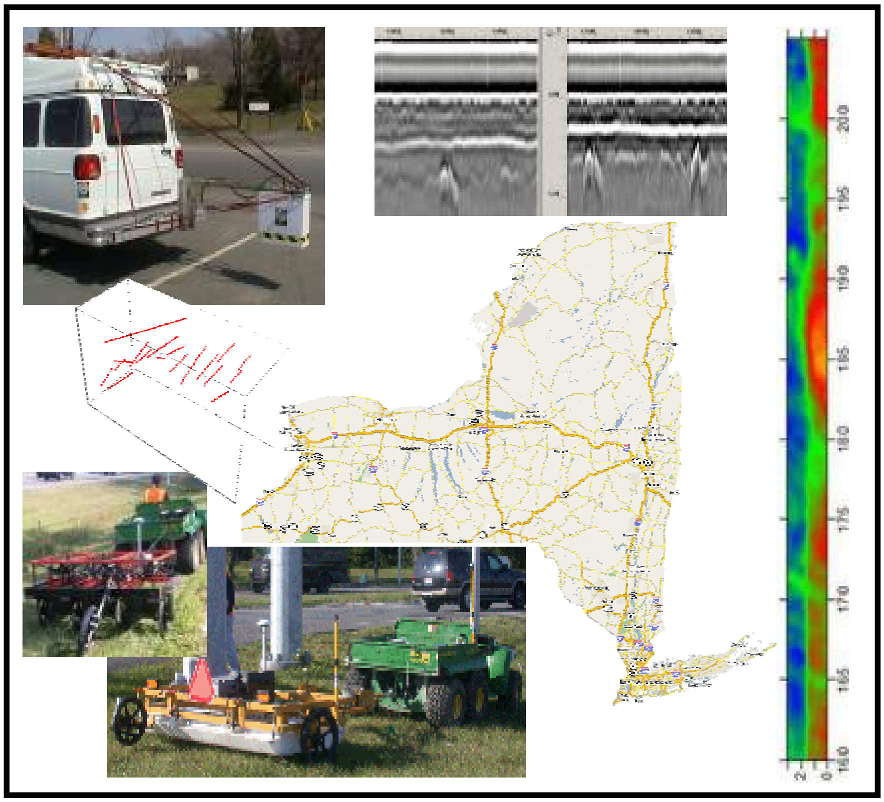
New York State Department of Transportation

NYSERDA TIRC Project C-04-04
"Applications of Ground Penetrating Radar for Highway Pavements"



Final Report

Submitted by

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Project funded in part with funds from the Federal Highway Administration.

16. Abstract
The research project objective was to develop an implementation strategy for the use of Ground Penetrating Radar (GPR) technology to address pavement systems and underground utilities. The project was divided into three tasks. Task 1 dealt with a review in the state-of-the-art in technology, relevant applications, and regulations in the use of GPR. Task 2 discussed the effort and results of GPR survey projects on pavements systems and underground utilities that were performed as part of this project in selected locations. Task 3 developed an implementation strategy for NYSDOT for defining and procuring GPR services in addressing problems in pavement systems and mapping & locating underground utilities.

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PROJECT TEAM MEMBERS

The Institute for Infrastructure Asset Management (IIAM) provides applied research, consulting, and educational services to help promote better management of engineering assets and the physical infrastructure. IIAM is the lead organization of this project.

Geophysical Survey Systems, Inc. (GSSI) is the manufacturer of GPR equipment used in this project.

GEO*Vision's* expertise includes specialized transportation GPR services.

Roadscanners Oy is a software development firm for GPR applications.

Spectra Engineering, Architecture and Surveying, P.C. is a service-providing firm.

Underground Imaging Technologies is a technology integration and service-providing firm in the field of underground imaging.

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1.0 EXECUTIVE SUMMARY

1.1 Project Objectives/Goals

The overall objective of this project is to develop an implementation strategy and work plan for the use of Ground Penetrating Radar (GPR) by the New York State Department of Transportation (NYSDOT). Of primary interest to NYSDOT are applications of GPR to address the needs of (a) pavement systems at the project and network levels, and (b) underground utilities.

Specific tasks of this project are as follows:

> **Task 1**: synthesis of the state-of-the-art in GPR technology, areas of applications, and case studies;
>
> **Task 2**: demonstration of GPR technology in applications to pavement systems and underground utilities; and
>
> **Task 3**: development of an implementation strategy and work plan for NYSDOT on the utilization of GPR services in these application areas.

1.2 Project Rationale: What Can GPR Achieve and Why Are These Goals Important?

NYSDOT identified a need to collect pavement thickness, materials, and subgrade condition data for the analysis of the impact of Superloads on NYS Corridors in a more reliable, consistent and efficient manner. To date, obtaining this information in a systematic and timely fashion – from individual Regions and their network and project-level files – has proven to be difficult, and in some instances, not possible at all to produce accurate condition assessment data.

Among the technologies available today, Ground Penetrating Radar (GPR) has been proven to be a valuable tool for such applications. GPR is a Non-Destructive Testing (NDT) imaging method used to obtain data from pavement structures for (1) determining thicknesses, (2) locating voids and/or other pavement defects, and (3) indicating relative changes in moisture content of subsurface pavement materials.

The multiple advantages of using GPR to assess pavement conditions include the ability to collect potentially tens or hundreds of miles of data per day with

- little or no need for maintenance and protection of traffic,
- minimal requirement for coring and laboratory testing, and
- the capability to provide a continuous subsurface profile of pavement layer structure and condition.

Other potential GPR applications for highway pavements include the following:

At the Project Level - GPR can be used for assessment of pavement uniformity; detection of anomalies; and determination of thickness and condition of asphalt and concrete pavements, both sub base and sub grade. GPR is used as an effective reconnaissance or detailed investigative tool for pavement rehabilitation studies, load transfer evaluation, and identification and location of shallow underground utilities or other buried structures.

1. High-speed Applications: In conjunction with Falling Weight Deflectometer (FWD) testing, use of GPR data (rather than interpolated data from sparsely-spaced cores) enables engineers to achieve a more reliable back calculated resilient modulus of pavement structures because of a better-determined layer thickness. Pavement condition assessment, relative moisture content of base layers, and pavement system uniformity are also capabilities of high-speed, non-contact pavement GPR investigations.

2. Low-speed Applications: Special applications (void detection, sub grade condition assessment, etc.) requiring deeper penetration (greater than 2 to 3 feet) typically utilize lane closures or limited traffic control, such as a moving closure with a chase vehicle (attenuator truck), as well as the use of ground-coupled (lower frequency) antennas. More detailed investigations of pavement systems within lane closures – such as individual pavement slabs or joints – can be performed under these conditions, and using high-resolution and/or deeper penetrating antennas in order to better assess specific suspected, or known, problems.

At the Network Level - GPR can be used to determine pavement layer thicknesses and pavement conditions for the entire network and provide valuable information about the existence of previously unknown or undocumented pavement structures, layers, and/or repairs. GPR can provide critical information for resource decisions to be made more efficiently and effectively as part of a methodological approach toward prioritizing and allocating funding for annual pavement construction, rehabilitation and maintenance projects.

For Utility Location and Mapping - The Department has had considerable experience with underground utility conflicts, each with tremendous potential for catastrophe, during construction and related activities. GPR has been used successfully with other technologies to identify and locate utilities—often previously unknown—prior to excavation, coring, or boring activities. Yet its full potential for augmenting subsurface utility-mapping had not been adequately researched, demonstrated, or determined. Part of this limitation has been due to the overwhelming use of single-channel GPR systems, as well as highly variable training and expertise in its use on an ad-hoc basis.

1) Over the past several years, significant technological progress has been made both in the hardware and software imaging systems dedicated to simplifying utility-detection, particularly multi-channel 3D imaging and mapping systems integrating GPR with complementary technologies and survey-grade GPS. These systems are capable of collecting larger areas of data more efficiently and more accurately demonstrating the results. These collective technological changes are redefining the state-of-the-art and practice of GPR technology.

2) The ability to rapidly and accurately map large subsurface areas for the purpose of identified underground utilities – whether beneath existing pavements or in parking areas, open fields, or highway right-of-way – allows GPR to now be utilized in a new way: as a planning or design-level tool which can be used as a complement to subsurface utility engineering (SUE) activities prior to construction or rehabilitation.

1.3 Applied Methods, Deployment of Systems and Use of Software to Achieve Project Goals

1.3.1 Survey Design, Data Collection, Interpretation and Analysis.

The research team collected GPR data for determining pavement thickness and pavement conditions at three project sites selected by the Department in Regions 1 and 2, as well as highway subsurface exploration at two project sites selected by the Department in Region 1 and Region 8. Data were analyzed to determine thicknesses, uniformity, anomalies, joint deterioration, underground utilities location, etc., and to generate information that could be either calibrated or validated using coring and other available in-situ data provided by the Department.

Each of these individual project sites was assessed using GPR as briefly described below, with complete reports of each specific project's specific constraints and scope of work defined in greater detail in the report:

A. Pavement thickness on I87, Northway (Region 1) – Determine HMAP overlay thickness, pavement condition and subgrade variability, and assess the ability to identify pavement joint problems as well as other anomalies using high-speed GPR equipment.

B. Sub base and joint condition on I890, Schenectady (Region 1) – Determine ability to assess pavement joint condition, as well as identify subgrade anomalies and moisture variation that could be contributing to existing problems

C. Load transfer evaluation and subgrade condition on Road 12/I790, Utica (Region 2) – Similar to I-890; determine ability of GPR to provide condition assessment of joints and possible subgrade conditions contributing to known joint (and slab) problems.

D. Subsurface utility investigation and mapping on Everett Road/Atrium Drive intersection, Colonie (Region 1) – Determine ability of GPR to be used to locate and identify (map) buried underground utilities, known and unknown.

E. Utility mapping on Route 4/Moon Street intersection, Ft. Edward (Region 8) – Determine ability of GPR to be used to locate and identify (map) buried underground utilities, known and unknown; same process, equipment and imaging/interpretation software as used for previous site.

1.3.2 Development of Implementation Strategy, Sample Contract and Work Plans

Last, the GPR Synthesis generated at the outset of the project (Task 1) and the results from the data collection/analysis (Task 2) were taken into account – along with stated NYSDOT objectives and a working knowledge of both the technology and barriers preventing its implementation at a level consistent with its capabilities – to define the critical elements of an implementation strategy, formulate the basis for a work plan, and provide a sample contract for equipment procurement and services. This final portion of the project (Task 3) is described in greater detail following the findings from Task 2, described immediately below.

1.4 Results of Task 2 (Data Collection and Analysis) Effort: Pavements and Utility-Mapping

1.4.1 High-Speed Pavement GPR Applications

Project and network level applications related to each of the findings below need to be developed to address specific NYSDOT needs. At the network level, a consistent approach to standardizing data collection, interpretation and analysis outputs must be developed with some forethought on extracting appropriate decision-making and prioritization data. At the project level, design-level considerations that can be impacted using available GPR data in a useful format for design engineers need to be defined, communicated, and developed on a case-by-case basis. Templates for various classes of problems where GPR can be used effectively ought to be defined with an appropriate scope of work as a "starting point".

A. I87 Northway – Succeeded in accurately determining HMAP overlay thickness, thickness variation, and identification of original reinforced concrete pavement (RCP) construction design as well as subsequent changes related to rehabilitation, improvements and/or spot-repairs.

B. Route 12, Utica – Bare PCC and RCP system (no HMA overlay, but evidence of different concrete slab design along different segments of the surveyed roadway), with slab length typically shorter than I87: Succeeded in establishing direct correlation between visible surface damage (severe transverse cracking and slab faulting, joint cracking and failure, etc.) and subsurface GPR anomalies consistent with pavement damage either (a) at the pavement bottom, (b) between the surface and reinforcement, or (c) both.

C. I890, Schenectady – Bare PCC and RCP system (no HMA overlay, but evidence of different concrete slab design along different segments of the surveyed roadway), with slab length typically shorter than I87 pavement: Similar results as Route 12 pavement; however, GPR/video/GPS were collected at night-time and in mid-winter (between Christmas and New Year's, during a period of severely cold weather that had prevailed for some time). The likely full-depth freezing of the pavement and base limited the ability of calculated dielectric (base/subgrade) to be used in any advantageous manner for correlation to pavement/joint condition.

1.4.2 Low-Speed Pavement GPR Applications

A. Route 12, Utica – A small ground-coupled GPR assessment (400 MHz antenna) was used to investigate the causes of a slab/joint failure on two adjoining slabs, on the nearby service road. The data shows features that indicate the presence of voids below the concrete slabs. Penetration to depths greater than 5 ft. was not possible to the clay content of the soil, as a result, a suspected failed storm sewer could not be confirmed as to the cause of the slab/joint failure.

C. I890, Schenectady – A slow-speed ground-coupled GPR survey was conducted using a 200MHz antenna, along a short stretch of shoulder and the travel lane of I890 near the Michigan Avenue exit, for the purpose of identifying subsurface cavities, voids and potential "sinkhole" formation…as well as to identify or confirm the location of old pavement infrastructure that could be contributing to known problems. These features were seen and identified in the data. Severe subsurface features, such as large voids, were also identified.

1.4.3 Utility-Mapping

Utility-mapping at both the Everett Road/Atrium Drive (Colonie) and Route 4/Moon Street (Ft. Edward) sites was successful in that GPR was able to (a) identify buried utility infrastructure both at previously known and unknown locations, (b) successfully cover the entire pavement intersection at both sites in relatively short period of time, and (c) achieve superior 3D image quality because of the multi-channel (array system) GPR/GPS capability that is not available in typical single-channel and even two-channel GPR systems. Furthermore, both sites were compared against Department CAD maps as well as subsurface utility engineering (SUE) information generated ahead of the GPR surveys – with the SUE data used as one means to successfully verify the GPR interpretations (maps) and validate the GPR results. On both test sites, GPR demonstrated a capability to be used as a planning or design-level tool to augment SUE activities.

1.5 Implementation Strategy and Elements of Work Plan and Sample Contract

Task 3 of the project involved the development of (1) an Implementation Strategy for NYSDOT to integrate GPR technology into the decision-making process, (2) a work plan for Network Level Pavement Applications and Subsurface Utility Mapping, and (3) a Sample Contract for NYSDOT to utilize in engaging GPR services.

Each of these efforts is described in detail within the report and will not be repeated here except to the extent that the three products of this task have been comprehensively reviewed and evaluated and represent an effort to address all of the elements necessary to initiate and internalize critical GPR information throughout the NYSDOT decision-making process.

A significant effort has been made with each of these products to be innovative in addressing the data needs for decision-making. To that end, the Implementation Strategy includes a comprehensive matrix related to equipment selection and cost, training and certification of both NYSDOT and service providers personnel, and specific recommendations on equipment procurement should the NYSDOT decide to pursue data collection without the use of consultants.

The work plan for Network Level Applications and Sub Surface Utility Mapping recommends for the development of a new and enhanced Pavement Condition Index to include the integration of a GPR Subsurface Index to better represent both the surface and sub surface conditions of a pavement. Using such an index will give better confidence to resource allocation decisions.

Among the routine elements of the contract process, the Sample Contract for GPR services describes specifically the responsibilities of the state and the contractor in pre and post GPR service work. Of particular importance is that the contractor will be responsible to provide expert testimony on behalf of the state in the event of any litigation.

2.0 INTRODUCTION

The present report summaries the New York State Energy Research and Development Authority (NYSERDA) Transportation Infrastructure Research Consortium (TIRC) Project C-04-04 entitled *Applications of Ground Penetrating Radar for Highway Pavements* that is sponsored by the New York State Department of Transportation (NYSDOT). The mission of the project is to demonstrate the use of ground penetrating radar (GPR) technology and how it can benefit the needs of NYSDOT in assessing pavement systems and subsurface utilities.

The research project is directed by Dr. Dimitri A. Grivas, Executive Director of the Institute for Infrastructure Asset Management (IIAM), with the support of: Geophysical Survey Systems, Inc. (GSSI), GEOVision Geophysical Services (GEOVision), Roadscanners Oy (Roadscanners), Spectra Engineering, Architecture and Surveying, P.C. (Spectra) and Underground Imaging Technologies, LLC (UIT).

The project is divided into three tasks that are:

1. Review the state-of-the-art in GPR technology and its applications in pavement systems and subsurface utilities.
2. Demonstrate GPR applications on a number of test sites.
3. Develop an implementation plan for addressing NYSDOT's needs in assessing and managing pavement systems and subsurface utilities.

Each task has its own report where more information of a topic can be found. Please contact the New York State Department of Transportation for more information.

3.0 GPR TECHNOLOGY AND EQUIPMENT

GPR is a nondestructive geophysical method that produces graphical images of features inside engineering structures and below the surface of the ground. In addition to rapidly assessing subsurface features, probing with GPR generates waveforms that lead to important information and analytical measurements needed to qualify subsurface features.

Fig. 1. Selection of GSSI Equipment

GPR operates by transmitting pulses of ultra high frequency radio waves into the ground through a transducer (antenna). Some of the transmitted energy is reflected back to the antenna from various buried objects or distinct contrasts between different earth materials. The ground penetrating radar antenna, usually pulled along the ground by hand, or mounted in front or behind a vehicle, typically transmits and receives the GPR waves and this information is sent to the data acquisition unit where it is measured and stored. Software tools used by data interpreters aid in processing and interpreting this data to generate useful information for designers and engineers.

GPR systems come in a range of configurations and capabilities that can be matched to a range of applications. Depth of penetration, image resolution, and data collection rate are the factors to consider in choosing a system. The range of products begins at a traditional system consisting of a single antenna with specific capabilities to the latest system that has an array of antennas that cover a broad range of capabilities.

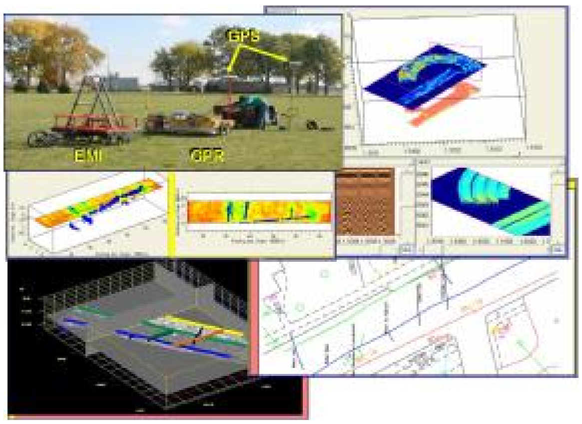

Fig. 2. UIT System for Subsurface investigation that includes integrated hardware and software Tools

In addition to GPR, modern systems have been integrated with other non-destructive techniques that complement GPR and tools to increase the accuracy of position. Other non-destructive techniques include Falling Weight Deflectometer (FWD) and Electromagnetic Induction (EMI). Position accuracy equipment includes the latest in GPS systems and video systems.

Fig. 3. JILS System with FWD, GPR and GPS

The software tools have also been improved to include enhanced data processing and interpretation algorithms as well as other data collected by other methods (GPS, video, core samples, etc.) to form a more complete data description of the subsurface.

4.0 PROJECT AND NETWORK LEVEL APPLICATIONS FOR HIGHWAY PAVEMENTS

Generally, a pavement investigation using GPR is performed in single or multiple passes, each pass with (a) one sensor along the lane centerline; (b) two sensors with one on each wheel path; or (c) some other configuration that is designed around a specific application requirement.

Project-level pavement investigations using GPR can help identify and quantify the thickness or presence of asphalt or concrete; thickness of the aggregate base layer(s) and subgrade; indications of asphalt-stripping; zones containing excess moisture; or areas containing voids in the natural geology beneath the pavement system. Application-oriented GPR surveys, performed on a section of pavement where specific problems are known to exist are often designed in conjunction with field investigations that include both observation and coring. This type of project level GPR investigation is typically performed, with high GPR scan density along each antenna survey path and also close line spacing between adjacent GPR scan paths in order to provide information precise enough to help make design, maintenance or rehabilitation decisions.[1]

Fig. 4. Vehicle Equipped for Performing High-Speed GPR Surveys. Equipment Includes Air-Horn GPR Antennas (Bottom Right), GPS, Video, and Positioning Laser (Bottom Left)

An investigation can be conducted on a network level to aid decision makers in allocating resources, prioritizing activities, cataloguing and identifying known and unknown pavements, qualitatively inventorying past maintenance history based on prominent GPR evidence of past subsurface activities.[2, 3]

4.1 Pavement Layer Thickness

GPR can be used to provide complete project or network coverage of a pavement system so that the most suitable locations for testing, sampling, and/or remediation can be determined. The same data are used for assessing pavement thickness uniformity, and identifying pavement structure. Though GPR can be used to measure both HMA (hot-mix asphalt) and Portland cement concrete (PCC) pavement thickness, its strength lies primarily in its use with HMA pavements. HMA is an electrically resistive material through which GPR readily penetrates. PCC pavements and structures can be good GPR media when fully-cured to complete maturity. PCC can also be poor GPR media when the concrete is immature with remaining alkaline material in solution or when it has been severely deteriorated by corrosion or impregnated with road salts or other conductive materials. The presence of conductive materials within the medium limits penetration of GPR waves.

4.2 Air Void Content, Segregation, Stripping, Pavement Uniformity

GPR has been used successfully in Europe and in Texas to measure air void content in new flexible pavements[4, 5] and to determine relative moisture content in base and subgrade materials.

Pavement homogeneity (or degree of heterogeneity) can be assessed by investigating the internal consistency of a pavement layer structure with GPR. Interpretation of GPR data can produce estimates of segregation, void formation, and stripping as well as degree of overall uniformity. Baseline condition assessments (on new pavements or as a starting point on existing pavements) are strongly recommended. Degree of uniformity can be marked at an initial point in time for comparison with subsequent assessments to determine where changes in uniformity are occurring over time. GPR has proven to be one of the most beneficial tools used by the Finnish Road Administration to investigate pavement systems from the time they are built (QC/QA) through various stages of preventive maintenance and design for rehabilitation, repair and replacement.

GPR has been extensively demonstrated, verified and validated, both in Europe and Texas, to be just as effective and reliable at measuring air void content in new pavements – the most important compaction parameter used to determine whether HMA pavements will perform properly – as the currently specified standard.

Several studies conducted in 2001 on various U.S. Highways are referenced, each proving GPR to be a much more objective and reliable tool than infrared thermography or nuclear density gauges for determining overall degree and extent of asphalt segregation, variations in asphalt quality and density (compaction) changes. However, as with so many other areas where GPR technology is applicable, it is most effective when employed as a primary nondestructive investigation tool – used to guide discrete sampling, testing or other localized assessments at anomalous, or representative, locations within the pavement.

GPR has the ability to indicate the presence of "asphalt stripping," which is moisture, heat or aggregate-related damage within HMA layers, before it manifests itself as surface damage[6]. Any early detection of moisture content variation within the pavement overlay system or segregation and variability (void formation) within the pavement layers allows for increased salvage value of the pavement layer, reducing immediate and future rehabilitation and overall life-cycle costs, while helping to maximize remaining service life.[7, 8, 9]

Studies have shown that a GPR pavement condition index can be successfully developed as part of a semi-automated analysis of GPR data collected over pavement systems. Pavements with varying degrees of stripping of the HMA layers can be graded and that information provided can be effectively used to guide additional investigations or aid in decision-making with regard to how a pavement will be considered for treatment during design-related activities.

A GPR survey performed in 1999 on an in-service PCC pavement system in Kentucky successfully identified locations where concrete variability (segregation and voiding) and uniformity could be determined and mapped. The maps guided extraction of cores at suspect locations on an adjacent pavement lane following a carefully controlled investigation (calibration) within an area known to have similar problems. The cores were visually examined for evidence of segregation and voiding and then tested for compressive strength variation. The study ranked various segments of the pavement based on measured GPR signal response versus measured compressive strength. A good correlation between core data and variations predicted by the GPR maps was obtained[10].

4.3 Additional Uses of GPR for Solving Pavement Problems

Other than the GPR investigations that have already been mentioned, the technology can be applied to a wide range of applications with importance to DOT's and DPW's, such as searching for sinkholes beneath existing pavements; detecting new and old utility lines that may be leaking and causing washouts, piping, or formation of zones of voided material; or determining the effectiveness of geocomposite membrane construction by evaluating soil moisture and segregation characteristics where they have been placed, or measuring placement of dowels and tie bars in PCC pavement joints after installation or construction.

5.0 HIGHWAY SUBSURFACE UTILITY EXPLORATION

Fig. 5. Presentation by TBE on the Role GPR Performs in Their SUE Services

GPR has been used for many years to detect and locate underground utilities, buried drums, sewers, and other subsurface objects, often beneath existing pavements, sidewalks, or highway right-of-ways. Though other methods exist for marking surface locations of utilities, no other technology can accurately place utility position and depth within inches of its actual location without any connection to the utility. It also has the capability to locate and position non-conductive, non-metallic materials (PVC, asbestos, clay pipe) used for subsurface utility collection and distribution lines. It can also identify trenches because of the signal response difference that exists between undisturbed earth, native backfill, and engineered (granular) backfill.

Public agencies, private industries, government, the public and others benefit from the use of GPR technology in pursuing damage prevention. Accurately mapping utilities ahead of highway construction can greatly assist in significantly reducing damage to utilities by excavation contractors. Avoiding damage to utilities during construction reduces the time delays and costs associated with repairing damaged utilities, but more importantly reduces safety hazards to workers and the public caused by such damages. Getting accurate maps of utilities can further benefit projects when they are obtained in advance of design by allowing planned relocation of utilities or redesign of the road due to utility conflicts. GPR has limitations in its capabilities to work in certain soils. GPR's effectiveness can easily be tested before full mobilization on a project. When deployed systematically prior to design and construction on roadway projects GPR can have great value.[11, 12, 13]

Deploying a multi-channel GPR system such as the UIT system can be very effective in finding known as well as unknown utilities. One problem in normal locating and mapping that affects DOT project costs, schedules and safety is finding utilities whose presence is not known to the project engineer or construction contractor and therefore not included in the planning. Fully covering project areas with 3D subsurface imaging GPR greatly reduces the risk of missing one of these utilities. In addition, the exact location and depth of known utilities is not always known well enough along their whole lengths to protect the project from the risk of hitting them. 3D GPR systems can aid with this problem as well. Even SUE results only provide depth information at testhole locations.

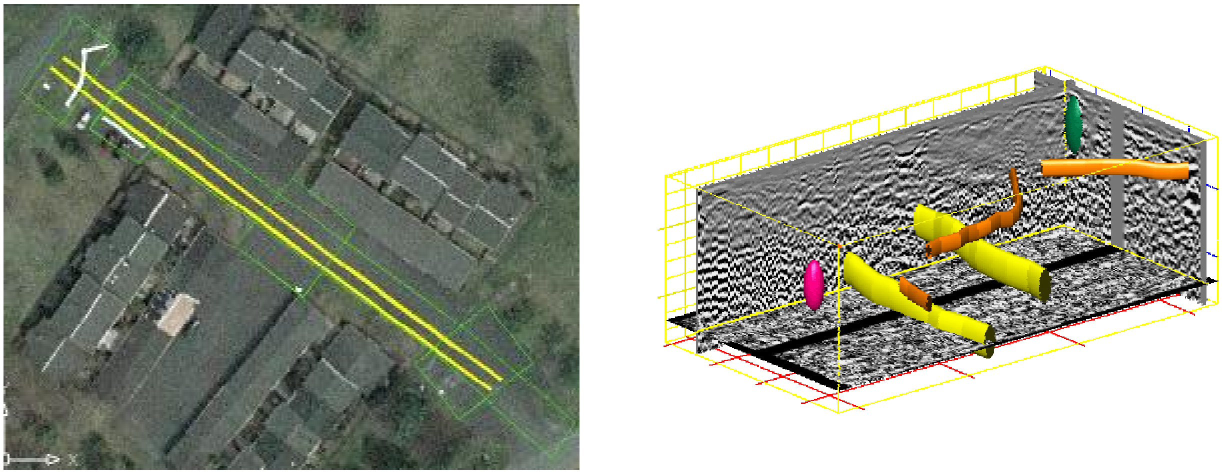

Fig. 6. (Left) Results of a GPR Subsurface Utility Survey Overlaid on an Aerial Photo. (Right) 3D View of a Section of the Surveyed Area Showing Location and Orientation of Buried Utilities.

6.0 TECHNOLOGY SPECIFICATIONS AND REFERENCES

As part of this project, technology specifications and references were reviewed. These documents discuss aspects of GPR that include the technology and its applications in pavement systems, subsurface utilities, bridge decks, and other structures. Below is a list of technology specifications and references that were reviewed.

FHWA Research and Technology: “Priorities, Market-Ready Technologies and Innovations-Ground Penetrating Radar”

AASHTO Technology Implementation Group- Ground Penetrating Radar

NCHRP Synthesis 255, “Ground Penetrating Radar for Evaluating Subsurface Conditions for Transportation Facilities”

ASTM 6432-99 (2005): Standard Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation

ASTM D4748-98: Standard Test Method for Determining the Thickness of Bound Pavement Layers Using Short-Pulse Radar

ASTM D 6087-05: Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar

AASHTO R37-04: Application of Ground Penetrating Radar (GPR) to Highways

AASHTO PP-40: Application of Ground Penetrating Radar (GPR) to Highways

ASCE Standard: “Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data”

The standards, guidelines and other information in the documents reference above were included in developing the implementation guidelines presented in Section 8.

7.0 REGULATIONS & RESTRICTIONS ON USE

The FCC restrictions on Ultra Wide Band emissions (July 15, 2002) have imposed limitations on GPR technology. These have had a significant impact on the manufacturers' abilities to continue improving systems because of limitations on transmit rate, frequency bandwidth and output power level. These limitations impact the survey speed, resolution and penetration capabilities of GPR systems.[14, 15] Most GPR manufacturers have redesigned their systems to be in compliance with the new restrictions and most GPR application areas for highway and utility investigations remain viable.

Many of the deeper investigations that are within the realm of GPR's capabilities (30ft and greater) and many high-speed, high-resolution applications (pavement and bridge deck evaluations at posted traffic speed) are limited with respect to further technology development because of the power output restrictions. Medium-to-high resolution GPR antennas designed to investigate between 1 and 25ft (for utilities, for instance) must currently be modified for sale in the U. S. to reduce power. The FCC restrictions provide certain limitations on the use of GPR but may also provide the impetus to develop different and perhaps better solutions to certain applications:

(1) Using currently available systems for highway investigations may have to be done at a slower transport speeds when very high spatial density data is necessary. Slowing down while using a slower pulse transmit rate allows the operator to maintain desired data density. This translates to slightly higher field data acquisition cost due to spending more time in the field. It also may result in the need for traffic control on projects where very high data density is required. These problems can be mitigated by only collecting high data density on projects where it is absolutely necessary, working at low traffic load times such as at night, and using rolling barriers so the GPR system can safely travel slower than the traffic.

(2) Utility mapping applications may be affected by reduced depth of penetration due to the lower power requirements. However, this is likely to happen only in marginal cases. Most utilities are well within the range of present systems when they lie in compatible soils. The limitation of soil type is by far a larger factor than the reduced power of GPR systems.

(3) Background radio noise (from cell phones, radio transmitters, cell towers, CB radios, etc…) can dramatically overwhelm or fully obscure GPR signals transmitted by the lower power, FCC-certified 1.0GHz and 2.0GHz sensors used for most road and bridge GPR work.

(4) *There may be engineering solutions to the above problems that can be pursued by industry, perhaps with government aid. Designing ground coupled or nearly ground coupled systems for road and bridge work could alleviate most or all of the*

difficulties mentioned above. Developing continuous wave, stepped frequency GPR systems may help with both the penetration and resolution issues resulting from the FCC restrictions on pulse GPR systems. These are fruitful areas for further research and development.

Some equipment manufacturers have been able to work within the FCC limitations to develop FCC-compliant GPR acquisition systems and sensors that meet the radio emission requirements and still manage to adequately address many civil engineering infrastructure problems. There may still be some significant limitations that the restrictions cause in several application-specific areas.

8.0 DEMONSTRATION OF GPR APPLICATIONS IN PAVEMENT SYSTEMS

A number of project sites were surveyed to demonstrate GPR capabilities and to aid in providing information on pavement and subsurface utilities investigations for this study. Project sites were selected for project level as well as network level analysis. The location of the three project sites as well as the objective for each are listed below.

<u>Project Sites for Pavements</u>

1. I-87 Northway, Region 1, Albany County, north of Western Avenue to Saratoga County Line
    a. Primary Objective: Asphalt overlay thickness and variation
    b. Secondary Objective: Overall pavement and joint condition

2. I-890, Region 1, Schenectady, just north of Exit 26 (I-90 Thruway) to Campbell Road
    c. Primary Objective: Concrete pavement joint condition
    d. Secondary Objective: Pavement uniformity
    e. Nearby Activity: Feasibility survey on I-890 near Michigan Avenue
        i. Objective: Identify void formation above existing culvert
        ii. Secondary Activity: Locate voids and grout-filled regions
        iii. Characterize surveyed site

3. NY Route 12/I-790, Region 2, Oneida County, Utica
    f. Primary Objective: Concrete pavement joint condition
    g. Nearby Activity: Survey at failed joint between two adjacent pavement slabs, on service road just north and east of high-speed study area
        i. Objective: Determine whether void exists beneath slab
        ii. Secondary Activity: Try and locate (identify) drain pipe beneath pavement (approx. 8ft deep)
        iii. . Determine whether data from this joint failure can be correlated to any potential problems on Route12 study

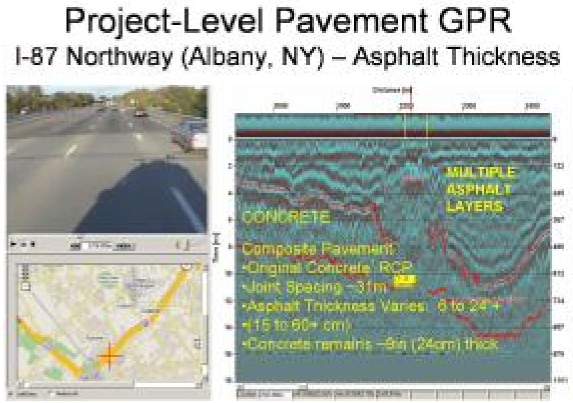

Fig. 7. Sample Screenshot from Road Doctor Showing Data from a Specific Location on I-87 which Includes Video, GPR, Location on a Map, and Findings of Interpretation

In each of these locations a high speed data collection was performed utilizing an air-horn GPR system with support hardware that included video capture and GPS. These three data sets are merged together within a software package called *Road Doctor* that was created by Roadscanners. The software was able to link the data sets together so that when a specific location was chosen by the data interpreter, the surface was shown through the use of the video data and the subsurface data collected by GPR was also shown. Since GPS data was collected, future investigations of a desired area can be performed and that data can be linked with the other data.

The results of the high speed surveys were able to characterize the pavement systems which included:

- Changes in layer thickness were identified and located
- Locations and the extent of full depth repairs
- Location of reinforcement in concrete pavement as well as the joint
- Assessing the condition of the concrete slabs and joints

Fig. 8. Linking Surface Features to Subsurface Features with Road Doctor

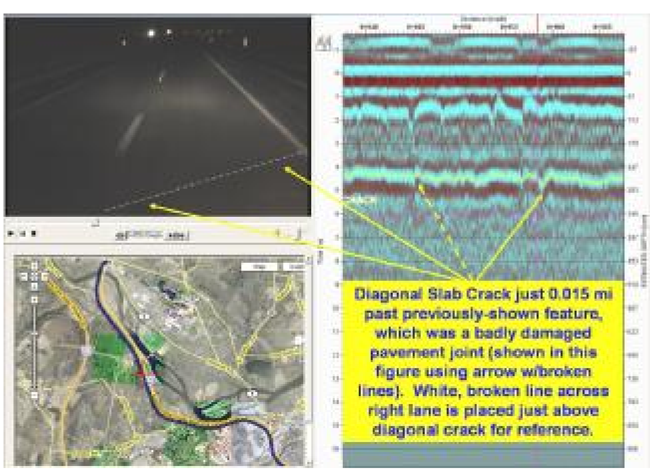

Fig. 9. Severe Crack in Pavement Slab Near Joint shown on the Surface (Video) and Subsurface (GPR)

A project level analysis is provided for locations 2 and 3. In location 2, a ground-coupled survey was performed to collect data from greater depths than can be collected by an air-horn antenna. Culverts and voids were identified and located as well as locations where previous grouting has occurred. Table 1 on the following page catalogs these features. In location 3, concrete slabs with potential problems were identified. The location on the slab and severity of the defect are presented in Table 2 for a 400 m segment.

A method for a network level analysis of a pavement system is also presented. Two sampling methods were presented that utilize average measured values over an interval. These intervals were 50 m and 20 m. A representative survey path was chosen along a section of roadway on the northbound side of I-87, where for each interval, measured data was averaged together as well as recording the maximum and minimum values. The measured values were asphalt overly thickness, asphalt overly dielectric value, reinforced PCC thickness, and reinforced PCC dielectric value. Intervals with full depth asphalt repairs, asphalt overlaid or bare concrete decks, and sections where reinforced concrete pavement is not evident have been identified. These results from the 50 m and 20 m intervals are presented in the following pages in Table 3 and Table 4, respectively. Ultimately, NYSDOT must choose the sampling interval and what data to include for a network analysis.

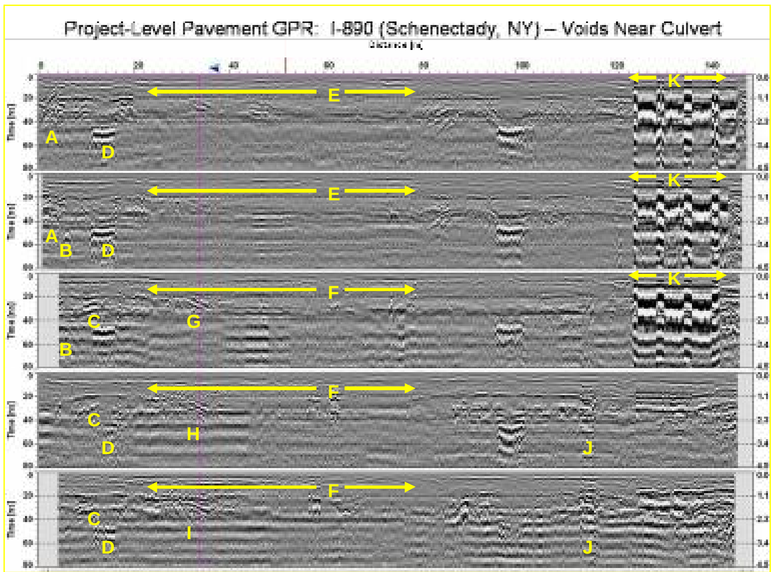

Fig. 10. Subsurface Features Labeled in Parallel Passes in GPR Survey in Section of Roadway in I-890. Description of Features can be found Below in Table 1.

Table 1. Features in Fig. 10 from Section of Roadway on I-890

	Distance Along GPR Line (m)		Type of Structure/Anomaly			Lane	Lane Position
Feature	Start Location	End Location	Structure	Void/Other	Repair	Designation	Left, Right, Center
A	0	4.5		VOID		RIGHT	LEFT, CENTER
B	6	6		VOID OR UTIL		RIGHT	CENTER, RIGHT
C	7	10		VOID		RIGHT/RT SHLDR	RIGHT/LEFT,CENTER
D	10	16	Culv/CBsn			RIGHT, RT SHLDR	ALL POSITIONS
E	23	80			GOOD	RIGHT	LEFT, CENTER
F	23	80			INTERMITTENT	RIGHT/RT SHLDR	RIGHT/LEFT,CENTER
G	31	36		VOID		RIGHT	RIGHT
H	32	36		VOID		RT SHOULDER	LEFT
I	30	36		VOID		RT SHOULDER	CENTER
J	114	117		VOID		RT SHOULDER	LEFT, CENTER
K	125	144+	Brg/Culv			RIGHT	LEFT, CENTER, RIGHT

Table 2. GPR/video assessment, 400m segment of reinforced PCC pavement, Route 12

Slabs w/Potential Problems: Mid-Slab and at Joints							
			Type of Defect & Proximity			Defect	
Slab #	Start Location	End Location	Mid-Slab	Lead Joint	End Joint	Location	Severity
2	1804.9	1810.9		X		1805.7	LOW-GPR
12	1865.5	1871.6	X			1868.4	HIGH
13	1871.6	1877.7	X			1874.5	MED/HI
14	1877.7	1883.8	X			1880.6	HIGH
14	1877.7	1883.8			X	1882.8	HIGH-GPR
15	1883.8	1889.9	X			1886.4	HIGH
16	1889.9	1895.8	X			1893.3	HIGH
17	1895.8	1902		X		1896.9	MED-GPR
17	1895.8	1902	X			1899.4	MED/HI
18	1902	1908.1	X			1905.4	MED/HI
19	1908.1	1914.3	X			1910.7	SEVERE
19	1908.1	1914.3			X	1913.3	HIGH-GPR
20	2058.2	2064	X			2060.4	HIGH
21	2064	2070.1	X			2066.7	HIGH
22	2070.1	2076	X			2074.5	HIGH
23	2076	2081.8	X			2079.3	MED/HI
24	2081.8	2087.8	X			2085.6	MED/HI
26	2093.4	2099.7	X			2096.3	MED/HI
26	2093.4	2099.7			X	2099.3	MED-GPR
29	2111.3	2117.3			X	2117	HIGH-GPR
30	2117.3	2123.2		X		2117.4	HIGHPGPR
30	2117.3	2123.2	X			2122.6	MED-GPR
31	2123.2	2129.2			X	2128.9	MED-GPR
32	2129.2	2135	X			2132.6	MED-GPR
32	2129.2	2135			X	2134.7	MED-GPR
33	2135	2141.2				2138.4	MED
34	2141.2	2147.1			X	2146.7	MED-GPR
38	2164.3	2170.4	X			2168.1	HIGH
39	2170.4	2176.7	X			2173.7	SEVERE
40	2176.7	2182.7	X			2179.9	SEVERE
41	2182.7	2188.7	X			2185.5	HIGH
41	2182.7	2188.7			X	2188.4	HIGH-GPR

Low-GPR, Medium-GPR and High-GPR are used to identify locations where there is no visual evidence of surface defect (crack), yet GPR provides subsurface indications consistent with defect formation. These low, medium and high qualifiers (for GPR-only data) are used to provide probabilistic indicators of whether core extraction would reveal damage at that location. SEVERE indicates areas where both video and GPR indicate significant slab damage, HIGH indicates areas where both GPR and video indicate slab damage w/one method indicating moderate damage, MED indicates video and GPR both indicate moderate slab damage. MED/HI means one video indicates moderate visual damage w/little or no indication of same from GPR or video shows possible damage (video not clear), yet GPR indicates high potential for same. It should be noted that this method of ranking does not incorporate any site sampling (cores), and represents a PRELIMINARY ASSESSMENT. Any responsible GPR service provider would recommend core locations for sampling so that a more robust prediction (condition assessment) can be made. Yellow-highlighted rows indicate bridge deck location (no slabs present); green rows indicate slabs with asphalt overlay (likely repaired concrete slabs).

Table 3. 2,500m of pavement thickness data along I-87 NB middle lane, 50m intervals, Station 110 + 00 to 135 + 00 (meters)

Section Start(m)	Section End(m)	Network Interval(m)	Asphalt O/L Ave Thck(mm)	Asphalt O/L Min Thck(mm)	Asphalt O/L Max Thck(mm)	Asphalt O/L Thck Dev(mm)	Asphalt O/L Dielectric(Er)	Asphalt O/L (Er)deviation	PCC(reinf) Ave Thck(mm)	PCC(reinf) Min Thck(mm)	PCC(reinf) Max Thck(mm)	PCC(reinf) Thck Dev(mm)	PCC(reinf) Dielectric(Er)
11000	11050	50	161	132	333	41	7.8	0.4	223	185	280	15	9.5
11050	11100	50	143	104	366	49	7.9	0.5	235	201	294	15	9.4
11100	11150	50	140	90	366	61	8.4	0.6	246	202	402	24	9.6
11150	11200	50	139	106	230	14	8.3	0.5	227	127	272	18	9.5
11200	11250	50	140	102	190	27	8.1	0.2	217	188	264	11	10.5
11250	11300	50	232	178	409	76	8.2	0.2	227	203	280	10	9.8
11300	11350	50	201	147	243	15	8	0.3	234	200	295	12	9.2
11350	11400	50	199	155	222	9	8.3	0.3	218	179	416	20	7.2
11400	11450	50					11.8	2.5					
11450	11500	50	194	169	224	9	10	2.3	165	136	204	18	
11500	11550	50	213	181	235	11	8.1	0.3	230	183	268	14	9.3
11550	11600	50	219	203	236	6	7.8	0.2	237	210	266	11	8.8
11600	11650	50	209	163	233	9	7.9	0.2	240	214	299	12	9.1
11650	11700	50	207	136	410	80	7.7	0.3	252	206	287	21	8.7
11700	11750	50	260	108	390	110	7.6	0.2	251	230	387	15	8.6
11750	11800	50	124	90	339	39	7.7	0.2	247	221	285	11	9.3
11800	11850	50	184	128	361	50	7.7	0.2	242	212	301	12	8.7
11850	11900	50	161	134	179	9	7.8	0.3	246	221	275	9	9.3
11900	11950	50	142	71	160	11	8.1	0.5	228	202	282	15	9.4
11950	12000	50	146	135	155	4	8.1	0.4	226	205	272	9	9
12000	12050	50	147	101	159	8	8.1	0.4	221	192	273	15	9.2
12050	12100	50	133	69	334	35	8.1	0.3	236	209	277	12	9.2
12100	12150	50	370	317	437	24	7.9	0.2					8.8
12150	12200	50	250	107	432	120	7.8	0.3	233	201	267	11	8.7
12200	12250	50	127	73	284	46	7.5	0.2	233	194	266	19	8.7
12250	12300	50	141	100	331	52	7.8	0.3	188	156	271	16	9.7
12300	12350	50	140	129	163	6	8	0.3	203	152	275	26	10.1
12350	12400	50	180	140	222	24	7.8	0.2	220	197	250	11	9.4
12400	12450	50	217	199	237	7	8.2	0.4	223	199	251	10	9.7
12450	12500	50	314	219	469	88	8.2	0.5	230	202	274	15	9.3
12500	12550	50	456	416	510	24	8.5	0.3					9.6
12550	12600	50	469	428	524	24	8.5	0.4					9.4
12600	12650	50	452	425	505	12	8.9	0.3					9.9
12650	12700	50	320	241	475	77	8.9	0.6	228	209	249	8	10.1
12700	12750	50	248	231	270	8	8.5	0.2	239	214	262	11	9.7
12750	12800	50	269	250	299	9	8	0.2	251	220	279	11	9
12800	12850	50	251	231	266	7	8.4	0.5	239	204	273	17	9.7
12850	12900	50	247	224	277	12	8.4	0.4	238	214	271	12	9.6
12900	12950	50	215	190	241	11	8.4	0.6	233	208	260	11	9.8
12950	13000	50	197	169	212	7	8.7	0.3	235	211	271	11	9.9
13000	13050	50	203	184	231	11	8.6	0.5	239	219	261	9	10
13050	13100	50	143	85	205	30	8.4	0.2	220	176	277	24	9.7
13100	13150	50	192	61	336	104	10	3.5	210	199	219	6	1.3
13150	13200	50					9.1	4.6					
13200	13250	50					8.3	0.4					
13250	13300	50					8.4	0.2					
13300	13350	50					8.8	4.6					

Yellow highlights indicate short sections along the pavement representing: (a) full-depth asphalt patch (no reinforced concrete pavement beneath), (b) asphalt-overlaid or bare concrete bridge deck, or (c) section where reinforced concrete pavement is not evident beneath the asphalt overlay. Note that there is one full-depth asphalt patch at least 150m in length (3rd highlighted group of data from Station 125 + 00 to 126 + 50), and there is a bridge deck that begins somewhere near Station 131 + 50 and continues at least until the end of this sample segment (Mohawk River Crossing at Saratoga County border with Albany County). Pavement layer dielectric values determined directly from the measured GPR waveform were used to calculate thickness from measured travel time are also shown in a similar format (average, minimum, maximum) as the pavement thickness output.

Table 4. 1,000m of pavement thickness data along I-87 NB middle lane, 20m intervals, Station 120 + 00 to 130 + 00 (meters)

Section Start(m)	Section End(m)	Network Interval(m)	Asphalt O/L Ave Thck(mm)	Asphalt O/L Min Thck(mm)	Asphalt O/L Max Thck(mm)	Asphalt O/L Thck Dev(mm)	Asphalt O/L Dielectric(Er)	Asphalt O/L (Er)deviation	PCC(reinf) Ave Thck(mm)	PCC(reinf) Min Thck(mm)	PCC(reinf) Max Thck(mm)	PCC(reinf) Thck Dev(mm)	PCC(reinf) Dielectric(Er)
12000	12020	20	145	101	157	10	7.7	0.3	236	207	273	13	8.6
12020	12040	20	148	139	157	4	8.3	0.2	211	195	229	7	9.8
12040	12060	20	140	125	159	10	8.4	0.2	216	192	230	7	9.5
12060	12080	20	130	124	139	3	7.8	0.3	238	218	251	6	9
12080	12100	20	138	69	334	55	8.1	0.2	243	219	277	10	9.1
12100	12120	20	353	317	387	16	8.1	0.2					9.2
12120	12140	20	387	336	437	18	7.8	0.2					8.5
12140	12160	20	382	335	432	25	7.9	0.3					8.8
12160	12180	20	289	107	391	106	7.8	0.3	239	229	267	10	8.6
12180	12200	20	139	117	154	6	7.7	0.2	231	201	257	11	8.8
12200	12220	20	123	116	137	4	7.4	0.1	249	217	266	11	8.5
12220	12240	20	108	73	123	12	7.6	0.3	219	194	251	12	8.9
12240	12260	20	187	86	331	89	7.5	0.2	217	203	271	11	8.7
12260	12280	20	115	100	129	8	7.6	0.2	193	173	225	11	9.8
12280	12300	20	137	117	149	7	8	0.2	176	156	211	8	10
12300	12320	20	140	132	163	5	8.2	0.2	178	152	237	20	10.4
12320	12340	20	137	129	149	5	7.8	0.2	222	204	275	16	10.1
12340	12360	20	147	139	154	3	7.7	0.1	215	198	224	4	9.8
12360	12380	20	173	150	190	10	7.9	0.2	213	197	231	8	9.6
12380	12400	20	204	187	222	10	7.7	0.1	228	210	250	10	9
12400	12420	20	221	209	236	5	7.9	0.2	228	213	244	6	9.2
12420	12440	20	213	199	237	7	8.4	0.4	218	203	242	7	10.2
12440	12460	20	225	212	249	8	8.3	0.2	221	199	251	12	9.8
12460	12480	20	264	244	292	9	7.7	0.4	234	214	274	14	8.9
12480	12500	20	405	249	469	72	8.5	0.3	252	248	253	2	9.6
12500	12520	20	480	435	510	20	8.4	0.2					9.2
12520	12540	20	441	426	461	7	8.4	0.1					9.6
12540	12560	20	443	416	466	11	9	0.3					9.9
12560	12580	20	459	428	497	17	8.7	0.2					9.5
12580	12600	20	491	461	524	16	8.2	0.3					9.2
12600	12620	20	457	426	505	12	8.8	0.3					9.8
12620	12640	20	455	432	476	7	8.8	0.2					9.9
12640	12660	20	438	417	457	9	9.4	0.2					10.5
12660	12680	20	321	241	475	66	9.1	0.6	226	213	239	7	10.3
12680	12700	20	261	244	284	8	8.4	0.1	228	209	249	8	9.7
12700	12720	20	252	240	270	7	8.4	0.2	229	214	253	7	9.6
12720	12740	20	241	231	255	4	8.4	0.2	247	225	262	8	9.6
12740	12760	20	258	242	277	9	8.3	0.4	247	225	270	9	9.6
12760	12780	20	273	261	299	7	8	0.1	247	220	279	12	9.1
12780	12800	20	268	251	288	10	8.1	0.3	254	235	273	9	8.9
12800	12820	20	250	231	266	7	8.9	0.3	227	204	260	13	10.2
12820	12840	20	251	238	261	4	8.2	0.3	246	205	273	16	9.6
12840	12860	20	258	240	277	8	7.8	0.2	250	226	271	9	8.9
12860	12880	20	249	232	265	8	8.6	0.3	231	214	267	10	10
12880	12900	20	237	224	249	5	8.5	0.3	239	222	256	7	9.6
12900	12920	20	220	193	241	11	8.8	0.2	230	208	256	9	10.7
12920	12940	20	214	194	231	9	8.2	0.7	229	210	253	9	9.3
12940	12960	20	197	169	218	12	8.1	0.2	249	236	271	6	9.2

Data shown in this table are shown in network level reporting intervals that are 40% of the length shown in Table 3, and include pavement thickness and dielectric data along an overlapping length of I-87 (same GPR line). At some future date, NYSDOT would have to determine an appropriate network interval length for GPR data output, though it would probably depend a lot on whether there are simple objectives (like pavement thickness and dielectric estimates) or if complex condition assessment information (joint or slab condition, etc.) is needed.

Project Sites for Utilities

The project sites for mapping subsurface utilities are listed below.

1. Intersection of Everett Road and Atrium Drive, Region 1, Colonie, NY
    a. Reference Project Limits: Everett Road & Atrium Drive GPR Lines
    b. Primary Objective: Map buried utilities
    c. Secondary Objective: Determine existence and extent of other subsurface features

2. Intersection of U.S. Highway 4 and Moon Street, Region 1, Fort Edward, NY
    a. Reference Project Limits: US Highway 4 and Moon Street Intersection
    b. Primary Objective: Map buried utilities
    c. Secondary Objective: Determine existence and extent of other subsurface features

Fig. 11. UIT Multi-Channel GPR System with GPS

In each of these locations a GPR system developed by UIT was used. This is a multi-channel GPR system that is integrated with a real-time, kinematic differential global positioning system (RTKD GPS). The results of this study illustrated the ability of multi-channel GPR technology to detect and map buried utilities; indicating the utility depths, orientations, and proximities to other surrounding infrastructure.

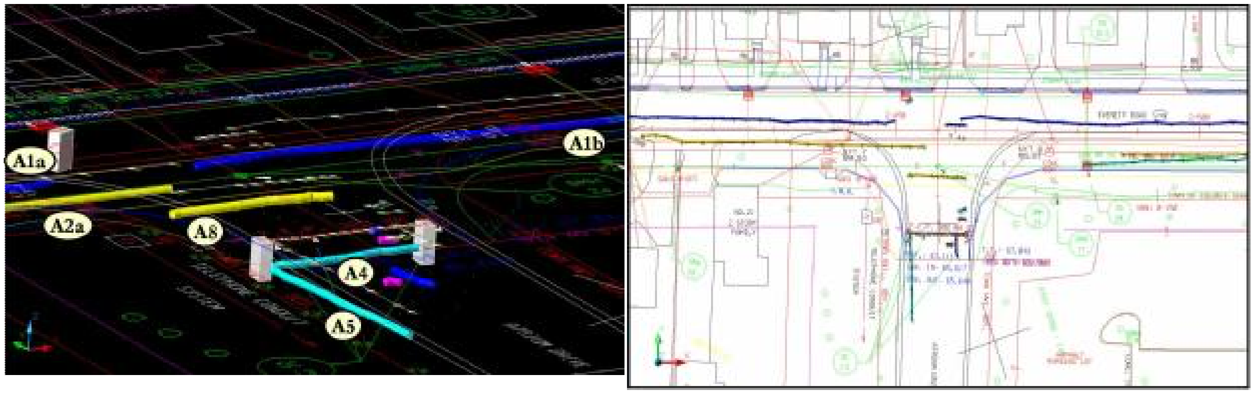

Fig. 12. Results of GPR Survey at Intersection of Everett Road and Atrium Drive in Colonie, NY Presented in 3D (Left) and Cad Drawing (Right)

The UIT system covers 5.12 feet with each instrument pass obtaining 14 channels of GPR data within each swath. Multiple parallel and transverse instrument passes were done at each site in order to obtain sufficient coverage to produce the 3D images shown. Post processing and interpretation were performed to generate the 3D images, maps and CAD drawings that were delivered for the project. The system produces utility locations in X, Y and Z coordinates to within a few centimeters, usually within one or two centimeters. Comparison with surveyed depths of exposed utilities with depths predicted using the UIT system on another project showed correlation as good as 0.1 to 0.2 inches.

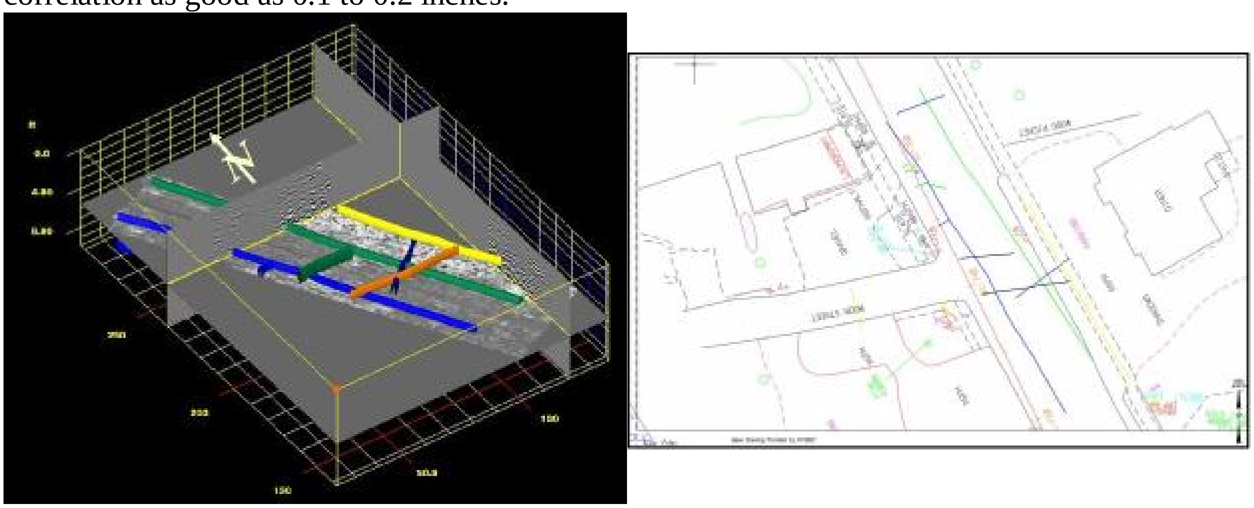

Fig. 13. Results of GPR Survey at Intersection of US Hwy 4 and Moon St. in Ft. Edward, NY Presented in 3D (Left) and Cad Drawing (Right)

9.0 IMPLEMENTATION STRATEGY OF GPR SERVICES

The implementation strategy of GPR services for addressing NYSDOT's needs in pavements and roadways is divided into six topics which are listed below. Each topic is summarized in the following sections.

1. Appropriate Formats for Reporting Data
2. Costs for Different Applications
3. Equipment Procurement Specification Sample
4. Evaluation for Improved Decision Making for Capital Projects
5. Training Needed for Implementation
6. Work plans for Network Level Applications and Subsurface Utility Exploration Applications

A sample service contract is presented in the appendix of this executive summary.

9.1 Appropriate Formats for Reporting Data

The appropriate formats for reporting GPR data include both tabular and graphic displays. This is true for pavements at the network and project level and also for underground utilities. The data reporting formats are determined, for the most part, by the differing parameters being measured in the field by the technology, for example: pavement layer thicknesses.

9.1.1 Highway Pavements

There are several factors that can be measured and displayed for pavements and their underlying materials. The air horn antenna attached to a van or other vehicle will exhibit some "bounce" as the vehicle encounters pavement irregularities. That bounce is recorded and eliminated from the subsurface data by means of analytical software. However, a graphic display of this phenomenon can be viewed as a qualitative indicator of pavement roughness. Other features that are routinely measured include:

- Pavement layer(s) thickness
- Layer thickness variability
- Asphalt interlayer reflections
- Asphalt air-void content (QC/QA compaction)
- Asphalt moisture content variation, segregation, voids
- Pavement cracks (project-level)
- Concrete reinforcement
- Significant moisture in base material beneath asphalt pavement

Each of these features can be displayed in electronic or tabular form and shown in 3D graphic form in color. In addition, a vertical data cross-section section showing subsurface features, can also be shown for each antenna used. All of these graphic formats of the GPR data can be video linked, via GPS, to a unique GPR survey line, resulting in a surface video log that correlates to the GPR subsurface data.

9.1.2 Pavement Joints

Both longitudinal and transverse transects over a pavement joint, using a single channel ground coupled antenna will provide important information, nondestructively, of the structure of pavement joints. Features that can be measured include:

- Presence of joint sealing material
- Presence and condition of load transfer devices
- Concrete breakup and spalling at the joint
- Presence of significant moisture content in the base under the joint

Using analytical software, the data delineating the measurement of these features can be displayed both in tabular and graphical form.

9.1.3 Underground Utilities

The data reporting formats for underground utilities would be similar to those identified above. The location/plan map can be supplemented with the video link tied to the project plan with GPS coordinates. In addition, CAD files showing the horizontal location of all utilities identified can be prepared for input to InRoads or any other software chosen. The CAD files contain digital position and depth information for each mapped feature. The primary deliverable format for utility data is these CAD files. Additionally, 3D displays of the underground utilities can be presented to aid in explanation of key features in the interpretation. These 3D images produced from UIT's specialized proprietary multiple antenna hardware and processing software, are much more illustrative and accurate than the vertical slice provided by a single antenna. For instance, the images can be rotated to achieve the optimal view of a critical utility crossing, and can be superimposed over pavement edges, curbs and other surface features for ease of identification and location of the subsurface features within a project. Sections can also be prepared both along each utility and across the roadway to better illustrate the depths of various utility lines. Lastly, all the data used to create the 3D and other graphic displays can be prepared in digital tabular formats as required.

9.1.4 Network Level

The data reporting formats at the network level are determined by the Work Plans for Network Level and Subsurface Utility Exploration Applications, or more specifically the Work Plans. As such, they will be discussed in detail in section 10, below.

9.2 Costs for Different Applications

The costs for providing professional services in different applications in utilizing ground penetrating radar technology will vary appreciably depending on a number of factors, and will change over time. Some of the factors impacting cost will be the complexity of the project, i.e. the length and type of transects required to gather the appropriate subsurface information, the complexity of the site, the number of days in the field, the type of antenna(s) and support equipment to be utilized, the particular software used to analyze the data and report the findings, and the final product of the GPR services desired by the client.

To eliminate the variables of the project complexity and passage of time, this section will focus on the levels of effort required for each of the applications envisioned for providing GPR services. There are distinct levels of effort shown for providing services for highway applications and for underground utility applications as outlined in Table 5.

Table 5. GPR Applications - Levels of Effort

Pavement			Utilities		
Antenna Type	**Crew Size**	**Coverage Estimate**	**Antenna Type**	**Crew Size**	**Coverage Estimate**
Single channel, ground coupled	1-2	750-1,500 linear feet per hour for project detail and joints	Single channel, ground coupled	1-2	750-1500 linear feet per hour for smaller projects
Single channel, air launched	2	45 MPH for some projects[1] and for networks	Multichannel, ground coupled	2	20,000 – 40,000 square feet per day for larger projects

In addition to the actual GPR antenna and recording equipment, other equipment and/ support staff may be needed depending upon the type of GPR survey and project objectives. For example, correlation of the physical location of the survey data to the earth's surface would typically be done by conventional surveying or Global Positioning System (GPS) techniques. GPR surveys performed with an air-launched antenna will require a specialized data collection vehicle, typically a van equipped with GPR acquisition and recording instrumentation, DMI, video camera and GPS and/or laser positioning equipment. The ground-coupled, multi-channel system will also require a tow vehicle such as a pick-up truck or all-terrain vehicle (ATV). It should be clear from the above that the design of any GPR project, and, therefore, the cost, must be specific to the project details and the desired results. Selection of the appropriate frequency antenna(s), the support equipment, the plan for the field data collection and the analysis of the data are critical to achieving the full potential of the technology.

In addition to the field aspects of GPR data collection, the processing, analysis and reporting phases are a part of any GPR based professional services project. These provide the critical bridge between the raw data collected in the field, interpretation and analysis of the data, obtaining the proper results, and providing appropriate reporting formats. As a rule of thumb for costing purposes, it can be assumed that the number of professional staff hours required for the analysis and reporting phase is two to ten times the number of field hours required for collecting data on a given project. This range is dependent upon the project size and complexity.

Table 6 contains the levels of effort for pavement and utility projects and for network level GPR projects. There are ranges of hardware and software costs necessary for the Department to acquire the basic ability to perform these activities. In addition, Table 6 includes a range of costs for these services to be performed by an outside organization. It should be noted that cost ranges for the latter are all inclusive with equipment, staff and direct expenses factored into the estimates.

Table 6. GPR Applications - Levels of Effort

	Costs for Different Applications		
	Department		Consulting Services
	Level of Effort	Hardware & Software	Total Cost[1]
Pavements (Project Level)	• Crew size: 1-2 • Coverage: 750 – 1,500 ft./hr (ground-coupled) or 5 to 10 miles of coverage per hour (air-launched).	• Single channel ground coupled system for simple GPR projects • Air-launched GPR system for complex projects that include GPS/video, asphalt QC/QA or ride quality outputs • $15-$25K	$2,000-$3,000 per lane mile
Joints	• Same as above	Same as above	$500-$1,500 per joint
Underground Utilities	• Crew size: 2 • 20-40k sq. ft./day	• Multi-channel array • NA	$ .40 to $1.25 per sq. ft.
Network Level	• Air launched single channel antenna (2) for each lane • Crew size: 2 • 45MPH	• $25-$60K	$50-$100K per lane mile [2]

(1) Includes data collection, processing, analysis and report.
(2) Includes one pass with 2 antennas.

9.3 Equipment Procurement Specification Sample

The following equipment procurement specifications are generic in nature and include both hardware and software necessary to provide GPR data, perform the analysis, and create the resulting graphics for reporting the results on pavements and underground utilities. The specifications are performance based and are stratified into single and multi-channel GPR applications. The single antenna specification is primarily related to applications where a single slice of data is sufficient. Such antennas are available from several manufacturers in a number of different frequencies, depending upon the specific application. The multi-channel application is focused on underground utilities where 3D mapping is desirable. These two GPR equipment systems can be categorized into their major components. The three major components of the specifications are 1) hardware consisting of single antennas and radar systems of several antennas, 2) GPR data collection software capable of handling up to two or more independent channels, and 3) a GPR data processing, analysis package, and graphics. There are four major manufacturers of the equipment and software. They are identified and described in detail in the Task 1 Report of this research.

Because various aspects of the component frequency and hardware specifications are rapidly evolving, possibly under review by the FCC and are proprietary in nature, these specifications have purposely been described in terms of expected performance outcomes for each of the major components

9.3.1 Highway Pavements and Joints

The system must be capable of producing output from layered systems which:

- identify and locate boundaries between different pavement materials
- determine layer thickness(es) and variation
- determine the presence and location of voids, segregation and/or moisture variation
- identify and locate reinforcing steel
- identify integrity of geotextiles based on pavement/base performance

On pavement and concrete structures the specific output must be able to:

- assess internal condition and deterioration
- quantify concrete cover depth
- identify and locate reinforcing steel
- address pavement joint condition such as joint filler, load transfer devices and displacement/spalling.

Also, the system should be capable of identifying and mapping geological and archeological subsurface features.

GPR antenna types available may be either air coupled or ground coupled or both depending on the application. Typical collection density (scan spacing) may be 6 scans/ft, 24 scans/ft and 1 scan per foot depending on the application.

Air coupled antenna types should mount above ground and be capable of producing high resolution survey data – ability to resolve layers 1 to 2 inches in thickness or targets within 1 to 2 inches of the pavement surface - at approximately 45 to 65 MPH, at the required data density, and with a penetration level of about 1 meter or less.

Ground coupled antenna types maintain ground contact or effective near-surface coupling and should be capable of producing high and medium resolution survey data at slower survey speeds with penetration ranges from 0.5 meters to 25 meters.

9.3.2 Underground Utilities

The subsurface utility imaging systems should be composed of an integrated system consisting of:

- A multi channel GPR system with associated software capable of producing three-dimensional subsurface images.
- An available EMI system including capability for inversion of the EMI data to independently obtain depth to utilities
- An in field integration system capable of handling GPS or laser positioning, GPR, and EMI
- Software for 3-D processing, visualization, and interpretation
- Final output in the Department's CAD and data formats

9.4 Evaluation for Improved Decision Making for Capital Projects

Decision making for capital projects involves 1) project selection from within total pavement needs, and 2) within funds available, selecting the optimum design to remedy the measured deficient conditions. The first, i.e. project selection, will be discussed in section 9 so this section will focus on the use of GPR in gathering subsurface information useful in capital project design.

In selecting the optimum remedy to address measured deficiencies, the cost and safety aspects related to collecting the data required by the designer is an important consideration. As shown in Task 2 of this research project, subsurface data using GPR technology can be collected non-destructively and can be collected faster, more accurately both vertically and horizontally, and at lower cost than other methods. The UIT technology for collecting vertical and horizontal data on underground utilities towed by a pickup truck or an ATV can provide data with coverage of up to 40,000 sq. ft /day. Having comprehensive utility data before construction will play a major role in limited excavation related damage to utilities and the corresponding risk to human safety. For network level data collection as well as a considerable amount of project-level work, the air horn antenna(s) mounted on the rear or front of a van can collect data at highway speeds, very often requiring no traffic control measures. Depending on the extent and concept of the GPR data collection effort, large amounts of subsurface data can be collected quicker and cheaper than other means and in a manner that is safer to the workers involved.

In selecting the scope of a capital project for a set of conditions, Department staff has certain information available upon which such decisions can be made. These include the record plans and maintenance records of the segment, pavement condition information and visual inspection data from the past several years, as well as the International Roughness Index data. On the other hand, the designer may have limited amounts of subsurface information on which to base a decision. There may be only a limited number of pavement cores, soil borings, and FWD data along the route under consideration. Due to the their destructive nature, time required to conduct, and their cost, these latter three data sets are often quite restricted in scope. Also, this information is collected at only discrete points along the segment may not be representative of the subsurface condition along the entire project length. GPR data can the solution to these problems since it can be taken so that it presents a continuous picture of subsurface conditions, providing critical information related to pavement structure variability that is otherwise unknown and unaccounted for in the design process. Additionally, employing GPR ahead of discrete sampling methods allows these investigations to be conducted at the appropriate pavement locations where these complementary methods will have their greatest benefit and impact.

As illustrated and discussed in Tasks 1 and 2, GPR data at the project level can provide the Department technical staff with significantly increased information about the materials and their condition under the surface of the pavement. As mentioned earlier in this report, the antenna displacement graphics and interpreted subsurface data can be compared to the condition and IRI data for a more complete picture of surface condition and roughness. Joints of old concrete pavement that are both bare or overlaid with asphalt can be studied. Other continuous information provided will include pavement layer interpretations, pavement layer thickness, extent of pavement that deviates appreciably from the average thickness, identification of uniform pavement segments, and relative moisture content and condition of both asphalt overlays and pavement base. Concrete pavement thickness, condition, and extent, even when asphalt overlays obscure its presence, can also be measured using GPR. Concrete joint information including the presence of joint filler, the condition of load transfer devices, and any significant displacement or concrete spalling of the joints could be provided if the GPR data collection is designed with that output in mind.

Clearly, this additional information about the underlying conditions on a segment of highway being advanced as a capital project will provide a more solid basis for decisions on the optimum remedy. Also, the lateral and lineal extent along each roadway or project over which these remedies are ultimately applied can more appropriately be determined using GPR to optimize pavement design decisions. Given that GPR subsurface information can be collected more quickly, accurately, and continuously at less cost, the value added by incorporating GPR information into the Department's capital projects process is very high.

9.5 Training Needed for Implementation

The implementation of GPR services and information within the Department will require training in both the general understanding and use of the technology and specifically how it can be applied in various Department functions. Subsurface information provided by the use of GPR equipment and software can be considered in the same vein as other engineering information used by design, planning, construction, research, etc. Information currently being used by engineers includes qualitative and quantitative information such as survey data, soils information, pavement coring, pavement condition data, output from the FWD, network needs study results, etc.

The organizational model for how the Department approaches such data collection consists primarily of the Department performing some of the data collection efforts with the remainder being done by engineering service providers. This model allows the Department technical staff to be trained in the use of the equipment and software adequately to manage and oversee the quality and cost effectiveness of the work of the consultants providing a large portion of the needed information. With limited staffing in the Department this same model is the most practical for the use of GPR data as well.

Following this model, the training needed for implementation for both pavements and underground utilities would be similar. Key technical staff from the Divisions and Regions who would utilize the information would be trained in the GPR technology, its theory and use and its application in their respective Divisions. Some of the Department functions, in both Main Office and Regions, to benefit from such training would include planning, design, construction, materials and research. As this technology gathers information not previously available, and does so more quickly and less costly, and at the same time non-destructively, staff from the Finance and Commissioners Office will benefit as well in making important budget and policy decisions. GPR data can assist in determining total needs and other critical policy matters for the Department.

With this approach, it is recommended that five technical staff from these program areas and from each Region be selected for GPR training. The training would consist of two separate courses. The first would consist of GPR technology theory and uses. The second would focus on the use of GPR data in respective functional areas such as design, construction, etc. Overall, about 75 technical staff would attend approximately 16 hours of training.

In addition, a Training Manual for use by the Department staff should be prepared. The Manual would be modeled after the two levels of training so it would have continuing utility to Department staff. On an as needed basis, there should be consideration given to follow up training as new uses for the technology are developed, new analysis software is developed, and technological improvements are implemented.

The increasing development of GPR related applications in project specifications makes the ability to assure competence in GPR related skills identified by consulting firms a necessary and urgent requirement.

The Ground Penetrating Radar Institute (GPRI) is a non-profit organization of professionals, manufacturers, researchers, and academics in the field of GPR. The GPRI currently provides training courses for professional credit in several areas of GPR applications and through its standards committee, it can establish and provide certification to professionals asserting competence in the field of GPR equipment operation and/or the interpretation of GPR data.

It is the recommendation of this study that a certification by an organization representing professional/engineering/manufacturing expertise in GPR technology be required of all persons seeking to provide these services to the Department.

9.6 Workplans for Network Level and Subsurface Utility Exploration Applications

9.6.1 Network Level Applications

The conclusion of the field collection phase determined that significant amounts of important subsurface information can be collected at the network level using GPR technology. Among the data obtained from GPR surveys that can be useful in making network decisions are continuous vertical antenna displacement (a ride quality indicator), pavement layer thicknesses and distribution, pavement structural integrity, certain base condition data, and a video/GPS link to correlate the GPR data to IRI and condition data on the same network links. It is recommended that the Department develop an overall Pavement Condition Index that incorporates the two current pavement ratings (Surface Condition and IRI) with a GPR Data Index for the same pavement segment, which is represented by a single numerical rating. This Index would be used in selecting projects and their limits for the capital program.

For network GPR data collection, it would be most appropriate to use two air launched antennas mounted behind a van or other vehicle with one located three feet and the other nine feet from the right edge of pavement, basically within the wheelpaths of a standard 12-foot lane. An added benefit to having two detailed vertical slices of information about the pavement structure would be the perspective (windshield view) video, linked by GPS and collected at the same time as the GPR data, providing a continuous visual record of the pavement network as it's being simultaneously imaged at both the surface and subsurface levels. This research has shown a strong correlation between subsurface anomalies within and beneath the pavement (asphalt or concrete) and visible surface distresses. Also, it has shown that the middle lane of a three lane section can typically be used to represent the entire width of roadway, as its data closely replicates both the right and median lanes.

It is recommended that a Region be selected to perform a pilot effort using the GPR technology to gather data at the network level and to develop an index that assimilates this information with the data sets gathered by IRI and the condition survey. A network sample would be chosen in the selected Region using variables that would include functional classification, pavement materials, i.e. whether bare of overlaid pavement, traffic volumes and perhaps other variables to select the sample. Such information by itself, or the developed index, could be used by the Department officials in a number of ways such as determining total pavement needs and costs, geographic resource allocation, priorities within Region and time series information to measure progress in improving the network over time.

An Action Plan to achieve the above results consists of a number of important decisions by the Department. An approach to arriving at these decisions as inputs to the results follows:

- Create a Technical Working Group (TWG), chaired by a Regional Director, consisting of the organization entities recommended in the section on training
- The TWG develops criteria for selecting the Region in which sample network data would be collected
- A network link sample size is determined for collecting GPR data
- The TWG established "data validation methods"
- Review the data files from the Sufficiency File, International Roughness Index (IRI) and GPR output and establish a common unit of measure (segments or .1 mile markers)
- Develop statistical method of correlating data files of GPR and IRI
- Correlate pavement layer thickness from GPR to Sufficiency File arrays, where applicable
- Explore and establish the relationship between GPR and Condition Survey data
- The TWG develops a qualitative pavement Index that is objective and reproducible, at

reasonable cost to produce and utilize

- The TWG coordinates these activities with – or includes within its membership – an experienced GPR service provider and an engineering consulting firm or similar industry advocate, familiar with the Department's pavement engineering systems and needs, so that the Action Plan is developed with expectations that are realistic with regard to the technology's capabilities, both in terms of what it can achieve and how it can be accomplished in a cost effective and productive manner

Each of these steps may require some analysis and/or research to achieve the desired results. However, the ultimate benefits to the Department in terms of more efficient and effective project selection for the capital program and greater cost effective remedies would be significant.

9.6.2 Subsurface Utility Exploration Applications

While a single GPR antenna can be used to collect information for locating subsurface utilities at the project level, it is very effort-intensive and the collected information can normally be portrayed in only two dimensions (X and Z). It is possible to produce three dimensional data with single channel system but with significant limits in both accuracy and cost-effectiveness. The most useful approach, from the perspectives of both productivity rates and obtaining the most effective final product, is the use of a multi-channel array of antennas. Multiple antennas allow the final product to be analyzed and presented in three dimensions (the Y dimension is immediately added because a full survey swath or subsurface volume is sampled in a single pass of the GPR system), and in an accurate manner with respect to position (location) because the GPR channel positions are housed within a fixed array. It is this 3D capability, combined with sub-decimeter GPS positioning (or other positioning system), that is so critical to accurately locate multiple levels of underground utilities, particularly in complex urban areas. As important is the capability of the multi-channel array 3D system to locate utilities that do not appear on any "as built" or "record plans". This latter capability is highly critical to ensuring public safety in construction projects.

The work plan for subsurface utility exploration applications at the project level would consist of several elements. The first would develop criteria for the use of GPR technology in subsurface applications similar to those the Department now uses to identify candidate projects for Subsurface Utility Engineering (SUE). These criteria result in SUE being applied to projects in built up urban areas, where record plans are outdated, where there are expected underground utilities within the project limits, and where recent utilities have been installed but not accurately mapped, etc. Where all or some of such criteria are met, the SUE approach of digging and measuring can be cost effective. At the opposite end of the spectrum, i.e., in rural areas where there is no expectation of underground utilities in a project, the SUE approach would have lower benefit for the cost. Therefore criteria should be developed for the use of GPR is not needed or to augment SUE appropriately in other cases.

The Action Plan, therefore, is for the Department to develop the criteria for the application of GPR data collection in the mid range of projects where the SUE criteria are not clearly positive or negative.

The framework for developing these criteria includes the following:

- Review the circumstances from past construction projects where the absence of the use of SUE resulted in some aspect of underground conflicts; also identify the number of projects with such conflicts and the related costs.

- From past conflicts in construction projects, determine the characteristics or risk factors such as population density, recent developments, the type of underground utilities (e.g., gas and electric would have higher associated risks than water and sewer), etc.

- For circumstances that have not changed after construction, utilize GPR technology on a pilot project basis so that the cost effectiveness of using GPR to locate the conflict can be determined.

- In projects where SUE is currently used, establish the threshold whereby GPR can locate utilities more accurately and less costly, and/or identify where the use of the GPR data can be shown to directly benefit the SUE process as a result of its use.

Once the above criteria are met, multi-channel GPR would, because of its advantages of speed and cost effective data coverage, become the technology selected to provide information for projects where underground utilities are known or anticipated to be present. It can become a screening tool for the use of SUE. The result should see a more effective use of the SUE process and, therefore, significant improvement in final product. Over time, this approach would result in further calibrating the accuracy, cost, and criteria for the use of GPR in the underground utility process. It would also assist in the improved use and allocation of SUE resources.

The deployment of GPR for utility mapping prior to construction will to provide improved safety and damage prevention on projects due to having comprehensive knowledge of all utility locations ahead of excavation.

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APPENDIX I. SAMPLE SERVICE CONTRACT

NEW YORK STATE DEPARTMENT OF TRANSPORTATION GROUND PENETRATING RADAR (GPR) SERVICES FOR PAVEMENTS, BRIDGES AND UNDERGROUND UTILITIES

I. EXECUTIVE SUMMARY

The New York State Department of Transportation is seeking to retain two (2) firms to provide "subsurface ground penetrating radar (GPR) services" on an as needed basis under two separate Federally Funded Agreements. The agreements will both cover NYSDOT Regions 1-11 (Statewide). The NYSDOT Regional Map is provided in **Attachment A**. The selected firms must be capable of providing the following services in support of the Department's planning, highway design and bridge design programs:

<u>Project Selection</u> - Determining the appropriateness and technical viability of using GPR, and the recommended equipment and field operations, on either a network or a project basis as requested by the Department. The Department will specify the desired features to be measured, e.g. utility locations, pavement thickness, depth of cover to reinforcing steel, etc. Similarly, for a network level GPR project, the Department will specify the geography and scope of the desired services.

<u>Data Collection</u> – Mobilizing the appropriate equipment and staffing to collect the information as required by the data needs for the design of the project. This will include all staff time, equipment use rates, and direct expenses.

<u>Data Management/Deliverable</u> – Analysis, evaluation, assembly and presenting the required information in a format compatible with the Department's Computer-Aided Drafting and Design System (CADD-Intergraph System) for use by the Department's staff or designated consultants. The Department's CADD Specifications are provided in Attachment B.

It is anticipated that these stand-by contracts will have a maximum value of $1 million each, will have a duration of two years, and funding will be provided on an assignment-by-assignment basis, as necessary.

The Department anticipates two separate awards from this solicitation. However, the Department reserves the right to award both contracts to one firm if it is determined to be in the Department's best interest.

The selected firm(s) will be required to maintain a strategically located base of operations (office) for the staff assigned to this contract. This office will be the official station from which the project will be progressed.

II. SCOPE OF SERVICES

It is the intent of this Request-for-Proposals (RFP) that the CONSULTANT selected from this solicitation employ qualified, competent, and experienced personnel to provide the services set forth herein, and that such services are commensurate with both the prevalent methodologies used by consultants practicing within the subject area of work and with the magnitude and intricacy of the work under consideration. The CONSULTANT will accomplish these services fully so that it will be unnecessary for the STATE to supplement any of them with its own personnel, except as noted hereinafter. The STATE may however, review the work from time to time to verify accuracy and evaluate the performance of the firm. The items that follow are not intended to be comprehensive or exclusive; they merely set forth in a general outline the work that is expected.

A. <u>GROUND PENETRATING RADAR SERVICES</u>

The CONSULTANT shall -

1. Obtain all necessary permits from city, county, municipal, railroad or any other entity to allow the CONSULTANT to work in existing streets, roads, or private property for the purpose of marking, measuring, and recording the location of facilities which are the subject of GPR data collection.

2. Secure any "as built" plans, plates, or other necessary data as supplied by utility companies or NYSDOT.

3. Perform GPR surveys as outlines in Paragraph B6 below, "Operations Procedure for GPR Assignments." The CONSULTANT will return data in a digital format compatible with the STATE CADD SYSTEM and record facility owner names on plan sheets provided by the STATE.

4. Determine and inform the STATE of the approximate information as determined by GPR techniques when readings appear valid. Both the CONSULTANT and the STATE understand this information to be approximate only and are intended to be used appropriately in the final design.

5. Provide all Maintenance and Protection of Traffic devices and equipment, according to the Department's "Manual of Uniform Traffic Control Devices."

6. Provide all necessary equipment and support personnel, including surveying capability, to secure the data identified in this section.

The STATE will -

1. Provide highway plans showing the alignment, profile, and benchmark data, and project coordinate data for the selected project;

2. Notify adjacent property owners about data collection/survey activities on the selected project if determined by the STATE to be necessary;

3. Provide a Letter of Introduction to assist the CONSULTANT in establishing the need for its presence in a particular area.

B. GENERAL REQUIREMENTS

1. TIME TO COMPLETE WORK

All network and project GPR services shall be completed and delivered by the CONSULTANT to the STATE within 30 calendar days after the notice to proceed on each assignment is given.

All Construction Consultant Support Services shall be completed and delivered to the STATE within a mutually agreed upon project-specific time period after the notice to proceed is given. The CONSULTANT, being aware of the time concerns involving ongoing construction projects, will make every reasonable effort to complete and deliver either part or all of the information before the end of the mutually agreed upon time period.

The Department may alter times for any aspect of GPR services based on the complexity of the project and any other applicable factors.

2. BILLING PROCEDURE

The CONSULTANT will submit each project billing to the appropriate Regional Office as follows:

a. An itemized bill, on a monthly basis or as appropriate, in a format acceptable to the STATE:

b. A monthly summary of work both completed and underway under the resultant assignment.

The Department’s Design Quality Assurance Bureau will assemble regional approvals and process the invoices.

3. STAFFING BY CONSULTANT

The control and supervision of all phases of the work performed under any resultant Agreement by the CONSULTANT will be under the direction of a project manager employed by the CONSULTANT who has at least three years experience in the type of work described herein. The CONSULTANT may not remove the project manager from the project until all work has been completed or until the STATE agrees in writing that the CONSULTANT may replace or remove the project manager.

The CONSULTANT must provide a qualified staff adequate in number and experience to perform the described work in the prescribed time.

4. LIAISON WITH CONSULTANT

The STATE may assign and maintain one or more representatives on the project at no cost to the CONSULTANT. This representative(s) will work in close cooperation with the CONSULTANT to ensure a thorough understanding of all methods and procedures employed by the CONSULTANT. The CONSULTANT will make such records, procedures, and methods related to the project available to this representative(s) as requested.

5. EXPERT WITNESS TESTIMONY

If the CONSULTANT's testimony is required in any legal proceeding in connection with claims brought against or prosecuted by the STATE, the CONSULTANT will appear as a witness on behalf of the STATE with appropriate remuneration for time and expenses.

6. OPERATIONS PROCEDURE FOR GPR ASSIGNMENTS

The following will be the procedure to be utilized in identifying suitable GPR projects and engaging the CONSULTANT for a particular project:

a. A Regional Design or Planning Engineer will identify a suitable project, prepare a Scope of Services, and contact the Design Quality Assurance Bureau for consultation.

b. The Regional Design or Planning Engineer will notify the CONSULTANT of an assignment requiring network or project level GPR Engineering Services and schedule an initial conference.

c. The CONSULTANT will prepare both an estimate of time required to complete the work and of the costs, including staffing and hourly pay rates, for review and approval by the Region.

d. The Regional Design or Planning Engineer will contact the CONSULTANT with written notice to proceed and transmit all required project information.

e. If the CONSULTANT becomes aware at any time, that the GPR Engineering Service expense will exceed the estimate, it shall notify and provide the Region with an explanation for the anticipated overrun prior to performing the work. All overrun requests will be reviewed by the STATE, and if justified, the CONSULTANT will be provided with a written notice to proceed.

f. If the CONSULTANT becomes aware at any time that the GPR Engineering Services are inappropriate for the technology or can not be delivered for any reason, it shall notify and provide the Region with an explanation.