment is compliant with FCC regulations, ensuring trouble-free usage.

3.1.2. Different Frequencies and Their Usage [28]

The frequency used for GPR scanning may vary depending on the specific objectives of the DOT. When using a higher attenuation rate, more details are portrayed in the GPR data. In most cases, GPR antennas operate at the range of 10 MHz-2.6 GHz. The most common ranges for reinforcement inspection are as follows:

1.5 GHz-1.6 GHz (40%): This is most often used as it achieves optimum level of detail and penetration depth for bridge decks.

2.0 GHz-2.6 GHz (32%): This higher frequency allows for more details within the GPR scan but is not optimal when scanning structures with deep covers or overlays like roadways. This range is often used in laboratory settings.

0.9 GHz-1.0 GHz (21%): Many used for air coupled GPR devices.

Figure 62 shows the U.S. national survey on the frequency range of GPR usage.

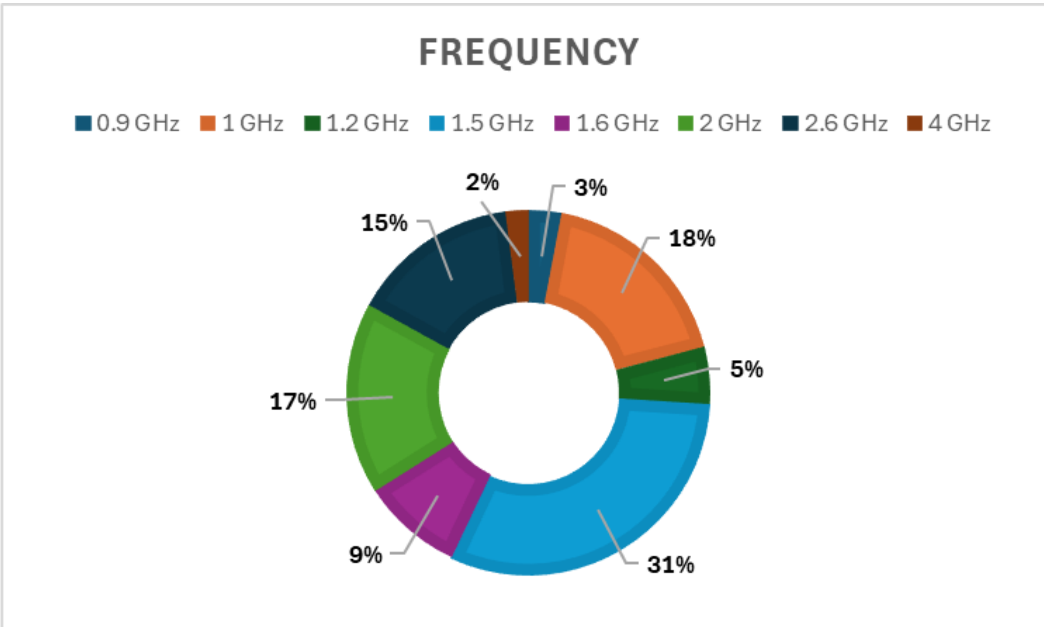


Figure 62. U.S. national survey on the frequency range of GPR usage[28]

3.2. Commercial GPR Hardware

This section provides an in-depth analysis of GPR hardware, focusing on the specifications of antennas and complete GPR systems. It highlights the frequency ranges, types, and applications of various systems used for infrastructure evaluation tasks, such as pavement assessments, subsurface mapping, and structural analysis. Additionally, the section discusses the cost of antennas and GPR systems, offering insights into their affordability and suitability for specific applications.

3.2.1. Specification of Commercial GPR Antenna

The Performing Agency analyzed the existing GPR equipment used by the DOTs. The Federal Communications Commission (FCC) regulations implemented in 2002 significantly impacted the use of

GPR devices, particularly 1-GHz horn antennas used in pavement assessments. This regulatory shift prompted the development of modern GPR hardware with improved capabilities, enabling seamless operation and compliance with FCC standards. Table 4 provides an overview of notable GPR hardware systems, showcasing their key capabilities and applications.

Table 4. GPR antenna and their key applications

Company	Antenna type	Frequency	Application
GSSI	Ground	2600 MHz, 2300 MHz, 2000 MHz, 1600 MHz, 900 MHz	Aims to determine the thickness of concrete cover, inspect concrete structures, and locate embedded reinforcement such as rebar, post-tension cables, and conduits.
		400 MHz, 270 MHz, 200MHz, 100MHz, 16 ~ 80MHz	Detection and mapping of utility pipes, shallow engineering, tunnel & void detection, environmental & archaeological applications, and karst investigations.
	Air (horn)	2GHz, 1GHz	Pavement evaluation and road condition assessment.
Kontūr	Near-surface (3D)	30 ~ 4,500 MHz, 30 ~ 1,500 MHz	Mapping and detection of both shallow and deeper subsurface objects and structures.
	Air (3D)	30 ~ 4,500 MHz	High-speed pavement assessment, airport and railroad inspection, buried object detection, landmine/improvised explosive device detection (IED).
IDS GeoRadar	Air	2GHz, 1GHz	Measuring asphalt pavement thickness, airport inspection, evaluating the multiple pavement layers, location cavities and delamination, wetland detection, and location of fractures.
Mala Geoscience	Ground	80 MHz, 100 MHz, 250 MHz, 450 MHz, 500 MHz, 750 MHz, 800 MHz 950 MHz,	Mapping of rebar, reinforcements, tendons, etc. Detecting conduits such as heating pipes and other utilities within a concrete structure. Record concrete thickness. Mapping layers in concrete.

Company	Antenna type	Frequency	Application
		1.2 GHz, 1.6 GHz, 2.3 GHz	Detection of cracks and voids. Mapping of water saturation/ moisture and corrosion.
Impulse RADAR	Air	450 MHz, 800 MHz	Bridge, road and runway investigations. Asphalt thickness, base layer profiling and thickness, reinforcement evaluations, structure, subsidence and voids. Road-mapping.

3.2.1.1. GSSI – 1600 MHz Antenna

- General purpose concrete antenna
- Used bridge decks for condition assessment, to determine concrete cover and inspect concrete structures.

Figure 63 shows the GSSI 1600 MHz antenna.

Figure 63: GSSI 1600 MHz Antenna (www.geophysical.com)

3.2.1.2. GSSI – 400 MHz Antenna

- Used for detection and mapping of utility pipes, void detection, tunnel voids, and archaeological applications.

Figure 64 shows the GSSI 400 MHz antenna.

Figure 64: GSSI 400 MHz Antenna (www.geophysical.com)

3.2.1.3. GSSI – 2 GHz Horn Antenna

- A high-resolution GPR antenna used for pavement thickness and road condition assessment.

Figure 65 shows the GSSI 2 GHz horn antenna.

Figure 65: GSSI 2 GHz Horn Antenna (www.geophysical.com)

3.2.1.4. ImpulseRadar – Raptor Antenna (3D-GPR Array)

- Used for pavement evaluation, bridge inspection etc.
- 450 MHz and 800 MHz frequency antenna are available.

Figure 66 shows the ImpulseRadar Raptor 3D-GPR Antenna Array.

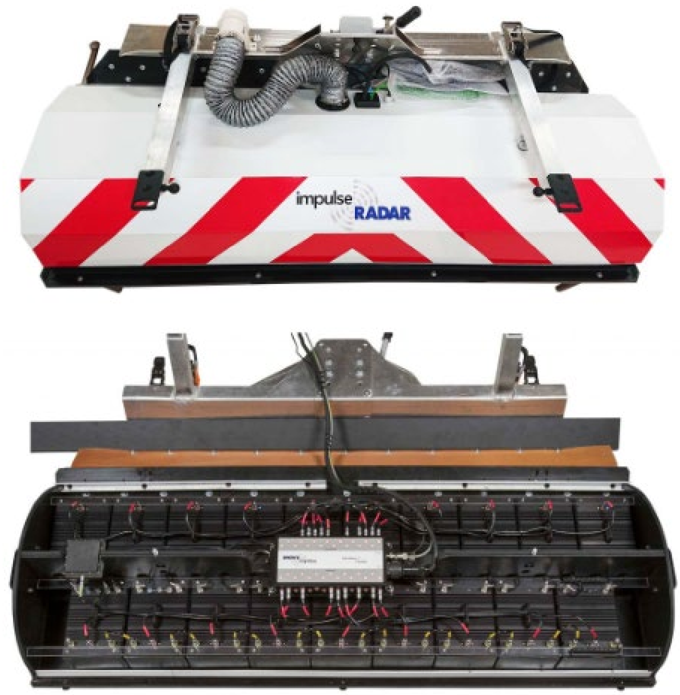


Figure 66: Raptor 3D-GPR Array (impulseradargpr.com)

3.2.1.5. Kontur – AIR (Air-lunched Antenna)

- Used for high-speed pavement assessment, airport and railroad inspection, landmine/improvised explosive device detection (IED)
- The number of channels may vary from 12 to 36 channels

Figure 67 shows the Kontur AIR Series Antenna.

Figure 67: AIR Series Antenna (www.kontur.tech)

3.2.1.5. IDS GeoRadar – Steam UP

- Use for utility mapping.
- Sensor frequency ranges from 200MHz - 600MHz.

Figure 68 shows the IDS GeoRadar Steam UP antenna.

Figure 68: Steam UP Array Modules Antenna (idsgeoradar.com)

3.2.2. Specification of Commercial GPR system

This section outlines the specifications of various Ground Penetrating Radar (GPR) systems, focusing on their features, capabilities, and applications. Each system is evaluated based on its performance, operational efficiency, and suitability for different infrastructure assessment tasks. The details provided will help in understanding the potential of these systems for tasks such as asphalt density evaluation, subsurface mapping, bridge deck analysis etc.

3.2.2.1. GSSI

a. PaveScan RDM 2.0

- Asphalt density assessment tool provides real-time dielectric constant monitoring.
- Surface depth analysis.
- The system utilizes 1 sensor but can be upgraded to operate up to 3 sensors at a time, with sensors operating at 2GHz frequency.
- Operated utilizing a pushcart system.

Figure 69 shows the GSSI PaveScan RDM 2.0 with 1 Sensor, Figure 70 shows the GSSI PaveScan RDM 2.0 with 3 Sensors, Figure 71 shows the specification of GSSI PaveScan RDM 2.0 and Figure 72 shows the visual output of GSSI PaveScan RDM 2.0 GPR data.

Figure 69. GSSI PaveScan RDM 2.0 with 1 Sensor (www.geophysical.com)

Figure 70. PaveScan RDM 2.0 with 3 Sensors (www.geophysical.com)

SPECIFICATIONS

Tablet	
Display	10.1" WUXGA 1920 x 1200 with LED backlighting
Processor	Intel® Core™ i5-10310U vPro™
Available Ports	USB-A, USB-C, Ethernet
Battery	Li-Ion Battery (10.8 V), 4 hours
Operating Temperature	-28°C to 60°C (-18°F to 140°F)
Environmental Rating	IP65
Durability	MIL-STD-810H
Measurement	
Repeatability (dielectric)	+/- 0.12
Accuracy (dielectric)	+/- 0.12
Minimum/ Maximum dielectric	2 to 16
Mechanical	
Dimensions	One sensor cart system – 157 x 63 x 111 cm (62 x 25 x 44 in) Three sensor cart system – 157 x 185 x 111 cm (62 x 73 x 44 in)
Environmental Rating	IP65
Operating Temperature	-20°C to 60°C (-18°F to 140°F)
Storage Temperature	-55°C to 85°C (-67°F to 185°F)

Figure 71: PaveScan RDM 2.0 Specification (www.geophysical.com)

Figure 72: Visual output of PaveScan data (www.geophysical.com)

b. RoadScan 30

- Mobile non-destructive evaluation system provides pavement thickness as well as subsurface conditions

- Controlled using an SIR 30 data collection system
- The RoadScan 30 works as a combined system utilizing 1 or 2 GHz
- Maximum scanning depth of 3 feet
- Multi-channel capabilities from 1-8 channels

Figure 73 shows the GSSI RoadScan 30 System with 1 Horn Antenna.

Figure 73. GSSI RoadScan 30 System with 1 Horn Antenna (www.geophysical.com)

As per GSSI, they only provide a 3-antenna mount setup and do not offer a 4-antenna mount. Therefore, to accommodate 4 antennas, a custom setup would need to be fabricated as shown in Figure 74.

Figure 74.GSSI RoadScan 30 System using 4 Horn Antennas (www.geophysical.com)

3.2.2.2. KONTŪR

a. KONTŪR AIR Sensor

- High speed GPR antenna system, with superior resolution
- Available in many channel configurations from 12-36 channels
- Ultra-wideband frequency range operates in a continuous 30 MHz to 4,500 MHz frequency range
- Equipped with RTK GPS and IMU for precise positioning

Figure 75 shows the KONTŪR AIR Series GPR system, Figure 76 Internal arrangement of KONTŪR AIR Series Antenna and Figure 77 shows the specification of KONTŪR AIR Sensor Specifications.

Figure 75. KONTŪR AIR Series GPR System (www.kontur.tech)

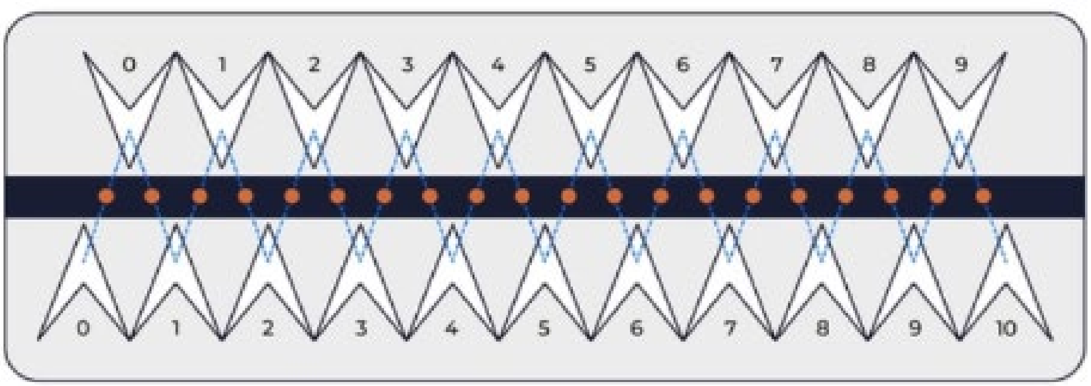


Figure 76. Internal Antenna Arrangement (www.kontur.tech)

	AIR 1212	AIR 1820	AIR 2124	AIR 2428	AIR 3036
Number of channels	12	20	24	28	36
Effective scan width	0.9 m 2,85 ft	1.5 m 4,92 ft	1.8 m 5,90 ft	2.1 m 6,88 ft	2.7 m 8,86 ft
Size (L x W x H m)	1.21 x 0.56 x 0.23	1.81 x 0.56 x 0.23	2.11 x 0.56 x 0.23	2.41 x 0.56 x 0.23	3.01 x 0.56 x 0.23
Weight	22 kg	33 kg	38 kg	44 kg	56 kg
Transport container size (L x W x H m)	1.4 x 0.7 x 0.3	2.0 x 0.7 x 0.3	2.3 x 0.7 x 0.3	2.6 x 0.7 x 0.3	3.4 x 0.7 x 0.3
Transport container weight	46 kg	60 kg	68 kg	76 kg	95 kg

Figure 77. KONTŪR AIR Sensor Specifications (www.kontur.tech)

3.2.2.3. IDS GeoRadar

a. RIS Hi-Pave

- RIS Hi-Pave designed for high-speed road assessment surveys. It can operate with several antennas at the same time. The system provides a complete assessment of road conditions, such as:
  - Pavement thickness measurement.
  - Surface, base and sub-base road course assessment.
  - Detection of cavities, voids and delamination.
  - Location of cracks.
  - Detection of wet areas.
  - Airport runway condition assessment.

Figure 78 shows the IDS GeoRadar RIS Hi-Pave GPR system and Figure 79 shows the specifications of IDS GeoRadar RIS Hi-Pave GPR system.

Figure 78: IDS GeoRadar RIS Hi-Pave GPR system (idsgeoradar.com)

SYSTEM SPECIFICATIONS	
RECOMMENDED LAPTOP	Panasonic FZ55 (or equivalent)
MAX. ACQUISTION SPEED (@ STD. SCAN INTERVAL)	260 km/h (150 mph) @ 1 antenna
POWER CONSUMPTION	13.3 W @ 1 antenna
POSITIONING	Survey wheel and/or GPS
NUMBER OF CONTROL UNIT	Depending on the configuration
SCAN RATE PER CHANNEL: (@512 SAMPLES/SCAN)	724 scans/sec @ 1 antenna
SCAN INTERVAL	10 scans/m
POWER SUPPLY	SLA Battery 12 VDC 12 AH
DEPENDING ON THE CONFIGURATION	
ANTENNA ENVIRONMENTAL	IP65
ANTENNA FOOTPRINT	51 x 22 cm
NUMBER OF HARDWARE CHANNELS	from 1 to 8
ANTENNA CENTER FREQUENCIES	HORN ANTENNA: 1 GHz or 2 GHz DUAL FREQUENCY: 400/900 MHz
ANTENNA POLARIZATION	Horizontal (HH)
ANTENNA TYPE	Air launched
CERTIFICATION	EC, FCC, IC

SOFTWARE SPECIFICATIONS	
ONEVISION ACQUISITION SOFTWARE	• Automatic calibration for an easy and quick start-up • Real-time visualization of radar tomography (time slices) • Connection with NMEA positioning device • Export to IDS GeoRadar GeoMap, dxf, shp and kml formats • Multilanguage support • Metric and Imperial units
GRED HD PROCESSING SOFTWARE	• Tomographic map view (C-Scan) including radar scan fusion • 3D data visualization • Advanced targeting using radarscan and tomographic view • Radarscan viewer, filter and advanced filtering macros, multiple radar scan viewer • Layer picking for automatic analysis of sub-layers • GPS and map track viewer including X, Y and Z axis and digital map importation • Video handling (option)

* This antenna is not FCC or IC approved for use in the USA or Canada

Figure 79: RIS Hi-Pave Features (idsgeoradar.com)

b. Stream UP

- Multi-channel, multi-frequency, and double polarized GPR system
- Assembly and operation can be handled with 2 operators due to the compact and modular design
- Stream UP can operate within urban environments due to its compactness
- Adjustable height system allows for quick deployment on the field
- When utilized with IQMaps software, it allows for real-time processing and 3D visualization of data
- Used for mapping utilities.

Figure 80 shows IDS GeoRadar Steam Up System Mounted onto Survey Vehicle and Figure 81 shows the specification of IDS GeoRadar Steam Up System.

Figure 80. Stream UP System Mounted onto Survey Vehicle (idsgeoradar.com)

SYSTEM SPECIFICATIONS

- Overall Weight: 95kg (209.44lb)
- Recommended Laptop: Panasonic FZ55
- Suggested Acquisition Speed: Up to 60 km/h (37.3 mph)
- Power Consumption: 65W (during acquisition)
- Radar Coverage: 1,58 m (5.18ft)
- Tow Ball: 50 mm ISO Standard
- Scan Rate: 9.230 scan/s @512 sample/scan
- Environmental: IP65
- Positioning: GNSS, RTK, TPS
- Number of Control Units: 10 array modules + 1 supply control unit
- Maximum Acquisition Speed: Up to 150 km/h (93.2 mph)
- Power supply: 12V car or external battery
- System Size: 1775 x 429 x 786 mm (69.9 x 16.9 x 30.9 in)
- Waterproofing: IP65
- Connector type: 13 pin connector

Figure 81. Stream UP GPR System Specifications (idsgeoradar.com)

c. Stream X

- Vehicle towed GPR system for 3D mapping of underground structures and geological features
- Able to be equipped with three antenna array configurations from 16 to 48 antennas, with antenna spacing as low as 4 cm (1.575 in)
- Can utilize different frequencies (200 MHz or 600 MHz) to tailor for either better depth penetration or better resolution

Figure 82 shows the Stream X System mounted on a survey vehicle, Figure 83 shows the example of data capture from Stream X System, Figure 84 shows the top view of time slice of figure 74, Figure 85 shows the Stream X System Components and Figure 86 shows the specification of Steam X GPR system.

Figure 82. Stream X GPR System Mounted on Survey Vehicle (idsgeoradar.com)

Figure 83. Example Data Capture from Stream X GPR System (idsgeoradar.com)

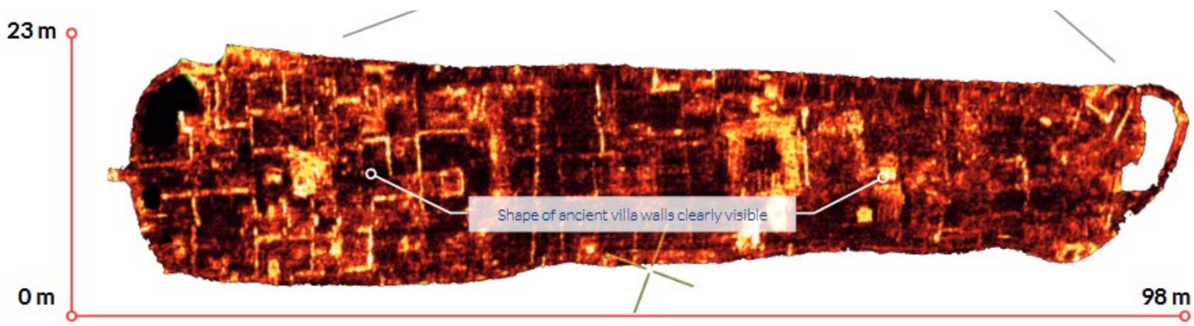


Figure 84. Top View Time Slice of Figure 83 (idsgeoradar.com)

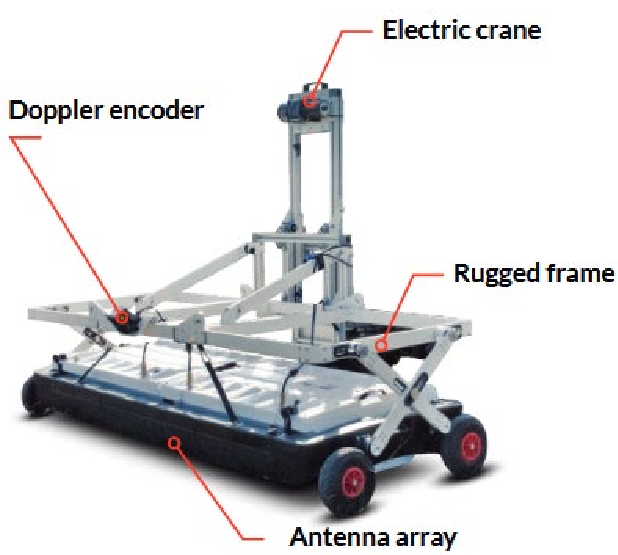


Figure 85. Stream X GPR System Components (idsgeoradar.com)

SYSTEM SPECIFICATIONS

- Recommmended Laptop: Panasonic CF-20 or Cf-31
- Max Acquisition Speed (@STD Scan Interval): 36 km/h (22mph)
- Power Consumption: 28W - 200 MHz version

  Positioning: Doppler Radar and/or GPS or Total Station
- Number of Contrul Unit:
  1 DAD MCH @200 MHz | 4 DAD MCH @600 MHz
- Scan Rate Channel (@512 Samples/Scan): 87 scans/sec
- Scan Interval: 8 scans/m
- Power Sypply: SLA Battery 12 VDC 12 Ah + electric crane

ANTENNA SPECIFICATIONS

- IP Grade: IP65
- Scan Width: 1.80m
- Number of Channels: 15/44

  Antenna Center Frequencies: 200 MHz or 600 MHz
- Polarization: W
- Antenna Spacing: 12cm / 4cm
- Certification: EC, FCC, IC

SOFTWARE SPECIFICATIONS

- OneVision Acquisition Software:
  - Real time tomography
  - Integrated navigator
  - Extensive survey management
  - System and survey set up
- IQMaps Post Processing Software:
  - Revolutionary interface that allows an immersive reality during post-processing phase
  - Large areas acquisition with no limit in software use even for acquisition of large areas
  - User friendly with ease of use and productivity dramatically increased (up to 30.000 sqm in a working day)
  - Georeferenced data: the new software has been developed with the precise aim to elaborate a georeferenced data after that it has been processed.

Figure 86. Stream X System Specifications

3.2.2.4. MALA

a. Easy Locator Core

- MALÅ Easy Locator Core is the state of the art, intelligent ground penetrating radar solution for identification and mapping of underground utilities, structures, and anomalies.
- Central frequency – 450 MHz

Figure 87 shows the MALA Easy Locator Core and Figure 88 shows the specification of MALA Easy Locator Core.

Figure 87: MALA Easy Locator Core GPR System

Technical Specification

MALÅ Easy Locator Core is a state of the art, high quality, intelligent ground penetrating radar for utility locating professionals. MALÅ Easy Locator Core includes real-time interpretation support through MALÅ AI; wireless data collection using mobile devices; cloud storage, post-processing and on-site reporting using MALÅ Vision.

MALÅ Easy Locator Core

Acquisition platform	MALÅ Controller App
Processing platform	MALÅ Vision
Recommended tablet	Samsung Galaxy Tab Active Pro
Artificial Intelligence	Real-time MALÅ AI
Core technology	MALÅ HDR real-time sampling
Data output	32 bit
Operating time	> 8 h
Dimensions (in operation)	102 x 49 x 79 cm
Dimensions (folded)	29 x 49 x 49 cm
Weight (in operation, excl. tablet)	15 kg
Max survey speed	> Highway speed
Environmental	IP65
Positioning	RTK GNSS (option), DGNSS, mobile device positioning, encoder, Total station support
Acquisition mode	Encoder wheel, time or manual
Antenna center frequency	450 MHz
SNR (signal to noise ratio)	> 102 dB
Bandwidth	> 121 %, fractional, -10 dB
Power supply	Dual interchangeable 12 V Li-Ion, external 12 V DC source
Rough terrain capability	MALÅ Rough Terrain Cart Mini (option)

Figure 88: MALA Easy Locator Core Specification (www.guidelinegeo.com)

b. MALA MIRA HDR

- MIRA HDR is designed for any large-scale 3D mapping project.
- Central frequency – 500 MHz
- Some of the more common application areas include:
  - Large area mapping
  - Utility mapping
  - Archaeology
  - Road investigation
  - Underground Storage Tank (UST detection)
  - Unexploded ordnance (UXO)
  - Sinkhole detection
  - Bedrock mapping
  - Clandestine graves
  - General site investigations

Figure 89 shows the MIRA HDR GPR system mounted in trailer and Figure 90 shows the specification of MIRA HDR.

Figure 89: MIRA HDR GPR system mounted in trailer (www.guidelinegeo.com)

Technical Specification

MALÅ MIRA HDR is the third generation 3D GPR array solution presented by Guideline Geo. Based on proprietary technologies, it produces unsurpassed quality and accuracy.

MIRA HDR Features

- MIRA Controller – the next generation acquisition software
- High Dynamic Range (HDR) for optimal resolution and penetration
- Accurate positioning using GPS Time Synchronization (PPS)
- 32bit data collection at highway speeds
- Real-time sampling technology

Technical Specification

Standard Antenna:	MIRA 500 HDR
Control Unit:	MALÅ MIRA HDR
Dimension:	171x61x37 cm (incl. handles)
Weight:	54kg / 119 lbs
Scan width:	140 cm / 4.6 ft
Power consumption:	150 W
Suitable Target depth:	0-5 meters / 0-17 ft
Max no. of data channels:	132
Data output:	32 bit
Number of samples:	Depends on no. of data channels
Standard Antenna Frequency:	500 MHz
Communication:	Gigabit Ethernet
Positioning input:	Supports all major RTK GPS and Total Stations
Environmental:	IP65
Certification:	EC, FCC, IC

Figure 90: Specification of MIRA HDR (www.guidelinegeo.com)

c. MIRA Compact

- MALÅ MIRA Compact is designed for any 3D mapping project. Some of the applications of MIRA compact are:
  - Utility mapping
  - Archaeology
  - Underground Storage Tank (UST) detection
  - General road assessment
  - Sinkhole detection
  - General site investigations

Figure 91 shows the MALA Compact GPR System and Figure 92 shows the specification of MALA Compact GPR System.

Figure 91: MALA Compact GPR System (www.guidelinegeo.com)

Technical Specification

MIRA Compact is a versatile and light weight 3D GPR array solution for high-detail mapping of the subsurface. It is designed and optimized for any hand-pushed 3D GPR mapping project – such as utility mapping and archaeological investigations. The MALÅ HDR technology delivers market leading data quality with optimal resolution at maximum penetration depth.

The MALÅ MIRA Controller acquisition software provides step-by-step guidance for your project, from start to finish. MALÅ Vision Desktop offers powerful tools for efficient data processing and analysis. The MALÅ software is user-friendly, streamlining your fieldwork and delivering quick results.

General

Antenna frequency:	500 MHz
Total weight (in operation):	42 kg (92.6 lbs)
Weight of antenna:	24 kg (53 lbs)
Weight of frame:	18 kg (40 lbs)
Dimensions (in operation):	116 x 96 x 100 cm (46 x 38 x 39”)
Maximum number of channels:	30
Channel spacing:	6.5 cm (2.56”)
Swath width:	60 cm (23.6”)
Maximum recommended survey speed:	Highway speed
Operating time:	8 hours (Hotswappable batteries)
Environmental protection:	IP65
Suitable applications:	Utility mapping, Archaeological Prospection, etc.

Figure 92: Technical Specification of MIRA Compact (www.guidelinegeo.com)

3.3. Commercial GPR Software

This section provides details on GPR data analysis software, including their specifications, capabilities, and pricing. It highlights the features and functionalities of various software tools, such as data processing and visualization and discusses their suitability for different GPR applications. Additionally, it outlines the costs associated with these software solutions to support informed decision-making.

3.3.1. Specification of Commercial GPR Software

The Performing Agency explored GPR software packages provided by leading manufacturers. GPR data requires external processing, and most hardware manufacturers provide proprietary software to complement their systems. Table 5 summarizes key GPR software along with their capabilities and applications:

Table 5: Summary of GPR software

Organization	Software name	Input data
TxDOT	PaveCheck	• Single channel Air-coupled Ground Penetrating Radar (GPR) • Falling Weight Deflectometer (FWD) • Dynamic Cone Penetrometer (DCP) • Coring Test • Photo Image • Global Positioning System (GPS)
Roadscanners (vehicle)	Road Doctor	• Multiple channel Air-coupled Ground Penetrating Radar (GPR) • Falling Weight Deflectometer (FWD) • Dynamic Cone Penetrometer (DCP) • Coring Test • Thermal Camera/ Video Camera • Global Positioning System (GPS) • inertial measurement unit (IMU) • LiDAR • 3D Accelerometer • Distance Measuring Instrument (DMI, Encoder)
GSSI	RADAN	• Multiple channel Air-coupled Ground Penetrating Radar (GPR) • Global Positioning System (GPS) • Distance Measuring Instrument (DMI, Encoder)
Kontūr	Examiner collect Examiner Specialist Examiner Explore	• Multiple channel Air-coupled Ground Penetrating Radar (GPR) • Global Positioning System (GPS) • Distance Measuring Instrument (DMI, Encoder) • Multiple Processing Options
ImpulseRadar	Condor	• Multiple channel Air-coupled Ground Penetrating Radar (GPR) • Global Positioning System (GPS)

Organization	Software name	Input data
IDS GeoRadar	GRED HD 3D	• Multiple channel Air-coupled Ground Penetrating Radar (GPR) • Global Positioning System (GPS)
MALA	MALA Vision	• Multiple channel Air-coupled Ground Penetrating Radar (GPR) • Global Positioning System (GPS)

3.3.2. Commercial GPR Software Capabilities

3.3.2.1. GSSI

a. Build-in software – SIR 30 Software

- This software is only used for collecting GPR surveys and is not used for postprocessing.
-

b. Radan 7

- This software is used for processing GPR data. It is used for evaluating pavement and concrete structures.
- Operates based on a module framework to tailor to specific processing needs
- 3D Module: Allows for additional 3D viewing capabilities of GPR data, including “image slicing” of data.
- RoadScan Module: To be used with horn antennas, calculates the propagation velocity of GPR signals through pavement.
- BridgeScan Module: Allows for identification of rebar within bridge decks, as well as rebar depth and deterioration mapping.

Figure 93 shows the Data at 400 MHz showcasing base and sub-base layers using Radan 7 and Figure 94 shows the Data at 900 MHz showcasing subsurface structure with several layers using Radan 7.

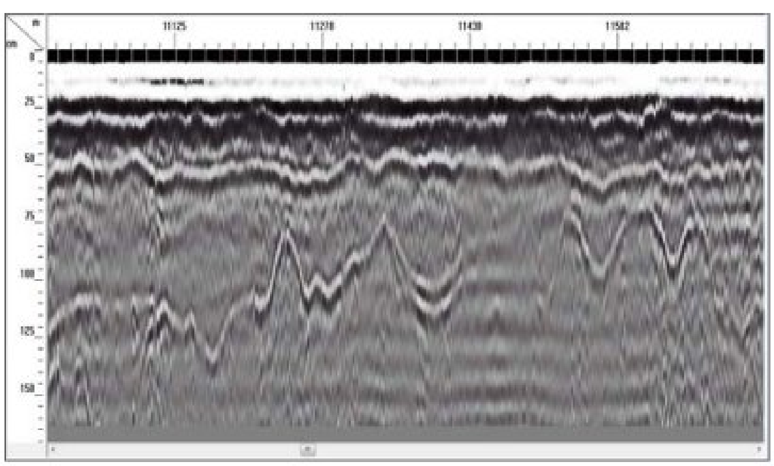


Figure 93. Data at 400 MHz showcasing base and sub-base layers using Radan 7 (www.geophysical.com)

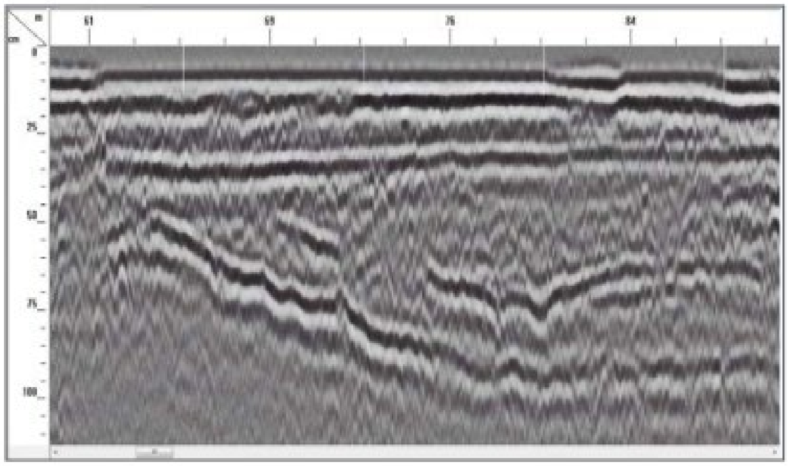


Figure 94. Data at 900 MHz showcasing subsurface structure with several layers using Radan 7 (www.geophysical.com)

3.3.2.2. KONTŪR

a. Built-in software: Examiner Collect

- This software is only used for collecting GPR survey data and not used for post processing.
- It is designed to be integrated with KONTŪR Air-Launched antennas and allows operators to control over scanning parameters.
- Offers real-time navigational assistance which visualizes vehicle trajectory and previously surveyed area.
- Includes GPS deviation maps that can check precision when acquiring data to better understand GPS coverage.

Figure 95 shows the Examiner collect interface.

b. Examiner Specialist

- This software is used for post postprocessing of GPR survey data. It is used for pavement evaluation, detecting cracks and their size, analyzing concrete structures etc.
- Provides fast processing of field data which can be formatted into 3D data cubes, as well as provides multiple processing options (filtering, background removal, 3D migration)
- Allows for full customization with included software development kit (SDK)
- Allows for multiple image export options including GIS, Sharfile, CAD, SEG-Y, ASCII, and Google Earth.

Figure 96 shows the annotations and 3D interface tracing using Examiner Specialist.

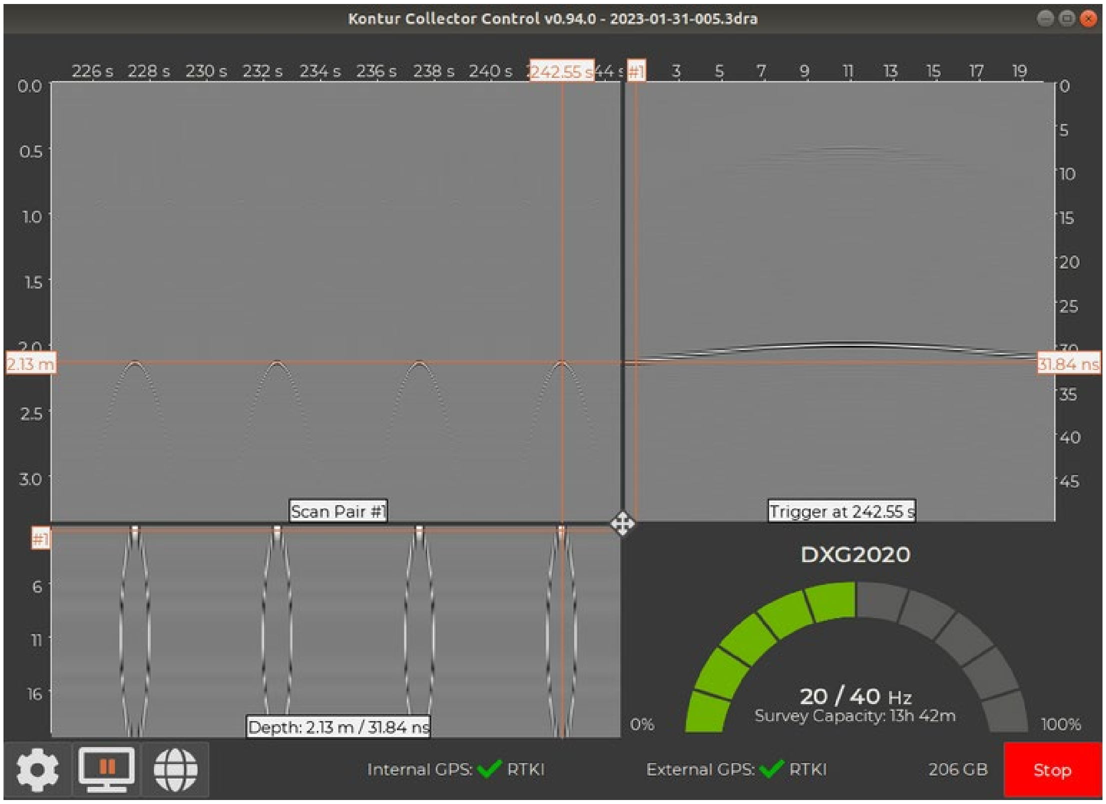


Figure 95. Examiner collect interface (www.kontur.tech)

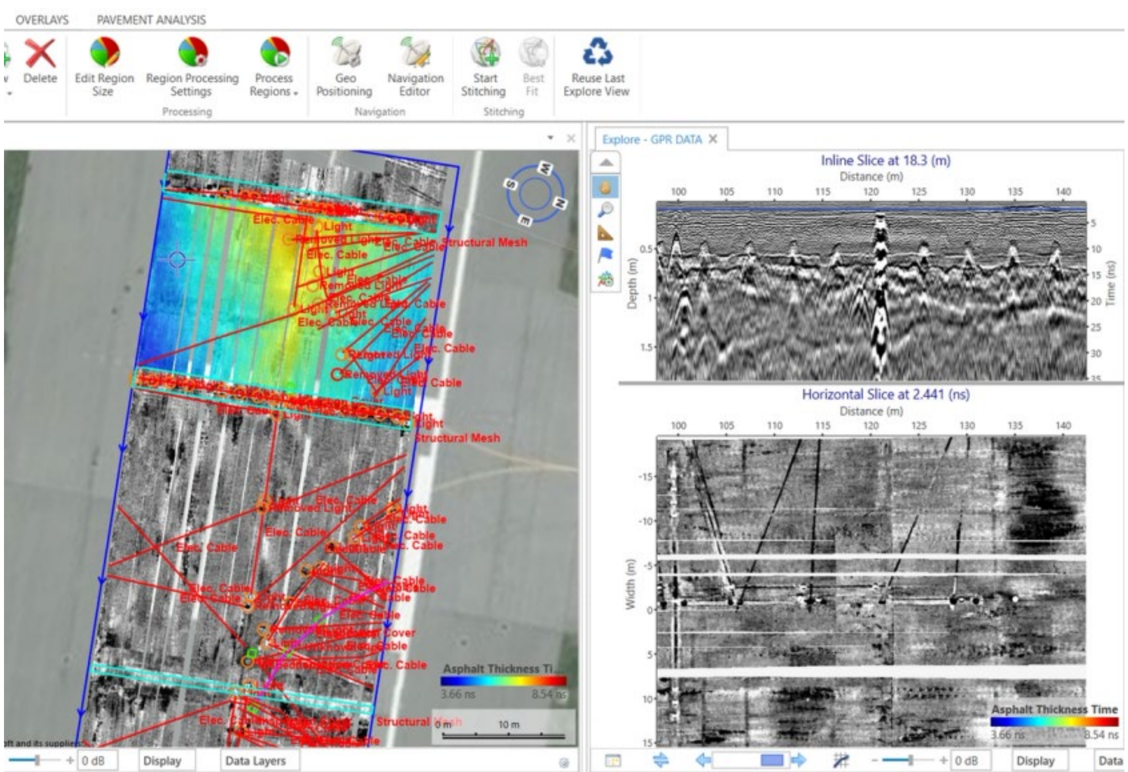


Figure 96. Annotations and 3D interface tracing using Examiner Specialist (www.kontur.tech)

c. Examiner Explore

- This software is not used for post processing.
- It is mainly a cloud-based tool designed for simplified visualization of GPR survey data and tracking within a georeferenced environment.
- It Is used for analyzing pavement layer thickness and finding distress in the pavement.
- Being a cloud-based GPR software, it allows engineers to easily share and present survey data in a clearer and simplified way.
- Provides cross-sectional views of target areas as needed by the operator.

Figure 97 shows the Examiner Explore interface.

Figure 97. Examiner Explore interface (www.kontur.tech)

3.3.2.3. IDS GeoRadar

a. GRED HD 3D

- It is basic post processing software.
- It provides 2D and 3D tomography for immediate visualization of buried objects (e.g.: buried pipes and utilities, cavities etc.) and anomalies.
- Supports automatic or manual layer insertion for precise data interpretation.
- Allows core sample insertion for data calibration and thickness verification.
- GRED HD 3D windows provide clear visualization of radar maps, road layers, core samples, and underground anomalies.

Figure 98 shows the GRED HD 3D-Layer recognition and exportation features.

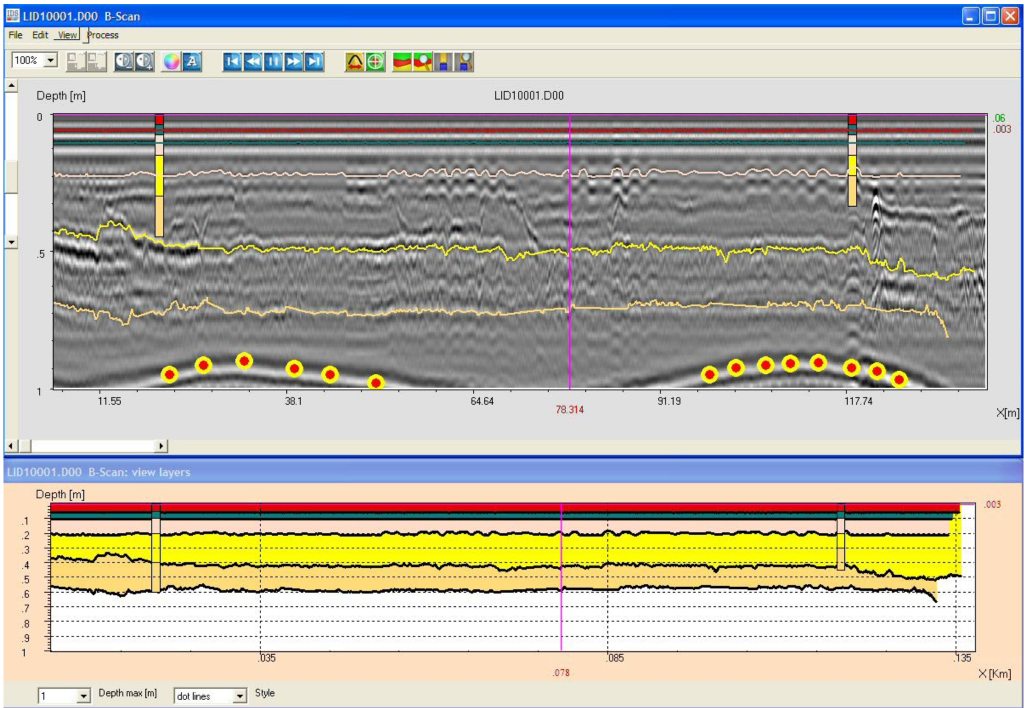


Figure 98. GRED HD 3D-Layer recognition and exportation (idsgeoradar.com)

b. IQMaps

- It is post-processing software designed for analyzing and interpreting GPR data.
- The software enables real-time GPR data analysis with 3D visualization of the survey area.
- It can integrate multiple data sources into a single project for comprehensive analysis.

Figure 99 shows the IQMaps Interface.

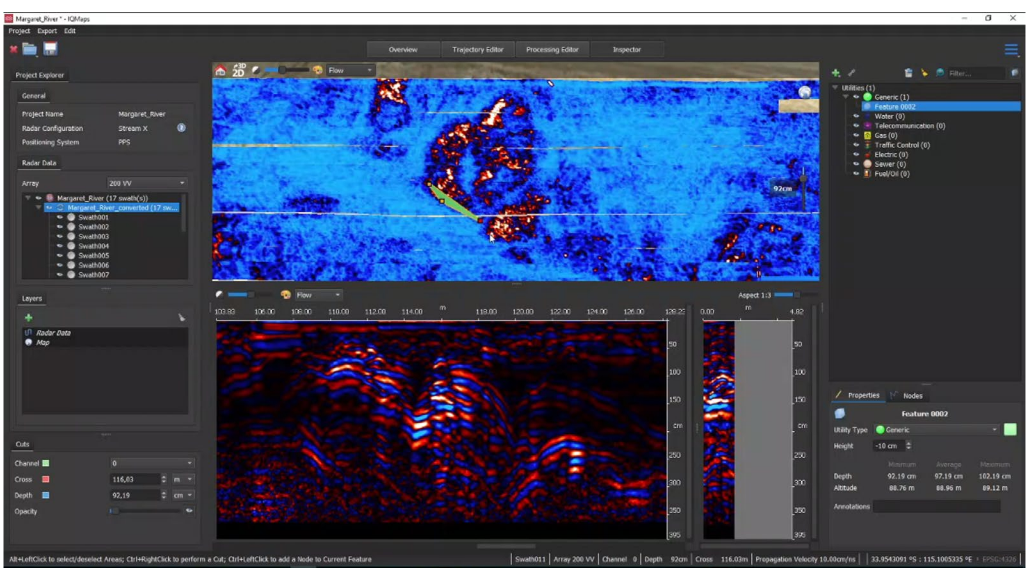


Figure 99. IQMaps Interface (www.idsgeoradar.com)

3.3.2.4. Impulse Radar

a. Condor

- It is 3D GPR processing and analysis software.
- It Includes data manager that allows the operator to view the data at different levels of processing.

Figure 100 shows the Condor software showing underground utilities.

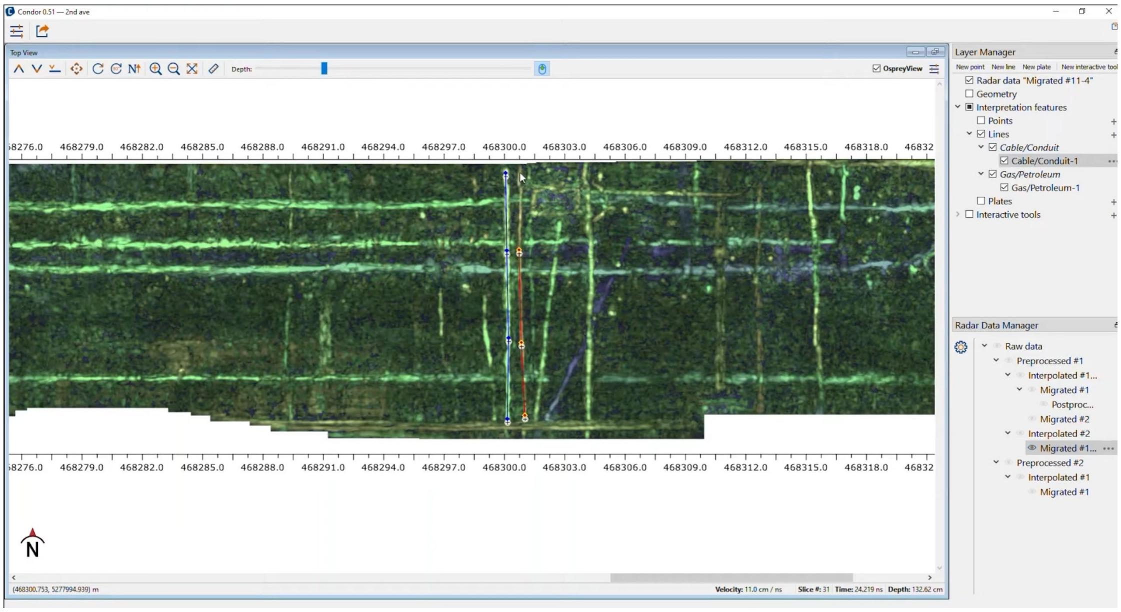


Figure 100. Condor software showing underground utilities (www.impulseradargpr.com)

3.3.2.4. MALÅ

a. Built-in Software – Mira Controller

- Data acquisition software design for GPR system. It is not used or post processing.
- Provides a modern and easy-to-use interface with integrated navigation aids.
- Tracks performance and guides speed and course during data collection for high-quality measurements.
- Support exporting to multiple formats for integration with other software packages.

Figure 101 shows the Mala controller interface.

b. MALÅ Vision

- It is a post-processing and visualization software.
- It supports 1D, 2D, and 3D views, allowing interpretation with site maps, 2D profiles, interpolated 3D images, and time slices for accurate subsurface analysis.
- It Includes the ability to add markers to survey data that include images, sound, screen captures and typed notes.

Figure 102 shows MALA Vision interface.

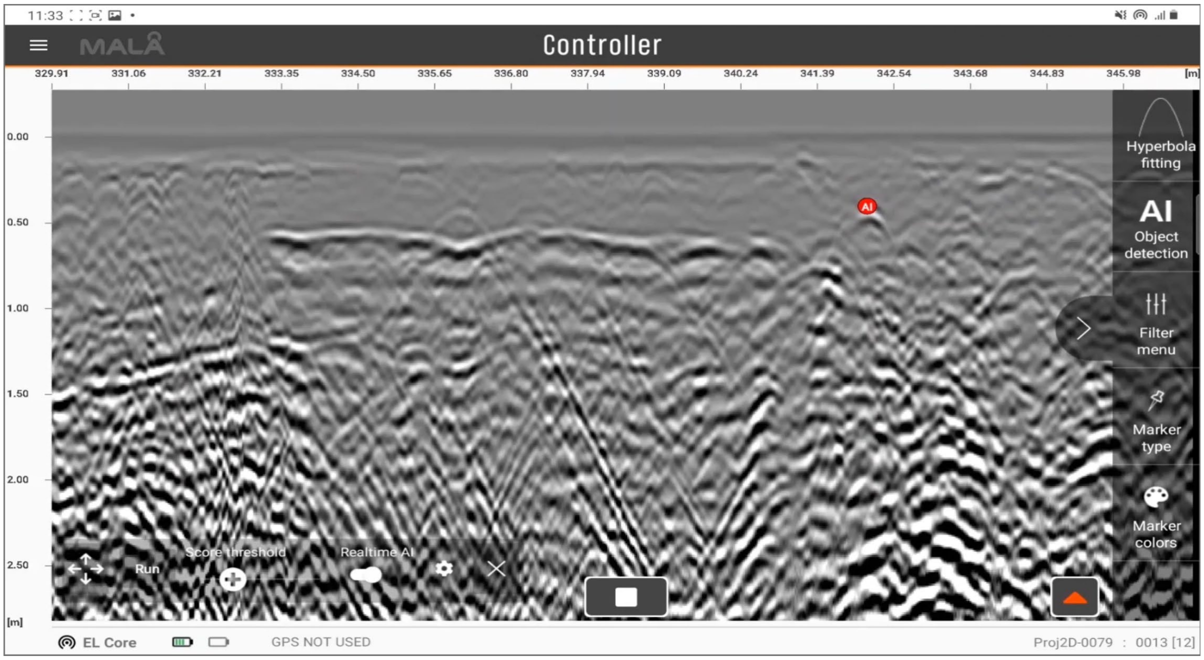


Figure 101: Mala controller interface(www.guidelinegeo.com)

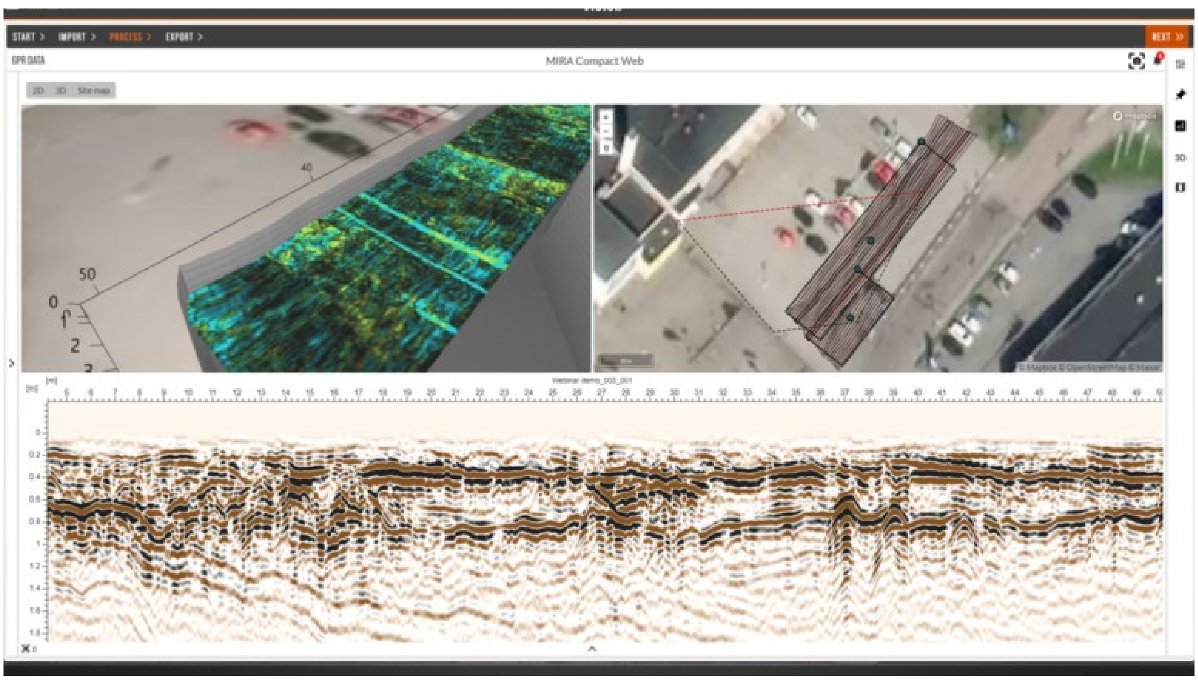


Figure 102. MALA Vision interface (www.guidelinegeo.com)

3.4. Significant Findings from Review of Commercial GPR Hardware and Software

This analysis highlights advanced FCC-compliant commercial GPR systems along with their key features and capabilities. Table 6 summarizes the key features of the reviewed commercial GPR systems, while Table 7 outlines the key features of the evaluated commercial GPR analysis software.

Table 6: Key features of the reviewed commercial GPR systems

Manufacturer	GPR System	Application
GSSI	RoadScan (2D) (Air coupled and Vehicle mount)	Pavement thickness measurement, sub-base condition assessment, moisture detection, crack identification, delamination mapping.
	Utility scan (2D) (Ground coupled and Hand Cart)	General underground utility locating, detecting voids, identifying soil and foundation characteristics.
	Bridge scan (2D) (Ground coupled and Hand Cart)	Bridge deck condition assessment, void detection and location, measure concrete thickness.
	PaveScan RDM 2.0 (2D) (Ground coupled and Hand Cart)	Measure dielectric of new pavement to determine pavement quality and uniformity (relates dielectric with air voids), pavement & asphalt density assessment
Kontur	AIR Sensors (3D) (Air coupled and Vehicle mount)	Compact 3D GPR system for high-resolution road, rail, and bridge deck surveys; mapping of asphalt, concrete, and subsurface layers; utility detection in small construction sites; localized damage assessments.
IDS GeoRadar	Hi-pave (2D) (Air coupled and Vehicle mount)	Rapid road and runway assessments, pavement thickness evaluation, asphalt and concrete layer detection, pre- and post-paving quality control, large-scale airport runway assessments, moisture retention and asphalt segregation detection, frost damage identification.
	Steam UP (3D) (Air coupled and Vehicle mount)	Rapid large-area utility detection, high-speed road and railway scanning, pavement evaluation, and bridge deck inspection. Operates without disrupting traffic, making it safe and efficient for city surveys.
	Steam DP (3D) (Ground coupled and Hand Cart)	3D high resolution mapping of underground utilities and features, detailed subsurface structural assessment, and in-depth pavement analysis.

Impulse Radar	Raptor 80 (2D) (Air coupled and Vehicle mount)	Pavement distress evaluation, bridge deck scanning for delamination and rebar detection, embedded utility mapping within asphalt/concrete, subsurface defect localization, structural deterioration assessment, roadbed integrity surveys.
MALA	MALA Easy Locator (2D) (Ground coupled and Hand Cart)	Smart AI-based utility locating, cloud-based system enabling instant field processing
	MIRA compact (3D) (Ground coupled and Hand Cart)	High speed, High-resolution 3D subsurface mapping
	MIRA HDR (3D) (Air coupled and Vehicle mount)	3D high-resolution GPR for road surveys, bridge deck assessments, utility detection, archaeological prospecting, sinkhole and cavity detection, and moisture content analysis in roadbeds, rail embankments, and runways.

Table 7: Key features of the reviewed commercial GPR software

Manufacturer	Software	Features
GSSI	SIR 30 Software	Data collecting software, capable of collecting up to eight channels simultaneously. Supports configurable connections with external devices like RTK GPS.
	RADAN 7	Post processing software. Batch processing for large datasets. Enhanced 3D visualization and seamless integration with GPS data. Seamless output of interpreted data results to AutoCAD Can detect rebar, corrosion, delamination, voids, distress, moisture, cracks.
	RoadScan Module for RADAN Software	Tools in RADAN 7 software used for determining pavement thickness, base thickness, and other properties without core

		samples. Designed for use with horn (air-launched) antennas.
Kontūr	Examiner Collect	Data collecting software with user-selectable parameters for depth investigation, data quality, and density. Provides real-time monitoring of sensor conditions and a navigation assistant for vehicle trajectory visualization. Supports configurable connections with external devices like RTK GPS.
	Examiner Specialist	Post-process large 3D GPR projects for optimal results with the fastest GPR processing tool . Aimed at advanced data analysis with real-time processing during field data collection. Offers a range of processing tools and supports various import and export formats, including DXF, DWG, SEG-Y, and more. Can detect rebar, corrosion, delamination, voids, distress, moisture, layer thickness, cracks.
	Examiner Explore	A cloud-based application aimed at asset owners, maintenance organizations and users with little to no GPR knowledge for large projects. Visualize pavement thickness, cracking, distress, and void in maps. Automated analysis provides easy-to-understand information of asset conditions and suggests areas of interest for further deep dives. Sharing of information and reports enabling more informed, data-driven project decision-making, and optimize asset maintenance priorities.
IDS GeoRadar	uMap	Data collecting software. Automatic calibration for an easy and quick start-up. Visualization and storage of antenna array data set. Connection with NMEA positioning device.

		Multilanguage support. Metric and Imperial units.
	IQ maps	Post-processing software for advanced GPR data analysis. Software designed for stream series. Introduces real-time processing, and 3D visualization. User-friendly, supports large-area acquisitions, and ensures georeferenced data processing. Can detect rebar, corrosion, delamination, voids, distress, moisture, layer thickness, cracks.
	GRED HD	Basic post processing software Offers 2D and 3D visualization capabilities. Utility and anomaly detection. Manual and automatic layer insertion. Integration of core sample information. Designed to process data from Hi-Pave GPR systems, enhancing the interpretation of subsurface conditions. Can detect rebar, corrosion, delamination, voids, distress, moisture, layer thickness, cracks.
Impulse Radar	Talon 2	Data collecting software. Features a modern user-friendly interface optimized for Windows touchscreen devices. Tools for examining incoming position data. Visualization of receiver or sync cable statuses. Displays temperature and battery levels for the array.
	CONDOR	Post processing, visualization, and interpretation software for efficient management of Raptor 3D GPR array data. Focuses on handling large datasets without loss of resolution or detail. Preserves depth and position accuracy. Facilitates precise target picking and exports to CAD environments.

		Can detect rebar, corrosion, delamination, voids, distress, moisture, layer thickness, cracks.
MALA	MALA Controller	Easy-to-use acquisition software designed for GPR data collection on mobile devices. Supports integration with MALÅ Vision for data upload with markers and metadata. Allows instant sharing and presentation of data.
	MALA Vision Premium	Post processing software Cloud-based GPR software that facilitates visualization and presentation of GPR data in 2D and 3D. Users can switch between views while working on a project, with all processing done in the background. Allows continuous analysis and interpretation. Can detect rebar, corrosion, delamination, voids, distress, moisture, layer thickness, cracks.

These findings will allow the Receiving Agency to make informed decisions, adopt advanced technologies, and improve infrastructure assessment processes while addressing current and future challenges efficiently.

4. Preliminary Analysis and Review of Available GPR

Since TxDOT has expressed interest in implementing air-coupled GPR technology for pavement evaluation, the Performing Agency, as part of Task 5 through task 8, conducted a comprehensive review and analysis of commercially available, vehicle-mounted AC-GPR systems. This multi-phase effort focused on identifying systems capable of collecting data at highway speed without traffic disruption and lane closure and aligned with TxDOT's pavement evaluation needs. The review also examined technical specifications, data output formats, software compatibility, and field performance characteristics of the commercial AC-GPR systems. Table 8 presents four commercial GPR systems—GSSI RoadScan, Kontur AIR Sensors, IDS GeoRadar Hi-Pave, and ImpulseRadar Raptor—that utilize air-coupled antennas, enabling signal transmission without surface contact and allowing efficient operation at traffic speeds.

Table 8: Air-coupled, vehicle mounted Commercial GPR System

Company	GPR System	Possible Frequency (GHz)	Channel	Mounting Type	Coupling Type	Dimension Type
GSSI	RoadScan	1 GHz, 2 GHz	Up to 8 Channels	Vehicle Mount	Air Coupled	2D
Kontur	AIR Sensors	0.03 - 4.5 GHz	Up to 40 channels	Vehicle Mount	Air Coupled	3D
IDS GeoRadar	Hi-pave	1 GHz, 2 GHz	Up to 8 Channels	Vehicle Mount	Air Coupled	2D
Impulse Radar	Raptor 80	0.8 GHz	Up to 30 channels	Vehicle Mount	Air Coupled	3D

4.1. Detailed Review of Selected GPR System

This section provides a detailed review of four selected air-coupled, vehicle-mounted GPR systems evaluated for pavement applications. The systems—GSSI RoadScan, Kontur AIR Sensors, IDS RIS Hi-Pave, and ImpulseRadar Raptor-80—were selected based on their compatibility with TxDOT's pavement evaluation requirements. The review outlines key operational features, functional configurations, and application areas for each system, with a focus on how they support pavement evaluation objectives such as layer thickness measurement, structural condition assessment, and real-time quality control. The goal is to provide a clear understanding of the practical use cases, configurations, and overall suitability of each system for deployment in the context of TxDOT's infrastructure assessment needs.

4.1.1. GSSI - RoadScan

RoadScan is a versatile system designed for pavement thickness evaluations, featuring high-speed data collection with multi-channel capability, ideal for evaluating surface and near-surface layers. It operates with a 2 GHz frequency, providing cost-effective solutions for high-speed pavement evaluations. Figure 103: GSSI's RoadScan GPR system (www.geophysical.com)Figure 103 shows the GSSI's RoadScan GPR system.

Figure 103: GSSI's RoadScan GPR system (www.geophysical.com)

Key Features:

- **Possible Frequency:** 1 GHz or 2 GHz.
- **Multi-channel Capability:** Up to 8 channels.
- **Data Collection Speed**: Capable of collecting data at highway speeds, eliminating the need for lane closures.

Technical Specifications:

- **Antenna Type:** Air-coupled horn antenna.
- **Control Unit:** SIR-30 or SIR-4000 system (field-hardened, compact).
- **Integration:** Compatible with GPS and Distance Measuring Instruments (DMI) for precise geolocation.

Software:

- **SIR 30 Software:** For collecting GPR survey data.

- **RADAN 7 and RoadScan Module:** Post processing software. Automated peak picking for layer identification, semi-automated dielectric calibration, layer thickness tools.
- **Output Formats:** ASCII, CSV, Shapefiles, GeoTIFF.

Field Performance:

- Ideal for projects that require standard compliance (ASTM D4748, AASHTO R 37).
- Reliable for 3-layer systems: HMA surface, Base, Subgrade.
- FHWA studies often cite GSSI systems for reproducibility.
- Widely adopted in DOT projects.

Applications:

- Pavement thickness measurement.
- Base and sub-base condition evaluations.
- Overlay design, quality control.
- Penetration depth can drop in wet or highly conductive surfaces.

4.1.2. Kontur - AIR Series

Kontur air-launched GPR systems, such as AIR 1212 and AIR 1820, excel in high-speed pavement, airport, and railroad inspections. They feature a wide frequency range (30 MHz to 4500 MHz), multi-channel capabilities, and 3D imaging, with the added advantage of being able to collect data without disturbing traffic flow. The systems offer geospatial 3D data for a range of applications, including rapid landmine detection. Figure 104 shows the Kontūr's AIR sensors GPR system.

Figure 104: Kontūr’s AIR sensors (www.kontur.tech)

Key Features:

- **Possible Frequency:** 0.03 GHz – 4.5 GHz.
- **Multi-channel System:** Up to 40 channels.
- **Data Collection Speed**: Capable of collecting data at highway speeds, eliminating the need for lane closures.

Technical Specifications:

- **Antenna Frequency Range**: AIR Sensors
- **Control Unit:** Integrated high-speed acquisition unit with modular interface.
- **Integration:** Integrated RTK GPS & IMU for high-accuracy geospatial data.

Software:

- **Examiner Collect:** For collecting GPR survey data.
- **Examiner Specialist:** Post-process large 3D GPR projects for optimal results with the fastest GPR processing tool.
- **Examiner Collect:** Cloud-based tool providing automated, easy-to-understand GPR analysis for asset management and informed decision-making (ideal for users with limited GPR expertise).
- **Output Formats:** GIS (GeoJSON), CAD (DXF/DWG), SEG-Y, ASCII and Google Earth (KMZ).

Field Performance:

- Offers stable signal acquisition even on rough pavement.
- Excels in situations where high maneuverability or drone-mounting is needed.
- Antennas optimized for low drag and heat resilience.
- Designed to operate without disrupting high-traffic areas like airports or railroads.

Applications:

- Pavement layer mapping, thickness evaluation, void detection.
- Airport runway inspection, landmine detection.

4.1.3. IDS GeoRadar - RIS Hi-Pave

RIS Hi-Pave is known for its high resolution and multi-channel capabilities, the Hi-Pave is ideal for rapid pavement and road evaluations. This system operates efficiently in various infrastructure assessments, offering excellent resolution even at high speeds. Figure 105 shows the IDS GeoRadar’s RIS Hi-Pave GPR system.

Figure 105: IDS GeoRadar's RIS Hi-Pave (idsgeoradar.com)

Key Features:

- **Frequency Range:** 1 or 2 GHz.
- **Multi-channel System:** Up to 8 antennas.
- **Data Collection Speed**: Capable of collecting data at highway speeds, eliminating the need for lane closures.

Technical Specifications:

- **Antenna Type:** Air-coupled horn antennas.
- **Control Unit:** DAD MCh Fast Wave.
- **Integration:** Supports configurable connections with external devices like GPS, DMI. Synchronized radar and video data.

Software:

- **UMap:** For collecting GPR survey data.
- **GRED HD 3D:** Post processing software. Modeling of pavement structures, including automated layer detection, 3D visualization, subsurface analysis and dielectric profiling.
- **Output Formats:** Excel, ASCII, HDF5, jpg, bmp

Field Performance:

- Able to scan with excellent resolution even at high speeds.
- Excellent layer discrimination, suitable for 3D reconstruction of complex road profiles.
- Semi-automated layer recognition boosts productivity.
- Performs well in high-temperature environments.

Applications:

- Pavement thickness measurement; Surface, base and sub-base road course assessment.
- Airport runway condition assessment.

- Detection of cavities, voids and delamination, location of cracks and detection of wet areas.

4.1.4. ImpulseRadar – Raptor-80

Raptor-80 is a high-performance system designed for road and bridge assessment. It provides high-speed scanning, optimized for large-scale evaluations with a focus on deep subsurface investigation. The Raptor's 3D GPR capabilities make it a robust solution for thorough evaluations. Figure 106 shows the : ImpulseRadar's Raptor GPR System.

Figure 106: ImpulseRadar's Raptor GPR System (americas.impulseradargpr.com)

<u>Key Features:</u>

- **Possible Frequency:** 0.8 GHz.
- **Multi-channel System:** Up to 30 channels.
- **Data Collection Speed**: Capable of collecting data at highway speeds, eliminating the need for lane closures.

<u>Technical Specifications:</u>

- **Antenna Type:** Air-coupled Antenna.
- **Control Unit:** High-speed modular unit (USB/Ethernet), rugged IP67-rated enclosure.
- **Integration:** Supports configurable connections with external devices like GPS, DMI, encoder.

<u>Software:</u>

- **Talon 2:** For collecting data.

- **Condor:** Post processing software. Real-time preview, layer modeling, dielectric estimation, void analysis.
- **Output Formats:** ASCII, DXF, KML, CAD and KMZ.

<u>Field Performance:</u>

- Deeper penetration and high-speed scanning with full 3D capabilities.
- Reliable in large-scale highway and infrastructure projects.
- Agile platform, designed for vehicle mounting or UGVs.

<u>Applications:</u>

- Rapid post disaster road inspection.
- Pavement evaluation, airport and bridge deck delamination assessment.
- Efficient detection and mapping of underground utilities.
- Works well in combination with AI for automated report generation.

4.2. Significant Findings from the Review of Selected Air-Coupled GPR Systems

While each system reviewed in this section offers different configurations and functional capabilities, all four align with TxDOT's interest in high-speed, vehicle-mounted, air-coupled GPR for pavement evaluation.

GSSI RoadScan is widely used in DOT applications and demonstrates reliable performance in routine pavement thickness measurements and quality control, making it a strong option for standardized surveys. Kontur AIR Sensors offers a modular, lightweight high-resolution 3D GPR system with a wide frequency range, enabling flexible integration and targeted assessments, particularly useful in research-driven or complex pavement conditions. IDS GeoRadar RIS Hi-Pave supports high-speed, multi-lane data acquisition and includes semi-automatic layer detection tools, making it well-suited for extensive pavement evaluations across major roadway or runway networks. ImpulseRadar Raptor-80 utilizes ultra-wideband step-frequency technology with deep penetration and AI integration, making it applicable in both field evaluations and research settings where advanced diagnostic capabilities are needed.

As GPR technologies continue to advance, selecting the right system depends on specific operational requirement such as survey speed, data resolution, layer depth, software capabilities, and integration with GPS or positioning systems. Each platform brings a distinct balance of speed, flexibility, data density, and ease of integration, making them suitable for different scales and scopes of monitoring infrastructure. The following Table 9 provides an overview of key operational features and performance parameters across four leading GPR systems—GSSI RoadScan, Kontur Air Sensors, IDS RIS Hi-Pave, and ImpulseRadar Raptor-80— to support informed decision-making for both TxDOT applications and broader infrastructure assessment needs.

Table 9. Operational features and performance parameters of four selected GPR Systems

Evaluation Criteria		GSSI: RoadScan	Kontūr: AIR Sensors	IDS GeoRadar: RIS Hi-Pave	ImpulseRadar: Raptor-80
1	**Survey Speed (mph)**	60 (Max: 80)	60 (Max: 80)	70 (Max: 80)	45 (Max: 80)
2	**Number of Channels**	8	40	8	30
3	**Resolution (scans/sec)**	1,000	1,000	724	800
4	**Data Type (2D/3D)**	2D (3D Capable)	Full 3D	2D (3D Capable)	Full 3D
5	**Depth Range (ft)**	Medium (~3 ft)	Medium–Deep (3–4.5 ft)	Medium (~3 ft)	Medium–Deep (3–4.5 ft)
6	**Frequency Range (GHz)**	1–2 GHz	0.03–4.5 GHz	1–2 GHz	0.8 GHz
7	**Layer Detection Automation**	Semi-Automated	Semi-Automated	Semi-Automated	AI-Compatible
9	**3D Capability**	Limited	Yes	Limited	Yes
10	**Warranty Duration (Months)**	24	12	24	24
15	**Data Density**	Moderate	Moderate	High	Very High
17	**Lane Coverage (1 Pass)**	Single/Double	Single	Full Width (Multi)	Modular (1–2)
19	**Best Use Cases**	DOT Pavement, QA/QC	R&D, Airport, Railways, Highway	Road & Runway	R&D, Road & Bridge, Smart Infrastructure

5. Investigating Data Formats of the New Commercial GPR System for PaveCheck

As part of Task 6, the Performing Agency reviewed the data output formats of selected commercial air-coupled GPR systems to assess their compatibility with TxDOT's PaveCheck software. PaveCheck is a pavement analysis and decision-support tool developed for TxDOT that uses GPR and Falling Weight Deflectometer (FWD) data to estimate pavement layer thickness, backcalculate layer moduli, and support structural evaluation of pavement systems. As TxDOT explores the use of modern air-coupled GPR systems from multiple vendors, it is important to determine whether their data can be used directly in PaveCheck or require preprocessing.

The review also identified several data format requirements within PaveCheck that may affect integration, including the need for uniformly spaced scans, predefined file structures, and specific header formats. While some commercial systems provide export options that meet these needs, others may require format conversion or custom preprocessing to ensure compatibility. Recognizing these requirements early helps prevent data loss, reduce processing time, and support consistent, accurate pavement analysis within TxDOT's workflow.

5.1. Study of Import Files Used by PaveCheck

The Performing Agency studied the GPR data file used by PaveCheck to understand its structure and to evaluate whether data from commercial systems can be integrated into PaveCheck. PaveCheck uses a primary input file with the extension .DAT, which contains GPR radar data and header information collected from highway surveys. In addition to the .DAT file, PaveCheck also requires a metal plate file (.dat) for calibration, an image file (.IMG) for synchronized field visuals, and optionally a Falling Weight Deflectometer file (.FWD) when structural backcalculation is performed. All these files must be correctly formatted and correctly associated with the corresponding project to ensure successful analysis.

5.1.1. Study of Structure of .DAT GPR Radar File Used by PaveCheck

The .DAT GPR radar file used by PaveCheck consists of two main sections: a plain-text header and binary radar data as shown in Figure 107. The header includes metadata such as project details, lane number, GPS coordinates, equipment settings, and operator notes, which help contextualize the survey. The radar data is stored as a matrix where each column represents a radar scan (trace) and each row corresponds to a depth sample.

TTI GPR PAVEMENT TESTING SYSTEM HEADER FILE
Data acquisition software version : Ver:3.0
GPR data file folder and file name: c:\data files\00 pave a&d\2024-07-24
Field Test date and Time : 07-24-2024 12:31:53
Field Test Operator name : JPW
Field Test Comment : US0029 OSWP K6 EB from 1174 to 183
Data acquisition card resolusion : 16 bits
District and County of test field : Paris Hunt
Highway name : SH34
pavement type :
Testing lane : K1
Testing running number : Run-1
Testing direction : EB
Testing surface condition :
Testing start location :
Testing weather condition : Clear

	A	B	C	D	E	F	G	H	I
1	21588	1951	2052	2049	2049	2051	2050	2050	2048
2	11593	1951	2051	2052	2050	2049	2050	2048	2050
3	20551	1952	2050	2047	2051	2048	2049	2050	2046
4	2642	1954	2048	2048	2049	2050	2047	2048	2048
5	25942	1957	2049	2049	2050	2048	2050	2049	2048
6	28531	1961	2051	2048	2048	2048	2050	2049	2047
7	14958	1965	2050	2052	2051	2050	2051	2049	2051
8	22048	1970	2052	2051	2053	2050	2050	2051	2048
9	29285	1975	2051	2051	2054	2055	2051	2053	2051
10	13114	1980	2054	2055	2056	2054	2054	2053	2052
11	12334	1986	2055	2055	2056	2056	2057	2058	2054

Figure 107: Example of Structure of .DAT GPR radar file used by PaveCheck

5.1.2. Additional Information Related to GPR for Pavement Evaluation

5.1.2.1. Metal Plate Reflection Amplitude[33]

The metal plate reflection refers to the radar signal response obtained when a GPR antenna is positioned over a flat, metallic surface (typically an aluminum or steel plate). Since a metallic surface reflects 100% of the incident radar signal, this measurement serves as a reference amplitude for calibrating other reflection data. The amplitude of the reflection from pavement layers is compared with the metal plate reflection to estimate dielectric constants, which directly affect thickness estimations. Figure 110 shows the metal plate reflection test setup in the field and Figure 111 shows the typical metal plate reflection.

Procedure of Calculating Metal Plate Reflection

- The antenna is mounted at a height to be used for data collection (typically 10-14 inches).
- A large metal plate (typically 4 ft x 4 ft) is then placed at the surface directly below the antenna.
- The 100% reflection case is recorded by the data acquisition system.
- The maximum amplitude value collected is used for the calculation of dielectric constant.

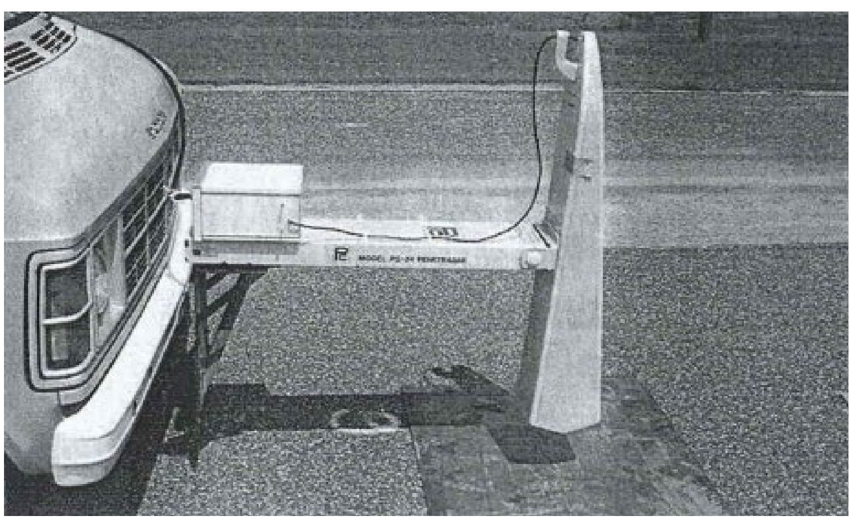


Figure 108: Metal plate reflection test setup[33]

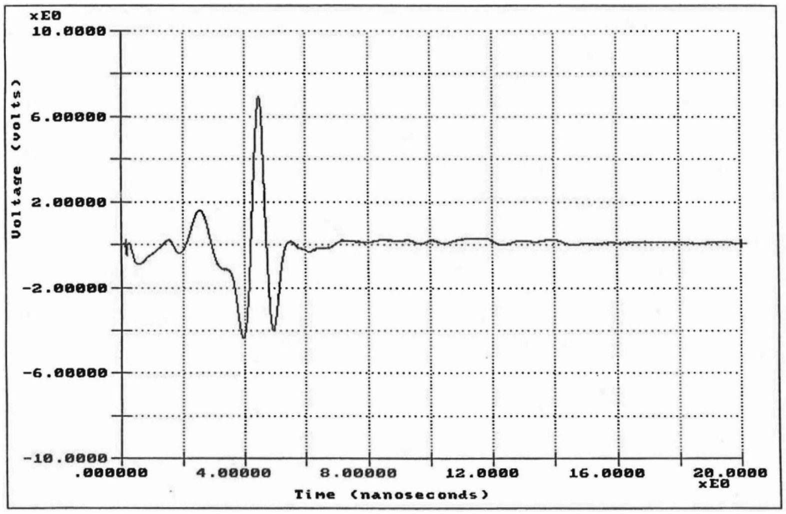


Figure 109: Typical Metal Plate Reflection[33]

5.1.2.2. End Reflection (System Noise)[33]

End reflection refers to the internal noise generated by the system, typically from the end of the antenna or waveguide, when the radar wave is not reflected back from the pavement but rather from the system's own components. Since system noise is superimposed on each waveform collected, it needs to be removed from the GPR data to ensure that the true subsurface signal is captured without interference from the system. Figure 112 shows the Typical end reflection generated by the GPR system.

Procedure for Measuring End Reflection

- The antenna is pointed toward the sky, away from the pavement and the signal data is collected.
- The captured signal will only contain internal system noise (not any real reflections).
- When collecting pavement data, the recorded end reflection signal is subtracted from each trace.

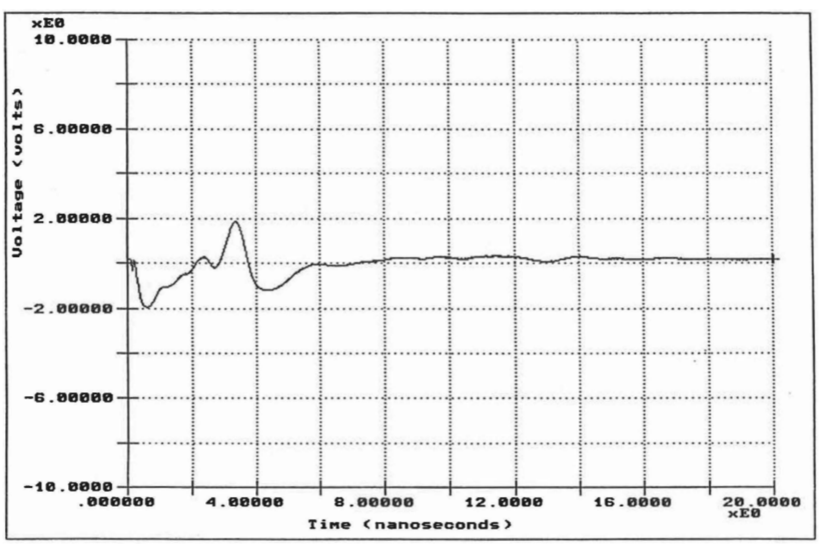


Figure 110: Typical end reflection[33]

5.1.2.3. GPR Velocity Factor (c) [33]

Velocity Factor represents the system-measured speed of the GPR wave in air, specifically in inches per nanosecond (ins/ns). The standard value for c is 5.9 inches per nanosecond (for two-way travel of the signal), but depending on system calibration, values from 5.1 to 5.2 ins/ns are common. C is used to calculate the thickness of layers of pavement or subsurface layers scanned by the GPR system.

Procedure for Measuring c

- Place a metal plate on top of a block of fixed height (h_1) (typically 12 inches).
- Record a GPR trace with the metal plate in place.
- Remove the block and place the metal plate directly on the ground.
- Take a second GPR trace with the metal plate resting on the ground.
- Identify the end reflection peak from both traces.
- The time difference between these reflections gives the time delay (Δt_1).
- The velocity of the wave is determined using the formula:

$$h_1 = \frac{c \times \Delta t_1}{\sqrt{\varepsilon_a}}$$

Where:

h_1 = Thickness of the top layer

c = Constant from time calibration procedure

Δt_1 = Time delay in the top layer

ε_a = Dielectric constant of the top asphalt layer (the dielectric constant of air is assumed to be 1)

5.2. Investigation of Selected commercial GPR System File Formats

The Performing Agency assessed the data formats used by selected commercially available GPR systems to determine whether the collected data can be directly integrated into PaveCheck. This evaluation included four commonly used air-coupled GPR systems: GSSI RoadScan, IDS GeoRadar Hi-Pave, ImpulseRadar Raptor, and Kontur AIR Sensors. Each of these systems generates data in its own proprietary format.

PaveCheck requires input data to be in a specific .DAT format, which includes both an ASCII header and binary waveform data. None of the reviewed GPR systems produce data in this format natively. As a result, none of the systems are directly compatible with PaveCheck, and each requires data to be processed or converted before it can be used in the software. Table 10 summarizes the file formats used by each vendor and notes the compatibility status with PaveCheck.

Table 10: GPR data file formats of selected commercial GPR system.

Company	File format	Compatible with PaveCheck	Comment
GSSI	.dzt	Not directly compatible; conversion might be possible using MATLAB, Python, or open-source tools, but this has not been fully verified.	Conversion is required to import into PaveCheck.
Kontur	.3dr	Not directly compatible; format conversion may be possible with vendor-supported workflows	Conversion is required to import into PaveCheck.
IDS GeoRadar	.gpr, .dtm	Not directly compatible; format conversion may be possible with vendor-supported workflows	Conversion is required to import into PaveCheck.
ImpulseRadar	.iprb	Not directly compatible; format conversion may be possible with vendor-supported workflows	Conversion is required to import into PaveCheck.

5.3. Significant Findings

The review of PaveCheck's data structure and the file formats of selected commercial GPR systems shows that direct compatibility is currently not available. Each system uses a proprietary format that differs from the standardized .DAT format required by PaveCheck. While file conversion or preprocessing may be feasible, additional steps are necessary to align external GPR data with PaveCheck's input requirements. In some cases, conversion might be possible using open-source tools such as MATLAB or Python scripts, but this has not been fully verified. Identifying these challenges and exploring potential solutions is crucial for ensuring the smooth integration of various GPR systems into TxDOT's pavement evaluation workflow.

6. Final Recommendation for New GPR System

The final recommendation provided in this section is based on the literature review, stakeholder feedback, system evaluations, and data format assessments conducted under Tasks 2 through 8 of TxDOT Project 0-7217. As TxDOT seeks to adopt a new AC-GPR system for pavement evaluation, four commercially available AC-GPR systems were studied in detail: GSSI RoadScan, Kontur AIR Sensors, IDS GeoRadar RIS Hi-Pave, and ImpulseRadar Raptor-80. All four systems meet the core criteria for high-speed, non-contact data collection and are aligned with TxDOT's pavement evaluation needs.

However, after careful consideration, the GSSI RoadScan GPR system appears to be the most suitable option for TxDOT's current pavement evaluation needs. The key reasons include: i) Widespread Use: GSSI RoadScan is already utilized by many U.S. DOTs for pavement evaluation, making it operationally familiar and easier to deploy within TxDOT districts. ii) PaveCheck Compatibility: Although not directly compatible, GSSI's GPR radar file format (.DZT) shows some potential for conversion to the .DAT format required by PaveCheck using tools such as MATLAB or Python scripts. While this approach has not been fully verified, it presents a possible path toward integration with TxDOT's existing workflow.

While GSSI RoadScan is recommended for TxDOT's immediate pavement evaluation needs due to its widespread adoption, all four evaluated systems—GSSI RoadScan, Kontur AIR Sensors, IDS GeoRadar RIS Hi-Pave, and ImpulseRadar Raptor-80—demonstrate strong technical capabilities and offer features that are highly valuable across a range of applications. Kontur AIR Sensors provides high-resolution 3D imaging and flexible sensor configurations that support research-driven assessments and specialized pavement investigations. IDS RIS Hi-Pave enables high-speed, multi-lane data acquisition and includes semi-automated layer interpretation, making it a strong candidate for comprehensive network-level surveys. ImpulseRadar Raptor-80 combines deep subsurface diagnostic capabilities with advanced antenna design and is well-suited for both field evaluation and academic collaboration. Although these advanced features are not immediate priorities for TxDOT's routine pavement surveys, the systems offer strong potential for future research pilots, targeted innovation projects, or phased adoption as TxDOT's technical capacity and operational objectives continue to evolve.

6.1. Hardware Recommendation

6.1.1. Antenna Selection

As of the 2002 regulatory update, new sales of 1 GHz horn antennas are restricted, and only pre-registered devices may continue to operate under legacy exemptions. Therefore, it is recommended that TxDOT utilize the GSSI 2 GHz air-coupled horn antenna, which is fully FCC-compliant and provides enhanced resolution capabilities.

6.1.2. Channel Configuration

GSSI RoadScan systems support both single-channel and multi-channel configurations. For routine pavement profiling, a single-channel setup with a 2 GHz horn antenna is typically sufficient. However, for applications requiring greater lateral coverage or enhanced resolution, a multi-channel configuration is strongly recommended.

6.1.3. Control Unit

For TxDOT's implementation, the GSSI SIR 30 control unit is recommended for its full compatibility with air-coupled RoadScan systems, high-speed data handling, and support for multi-antenna configurations. While GSSI's SIR 4000 is widely used in ground-coupled GPR applications, it is not compatible with the RoadScan air-coupled configuration.

6.1.4. Data Collection Mode

The GSSI RoadScan system offers flexible data collection modes —including distance-based, time-based, and point-triggered acquisition—allowing users to tailor data acquisition settings based on project objectives.

6.2. Software Recommendation

TxDOT intends to continue relying on its in-house PaveCheck software as the primary tool for pavement evaluation. However, the newly recommended commercial GSSI RoadScan system, which stores GPR data in proprietary formats (e.g., .DZT), is not directly compatible with PaveCheck. To enable seamless integration, this data must be properly converted into the PaveCheck-compatible .DAT format. This conversion process requires a clear understanding of both the commercial GPR data structure and PaveCheck's input data format to ensure accurate translation between systems. Once converted, the resulting output, particularly dielectric and thickness calculations, should be carefully verified to confirm the reliability and accuracy of the conversion process.

While PaveCheck continues to serve an important role in TxDOT's pavement analysis operations, survey feedback from district personnel indicated that the software is difficult to use, and is outdated in terms of interface design, format compatibility, and data processing flexibility. In light of these concerns, it is recommended that TxDOT support the development of a modernized version of PaveCheck—one that preserves its core analytical capabilities while introducing enhanced usability, streamlined workflows, and expanded compatibility with commercial data formats to better support current and future statewide GPR operations.

To proactively support this modernization, the Performing Agency has already developed a preliminary software tool capable of calculating dielectric constants and pavement layer thickness, similar to the existing PaveCheck software. Initial results from this tool have shown strong alignment with PaveCheck outputs, indicating that it may serve as a solid foundation for a next-generation GPR analysis platform. Additionally, the Performing Agency has developed a preliminary data conversion module that transforms commercial GPR data into the PaveCheck-compatible import format, enabling integration with existing TxDOT workflows. To fully validate and refine the new software, the following steps are recommended:

- Fully understand the commercial GPR data structure and PaveCheck import format to guide accurate data conversion.
- Use metal plate calibration to ensure the accuracy of constant dielectric measurements and to correct any systematic errors in the GPR system
- Verify the data conversion process by comparing A-scan and B-scan plots from raw and converted datasets.
- Cross-verify dielectric and thickness calculations between the new software and PaveCheck using identical datasets.
- Conduct laboratory testing using asphalt cores to validate dielectric and thickness outputs from the new software.
- Perform field validation by comparing new software results with thickness measurements from core samples.
- Compare output from the new software and PaveCheck using data from TxDOT’s current GPR system on the same roadway sections.
- Compare output from the new software using data from both TxDOT’s current GPR system and the new commercial GPR system on the same roadway sections.

This staged validation process will not only ensure analytical reliability but also demonstrate the new software’s readiness for broader deployment—positioning TxDOT to upgrade its data analysis capability and potentially support future research and system integration projects.

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APPENDIX A

A1. Results of Survey of TxDOT Districts

1. To what extent is Air-Coupled Ground Penetrating Radar (AC-GPR) incorporated into the district's decision-making process regarding pavement evaluation?

Brownwood: Regularly used.

Atlanta: Occasionally used (project-specific).

Wichita Falls: Occasionally used (project-specific).

El Paso: Standard part for routine pavement design/maintenance process.

Pharr: Standard part for routine pavement design/maintenance process.

San Angelo: Not used.

Abilene: Occasionally used (project-specific).

Fort Worth**:** Standard part for routine pavement design/maintenance process.

Paris: Not used.

2. How is AC-GPR data collected in your district? (Select all that apply)

Brownwood: Division provided support; Consultant or IAC contract.

Atlanta: Division provided support.

Wichita Falls: Division provided support.

El Paso: District operated equipment.

Pharr: Division provided support.

San Angelo: N/A

Abilene: Division provided support.

Fort Worth: District operated equipment.

Paris: N/A

3. If selected "other" for #2 - please specify below:

All districts: N/A

4. What are the primary uses of AC-GPR data in your district? (Select all that apply)

Brownwood: Pavement design; Maintenance and Rehabilitation; Other.

Atlanta: Pavement design; Maintenance and Rehabilitation.

Wichita Falls: Pavement design; Maintenance and Rehabilitation.

El Paso: Pavement design; Maintenance and Rehabilitation.

Pharr: Pavement design.

San Angelo: N/A

Abilene: Maintenance and Rehabilitation; Other.

Fort Worth: Pavement design; Maintenance and Rehabilitation.

Paris: N/A

5. If selected "other" for #4 - please specify below:

Brownwood: GPR is also used for determining existing pavement thickness for milled-in rumble strip projects for safety.

Atlanta: N/A

Wichita Falls: N/A

El Paso: N/A

Pharr: N/A

San Angelo: N/A

Abilene: Forensic studies

Fort Worth: N/A

Paris: N/A

6. When AC-GPR is used, are other test methods commonly used alongside it? If so, which ones? (Select all that apply)

Brownwood: Falling Weight Deflectometer (FWD); Core sampling; Dynamic Cone Penetrometer (DCP).

Atlanta: Falling Weight Deflectometer (FWD); Dynamic Cone Penetrometer (DCP); Core sampling; Ground-couple GPR.

Wichita Falls: Falling Weight Deflectometer (FWD); Dynamic Cone Penetrometer (DCP); Core sampling.

El Paso: Falling Weight Deflectometer (FWD); Dynamic Cone Penetrometer (DCP).

Pharr: Falling Weight Deflectometer (FWD), Core sampling.

San Angelo: N/A

Abilene: Falling Weight Deflectometer (FWD); Core sampling.

Fort Worth: Falling Weight Deflectometer (FWD); Dynamic Cone Penetrometer (DCP); Core sampling.

Paris: N/A

7. If selected "other" for #6 - please specify below:

All districts: N/A

8. How many personnel in your District are trained in interpreting AC-GPR data using TxDOT's GPR analysis software (PaveCheck)?

Brownwood: None

Atlanta: 1–2

Wichita Falls: 1–2

El Paso: 1–2

Pharr: 1–2

San Angelo: N/A

Abilene: None

Fort Worth: 3–5

Paris: N/A

9. How would you rate the usability of PaveCheck?

Brownwood: Not familiar / not used

Atlanta: Very difficult

Wichita Falls: Difficult

El Paso: Neutral

Pharr: Difficult

San Angelo: N/A

Abilene: Not familiar / not used

Fort Worth: Neutral

Paris: N/A

10. If your district does not use AC-GPR, what alternative methods are used for layer thickness and subsurface evaluation?

Brownwood: N/A

Atlanta: N/A

Wichita Falls: N/A

El Paso: N/A

Pharr: We use GPR but we also core at times or drill as needed.

San Angelo: Traditional GPR

Abilene: N/A

Fort Worth: N/A

Paris: GPR, pavement cores, soil boring data

11. What are the main barriers to using AC-GPR more effectively in your district? (Select all that apply)

Brownwood: Lack of trained personnel; Time constraints.

Atlanta: Data interpretation complexity; Time constraints

Wichita Falls: Limited equipment availability; Lack of trained personnel; Time constraints; Data interpretation complexity

El Paso: Limited equipment availability.

Pharr: Limited equipment availability.

San Angelo: Limited equipment availability; Lack of trained personnel.

Abilene: Limited equipment availability; Lack of trained personnel, Data interpretation complexity

Fort Worth: N/A

Paris: Lack of trained personnel.

12. If selected "other" for #11 - please specify below:

All districts: N/A

13. Do you anticipate AC-GPR playing a larger role in your district's decision-making in the next 3–5 years?

Brownwood: Yes

Atlanta: Yes

Wichita Falls: Yes

El Paso: Yes

Pharr: Yes

San Angelo: Uncertain

Abilene: Uncertain

Fort Worth: Yes

Paris: Uncertain

14. If selected "other" for #13 - please specify below:

All districts: N/A

15. What support would help your district the most to better utilize AC-GPR? (Rank top 2)

Brownwood: Training on data interpretation (PaveCheck), Better guidance documents.

Atlanta: Increased access to equipment; Training on data interpretation (PaveCheck).

Wichita Falls: Training on data interpretation (PaveCheck); Better guidance documents.

El Paso: Increased access to equipment; Training on data interpretation (PaveCheck).

Pharr: Training on data interpretation (PaveCheck); Increased access to equipment.

San Angelo: Increased access to equipment; Other.

Abilene: Training on data interpretation (PaveCheck); Better guidance documents.

Fort Worth: Training on data interpretation (PaveCheck); Better guidance documents.

Paris: Increased access to equipment; Training on data interpretation (PaveCheck).

16. If selected "other" for #15 - please specify below:

Brownwood: N/A

Atlanta:N/A

Wichita Falls: N/A

El Paso: N/A

Pharr: N/A

San Angelo: All of the above. Not at all familiar with AC-GPR.

Abilene: N/A

Fort Worth: N/A

Paris: N/A

17. Do you have experience using other AC-GPR units and/or data other than our system?

All districts: N/A

18. If selected "Yes" for #17, please specify below:

All districts: N/A

19. How did the other GPR system(s) perform relative to ours?

All districts: N/A

20. Please share any examples where AC-GPR data significantly helped a project.

Brownwood: We have used GPR in the past for layer thickness. We have experienced issues where the water table in the area has affected the scans. But on SH 155, it was just utilized to see overall bituminous thickness for more than one project on the corridor. We do appreciate the technology, but we know that we require assistance to be confident in the conclusions.

Atlanta: N/A

Wichita Falls: N/A

El Paso: Pavement structure check, identifying moisture-related issues.

Pharr: We need to work on MODULUS software to get the modulus which we use in FPS21.

San Angelo: Don't know

Abilene: N/A

Fort Worth: Pavement structure check, identifying moisture-related issues.

Paris: N/A