GEORGIA DOT RESEARCH PROJECT 17-30

Final Report

GEORGIA'S LONG-TERM PAVEMENT PERFORMANCE MONITORING AND MANAGEMENT PLAN - DETAIL DESIGN OF PLAN

GDOT
Georgia Department of Transportation

Office of Performance-based Management and Research
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7. Author(s): Yichang Tsai, Ph.D., P.E. (https://orcid.org/0000-0002-6650-2279); Yiching Wu; Ryan Salameh (https://orcid.org/0000-0002-6155-4061)		8. Performing Organ. Report No.: 17-30
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16. Abstract:
GDOT is actively seeking opportunities to improve its data collection and utilization to better support data-driven decision-making. This research project is to develop a long-term pavement performance monitoring and management plan that can cost-effectively provide sufficient, quality data to support pavement design and pavement management, including the calibration of the Mechanistic-Empirical Pavement Design Guide, the state route prioritization policy, and the quality assurance of pavement data in the coming 5 to 10 years. First, the data collected throughout pavement life-cycle activities by different offices were identified through interviews with engineers in different GDOT offices. Such information (including data items, data utilization, data collection frequency, data access, etc.) can be disseminated among GDOT's offices for improving data awareness and data utilization. Second, the potential opportunities for (a) improving data sharing; (b) optimizing data collection for multiple purposes; (c) maximizing sensor data utilization; (d) optimizing resources throughout activity collaboration; (e) improving information flow throughout pavement life-cycle activities among different offices; and (f) collecting the data needed for now and in the future (e.g. asset management, ADA compliance, pedestrian and bike, etc.) were identified through the discussion with GDOT's engineers. These discussions provide GDOT potential opportunities for and insight about improving GDOT's operational efficiency. GDOT is in the process of transitioning towards a new pavement data production operation with an outsourced, automated pavement data collection process, so this project provides recommendations for GDOT's successful transition. It layouts the utilization of 3D pavement data at 3 different levels and suggests the applications of video images and Lidar could data. Finally, the project provides a plan that includes an optimal site selection strategy, proposed collection sites, and a data collection plan to gather the data needed for GDOT's pavement design and pavement management operations.

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By

Yichang (James) Tsai, Ph.D., P.E.
Professor of Civil and Environmental Engineering

Yi-Ching Wu
Research Engineer

Ryan Salameh
Ph.D. Student

Georgia Institute of Technology

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Georgia Department of Transportation

In cooperation with
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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The Georgia Department of Transportation (GDOT), like other state DOTs, collects various pavement-related data to support its decisions on pavement life-cycle activities, including planning, design, construction, management, and maintenance and rehabilitation (M&R) activities. GDOT is actively seeking opportunities to improve its data collection and utilization to better support data-driven decision-making processes. The objectives of Phase I (Detail Design of Plan) of this research project are 1) to summarize the data collected by different GDOT offices, 2) to identify the opportunities for consolidating data collection effort and maximizing data utilization (including the 3D pavement data), and 3) to develop a site selection and data collection plan for pavement design and pavement management. This project also provides recommendations for GDOT's successful transition to a new pavement data production operation and for maximizing the utilization of collected data, including 3D pavement data, video log images, etc. The outcomes of this research project include the following:

1) The data collected throughout pavement life-cycle activities by different offices were identified through interviews with engineers in different GDOT offices and summarized. Such information (including data item, data utilization, data collection frequency, data access, etc.) can be disseminated among GDOT's offices for improving the engineers' awareness of the available data (i.e., bridge the gap in knowledge regarding currently available data) and, hence, data utilization.
2) All interviewed offices are very willing to share their data with other offices. The following are the recommendations:

a) Conduct a study focusing on a plan that synthesizes, updates, and coordinates data collection efforts and that promotes sharing and maximizes utilization of the data collected by different offices.

b) Publish the GALTPP data in a GIS format to make GDOT engineers aware of the sites to be used for long-term performance monitoring. A study to develop a plan for enhancing the data sharing and data awareness is recommended.

c) To develop a quality assurance program for the new pavement management production operation that includes a critical assessment of the impact of the revised distress protocol, a quality review process, acceptance criteria, and a training program.

d) The high-resolution 3D pavement surface data has already been collected and is available in GDOT. Besides recommending the utilization of video images, Lidar could data to create value-added for transportation agencies, this project layouts the utilization of 3D pavement data at 3 different levels (Level 1: use the extracted pavement distresses at 0.1-mileor 1-mile interval; Level 2: use the extracted pavement distresses at original 5-meter interval; Level 3: use 3D pavement data to extract distresses for different needs). A study to develop a research roadmap to maximize the utilization of 3D pavement data is recommended.

e) Using advanced technologies like artificial intelligence and machine learning, GDOT could add value by using the video log images already collected to cost effectively extract the following roadway features:

- **Guardrails**, a very important countermeasure; the 2014 guardrail map must be updated based on the current, required standards.

- **Pedestrian crossings**, to provide the data needed for ADA compliance.

3) By consolidating the sites for different purposes and integrating the data collection effort into the quality assurance process for the new pavement data production operation, a sustainable, cost-effective long-term pavement monitoring and management plan was developed. A plan, including an optimal site selection strategy, the proposed data collection sites, and a data collection plan, is proposed to support the data needed for the calibration of the Mechanistic-Empirical Pavement Design Guide, the state route prioritization policy, and the quality assurance of the new pavement data.

CHAPTER 1. INTRODUCTION

BACKGROUND AND RESEARCH NEEDS

The Georgia Department of Transportation (GDOT), like other state DOTs, is collecting various pavement-related data (e.g. pavement condition, traffic, and crash data, etc.) at different accuracies, spatial resolutions, coverages, frequencies, etc., to support the effective and efficient operations of pavement life-cycle activities, including planning, design, construction, management, and maintenance and rehabilitation (M&R) activities. GDOT is actively seeking opportunities to improve its data collection and utilization to better support data-driven decision-making and optimize the limited resources.

GDOT has been actively enhancing its pavement design and management practices; several changes have been made in recent years. New or additional data is needed to better support these changes. GDOT has conducted the initial local calibration of the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) (NCHRP, 2004) using the long-term pavement performance (LTPP) sites in Georgia and selected calibration sites (Von Quintus, et al., 2016). There is a need to continue monitoring the pavement distresses on these sites for their use in the future calibration and to include additional sites with common design features used in Georgia for better support of the MEPDG local calibration. In addition, GDOT has established its new state route prioritization policy with four categories of roadways (Critical, High, Medium, and Low) (Wiegand and Susten, 2016) for more cost-effective and efficient management of its pavements. There is a need to study the long-term performance and detailed level of performance behavior of each prioritization category, which can be achieved by performing long-term monitoring on selected sites for each prioritization category. GDOT is also in the process of transitioning to a new pavement data production operation (i.e., outsourcing pavement data collection to use an automated means). Therefore, there is also a need to select sites for quality check to ensure the data quality and to explore the opportunities for maximizing the utilization of collected data, including 3D pavement data, video log images, etc.

Georgia has an existing program known as the Georgia Long-Term Pavement Performance (GALTPP) program (Wu and Tsai, 2016) that maintains the sites used for the initial calibration of the MEPDG (Von Quintus, et al., 2016) and special test tests. However, there is a need to develop a long-term pavement performance monitoring and management plan that identifies the full number of monitoring sites needed and provides guidance on the data collection, analyses and management that will support pavement asset management beyond pavement design. The aim of this research project is to develop a long-term pavement performance monitoring and management plan that can cost-effectively provide sufficient and quality data to support pavement design and pavement management in the coming 5 to 10 years.

The proposed project consists of two phases. Phase 1 (Detail Design of Plan) is to develop the overall data plan, including the site selection and data collection plan. Phase II (Implementation) will focus on implementing the proposed plan, including the development of a site database published with data (e.g., location information, historical pavement condition data, etc.) on the selected sites and data collection (if needed).

RESEARCH OBJECTIVES AND SCOPE

The objectives of this research project (Detail Design of Plan) are 1) to summarize the data collected by different offices and their primary uses, 2) to identify the opportunities for improving data sharing, optimizing data collection for multiple purposes, maximizing sensor data utilization, optimizing resources throughout activity collaboration, improving information flow throughout life cycle activities, and determining the data needed now and in the future, and 3) to develop a site selection and data collection plan for pavement design and pavement management purposes based on optimal data collection strategy. This includes determining the number and locations of monitoring sites needed and the tests and data needed (e.g. coring, FWD, IRI, surface distresses, etc.) and recommending data collection frequencies, and data collection strategies. This project includes the tasks of 1) interviewing GDOT management and engineering staff to identify the needs of pavement performance monitoring and management, 2) identifying the opportunities for improving data sharing, optimizing data collection for multiple purposes, maximizing sensor data utilization, optimizing resources throughout activity collaboration, improving information flow throughout life cycle activities, and determining the data needed now and in the future, and 3) developing a cost-effective, sustainable long-term pavement monitoring and management plan, including an optimal site selection strategy, the proposed sites for flexible and rigid pavements, and the data collection plan.

REPORT ORGANIZATION

This report is organized as follows:

1. CHAPTER 1 introduces the background, the objectives, and the organization of this research project.
2. CHAPTER 2 presents the summary of the data collected by different offices and their primary uses.
3. CHAPTER 3 presents the opportunities for improving data sharing, optimizing data collection for multiple purposes, maximizing sensor data utilization, optimizing resources throughout activity collaboration, improving information flow throughout life cycle activities, and determining the data needed now and in the future.
4. CHAPTER 4 presents a proposed site selection and data collection plan that consolidates the data collection effort for meeting both pavement design and pavement management purposes.
5. CHAPTER 5 presents conclusions and recommendations for future research.

CHAPTER 2. SUMMARY OF DATA COLLECTED BY DIFFERENT OFFICES

During the course of the project, the GT research team conducted interviews with engineers in different GDOT offices to gather the information on the data collected throughout pavement life-cycle activities by different offices, their utilization, and data need (or gaps) in each office. This chapter summarizes the data items collected by different offices, including their utilization, collection frequency, access, etc. The subsequent chapter presents the challenges and opportunities for data sharing, coordination, and life cycle activity optimization.

DATA COLLECTED AND USED BY DIFFERENT OFFICES

To gather the information on the data collected and utilized by each office, the GA Tech research team conducted interviews with various offices, including the Office of Maintenance (OM), the Office of Materials and Testing (OMAT), the Office of Transportation Data (OTD), the Office of Traffic Operations (OTO), the Office of Planning (OP), the Office of Design Policy and Support, the Bridge Maintenance Unit (BMU), and one of the seven District Maintenance Engineers. Figure 2-1 summarizes the data collected by each office and tracks its utilization for different purposes by different offices. Some data, such as traffic and highway data by OTD and crash data by OTO, are collected to several different offices. Other data, such as pavement condition evaluation, testing, and bridge inspection data, are collected to fulfill the corresponding responsibilities and program needs of an individual office.

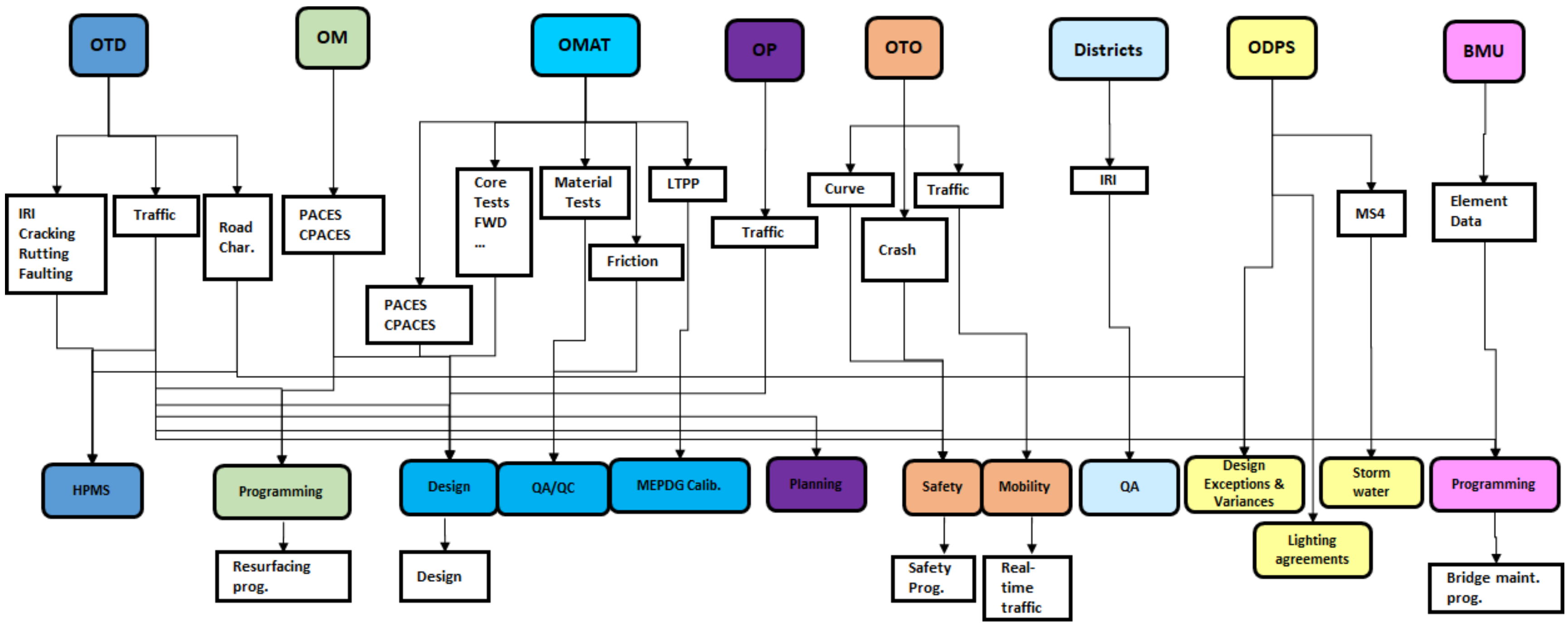

Figure 2-1. Flowchart. Data collected by different offices.

Table 2-1 and Table 2-2 further summarize the data collected by the different offices by identifying the data category (e.g., pavement, traffic), its primary use, coverage, the location identifier used, the collection frequency, the method of collection, and the party conducting the collection. Moreover, the tables identify the data reporting interval, format, and storage location, which can be used to evaluate the data accessibility (or data sharing). The following subsections describe the data collected by each office, including the collection methods involved, the data management practices, the data's current utilization, and the data need (or gaps).

Office of Maintenance (OM)

OM is responsible for maintaining the 18,000 centerline-miles of Georgia's state route system, including pavements and other roadway assets, such as road signs, pavement markings, guardrails, etc. As shown in Table 2-1, OM collects pavement distress data on the entire state route system (including both flexible and rigid pavements) on an annual basis to support its M&R programming. The data is collected according to the distresses (including type and severity) and measurement method (such as extent and sample location) specified in GDOT's pavement condition evaluation systems (GDOT, 2007; GDOT 2018a; GDOT 2018b). Table 2-3 lists the distresses collected on the flexible pavement (10 types), jointed plain concrete pavement (7 types), and continuous reinforced concrete pavement (6 types). The distresses are collected and recorded for each mile along with a location reference (RCLINK and milepoint). A rating is computed (based on distresses) to represent the overall pavement condition.

Table 2-1. Summary of pavement data collected by DO, OTD, OM, and OMAT.

Office		DO	OTD				OM		OMT								
Data Item		IRI	IRI	Cracking	Rutting	Faulting	PACES Distresses	CPACES Distresses	Material Testing	IRI	Core	Core Tests	PACES Distresses	C/CR-PACES Distresses	FWD	Friction	LTPP
Pavement type		AC	AC & PCC	AC & PCC	AC	PCC	AC	PCC	AC & PCC	AC & PCC	AC & PCC	AC & PCC	AC	PCC	AC & PCC	QA	AC & PCC
Prime use		QA	HPMS	HPMS	HPMS	HPMS	Programming	Programming	QA/QC	Decision making	Decision making	Decision making	Decision making	Decision making	Decision making	QA	MEPDG Calibrtion
Coverage		Project	NHS	NHS	NHS	NHS	Network	Network	Project	Project	Project	Project	Project	Project	Project	HFST sites	LTPP & GaCal Sites
Data reporting Interval		Varies	0.1 mile	0.1 mile	0.1 mile	0.1 mile	1 mile	1 mile	-	0.1-mile (or vary)	-	-	-	-	-	-	500 ft
Reporting Frequency	Annual		x	x	x	x	x	x									
	By request	x							x	x	x	x	x	x	x	x	x
Data Collection	GDOT	x							x	x	x		x	x	x	x	
	Vendor		x	x	x	x	x	x	x							x	x
Data Reporting Format	Raw file(s)	x													x		
	Report(s)	x							x		x		x	x	x		x
	Table(s)		x	x	x	x	x	x									x
Location Reference	Description	x							x	x	x	x	x	x	x	x	
	PI number	x							x	x	x	x	x	x	x	x	
	LRS or XY		x	x	x	x	x	x									x
Data Access	Office						x	x	x		x		x	x	x		x
	GDOT	x	x	x	x	x											
	Web (external)																

Table 2-2. Summary of traffic data collected by OTD, OTO, and OP.

Office		OTD		OTO	OP
Prime use		HPMS Reporting		Real-time Traffic Info	Planning
Data Item		Traffic Volume		Traffic Volume & Speed	Traffic Volume
Coverage		State-wide network		Metro areas	By project
Device		Continuous Count Stations (CCS) ~256	Short-Term Counts (48 hours) ~7000	Cameras & Loop detectors	Short-Term Counts (48 hours)
Data Collection Frequency	Continuous			x	
	Annual	x	x		
	By request				x
Who performs data collection	GDOT				
	Vendor	x	x	x	x
Data Item	Minimum Interval	5 min	1 hour	20 seconds	15 minutes
	Truck %	x	x*		x
	Single/Combo units	x	x*		x
	Vehicle classification	x	~2000		
	Turn movement				x
Data Reporting Format	Raw files				
	Report	x	x	x (Map)	x (Diagram)
	Table(s)	x	x		
Location Reference	Description				x
	PI number				x
	XY	x	x		
	LRS	x	x	x	
Data Access	Office Drive				
	411				x
	Web (external)	TADA	TADA	511	GeoPI

The data is stored in a database (COPACES) and managed by the data management unit, the Office of Information Technology. OM uses this data via the modules in its pavement management system to determine the treatment method, prioritize projects (i.e., ProjectSelection module), and allocate funding (i.e., FundingAllocation module) (Tsai and Wu, 2016). From the 1980s to 2018, the pavement data has been collected in-house by OM using a hierarchical 3-tier process through a collaborative effort which starts with the area offices first, followed by the district offices and the general OM, to ensure a good quality condition data. Currently, OM is in the process of outsourcing the data collection to establish a new pavement data collection production.

Table 2-3. Pavement distresses in GDOT's pavement condition evaluation systems.

Pavement Condition Evaluation System	**PACES (GDOT, 2007)**	**JPCPACES (GDOT, 2018a)**	**CRCPACES (GDOT, 2018b)**
Surveyed Distresses	- Load Cracking *(Severity Levels 1 – 4)* - Block/Transverse Cracking *(Severity Levels 1 – 3)* - Reflection Cracking - Rutting - Raveling - Edge Distress - Bleeding and Flushing - Corrugation and Pushing - Loss of Pavement Section - Patches and Potholes	- Longitudinal Cracks *(Severity Levels 1 & 2)* - Transverse Cracks *(Severity Levels 1 & 2)* - Corner Breaks - Shattered Slabs - Replaced Slabs - Failed Replaced Slabs - Joint Distresses	- Longitudinal Cracks *(Severity Levels 1 – 3)* - Transverse Cracks *(Severity Levels 1 & 2)* - Punchouts *(Severity Levels 1 & 2)* - Patches *(Severity Levels 1 & 2)* - Longitudinal Joint Spalling *(Severity Levels 1 & 2)* - Shoulder Distress *(Severity Levels 1 & 2)* - IRI*

* IRI is collected using the road inertial profiler by District Offices.

In addition, OM also conducts daytime and nighttime inspection on other roadway assets to identify the maintenance needs, including deficiencies of signs and guardrails, the presence of shoulder-drop-offs, vegetation management needs, etc. Nighttime inspection is typically performed in the winter, focusing on the nighttime sign visibility. Through the interviews with OM, the following data needs (gaps) are pointed out:

- As OM adapted a new pavement data collection method (i.e., outsourcing pavement data collection to use sensing technologies, such as 3D pavement data, as an automated means for pavement data collection), it identified the need for a quality assurance procedure to ensure that the distresses comply with GDOT's protocols with good data quality.
- OM is responsible for maintaining the pavements, including the high friction surface treatment (HFST) that were installed by the OTO for improving curve safety. OM identified the need for a HFST inventory (or locations) to monitor and restore the friction course on the pavements when needed (HFST deterioration or pavement resurfacing).
- While OM conducts inspections on other assets (such as signs and guardrails), it does not have an inventory for these assets. Such an inventory could help valuate these assets for reporting purposes, in addition to managing them for a better performance.

Office of Materials and Testing (OMAT)

OMAT is responsible for testing the materials used in construction and maintenance activities and for the design of new and rehabilitated pavements. In addition to reviewing the historical pavement data on the project, OMAT collects various data to support its Pavement Evaluation Summary (PES) and/or Pavement Type Selection (PTS) (GDOT, 2017) per project request. Data collected for PES includes the following: non-destructive testing, such as pavement distress surveys, International Roughness Index (IRI) measurements, pavement drainage surveys, falling weight deflectometer (FWD) measurements, ground penetrating radar (GPR) testing, seismographic techniques, and photographic documentation. Field destructive testing may also be included (such as coring and exploration holes) and laboratory testing may be conducted to obtain different parameters (such as air voids of cored specimens, soil support values, modulus of elasticity, concrete compressive strength, etc.) (GDOT, 2019). The data is collected in accordance with GDOT's standards by OMAT's crew and/or a contractor. The PES and PTS reports are in document format (e.g., PDF, Word, or Excel) and stored in the project repository (such as "Project Wise") in appropriate correspondence folders. Raw data is often kept within the data collection unit and/or the project engineer.

OMAT also performs QA testing to ensure that the material being used satisfies the set requirements. This includes friction testing using a Dynamic Friction Tester on the HFST sites. During the discussion with GT, OMAT pointed out the following data needs (gaps).

- Pavement condition data at finer levels (e.g., 0.1 mile or 100 ft.) can help OMAT effectively identify potential coring locations in house and enable better planning for the field work, which can save time in the field, reduce traffic interruption, and improve safety.

- While pavement condition data is regularly collected on Georgia's roadways, there is limited data collected on the structure capacity of a pavement.
- Currently, there is no data repository to host the various data items collected by OMAT, such as FWD, IRI, core measures, friction, etc. This makes it difficult (or less efficient) to support data-driven decision-making.

Office of Transportation Data (OTD)

OTD is the principal source for highway and traffic data; it is responsible for the collection of Highway Performance Monitoring System (HPMS) data, which is required by the FHWA (23 U.S.C. 315; CFR title 23). The HPMS includes data on the extent, condition, performance, use, and operating characteristics of the nation's highways collected according to the HPMS Field Manual (FHWA, 2016).

OTD is in charge of the Georgia Traffic Monitoring Program, which collects traffic data covering the state route system; it uses approximately 256 continuous-count stations (CCS) and 7000 short-term (48-hours) counts. CCS data is collected in a 15-min interval to generate the AADT and vehicle classification, which includes single/combo unit counts and truck percentage. Short-term count data is collected in a 1-hour interval to generate the AADT and may include vehicle classification for certain roads. The data is collected in accordance with HPMS requirements (FHWA, 2016), and the data collection, quality control and assurance, data processing, and reporting are documented in the Georgia Traffic Monitoring Program (GDOT, 2018c). The data is stored in a database and published through the Traffic Analysis and Data Application (TADA), a web-application that provides easy visualization, query, and reporting of the data.

As part of HPMS, OTD also collects pavement data on the National Highway System (NHS) at a 0.1-mile interval. As shown in Table 2-1, 5 types of distresses are collected for pavements, mainly to measure the pavement performance. Note that the distress types and definitions in HPMS are different from those in GDOT's distress protocols, which were designed for determining treatment methods and timing.

OTD also collects road characteristics data, including vertical grade, cross slope, and curve. Although HPMS requires the aggregate data reported at 0.1-mile interval, this data is available at a finer interval.

OTD is looking forward to sharing the data with other GDOT offices to maximize the use of this set of data. In addition, as OTD collects the data by an automated means using sensor technologies, it is looking forward to maximizing the utilization of the raw data (such as GPS and video log images) for extracting other assets.

Office of Traffic Operations (OTO)

OTO is responsible for the statewide transportation safety and mobility. It performs traffic engineering, implements intelligent transportation systems (ITS), and designs pavement markings, traffic signals, and signage. Moreover, OTO provides safety and incident management by performing vehicle crash analysis and reporting, running the Highway Emergency Response Operators (HERO) program and implementing safe access management on the state network.

OTO collect real-time continuous traffic data through a vendor using cameras and loop detectors installed in the metro areas to provide traffic speed data with a collection interval of 20 seconds. This data is used mainly for traffic monitoring. A traffic speed layer is published on a map in real-time at GDOT's 511 website (also known as Navigator); it has open and free access to the public and includes real-time data, such as incidents, work zone locations, and other special events or alerts.

OTO is also in charge of crash data; the Georgia Electronic Crash Reporting System (GEARS) serves as a repository for traffic accident reports completed by Georgia law enforcement agencies. OTO works with a contractor to locate crashes that result in injuries or property damage exceeding $500 and to maintain GEARS portal. This data also serves GDOT's Highway Safety Improvement Program, which aims to provide a continuous and systematic procedure that recognizes and reviews specific traffic safety issues around the state, especially identifying locations that have a potential need for improvement. This crash data is currently being reported using GPS coordinates. During its discussion with GT, OTO pointed out the following data need (gap).

- OTO currently has dedicated personnel responding to requests for crash data from other offices. A map-based web application for visualizing, querying, and retrieving the crash data will allow the data more assessable to other offices and release the resources from OTO.
- Because certain safety projects/programs have long programming cycles, OTO would like to have the information on upcoming resurfacing projects (e.g., 3-5 years) to better coordinate work at the same location.
- Besides providing real-time traffic conditions, OTO would like to explore the utilization of this data.

Office of Planning (OP)

OP manages Georgia's transportation planning program and develops the Statewide Transportation Plan (SWTP) and State Transportation Improvement Program (STIP). OP utilizes various sources of data (including traffic counts by OTD, freight data, lane use data, etc.) to determine traffic patterns and forecast future transportation needs for modeling purposes. OP often uses "411" and TADA for retrieving project information and traffic data.

In addition, OP is responsible for the design traffic forecast, which estimates the traffic loads (including initial AADT, truck percentage, traffic growth rate, etc.) for specific proposed projects based on the Design Traffic Forecasting Manual (GDOT, 2018). As shown in Table 2-2, OP collects traffic count data (including the turning movement) at specific sites using the same short-term (portable) devices used by OTD. The traffic forecast is provided in a traffic diagram during a project's development process and archived in the project information ("Project Wise"); the traffic counts are available on TADA. Through its discussion with GT, OP identified the following needs (gaps).

- OP uses "411" for retrieving data from various offices. OP pointed out that, sometimes, there is insufficient documentation of the data (such as lack of metadata and/or data dictionary). This knowledge can help the user to enhance the data utilization and to identify its limitations.

- OP uses TADA for retrieving the traffic data for projects; it suggests that having a function to query the traffic count by the project number can improve the data retrieving efficiency.

Office of Design Policy and Support (ODPS)

ODPS is responsible for developing and maintaining design policy, guidelines, and standards and providing engineering technical support. It is also responsible for the review and approval of design exceptions and variances and maintaining the lighting agreements with local governments. ODPS utilizes various data, including crash data and road characteristics data to study the risks of design exceptions and variances. ODPS maintains a repository of the design exceptions and variances within the office; the data is location referenced in .kmz format.

ODPS also collects a drainage structure inventory to meet the MS4 (municipal separate storm sewer system) program requirements for managing the stormwater runoff that discharges to the nation's waters via regulated MS4s along streets, roads, and highways. The data is collected and hosted by a consulting company, ARCADIS, in the Atlanta metropolitan area (~24 counties); it identifies the location and type of drainage structures. Through its discussion with GT, ODPS identified the following needs (gaps):

- A statewide road characteristics inventory that can identify the locations with certain features (such as 4-ft shoulder, median, etc.) can help ODPS in studying the risks of design exceptions and variances.

Bridge Maintenance Unit (BMU)

Bridge Maintenance is under the Office of Bridge Design; it has 12 inspection teams that inspect every bridge in the state (i.e., bridges and culverts longer than 20 ft.) at least every 2 years, except for cable bridges. BMU has replaced PONTIS with element data that is stored in Agile for four years, and an inspection report (customized by GDOT) is generated within Agile. BMU would like to use this element data to develop degradation curves and a bridge health index and to define maintenance needs. BMU uses “411” to identify the work need to be coordinated with other offices. However, due to the concern that the data is not always up to date, BMU also contacts project managers directly when concerns that a project may affect bridge maintenance work. Through the discussion, BM identified the following needs (gaps):

- BM would like to have the information on upcoming resurfacing projects (e.g., 3-5 years) to better coordinate work at the same location.

District Office

Seven district offices act as the regional executive force of GDOT’s General Office to perform maintenance, construction, traffic operations, permitting, and emergency work within the region under their jurisdiction. Each region is comprised of a cluster of counties being served by one district office that is led by a district engineer who is assigned to oversee all ongoing transportation activities and projects. These districts are further divided into several area offices that closely manage subgroups within a region’s counties.

One of the major roles assigned to district offices in partnership with OM is the condition assessment of all the transportation assets present on a right-of-way. This includes a pavement condition evaluation on state routes, a daytime inspection to manually identify deficiencies in roadway assets (e.g., signs, guardrails, etc.), a nighttime inspection to visually check the reflectivity of the signs, raised pavement markers, and the pavement marking, and a drainage structure inspection by county foremen to check for cleaning, relining, or replacement. Note that there is a change in the pavement condition evaluation due to the introduction of the new production operation, as mentioned in the section above.

Besides condition assessment, district offices also play an important role during the construction phase of a resurfacing project. For all projects on roads with lengths greater than 1 mile and on ramps with lengths greater than ½ mile, the district office collects Half Car Simulation (HCS) IRI using a Laser Road Profiler before and after the resurfacing is done. This helps to set the goal for contractors as a defined target IRI value or a target percent improvement over the pre-resurfacing value. HCS IRI values are all stored in "Project Wise," a project repository in which all project documents and records are stored. Besides IRI, the district office also performs QA/QC on the tests performed by the contractor on asphalt mixes to determine the gradation, asphalt cement content, and compaction quality (air voids). Thus, the DO will select random samples to perform a comparison and quality assessment to ensure the accuracy of the contractor's testing program. The results of this assessment are recorded in a DOT-159 report and also stored in "Project Wise." Moreover, a field inspection on asphalt batches is performed on site during construction to check for discoloration and temperature requirements; straight edge inspections and pavement spread checks are conducted to ensure a satisfactory quality/level of workmanship is maintained in accordance with the contract.

SUMMARY

Data Collected through Pavement Life-Cycle Activities

Figure 2-2 illustrates the various data collected throughout pavement life-cycle activities as follows:

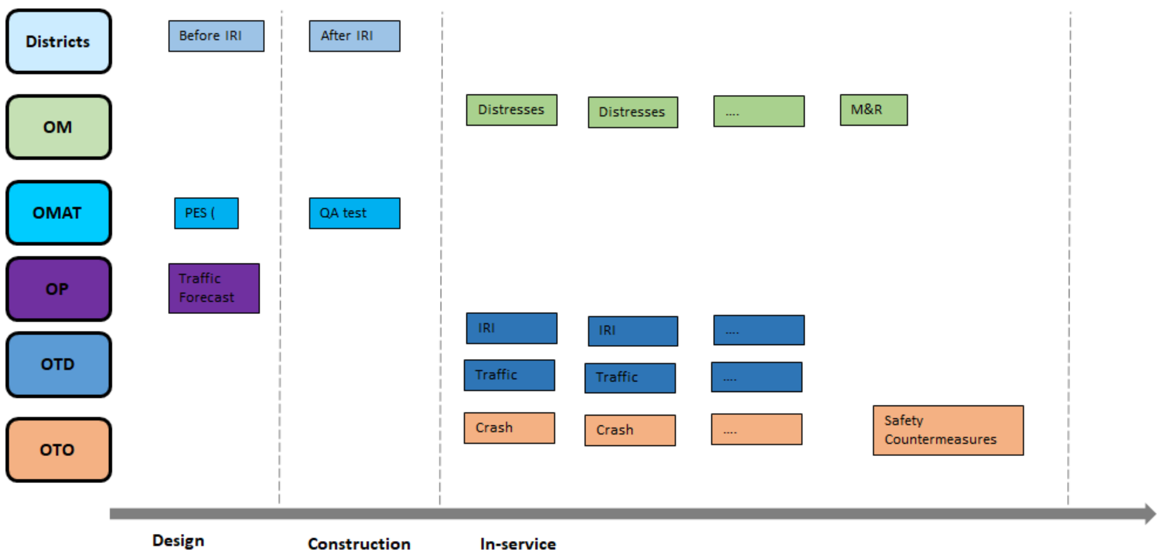

Figure 2-2. Chart. Data collected through pavement life-cycle activities.

- During the project development, traffic data is collected by OP for traffic forecasting; pavement data (including pavement condition survey, coring, etc.) is collected by OMAT for pavement design recommendations; IRI is collected by district offices to support pavement evaluation and to measure the improvement. These data are collected per project request, and the reports (including traffic diagram, PES, PTS, etc.) are stored in the project repository, “Project Wise,” based on the project number. While location information is available (often as a description), it is primarily searched by the project number.

- During the construction, various tests are conducted based on GDOT’s standards. For example, density and HCS IRI test data are collected on newly paved asphalt pavements for quality acceptance, and a friction number is collected on HFST sites. Again, these data are stored in “Project Wise.”
- Once the pavement is in service, OM conducts pavement condition evaluation each year to monitor the pavement condition and determine any necessary M&R treatments. In addition, IRI is collected every year by OMAT via HPMS program.
- Throughout a pavement’s service life, M&R activities, such as crack sealing, surface treatments, and resurfacing, are determined by OM and carried out by the district force or contractor. The let projects are stored in GeoPI, and the works by a district are recorded as the HMMS. In addition, safety countermeasures, such as HFST and raised pavement markers, can be installed by OTD. This data is not integrated into the asset management system.

In summary, the data collected throughout a pavement’s life-cycle activities are in different silos, which makes it difficult to retrieve all the data at a specific location (or project).

Summary of Data Collected by Different Offices

- Data, such as traffic data by OTD and crash data by OTO, are collected as principal sources for traffic and crash data that serve other offices and/or fulfill

FHWA reporting purposes. These data are, in general, collected in compliance with Federal regulations and guidelines. The data collection method, quality control and assurance, data processing, and reporting are documented, and the data are often shared via web applications with internal and external audiences.

- Data, such as pavement data, are collected regularly to fulfill an individual office's program needs. OM collects pavement condition evaluation data to support its annual pavement preservation programming; Bridge Maintenance collects element data to determine the deficiencies that need maintenance; Districts collect HCS IRI data for quality assurance. While each office has its own documentation and data quality control procedure, in general, the data collected and consumed by a single office is less documented (e.g., data dictionary), less formal in terms of QA/QC, and less assessable compared to the data collected to serve multiple offices.

CHAPTER 3. OPPORTUNITIES FOR ENHANCING GDOT'S DATA COLLECTION, SHARING, AND CONSOLIDATION

This chapter discusses the potential opportunities for data and activity sharing, coordination, and collaboration among different GDOT offices. This will improve GDOT operational efficiency and optimize its resource utilization while different offices in GDOT move towards better data sharing and coordination.

IMPROVING DATA SHARING

This section presents data sharing opportunities and recommended components and functions to facilitate data sharing among different offices.

- A GIS file, which includes GALTTP sites with regular pavement designs, special designs, and maintenance and rehabilitation (e.g. HFST sites, micro-milling and thin overlay, etc.) (Wu and Tsai, 2016), is available and can be shared among offices. It is suggested this data be published in a map format so various offices know where these sites are for long-term performance monitoring and enabling GDOT to take advantage of the data available. For example, GDOT engineers can easily map out where HFST sites are.
- Maintenance and rehabilitation projects, like resurfacing projects, have been made available through tools such as GeoPI, 411, etc. The main issue is that the upcoming projects may not be uploaded (or updated) frequently to keep the

information up to date. These tools provide user-friendly search function for a given project number. An interactive map query (e.g., search historical M&R projects (e.g., resurfacing) at a given location) can assist the users to find the projects by location.

- It is noted that location information is not recorded in a consistent format among different data sets. The location can be referenced using a milepoint (e.g., COPACES), a milepost (e.g., CPACES), and/or a description (e.g., resurfacing projects). It is recommended to have a common (or standardized) location reference, since it is essential for data sharing and coordination.
- Decision-making outcomes, including annual pavement resurfacing projects and safety improvement projects with different countermeasures, are important data for transportation asset inventory. They should be stored in the Georgia Asset Management System (GAMS) to support GDOT's asset management plan. For example, it is important to know where new M&R and safety countermeasures have been applied and how effective they are.

To facilitate data sharing among different offices, it is important to implement standardized metadata (i.e., a summary of basic information about the data), a data dictionary, and a common location reference system that can be accessed easily with an interactive map query. QA/QC of the data to be shared also needs to be in place. It is also to GDOT's overall benefit to study cases on how to utilize the available data collectively to provide the best data input for decision-makers. It is recommended to conduct a study to develop a plan that synthesizes, updates, and coordinates data collection efforts and that promotes sharing and maximizes utilization of the data collected by different offices.

OPTIMIZING DATA COLLECTION EFFORT FOR MULTIPLE PURPOSES

There are potential opportunities for GDOT to optimize its data collection efforts, which will save GDOT money and improve various operations.

- CHAPTER 4 presents a sampling data collection plan that combines the purposes of LTPP data for pavement ME design, calibration, and pavement management (long-term performance forecasting for each of the new state route prioritization categories).
- While the Office of Maintenance (OM) is moving towards a new pavement management production plan that has an outsourced, automated pavement data collection method, there is an urgent need to establish a quality assurance program. The data collected for both data quality assurance and long-term performance forecasting could be combined to optimize the data collection effort.

MAXIMIZING UTILIZATION OF NEW SENSOR DATA

With the advancement of sensing technologies (2D imaging, 3D laser, and 3D Lidar), the high-resolution sensor data (video log images, 3D pavement surface data, and 3D Lidar cloud data) have become widely available. There are opportunities for GDOT to take full advantage of this sensor data (e.g. 3D pavement data).

The high-resolution, full-coverage 3D pavement data is used to automatically or semi-automatically extract pavement distresses and is used to replace GDOT's visual and manual survey. 3D pavement data can provide an automatic and objective pavement condition evaluation using image processing techniques and/or artificial intelligences. Previous studies have demonstrated it is feasibility to automatically detect and measure cracking (Tsai & Li, 2012; Jiang & Tsai, 2015) and its deterioration (Jiang et. al., 2016), rutting (Tsai et. al., 2013), concrete joint faulting (Tsai et. al., 2012), and automatic pothole detection (Tsai & Chatterjee, 2017). 3D laser technology has been successfully implemented by the Georgia Department of Transportation (GDOT) in a large scale interstate highway system through the research project of "Implementation of Automatic Sign Inventory and Pavement Condition Evaluation on Georgia's Interstate Highway" and has been competitively selected as the 2017 AASHTO High Value Research (HVR) Award (Sweet 16) (https://research.transportation.org/sweet-sixteen-2017/) (Tsai et. al. 2017) because of its successful implementation of 3D laser technology and Lidar technologies along with automatic feature extraction on a large-scale infrastructure system. Figure 3-1 illustrates the utilization of 3D pavement data at 3 different levels.

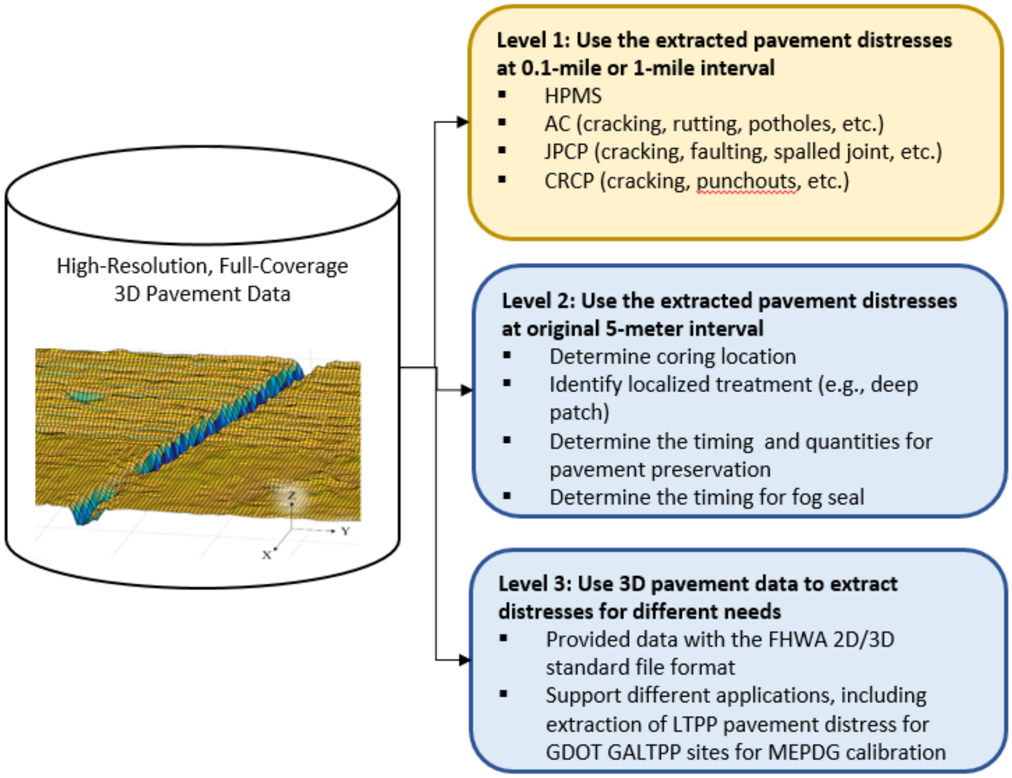

Figure 3-1. Illustration. Utilization of 3D pavement data at 3 different levels.

- ***Level 1: use the extracted pavement distresses at 0.1-mileor 1-mile interval***

  3D pavement data is used to enhance the pavement condition data collection over the current manual and visual pavement distress survey. GDOT is currently conducting a 3D pavement data collection effort. As shown in Figure 3-1 (Level 1), the vendors provide the aggregated pavement distress at 0.1-mile or 1-mile interval although the pavement distress extracted by vendors is at a 5-meter interval. At this level, these applications, using 0.1-mile or 1-mile interval pavement distresses, include 1) HPMS pavement distress reporting (e.g. cracking on wheel path, rutting, IRI, etc.) for OTD and 2) the Pavement Condition Evaluation System (PACES) data needed by OM.

- ***Level 2: use the extracted pavement distresses at original 5-meter interval***

  As shown in Figure 3-1(Level 2), the pavement distress data extracted by the vendor is at a small interval (e.g., 5 m), there is an opportunity for GDOT to use this detailed interval of pavement distress data already available to support different business operations in GDOT. One example is for OMAT to use this data for its pavement condition evaluation for M&R decisions at the project level. OMAT can review pavement distresses at 100-ft interval to identify the coring locations and problematic areas effectively. OM and OMAT can also use this detailed data to better determine the localized treatments (e.g. a few hundreds of feet) to optimize the pavement maintenance and rehabilitation decision and cost.

- ***Level 3: use 3D pavement data to extract distresses for different needs***

  Finally, as shown in Figure 3-1 (Level 3), 3D pavement data can be used to extract distresses for different needs. GDOT can request vendors to provide 3D pavement surface data with the FHWA 2D/3D standard file format. The 3D pavement data can be used to extract different distresses, like raveling, etc. by GDOT with more advanced pavement distress methods in the future. The 3D pavement data with the standard file format can be used to extract other pavement distress protocol, like LTPP (rather than GDOT PACES) to support MEPDG calibration using the same 3D pavement data. It can be used to extract other pavement distresses and performance indicators with the same 3D pavement data. For example, it can be used for project-level micro-milling pavement surface texture construction quality control (Tsai et. al. 2014), raveling detection and classification (Tsai & Wang, 2015), and faulting computation using a new area-based faulting measurement (Geary et. al, 2018). These can be achieved by requesting the contactor to provide 3D pavement surface data with FHWA's open and standard file formats. It is recommended 3D pavement surface raw data be obtained so GDOT can flexibility reprocess the data for use by different offices.

Besides 3D pavement data, other sensor data, such as video log images and Lidar data, can be used to support GDOT's other assets (e.g., sign, guardrail, etc.).

- GDOT could take advantage of the video log images already collected by contactors to cost effectively extract roadside features, including signs, guardrails, pedestrian crossings, etc. By doing so, the transportation agency could optimize its data collection effort and process the video log image data based on different purposes/requirements. Thus, it is essential for GDOT to acquire good quality video log image data to support different applications.
- 3D Lidar cloud data provides a means to cost effectively assess the retro-reflectivity condition (nighttime visibility) of pavement striping and signs. It can also be used to accurately measure the grade, cross slope, and sight distance, which are important to roadway safety and design. The contractors typically collect Lidar data in their data collection projects. GDOT can take full advantage of the 3D Lidar cloud for roadside asset management and roadway safety assessment. Lidar technologies have been widely applied to intelligent transportation asset management and safety analysis applications, which have been discussed in various peer-reviewed journals. They include automatic sign

detection (Ai & Tsai, 2014), sign retro-reflectivity assessment (Ai & Tsai, 2016a), cross slope measurement (Tsai, et. al., 2013), sidewalk and sidewalk ramp compliance with Americans with Disabilities Act (ADA) requirements (Ai & Tsai, 2016b), and roadway curve safety assessment (Tsai et. al., 2018).

OPTIMIZING RESOURCES THROUGH ACTIVITY COLLABORATION AMONG DIFFERENT OFFICES

GDOT has actively sought to improve its operational efficiency. This section presents the opportunities for GDOT to improve its operational efficiency and optimize its resources utilization by data and activity collaboration among different GDOT offices. The following is an example:

- Besides data sharing and coordination, both OM and OTO mentioned the opportunity for further collaboration on projects. OTO is working with OM to ensure the pavement marking laid down after resurfacing meets current standards. Incorporating safety into annual resurfacing projects is part of the recommendations in RP 09-11, "Optimization of Safety on Pavement Preservation Projects" (Tsai et al., 2011). Such collaboration provides a systematic approach to upgrading all striping on roadways to the standard within the resurfacing cycle (e.g., 10 years). An enhanced, safety-incorporated program consisting of three components was proposed to seamlessly integrate safety improvements into GDOT's current fast-paced resurfacing program. A two-stage approach is established (Tsai et al., 2011) to identify the projects with potential pavementdeficiency-induced safety concerns and roadway upgrade needs to meet enhanced safety standards is proposed. The two stages are 1) a computerized search based on integrated data, including pavement condition (e.g., distress type, severity), roadway characteristics (e.g., shoulder width), and crash history (e.g., type, frequency, and severity of crashes), and 2) a field evaluation to confirm the safety concerns and roadway upgrade needs. A safety index to quantify the safety concerns/risks identified through the two-stage approach is also proposed.

IMPROVING INFORMATION FLOW THROUGHOUT LIFE-CYCLE ACTIVITIES

There are information gaps among different life cycle activities (from planning, design, construction, performance measure, and maintenance and rehabilitation) because these activities are in different silos. More cost-effective decisions could be efficiently made if the information could easily flow throughout the life cycle activities through various GDOT offices, thus significantly improving GDOT's operational efficiency. It is currently difficult to find the planning, design, construction, maintenance activities, and performance data in one single location. Linking the information flow among different life cycle activities using a common location reference is highly recommended so that life cycle activities at the same location could be integrated, linked, and easily retrieved using the location information (or clicking a point on the map) to support efficient and effective decision making. Currently, design projects, construction projects, and maintenance projects (e.g. let project ID) have separate keys, which makes it difficult to link all of them. They have different location references. Thus, it is difficult to integrate them. Having standard, integrated location data with the same linear location reference system (LRS) for design, construction, and MR&R projects is highly recommended.

The following two cases illustrate the challenges and potential opportunities to make a more cost-effective decisions after establishing the information flow among different life cycle activities.

- **Case 1: e-HFST**

  HFST projects are first selected in the planning and design stage. The data in planning and designing are in one silo. When the HFST projects have been moved to construction, this is another silo in which the actual locations of HFST installation might be removed or adjusted due to the field pavement condition or other considerations. However, all the information is not passed on to the maintenance office that is in charge of performing the performance measures and maintaining and restoring HFST when it comes to the end of its service life. This is another silo. It would be valuable if the information throughout the life cycle activities among three different silos could be shared and coordinated. The standard and consistent location info with a common location reference system for the project could be electronically mapped out at different stages of its life cycle and would be essential for determining HFST activities at different stages of a project's life cycle. This will improve the operational efficiency and effectiveness in making HFST decisions during planning, design, construction, performance monitoring, and maintenance and rehabilitation. For example, the locations with pending resurfacing projects could be coordinated with the planned

HFST projects, which would enable the most cost-effective decisions, thus optimizing GDOT's resources.

- **Case 2: e-Pavement life cycle activities (design, construction, and performance, and M&R)**

  With the use of a common location reference for all activities throughout the life cycle, GDOT engineers would be able to obtain the history of a selected pavement project (its design, construction, performance data, M&R history, and traffic history) by clicking a point on the GIS map. This information is essential for GDOT engineers to make effective and efficient M&R decisions. Although this information is available, it is currently difficult to get and integrate throughout a project's life cycle because of the current data formats. For example, Construction has a PI number different than Design and Construction, and location information may not be consistent. Thus, the current data formats make it difficult for GDOT offices to share this information. In turn, this makes it difficult to support MEPDG calibration or to evaluate the cost-effectiveness of a specific treatment method, it is necessary to find the pavement design, MR&R, and pavement condition over several years, which is quite difficult.

CURRENT AND FUTURE DATA NEEDS

This section discusses the current and future data need. Besides actively collecting the data needed now, GDOT has also proactively prepared the data needed in the future for improving roadway safety, asset management, Americans with Disabilities Act (ADA) compliance, active transportation/complete streets, pedestrian and bicycle safety consideration, and connected and autonomous vehicles, etc.

- **Knowledge Retention and QA/QC**: GDOT and other state DOTs are facing the retirement of many experienced engineers and reductions in personnel. It is essential to develop a knowledge base that can retain the valuable knowledge and experience of these departing personnel, especially their knowledge and experience of pavement distresses and treatments, in order to maintain a sustainable pavement program. Also, GDOT is in the process of outsourcing its data collection, and a data quality assurance program is urgently needed to ensure the data quality collected from vendors.
- **Americans with Disabilities Act (ADA) compliance**: A great amount of roadway data is needed to support the evaluation of ADA compliance, including sidewalk ramps, pedestrian crossing, etc. There is a need to explore the technologies, like Lidar technologies to cost effectively collect these data.
- **Asset Management**: Besides the roadway conditions (like pavements, bridges, safety), roadside assets (including pavement markings, signs, guardrails, and other safety countermeasure devices, like rumble strips, central cable barriers, etc.) will be needed in the future. Other assets, including retaining walls, noise barriers, etc. will also need to be collected in the future to establish a comprehensive roadway asset management. ADA compliance and active transportation will also be incorporated into the mainstream asset management. Therefore, GDOT will need to prepare ahead of time for how to cost effectively collect the needed data.

- **Active transportation and complete streets**: Complete streets and active transportation concepts have become demands for meeting future trends in roadway design. These trends in development will need to include information on such things as sidewalks, bike paths, the use of various kinds of vehicles, etc. Therefore, transportation agencies like GDOT will need to collect data on such assets in the near future and incorporate active transportation and complete streets planning into mainstream asset management methods and plans.
- **Pedestrians and bike users:** With the changes in transportation behavior, walking and biking have increased. The number of pedestrian/bike crashes has become a concern. It is, therefore, important to study the behavior of pedestrians and bikers to improve their safety and understand the infrastructure needs for sidewalks and bike paths.
- **Safety improvement:** Much money has been spent in the US by transportation agencies, like GDOT, to apply different countermeasures to roadways, including High Friction Surface Treatment (HFST) to improve the safety in critical sections (e.g. curves and merge sections requiring good friction for acceleration and deceleration). GDOT has actively explored different countermeasures to improve roadway safety, including light-weight aggregates, a cost-effective material that maintains pavement friction. Although there is research project to measure the performance of these countermeasures, HFST and light-weight aggregates (friction), there is a need to assess them systematically so their performance can be measured; the resulting feedback can then be effectively applied to the system. In addition, it can also be used to support crash-reduction analysis.

- **Connected and autonomous vehicles:** Transportation agencies will continue to serve roadway infrastructure needs, even in the new transportation ecosystems with their connected and autonomous vehicles. Although lots of studies on the fully autonomous vehicle era, we will have decade to come with a mix of human drivers and autonomous vehicles coexisting on the road network. We need to think about what infrastructures, like pavement marking and signs, will be needed to support the mix of highway users (human drivers and autonomous vehicles). In addition, we need to discover what information GDOT and other state DOTs will need to collect to provide road users with the new, efficient transportation ecosystems.

CHAPTER 4. PROPOSED GALTPP MONITORING AND MANAGEMENT PLAN

Based on the opportunities presented in CHAPTER 3, a pavement monitoring and management plan that consolidates the sites and optimizes the data collection effort is proposed to provide the data needed for pavement design and pavement management. This includes the data to support 1) the future local calibration of the MEPDG performance models for use in Georgia, 2) the new state route prioritization policy with four categories of roadways (critical, high, medium and low) for more cost-effective and efficient maintenance and management of the pavements, and 3) the quality assurance for the new pavement data production operations. The proposed plan was designed to leverage the 3D pavement data collected through the new pavement data production operation and its quality assurance processes to obtain the pavement distress data needed for the pavement design and state route prioritization policy. This chapter presents the proposed plan, including the site selection strategy (including the proposed sites) and the data collection plan.

DESIGN OF SITE SELECTION

This section lays out the site selection strategy used to select the sites to fulfill the aforementioned purposes. Three types of sites, including MEPDG calibration sites, state route prioritization category sites, and quality assurance sites, are included in the proposed plan for supporting the pavement design and pavement management. Figure 4-1 presents the site selection strategy and steps.

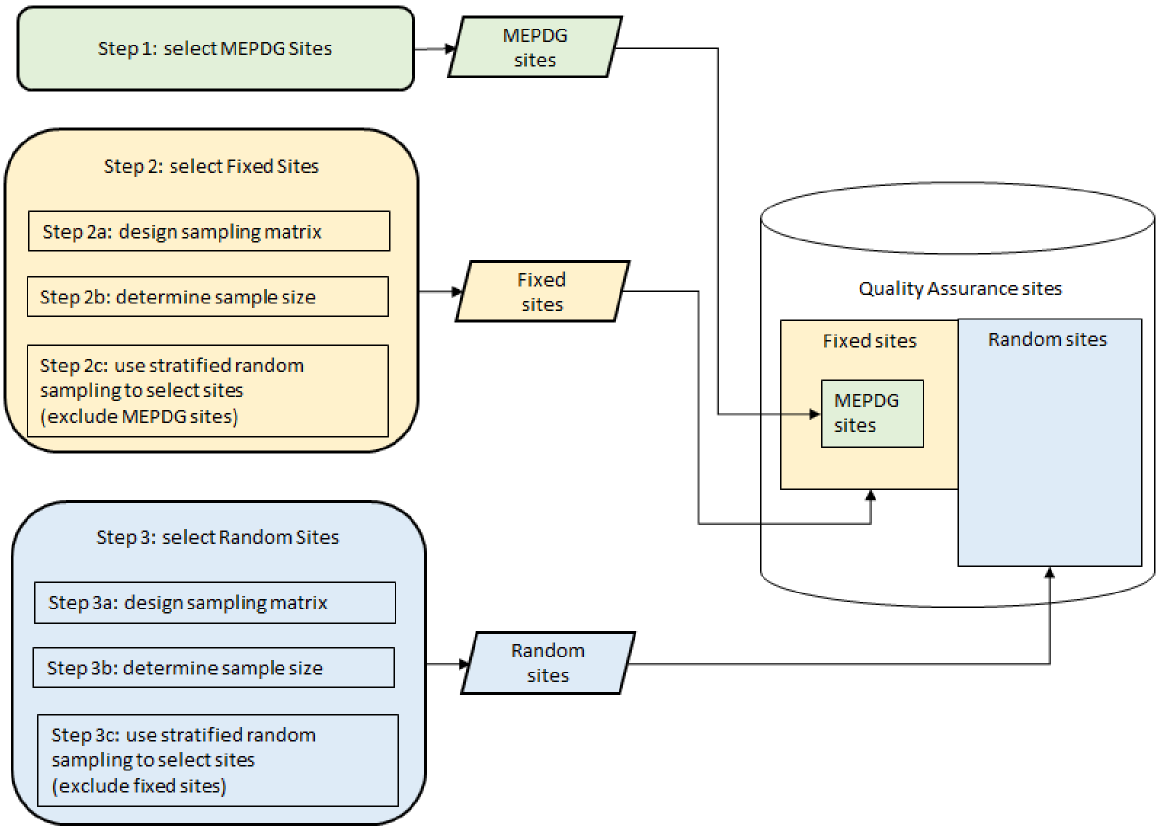

Figure 4-1. Illustration. Site selection strategy and steps.

The site selection strategy is to design the same site to serve multiple purposes (as much as possible), to maximize the utilization of the sites, and to consolidate the data collection effort. Therefore, the MEPDG calibration sites (which have the least number of sites and the most detailed data) will serve as state route prioritization category sites and quality assurance sites. Similarly, the state route prioritization category sites will also serve as quality assurance sites. As shown in Figure 4-1, the quality assurance sites, which require the largest number of sites, are divided into fixed and random sites. The fixed sites refer to the sites at fixed locations (i.e., the data will be collected at the same location each year). These include the sites that support the MEPDG local calibration and the state route prioritization policy. The random sites are selected randomly each year (at different locations) to ensure the data quality. By incorporating the MEPDG calibration sites and state route prioritization category sites into the quality assurance processes, GDOT can consolidate the sites and the data collection effort. This can result in cost savings and provide a sustainable, long-term performance monitoring program. In addition, through the quality assurance processes, the pavement condition data will be reviewed by both the contractor and GDOT. Thus, good quality data can be obtained on these sites. A stratified random sampling is used in the site selection. For each type of site, a sampling matrix is designed based on the factors that are critical for the purpose it serves, and random sampling is then used in each cell for selecting the sites unbiasedly. The site selection follows the three steps described below:

1) First, the sites used in the initial MEPDG local calibration (Von Quintus et al., 2016) are included as the default sites. These sites were selected based on a sampling matrix with the design feature factors (e.g., thickness) that have an impact on the pavement performance; additional sites can be added for studying the design features of GDOT's interest.
2) Second, a stratified random sampling is used to select state route prioritization category sites (or fixed sites). This involves several steps.
   - A sampling matrix is designed for the state route prioritization category sites by considering the prioritization category and additional factors that affect the pavement performance.

- The total sample size is then determined based on the modification for the Cochran's formula for sample size calculation in smaller populations (Cochran, 1977). The formula (Equation 1) allows one to calculate an ideal sample size given a desired level of precision, desired confidence level, and the estimated proportion of the attribute present in the population. The sample size is modified using Equations 2 if the population size is known.

  $$n_0 = \frac{Z^2 \text{pq}}{e^2} \quad \text{(Equation 1)}$$

  $$n = \frac{n_0}{1+(n_0-1)/N} \quad \text{(Equation 2)}$$

  Where:

  e is the desired level of precision (i.e. the margin of error).
  p is the (estimated) proportion of the population which has the attribute in question.
  q is 1 – p.
  The z-value is found in a Z table.
  N is the population size.

- The total sample size is distributed to each cell in the sampling matrix based on roadway proportion (i.e., percentage of length in that cell); the existing MEPDG calibration sites are assigned to each cell based on their corresponding factors as well. The sample size in each cell is then updated by subtracting the assigned MEPDG sites from the sample size for that cell. The remaining sites in each cell are then selected randomly to fulfill the updated sample size.

3) The same procedure described in Steps 2 is repeated for selecting random sites. Again, a sampling matrix is first designed with factors that affect the data quality. The sample size is determined by the sampling rate suggested by FHWA (FHWA,

2003) and distributed into each cell based on roadway proportion. After taking out the fixed sites in each cell, the sites in each cell are selected randomly.

SITE SELECTION

This section describes the site selection based on the strategy and steps described in the previous section.

Table 4-1. Sampling matrix for quality assurance sites.

Pavement Type	Route Type	Route Prioritization	Traffic	MEPDG Sites	Fixed Sites				Random Sites			
					Total	Condition: Good[d] (50%)	Condition: Fair[d] (40%)	Condition: Poor[d] (10%)	Total	Condition: Good[d] (50%)	Condition: Fair[d] (40%)	Condition: Poor[d] (10%)
Flexible Pavement	Interstate	Critical	H[a]	2	6	3	2	1	15	2	6	7
			M[a]	3	4	2	2	0	12	1	5	6
			L[a]	1	5	2	2	1	13	1	5	7
	Non-interstate	Critical	H[b]	10	9	5	3	1	42	4	17	21
			M[b]	3	14	7	6	1	35	3	14	18
			L[b]	3	12	6	5	1	33	3	13	17
		High	H[b]	3	15	7	6	2	51	5	20	26
			M[b]	0	10	5	4	1	27	2	11	14
			L[b]	3	19	10	7	2	62	6	25	31
		Medium	-[c]	3	24	12	10	2	64	6	26	32
		Low	-[c]	5	26	13	10	3	71	7	28	36
Rigid Pavement	Interstate	Critical	H[a]	0	2	1	1	0	6	1	2	3
			M[a]	0	3	2	1	0	9	1	3	5
			L[a]	5	1	1	0	0	18	2	7	9
	Non-interstate	-	-[c]	15	0	0	0	0	0	1	3	4

a: For interstate highway, traffic categories are defined as H (>75,000), M (50,000-75,000), and L (<50,000).
b: For non-interstate highway, traffic categories are defined as H (>10,000), M (10,000-5,000), and L (<5,000).
c: For non-interstate, traffic categories are not used for the Medium and Low priority routes.
d: The pavement conditions are categorized into Good (100-85), Fair (85-70), and Poor (<70).

Table 4-1 represents the sampling matrix along with the number of sites in each cell. These sites were selected based on the factors and assumptions discussed in this section. These proposed sites can be updated using the same steps when the factors or data (e.g., pavement condition) are changed.

- **MEPDG calibration sites**

  During the initial MEPDG local calibration (Von Quintus et al., 2016), 36 flexible pavement sites s (including 15 LTPP sites and 21 GA calibration sites) and 20 rigid pavement sites (including 8 LTPP sites and 12 GA calibration sites) were used for the calibration. These sites were selected based on the factors that represent current GDOT design practices and materials (such as thickness, binder type, soil type, etc.) (Von Quintus, 2016). A wealth of information was collected on these sites. These sites are selected as part of the fixed sites for long-term performance monitoring, as shown in Table 4-1 (MEPDG sites). The total number of MEPDG sites (56) fulfill the requirement in the MEPDG Local Calibration Guide (AASHTO, 2010). It is suggested below that additional sites, interstate sites and soil cement sites, be included for future calibration of these two pavement designs.

  - Currently, there are only three Georgia calibration sites (GaCal sites) on interstate highways (I-85, I-95, and I520) with the use of SMA (stone matrix asphalt). Since the 1990s, Georgia has used a 0.875 – 1.25-in of porous friction course (e.g., open graded friction course, OGFC or porous European mix, PEM) and a 1.5 – 2-in of 12.5-mm SMA to provide durability and enhance safety on the roadways (e.g., reducing splash and spray during wet weather). As this has become the standard practice on Georgia's interstate highways, it is suggested that additional sites be included for supporting future MEPDG calibration of this design. Five sites (2 with high traffic; 2 with medium traffic; 1 with low traffic) can be added to better calibrate the pavement performance on the interstate highways.

- The MEPDG calibration sites include six soil cement sites, which are common pavement design in southern Georgia. All six sites are in District 4, including two sites on State Route 300 and one site each on State Routes 1, 25, 38, and 67C. It is suggested additional two sites in Districts 2, 3, or 5 be included to better study the performance of the soil cement sites.

- **Fixed site selection**

  The factors, including pavement type (asphalt pavement and concrete pavement), route type (interstate and non-interstate), prioritization category (Critical, High, Medium, and Low), and traffic were identified as having an impact on the pavement deterioration and M&R policy; thus these factors are considered in the sampling matrix. It is noted that the route prioritization is not applied to the rigid pavements because majority of rigid pavements are on interstate highways and only limited miles (~168 miles) are on non-interstate highways. The traffic data was analyzed to determine the categories. Figure 4-2 shows the accumulated percentage of AADT on interstate highways and on non-interstate highways (Critical and High priorities). The interstate highways carry significantly more traffic than the non-interstate highways. Based on the distribution, the traffic is categorized into three categories (Low: 0-50,000, Medium: 50,000-75,000, and High: >75,000). The AADT on Critical and High categories (in green and orange) show similar distributions with approximately

80% of the roadways with an AADT less than 25,000. Thus, three traffic categories are determined (Low: 0-5,000, Medium: 5,000-10,000, and High >10,000). As the roadways in Medium and Low categories in general have an AADT less than 3000, the traffic in these two categories are not further categorized.

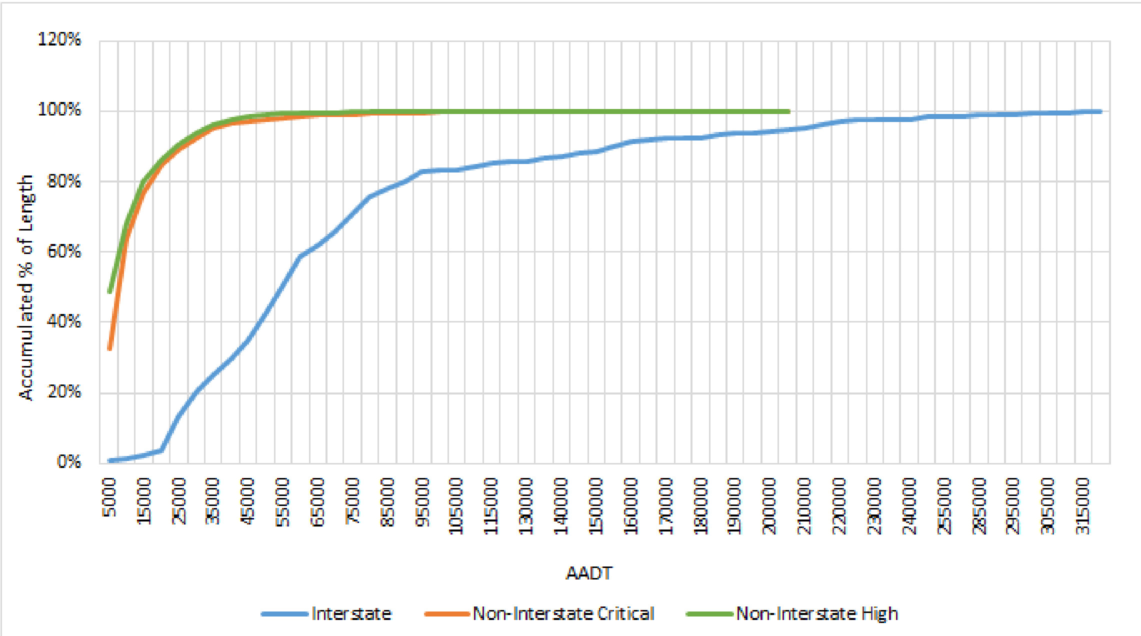

Figure 4-2. Graph. Accumulated percentage of AADT.

The total sample size is determined using the sample size estimation formula by Cochran (1977). There are approximate 22,000 surveyed miles. With a precision level of 7% (0.07), a confidence level of 95%, and an estimated proportion (p) of 0.5, the sample size is 194. This provide a sampling rate of 0.88% out of the 22,000 surveyed miles. Note that this sample rate was the adjusted based on road type and prioritization category to have more samples in Critical and High categories. An adjusted sampling rate of 1.3% is used for interstate highways; a rate of 1.2%, 0.9%, 0.6%, and 0.6% is used for Critical, High, Medium, and Low priorities on non-interstate roadways. Various spatial analyses were performed to integrate all factors (including state route prioritization, traffic, and pavement condition) from different data sources onto each section of the roads using GDOT's linear referencing system (GDOT, 2018). The length for each cell in the sampling matrix (Table 4-1) was computed, and the sample size was computed by multiplying the length and sampling rate. As the MEPDG sites are already included in the fixed sites, they were, then, subtracted from the corresponding cells. Table 4-1 summaries the fixed sites (exclude the MEPDG sites). The sites are further split by the pavement condition. For fixed sites, most sites (90%) were in Good or Fair conditions, so a performance curve can be established for these sites. Finally, the candidate sites were randomly selected based on the sample size in each cell.

- **Random site selection**

  The random sites share the same sampling matrix as the fixed sites; however, the sample size was determined separately. FHWA guideline (FHWA, 2013) suggests a 2% to 10% sampling for quality assurance; a review of various DOTs' practices shows a 2.5% to 15% sampling is used by different states for quality assurance. Currently, a 3% check is conducted by Pathway in its internal quality control process. Thus, a 3% sampling is tentatively proposed for quality assurance. This 3% quality assurance would require GDOT to check approximately 690 miles of its 22,000 miles of roadways. Among the 660 sites, 194 sites are already selected as fixed sites and the remaining 466 sites are random sites. The quality assurance should be conducted on the sites with more distresses (i.e. lower rating). Thus, more sites are selected from the pavements in Fair (40%) and Poor (50%) conditions. Table 4-2 summarizes the random (4466) sites based on the assumptions and factors discussed above. Figure 4-3 shows a map of the proposed sites.

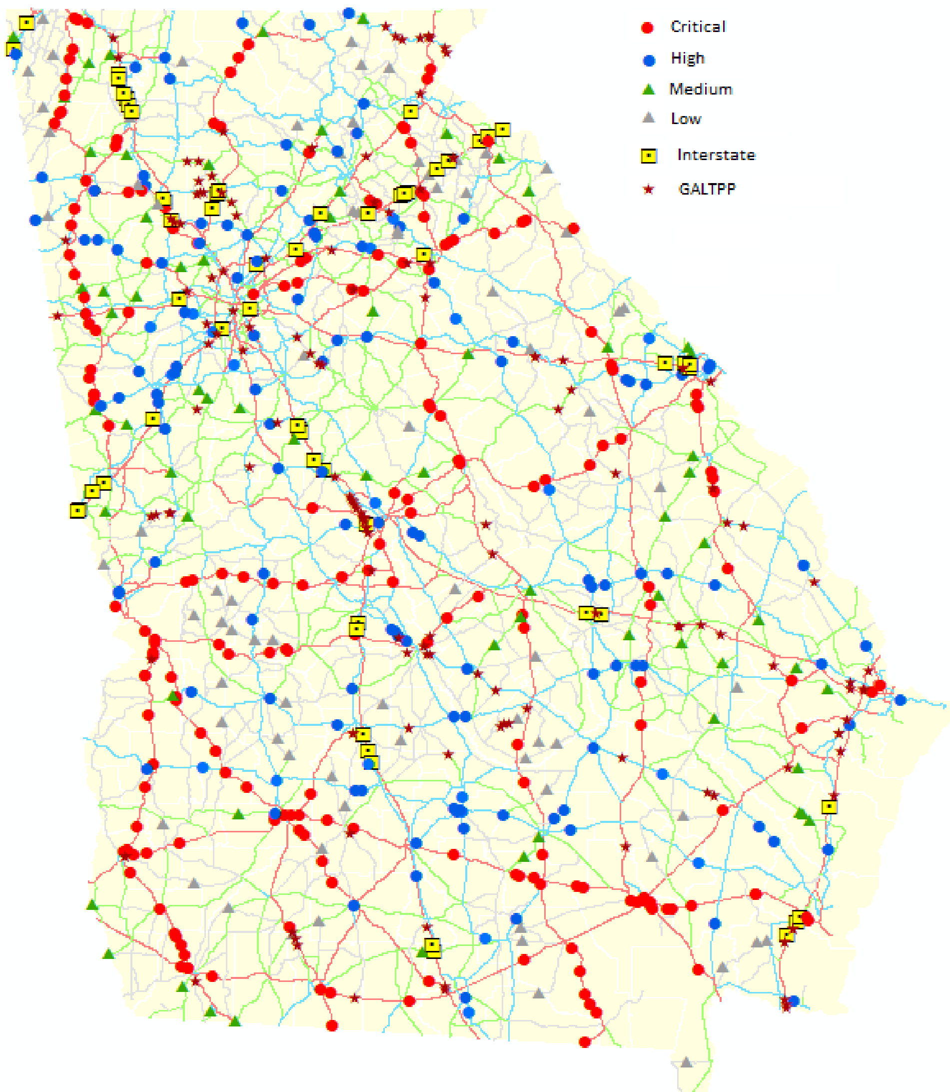

Figure 4-3. Map. Proposed sites.

DATA COLLECTION

This section describes the layout of the different sites (length) and the data to be collected for each type of site to serve its corresponding purpose.

Site Layout

Table 4-2 summarizes the length of different sites, including the MEPDG calibration sites, the state route prioritization category sites, and the quality assurance sites.

Table 4-2. Summary of site length.

	Site Length
MEPDG calibration sites	500 ft. (~ 0.1 mile)
State route prioritization category sites	1 mile
Quality assurance sites	1 mile

- All the MEPDG calibration sites (existing sites and additional sites to be added) maintain a length of 500 ft. (~0.1 mile) to be consistent with the site layout specified by the LTPP program (FHWA, 2003).
- As the state route prioritization category sites are part of the quality assurance sites, a length of 1-mile can be used to be consistent with the quality assurance sites. Simpson et al. (2018) studied the standard deviation of different distresses (rut, crack and IRI) along the segment based on different sample length using HPMS data. For all three distresses, the standard deviation decreases with longer sample length, as shown in Figure 4-4. The pavement distresses on concrete pavement vary more within one mile. Figure 4-5 shows the slab condition along a 1-mile section. An index of zero indicates no distress on the slab. The higher the index, the more severe distresses on the slab. An index of 3 indicates a shattered slab. As shown in Figure 4-5, while this mile has significant distressed slabs, there are locations (e.g., 0.6) with very little distresses. The use of a short site length

increases the risk of over or underrepresenting the distresses. Therefore, a 1-mile length is used for the state route prioritization category sites and quality assurance sites.

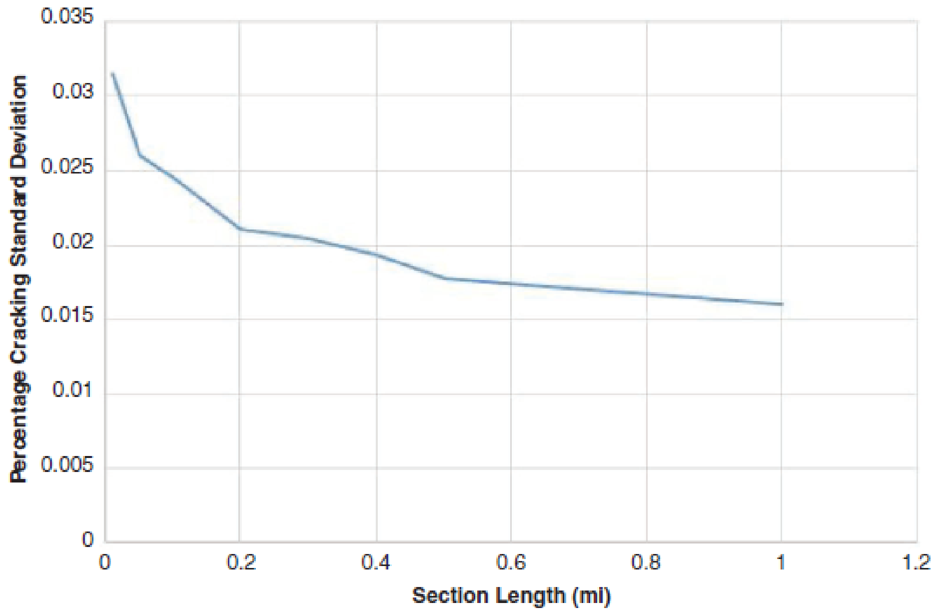

Figure 4-4. Graph. Change in standard deviation of percentage cracking by section length (Simpson et al., 2018).

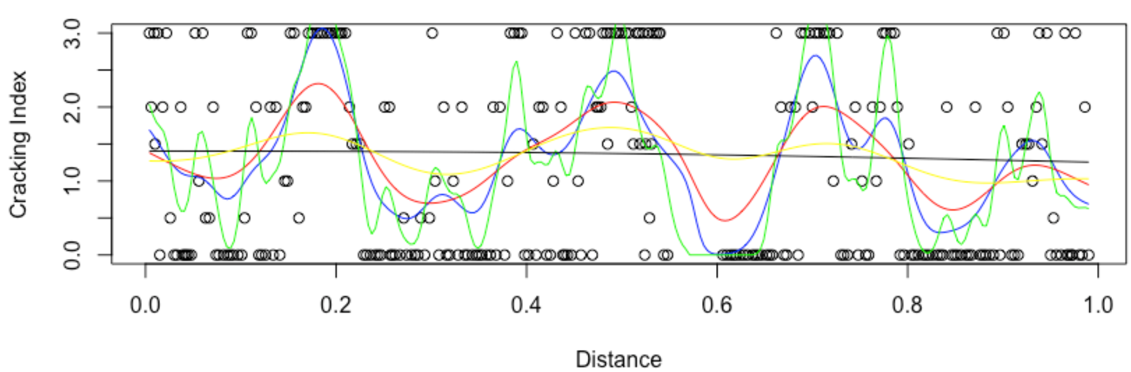

Figure 4-5. Graph. Cracking index on 1-mile of JPCP by section length.

Data to be Collected

Table 4-3 lists the data items, along with suggested frequency, to be collected on the three types of sites. The MEPDG calibration sites require the most extensive data collection, including distress data, traffic data, pavement structure, maintenance and rehabilitation activities, and material properties. Note that the distress data should be collected based on the LTPP distress protocol. Annual data collection is preferred or, at least, every two years. Traffic data is collected each year for the accumulated traffic. Other data, such as material properties and pavement structure, are collected one time. Note that the pavement structure data can be collected every two years to study the trend. The M&R activities should be collected as they occur.

Table 4-3. Quality assurance sites.

	MEPDG sites	Fixed sites	Random sites
IRI	✓	✓	✓
Pavement Distresses	✓[a]	✓[b]	✓[b]
FWD	✓	✓	
Core	✓		
Lab Tests	✓		
M&R activities	✓	✓	

a: pavement distress data is collected in according with LTPP distress protocol.
b: pavement distress data is collected in according with GDOT's distress protocol.

Monitoring data is required on the state route prioritization monitoring sites for long-term performance monitoring. The pavement condition evaluation based on GDOT's distress protocol is essential for long-term performance monitoring and needs to be collected annually (or at least every two years). FWD is also recommended on these sites to provide a better understanding of the change in structure capacity. FWD can be collected every two years. The only data collection needed on the quality assurance sites is to review the distress data based on GDOT's distress protocol. The data need for each of the purposes is described below:

- IRI: The reported IRI values should be computed from pavement profile data in accordance with AASHTO Standard R43-13 "Standard Practice for Quantifying Roughness of Pavement" (AASHTO, 2014). This method requires the calculation of IRI for each wheel path in a section, then averaging the two IRI values to determine the Mean Roughness Index (MRI) for the section which is reported.
- Pavement distresses: Distress surveys on the MEPDG calibration sites should be conducted in accordance with the FHWA Distress Identification Manual to measure the magnitude and identify the severity level of distress observed along the segment. Specifically, the longitudinal cracking, alligator cracking, transverse cracking, and rutting need to be measured for the calibration.
- Distress surveys on the fixed and random sites should be conducted in accordance with GDOT's distress protocols, including PACES (GDOT, 2007), JPCPACES (GDOT, 2018a), and CRCPACES (GDOT, 2018b).
- FWD: FWD deflection basin measurements was collected every 50 feet over the length of the section within the right wheel path (Von Quintis et al., 2016). The LTPP specifies the testing interval within the section as 25, 50, or 100 ft. for flexible pavements, and every 10 or 20 slabs or every third joint for rigid pavements (FHWA, 2006). It is suggested the FWD is collected every two-years on both the MPEDG calibration sites and the state route prioritization monitoring sites to provide monitoring on the pavement structure capacity.

While GDOT is not collecting FWD at a network-level, several states, such as Kansas and Texas, collect FWD at the network level. A study for the Kansas DOT demonstrated that conducting 3 to 10 FWD tests per 1-mile section (0.33-mile interval to 0.1-mile interval) showed no significant difference between their resulting mean deflection values, which confirms that 3 test points per 1-mile are sufficient for characterizing the section's structurally done for Texas DOT (Damnajovic and Zhang, 2006).

- Core: Nine 6-inch diameter cores were drilled through the depth of the pavement. The nine cores from each test location were spaced over the length of the section. Three cores were taken in distressed areas, and the other six were selected randomly in areas without cracking. The cores should be photographed by a special GPS camera provided by GDOT.
- DCP: DCP measurements were performed at three core holes over the length of the section. The DCP penetration rates were used to estimate the in place resilient modulus for the unbound layers in comparison to the back calculated values from the FWD deflection basins.
- Lab tests: Core thicknesses and individual layer heights were measured. The base and surface layers were sawed or separated into individual layers using a wet saw. The bulk specific gravity of each layer was measured in accordance with AASHTO T 166, "Bulk Specific Gravity (G_{mb}) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens" (AASHTO, 2008). The maximum specific gravity of each layer was measured in accordance with AASHTO T 209, "Theoretical Maximum Specific Gravity (G_{mm}) and Density of

Hot Mix Asphalt (HMA)" (AASTO, 2012). The asphalt content was measured for selected layers near the bottom of the pavement using the NCAT ignition oven.

- M&R activities: Examples include seal coats, crack sealing, patching, joint sealing, grinding, milling less than 25 millimeters (mm) (1 inch) deep, and grooving. The collected maintenance data provides such information as what maintenance activity was performed and when it was performed.

The data collected on the MEPDG calibration sites, state route prioritization category monitory sites, and quality assurance sites can be stored and managed in the GALTPP database. The GALTPP database already contains the tables for the pavement structure, traffic, and pavement distresses. The following updates are needed.

- Include the state route prioritization category monitoring sites into the GALTPP database
- Add a table for storing pavement distress data based on GDOT's distress protocol.

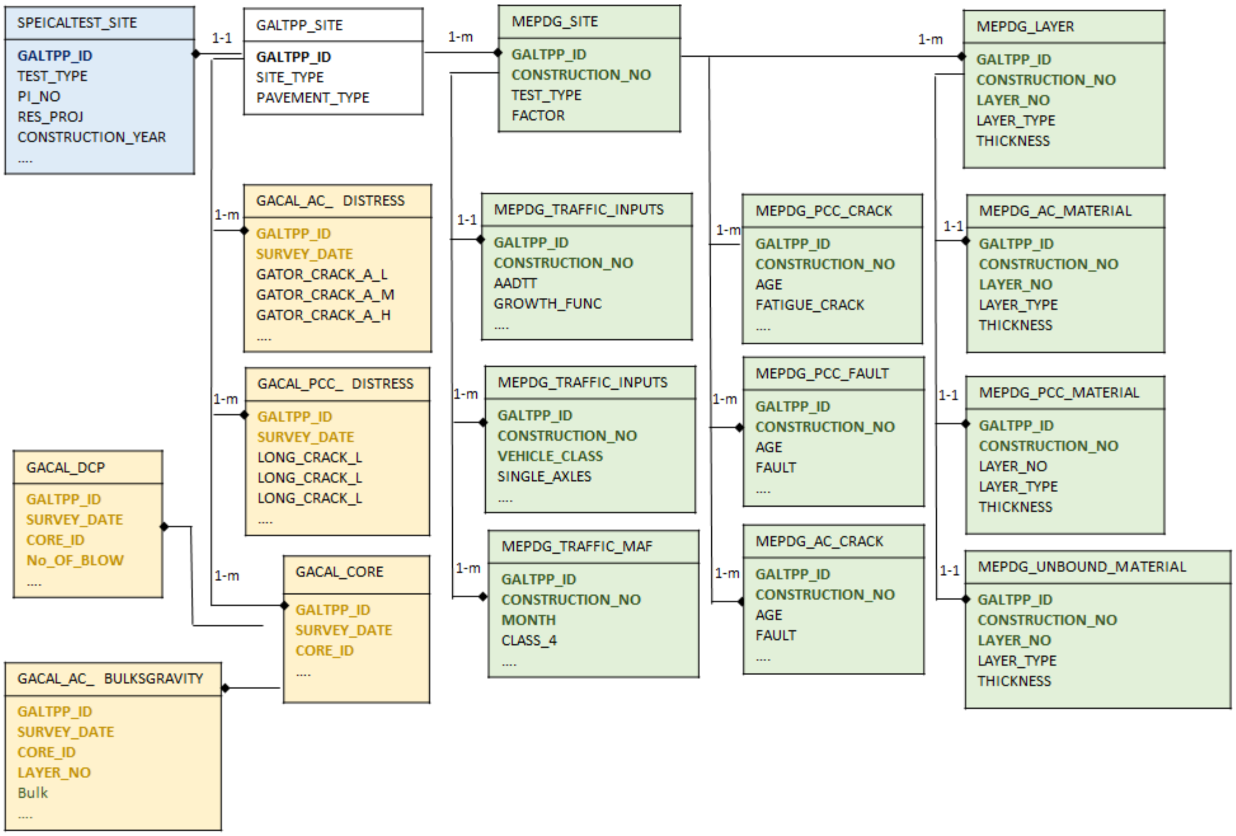

Figure 4-6. Flowchart. GALTPP database schema (Wu and Tsai, 2019).

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

This research project develops a long-term pavement performance monitoring and management plan that can cost-effectively provide sufficient, quality data to support pavement design and pavement management in the coming 5 to 10 years. In the course of this project, GDOT will be transitioning towards a new pavement data production operation with an outsourced, automated pavement data collection. Therefore, this project provides recommendations and a roadmap for GDOT's successful transition and, also, opportunities for maximizing utilization of collected data. The objectives of Phase I (Detail Design of Plan) of this research project are 1) to summarize the data collected by different offices, 2) to identify the opportunities for consolidating data collection efforts and to maximize data utilization by leveraging the data already collected by GDOT and new pavement data collected, and 3) to develop a site selection and data collection plan for pavement design and pavement management. The outcomes of this research project include the following:

1) Through interviews with engineers in different GDOT offices, a summary documenting the data collected and their primary uses was developed. This documentation provides up-to-date data collected by different GDOT offices. The documentation will be useful for improving data sharing and utilization among different offices. All interviewed offices expressed their willingness to share their data with other offices.

2) Identification of the potential opportunities for (a) improving data sharing; (b) optimizing data collection for multiple purposes; (c) maximizing sensor data utilization; (d) optimizing resources throughout activity collaboration; (e) improving information flow throughout life cycle activities among different offices in state DOTs; and (f) collecting the data needed now and in the future (e.g. asset management, ADA compliance, active transportation/complete streets, pedestrian and bike safety, connected and autonomous vehicles, etc.). In addition, specific recommendations for GDOT's successful transition and maximum utilization of collected data are made.
3) As the high-resolution 3D pavement data has already been collected and is available in GDOT, it is worth to explore how 3D pavement data can be used to support GDOT's operations in addition to OM's pavement distress data. This project layouts the utilization of 3D pavement at 3 different levels. Level 1 is to use the extracted pavement distresses at 0.1-mileor 1-mile interval to support the existing operations (e.g., Pavement Condition Evaluation System (PACES) data needed by OM and HPMS data needed by OTD). Level 2 is to use the extracted pavement distresses at original 5-meter interval to support different business operations in GDOT. This includes supporting OMAT's pavement condition evaluation and M&R decisions at the project level. The detailed data (5-m or 100-ft interval) can be used to effectively determining coring locations and problematic areas. Level 3 is to use 3D pavement data to extract distresses for different needs. The 3D pavement surface data can be used to extract different distresses (like raveling by GDOT), distresses in different protocols (like LTPP to

support the MEPDG local calibration, and/or other pavement distresses and performance indicators defined by the agency in the future.

4) By consolidating the sites for different purposes and integrating the data collection effort into the quality assurance processes for the new pavement data production operation, a sustainable, cost-effective, long-term pavement monitoring and management plan was developed. A plan, including an optimal site selection strategy, the proposed sites, and the data collection process, is proposed to support the collection of the data needed for the calibration of the Mechanistic-Empirical Pavement Design Guide, the state route prioritization policy, and the quality assurance of the new pavement data.

Recommendations for implementation of the research outcomes are as follows:

1) To maximize the data sharing and utilization of the data collected by different offices, it is recommended that GDOT conduct a study to develop a plan that synthesizes, updates, and coordinates data collection efforts and, also, to promote data sharing and utilization.
2) To share the GALTPP sites, it is suggested that GDOT publish the GALTPP data in GIS format on its GIS platform so different offices know where the sites for long-term performance monitoring are. A study to develop a plan for enhancing the data sharing and data is recommended.
3) To ensure OM obtains quality data through the new pavement data production operation, there is an urgent need to establish a quality assurance program,

including a critical assessment of the impact of the revised distress protocol, a quality review process, acceptance criteria, and training.

4) As the high-resolution 3D pavement data has already been collected and is available in GDOT, it is worth to explore how 3D pavement data can be used to support GDOT's operations in addition to OM's pavement distress data. This project layouts the utilization of 3D pavement at 3 different levels. Level 1 is to use the extracted pavement distresses at 0.1-mile or 1-mile interval to support the existing operations (e.g., Pavement Condition Evaluation System (PACES) data needed by OM and HPMS data needed by OTD). Level 2 is to use the extracted pavement distresses at original 5-meter interval to support different business operations in GDOT. One example is to support OMAT's pavement condition evaluation at the project level. The detailed data (5-m or 100-ft interval) can be used to effectively determining coring locations and problematic areas. Level 3 is to use 3D pavement data to extract distresses for different needs. The 3D pavement surface data can be used to extract different distresses (like raveling by GDOT), distresses in different protocols (like LTPP to support the MEPDG local calibration, and/or other pavement distresses and performance indicators defined by the agency in the future. This requires the raw 3D pavement surface data stored in a standard file format for reprocessing in the future. It is suggested that GDOT conduct a study to develop a research roadmap that takes advantage of 3D pavement data and maximize its utilization. Potential applications include but not limited to the following:

- Submit 3D pavement surface data along with FHWA's open and standard file formats so GDOT can flexibility reprocess the data to match GDOT's legacy data with the same distress protocol.
- Derive an LTPP pavement distress protocol for MEPGD calibration sites by leveraging the 3D pavement surface data already collected.

5) Using advanced technologies like artificial intelligence and machine learning, GDOT could add value by using the video log images already collected to cost effectively extract the following roadway features:
    - **Guardrails**, which are important countermeasures; the 2014 guardrail map must be updated based on the current, required standards.
    - **Pedestrian crossings**, which are needed for ADA compliance.
6) It is recommended that GDOT improve roadway safety and asset management by exploring the means necessary to collect the data for compliance with the Americans with Disabilities Act (ADA), for planning active transportation/complete streets, considering pedestrian and bicycle safety needs, planning for connected and autonomous vehicle use, etc. GDOT can start exploring a cost-effective means for collecting these data, like video log images or Lidar cloud data for sidewalk detection (Ai and Tsai, 2016).
7) Collecting data on safety improvement projects with different countermeasures is necessary for good, current transportation asset data files. They could be stored in the Georgia Asset Management System (GAMS) with location references to support GDOT's asset management plan.

8) It is recommended that standardized metadata, a data dictionary, and a common location reference system be established to enhance data sharing and utilization.

9) An enhanced, safety-incorporated program consisting of three components was proposed to seamlessly integrate safety improvements into GDOT's current fast-paced resurfacing program. This provides a systematic approach for upgrading all striping to meet standards within the resurfacing cycle (e.g., 10 years).

10) Implementing an e-HFST is recommended and that includes HFST site locations and maps that are essential for determining HFST activities at different stages of a project's life cycle. An e-HFST will improve HFST decision-making during roadway planning, design, construction, performance monitoring, and maintenance and rehabilitation.

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